NUTRIENT MANAGEMENT WITH BIOFERTILIZERS IN A FODDER MAIZE-COWPEA INTERCROPPING SYSTEM

BY

KAVITHA, P. K.

THESIS
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Dedicated to my beloved parents

DECLARATION

I hereby declare that this thesis entitled "Nutrient management with biofertilizers in a fodder maize-cowpea intercropping system" 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 at any other university or society.

Kavitha. P.K

KAVITHA.P.K.

Vellayani,
20-1-1996

CERTIFICATE

Certified that this thesis, entitled "Nutrient management with biofertilizers in a fodder maize-cowpea intercropping system" is a record of research work done independently by Mrs.KAVITHA.P.K. 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.

Vellayani
20-1-1996

Dr. G. RAGHAVAN PILLAI
CHAIRMAN,
Advisory committee

APPROVED BY

CHAIRMAN

Dr. G. RAGHAVAN PILLAI

MEMBERS

1. Prof. P. CHANDRASEKHARAN

2. Dr. P. SIVAPRASAD.

3. Dr. (Mrs.) P. SARASWATHY.

EXTERNAL EXAMINER.

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KAVITHA.P.K.

CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

LIST OF ABBREVIATIONS

t	tonnes
ha	hectare
N	nitrogen
P	phosphorus
K	potassium
Kg	kilogram
cm	centimetre
LAI	Leaf Area Index
LSR	Leaf Stem Ratio
mg	milligram
mm	millimetre
%	percentage
gm	gram
VAM	Vesicular arbuscular mycorrhiza
&	and
q	quintal
IAA	Indole Acetic acid
Ca	calcium
Mg	magnesium
Mn	manganese
Na	sodium
Zn	zinc

n moles	nano moles
max	maximum
min	minimum
temp	temperature
Rel	Relative

INTRODUCTION

INTRODUCTION

The production of milk and other live stock products in India is lower than that of the developed countries in the world The daily percapita consumption of milk in India is about 114g while that recommended by medical authorities is 280g. Despite the striking numerical cattle wealth, the total milk production in the country is only about five percent of the world's milk production. One of the reasons for low production is the shortage of nutritious fodder.

Kerala with a cattle population of 3.42 million, produces 20.0 lakh tonnes of milk per year. Milk production in Kerala mainly depends on highly priced concentrates and roughages like straw, weeds and crop wastes, which account for about 65-70 percent of the production cost. The requirement of state's annual fodder on dry matter basis is 67.6 lakh tonnes. But the present availability is only 40 lakh tonnes, of which cultivated fodder contributes only 0.4 lakh tonnes. Thus 27.6 lakh tonnes of dry fodder is additionally required to meet the targeted milk production by 2000 A.D.

The scarcity of fertile farm land and the existing heavy pressure on land make it impossible to attain self sufficiency in cultivated fodder. The escalating prices of concentrates necessitate an increased availability of good quality grasses and legumes for economic milk production. Hence, the only alternative to meet the requirement is to increase the fodder yield per unit time, which can be achieved by mixed cropping of cereal fodders with legumes. The mixed crop helps in increasing the yield of green fodder of better quality.

Hybrid maize (Zea mays Linn) is a cereal fodder crop suited to Kerala conditions. It is a splendid silage crop highly nutritious (6 to 8 percent protein) and palatable with an average yield of 30 to 35 t ha^{-1}. It can be safely fed at any stage of growth without any danger from prussic or oxalic acid.

Cowpea (Vigna unguiculata (L.) walp.) is an excellent leguminous crop of short duration, quick growth, high palatability and high protein content (14 to 15 percent). Most of the varieties are shade tolerant and the average fodder yield under rainfed condition is 20 to 30 tha^{-1}.

Tropical countries, like India always face an acute shortage of fertilizer inputs, chiefly nitrogen which is doubtless the most crucial nutrient limiting, cereal fodder yields. Among the principal cereal fodders of India, maize requires much nitrogen. Since a vast majority of our farmers cannot afford adequate application of this nutrient, it is worth examining intercropping maize with N-fixing legumes. Legumes which fix atmospheric N besides meeting their own requirement, serve as a viable media for soil enrichment. This eventually helps in meeting the N needs of the cereal fodders partially.

With the exorbitant rise in the price of chemical fertilizers, it becomes highly demanding for farmers to use fertilizers even for food crops. Because of this reason, the farmers in Kerala although grow fodder maize along with cowpea, they donot apply adequate amount of fertilizers. Hence, though the fertilizers cannot be substituted, the use of costly fertilizers to forages could be reduced to the maximum extent possible by exploring new avenues.

In this context biofertilizers (microbial inoculants) seem to be a welcome boon to farmers. With the rapid depletion of fossil fuels, which are the source of energy for manufacture of fertilizers, efforts should be oriented towards increasing the use of biofertilizers. Azospirillum is a free living nitrogen fixing micro-organism and in associative symbiosis with roots of graminaceous crops. Besides fixing nitrogen, Azospirillum secretes growth promoting substances. Rhizobium is a nitrogn fixing micro-organism and in symbiotic association with the roots of legume crops. In addition to economising nitrogen fertilizers, Rhizobium inoculation serves to enrich soil fertility by augmenting nitrogen fixation.

In Kerala, with predominantly acid soils, phosphorus fixation as iron and aluminium phosphates is a major problem. Phosphorus is a vital element in almost all biological systems (Westheimer, 1987) and is required in large quantities. Vesicular arbusular mycorrhiza (VAM) which is a fungus in symbiotic association with the roots of crops have the ability to harvest even the unavailable or sparingly soluble forms of soil phosphorus and absorb it more readily than roots (Young et al., 1986). In addition to phosphorus, VAM fungi are known to increase the availability of micro nutrients. Hence it could be beneficial if the potentiality of these organisms to enhance the acquisition of nutrients and hence increase the productivity could be exploited to our advantage.

The effect due to inoculation and its role in increasing productivity and reducing the fertilizers has to be investigated and hence the present study was undertaken with the following objectives.

1) To compare the effects of different bio-inoculants (Azospirillum, Rhizobium & VAM) in increasing the fodder productivity of maize - cowpea intercropping system.

2) To find out if there is any reduction in fertilizers requirement due to inoculation treatment.

3) To compare the economics of the above treatments.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

The present investigation was undertaken with the object increasing the herbage production of maize-cowpea intercropping system by biofertilizer inoculation and to save fertilizer without affecting productivity, so that the production cost could be reduced considerably.

The relevant literature on the fodder production of maize-cowpea intercropping system due to the influence of biofertilizers especially with respect to Azospirillum, Rhizobium and mycorrhizal application along with chemical fertilizers are reviewed hereunder. Other related crops are also taken into consideration wherever found needful.

2.1. Effect of cereal-legume association

Two plant species with contrasting morphological and physiological characters will together be able to exploit their total environment more effectively than their monoculture and will thereby give increased yield and net return.

2.1.1. Growth and growth characters

Meenakshi et al. (1974) reported no adverse effect on the maize crop when it was intercropped with cowpea.

Singh and Guleria (1979) found that intercropping soybean in maize did not affect adversely the growth and development of maize measured in terms of plant height, functional leaves per plant, leaf area index and drymatter accumulation.

Gangwar and Kalra (1981) found that growing of greengram, blackgram and cowpea has stimulating effect on maize growth.

Studies on the competitive ability and growth habit of indeterminate beans and maize in intercropping had shown that the most competitive bean varieties yielded the most, when intercropped with maize, but these varieties were not necessarily the highest yielding in sole culture. (Darvis and Garcia, 1983)

Uddin and Irabagen (1986) reported that the height of corn plants intercropped with soybean was significantly higher than that of corn with cowpea.

Geethakumari (1989) stated that the growth characters of both maize and cowpea were maximum when they were provided with their recommended dose of fertilizers.

Dahatonde et al. (1992) noticed that when wheat was intercropped with french beans, the growth of maize was affected. Reduction in growth due to intercropping was recorded for maize and french beans by Singh and Singh (1993).

2.1.2. **Yield and dry matter production.**

The companion cropping of maize with cowpea produced significantly higher total drymatter yield compared to growing maize alone or in association with cluster beans (Chauhan and Dungarwal, 1980). Similar results were reported by Gangwar and Kalra, 1981; Nair et al., 1982; Borse et al., 1983; Muthuvel et al., 1984.

On the contrary, Maliwal et al. (1980) obtained higher yields of green fodder in the sole crops of sorghum, maize and bajra than their mixtures with cowpea.

Subramanian and Govindaswamy (1985) reported that sorghum grown mixed with soybean recorded the maximum fodder yield of 56.00 t ha^{-1}.

Bandyopadhyay and De (1986) observed an increased drymatter yield of sorghum intercropped with cowpea.

Tripathi et al. (1987) stated that in intercropped stands of sorghum + cowpea and maize +cowpea, drymatter yields were similar to those in pure stands which yielded 10.18 and 9.33 t ha^{-1} respectively.

Angadi and Gumaste (1989) reported that intercropping of seven legumes in maize gave total fresh fodder yields of 61.06 to 67.95 t ha^{-1} compared with 60.52 t for maize in pure stands.

But Shahapurkar and Patil (1989) indicated that the maize yields were not significantly affected by intercropping it with cowpea. Senaratine *et al*. (1992) found that by intercropping of maize and groundnut, drymatter production was decreased except when 40 kg N ha^{-1} was applied.

Gangwar and Sharma (1994) found that intercropping of blackgram in maize recorded maximum green forage yield. Takita *et al*. (1994) found that intercropping of sorghum and pigeon pea gave greater amount of drymatter production relative to single cropping.

Majority of the research results on intercropping showed increase in total yield when maize was intercropped with legumes.

2.1.3. Quality

Leguminous crops grown in association with cereals are found to influence some of the quality parameters such as crude protein, crude fibre, total ash and mineral content and make the forage more palatable.

Results of field experiments, conducted at Rajasthan College of Agriculture, Udaipur showed that companion cropping of maize with cowpea resulted in significant increase in quality of forage when compared with growing maize alone (Chauhan and Dungarwal, 1980).

On the other hand, Maliwal et al. (1980) reported that intercropping of sorghum, maize and bajra with cowpea and cluster bean reduced the crude protein, digestible energy, total digestible nutrients and fat content in the fodder.

Tiwana et al. (1983) noticed that maize-cowpea mixture harvested at various growth stages, gave the highest crude protein (1.43 t ha^{-1}) yields when harvested 73 days after sowing, when compared to monocrop of maize which yielded only 786 Kg ha^{-1} of crude protein, harvested at 73 days after sowing.

Tripathi et al. (1987) observed that in intercropped stands of maize with cowpea, crude protein yield was 1.01 to 1.05 t ha^{-1} when compared with 0.68 t ha^{-1} in pure stands.

Gangwar and Kalra (1988) reported that growing maize with legumes like blackgram, greengram and cowpea resulted in early maturity and increased protein content of maize and greater protein productivity.

Intercropping of maize with legumes, was found beneficial in terms of crude protein yield per unit area, compared to maize crop alone (Angadi and Gumaste, 1989).

Lee (1989) reported that the crude protein yield was increased to 1.54 t ha^{-1} in maize-soybean intercrop when compared to 1.28 t ha^{-1} in the case of monocrop of maize.

Gangwar and Sharma (1994) showed that among the different legumes tried as intercrop in maize, crude protein yield was highest in prickly sesban (3.7 q ha^{-1}) followed by cowpea (3.6 q ha^{-1})

2.1.4. **Fertilizer economy due to intercropping**

A mixture of maize plus cowpea fodder fetched relatively higher price in the market since it was more nutritive and palatable and hence the return from unit quantity of fertilizer was high (Singh, 1973).

Datta and Prakash (1974) reported a mean return of Rs. 3.19 and 2.62 per rupee invested in nitrogen and phosphorus respectively in a maize + legume mixture.

For hybrid maize variety Deccan, the economic optimum was 182 kg N ha^{-1} (Kumaraswamy et al 1975). They also found that it was not economical to apply phosphorus and potassium fertilizers to the maize crop when the inherent availability of these nutrients in the soil was either low, medium or high status.

Morachan et al. (1977) observed that about 30 kg N ha^{-1} could be reduced from the fertilizer requirement of sorghum by growing blackgram, greengram or cowpea as intercrop.

In all the five experiments conducted by Ahmed and Gunasena (1979) regardless of crop combinations used, the intercropping system provided higher returns than the sole crop system at corresponding nitrogen levels.

Singh and Guleria (1979) reported that soybean could be sown as intercrop with maize to minimise the economic losses. Part of nitrogen fixed by the legume might have been made available to the adjacent maize crop (Chauhan and Dungarwal, 1980).

Gangwar (1980) stated that by growing maize + legume varieties in association, the productivity could be increased considerably without proportionate increase in the use of nitrogenous fertilizers. This might be due to the fact that nitrogen fixation would have been inhibited by the application of higher levels of nitrogen.

Malik and Surinder singh (1981) showed that in a bajra - cowpea mixture, one rupee spent on fertilizer use produced the fodder yield worth Rs.6/-. Further, the harvest of bajra + cowpea as green fodder was more economical than keeping it for grain yield, as the grain yield remains low in moisture stress conditions.

Mercy George (1981) noticed that the available phosphorus and potassium content of the soil increased by maize - cowpea intercropping system, indicating fertilizer economy due to intercropping. Similar result was also reported by Muthuvel et al. (1984).

Intercropping of legumes with cereals like maize economizes the use of nitrogen fertilizer and increases the production per unit area (Singh et al., 1988).

2.1.5. **Uptake of nutrients**

Muthuswamy et al. (1980) reported that higher uptake of nitrogen, phosphorus and calcium in maize - legume mixture than in sole crop of maize.

Muthuvel et al. (1984) found that the total nitrogen content of sorghum was maximum in sorghum - red gram intercropping system.

Reddy and Havanagi (1991) observed that the nitrogen and phosphorus content in finger millet (*Eleusine coracana*) were higher in intercropping system as compared to sole finger millet, at all stages.

Senaratine et al. (1992) reported that intercropped maize derived 30 to 35 percent of its nitrogen content from the associated groundnut plants.

2.2. Effect of *Azospirillum* on grasses

2.2.1. Occurrence

In a survey conducted by Dobereiner *et al*. (1976) it was found that *Azospirillum* was a common inhabitant of the tropics. The occurrence of *Azospirillum* in Indian soils has been reported by Kumari *et al*. (1976) and Lakshmi *et al*. (1977). Nair (1981) reported that *Azospirillum brasilense* could colonize in the root elongation zone and base of root hairs and proliferate in the innermost layer of cortex and conducting vessels, in addition to epidermal and other cortical cells in inoculated sorghum plants. The association of *Azospirillum* with the roots of several annual and perennial crops in coconut based farming systems of Kerala was reported by Ghai and Thomas (1989).

2.2.2. Growth and growth characters

It has been already established that inoculation of many crop plants with *Azospirillum* could result in significant change in various plant growth parameters.

Kapulnik *et al*. (1981) reported that in forage maize, there was an increase in number of leaves, weight of leaves and stems.

Govindan (1982) found that most of the growth parameters were improved due to *Azospirillum* inoculation in bajra.

Sanoria et al. (1982) obtained significant increase in the plant height of paddy by Azospirillum inoculation and reported that use of inoculation alone with no application of fertilizer nitrogen was more desirable.

Venkatachalam (1983) found that plant height, tiller number and leaf area index were increased due to Azospirillum inoculation in cowpea.

Gallo et al. (1989) reported that inoculation of Zea mays with Azospirillum brasilense increased plant height in comparison with uninoculated control.

Sangwan and Kundu (1992) observed that growth of bajra was improved due to inoculation.

Rangasamy et al. (1994) found that the growth characters of sorghum were improved due to inoculation.

Bangar et al. (1995) noticed that growth parameters of sugarcane were increased due to Azospirillum inoculation.

2.2.3. **Yield and drymatter production**

Cohen at al. (1980) reported that maize plants inoculated with Azospirillum had significantly increased plant dry weight upto 50 to 100 percent.

Kapulnik et al. (1981) found that inoculating Zea mays, Sorghum bicolor, Panicum miliaceum and Setaria italica with Azospirillum resulted in significant increase in yield of grain and forage of commercial value.

Pahwa and Patil (1984) reported that simple seed inoculation with Azospirillum resulted in increased green yield to the tune of 18.6, 32.6, 30.9, 41.4 and 38.5 percent in teosinte, maize oats and barley respectively.

Sarig et al. (1984) noticed that Azospirillum inoculated sorghum plants resulted in significant increase over control of 19 percent in forage yield.

Tanwar et al. (1985) also observed better forage yield with inoculation of Azospirillum than control in oats.

Fages and Mulard (1988) reported that Azospirillum lipoferum had a strongly beneficial effect on dry matter production in Zea mays. Gautam and Kaushik (1988), Pareek and Shaktawat (1988), Tilak and Dwivedi (1989) were also of the same view.

Vasyuk and Bovkov (1990) found that seed inoculation of barley with Azospirillum lipoferum increased yield from 410 gm^{-2} in the control to 495 to 577 gm^{-2}.

Bhattarai and Dieter Hess (1993) observed that wheat cultivars responded positively and significantly in yield due to inoculation of *Azospirillum*. Tomar and Agrawal (1993) also have the same view.

Rangasamy *et al*. (1994) found that inoculation with *Azospirillum* increased the green fodder yield in sorghum.

Rao and venkateswarlu (1995) reported that the dry matter yield in pearl millet increased due to *Azospirillum* inoculation.

2.2.4. **Quality**

Tanwar *et al*. (1985) reported 41 percent increase in crude protein content of oats fodder inoculated with *Azospirillum*.

While reviewing the research works on *Azospirillum* inoculation to the field crops, an appreciable increase in the protein content was reported by Boddey *et al*. (1986) and Dart (1986).

But Pacovsky (1986) reported that the *Zea mays* inoculated with *Azospirillum* contained less nitrogen, soluble sugars, soluble protein, leucine and isoleucine but more leaf area and glutamate than corresponding nitrogen fertilized plants.

2.2.5. **Root characters**

Gautam *et al*. (1985) found that *Azospirillum* application promoted root growth and thereby more nitrogen fixation in soil for luxuriant crop growth.

Okon and Kapulnik (1986) reported that the root growth root hair formation, root elongation and root surface area were improved due to Azospirillum inoculation in cereal crops.

Fallik et al. (1989) found that the roots of maize seedlings inoculated with Azospirillum brasilense were found to have higher amounts of both free and bound IAA, significantly increased in the inoculated roots two weeks after sowing.

Bashan et al. (1990) obtained significant increase in root growth by inoculating wheat with Azospirillum. Rangasamy et al. (1994) and Rao and venkateswarlu (1995) were also of the same view that the root growth was improved due to inoculation.

2.2.6. Uptake of nutrients

2.2.6.1. Nitrogen

Tien et al. (1979) reported that Azospirillum inoculation increased the nutrient absorbing surface in pearl millet resulting in greater nutrient uptake.

Cohen et al. (1980) found that maize plants inoculated with Azospirillum had significantly increased total nitrogen content by 50 to 100 percent.

Kapulnik *et al*. (1985) found that the wheat plants inoculated with *Azospirillum* accumulated 20 percent more nitrogen at the booting stage than did the uninoculated control. Increased nitrogen content in wheat by *Azospirillum* inoculation was obtained by Boddey *et al*. (1986).

Sreeramulu *et al*. (1988) reported that in maize inoculated with *Azospirillum brasilense*, nitrogen contents in roots and shoots were higher than in the uninoculated plants. Sangwan and Kundu (1992), Bhattarai and Dieter Hess (1993) were also of the same view.

2.2.6.2. **Phosphorus.**

Azospirillum inoculation has shown favourable influence for phosphorus uptake. This might be due to nitrogen fixation by the inoculated plants and better growth leading to increase in dry matter production.

Venkatachalam (1983) reported increased nitrogen and phosphorus uptake due to inoculation on two wheat varieties.

2.2.6.3. **Other nutrients**

Azospirillum inoculation had no significant influence on potassium uptake.

However, Lin *et al*. (1983) reported enhancement in the uptake of minerals by roots of Zea mays and sorghum bicolor inoculated with Azospirillum. Bashan et al. (1990) evaluated the capacity of Azospirillum strains to enhance the accumulation of k^+, p^+, Ca^{+2}, Mg^{2+}, Mn^{2+}, Na^+ and Zn^{2+} in inoculated wheat and soybean plants. They reported that a strain capable of accumulation of a particular ion in one plant species or cultivar often lacked the ability to do so in another..p161

2.2.7. **Fertilizer economy**

Subba Rao et al. (1979) reported that application of Azospirillum promoted root growth and more nitrogen fixation in soil which helped in increasing fodder yield.

Inoculating cereal crops with Azospirillum saves valuable nitrogen fertilizer (Kapulnik et al., 1981). By inoculation about 25 percent nitrogen could be saved (Venkatachalam, 1983).

Pahwa and Patil (1984) also indicated the possibility of saving 15-20kg inorganic nitrogen $hectare^{-1}$ by inoculating forage crops with Azospirillum lipoferum.

Sawicka and Aleksandra (1987) found that the highest nitrogen fixing activity of 125 - 610 n moles C_2H_2 m^{-1} h^{-1} was observed under corn in the flowering stage.

Purushothaman (1988) obtained grain and straw yield increase equivalent to the application of 25 kg N ha^{-1} by Azospirillum inoculation in rice.

According to Porwal and Singh (1989), about 40 kg N ha^{-1} could be saved by Azospirillum inoculation without significant reduction in grain and straw yield of sorghum.

2.3. Effect of Rhizobium

2.3.1. Occurrence

Hellriegel and Wilfrath (1888) conducted pot experiments on peas and clovers to show that nodules on roots of these legumes fixed nitrogen from the atmosphere.

Rhizobium is known to infect the plant roots of legumes. Presence of Rhizobium on legume roots is a well known symbiotic association. Rhizobium derives carbon and energy from legume host and inturn it provides nitrogen to legumes through atmospheric nitrogen fixation (FAO, 1984).

2.3.2. Growth and growth characters

Karyagin (1980) found that Rhizobium strains increased the plant height in soybeans. But Koshy (1982) reported that inoculation had no beneficial effect on plant growth.

Rhizobium inoculation resulted in significant increase in number of leaves and branches of greengram (Srivastava and Sharma, 1982). Maiti *et al*. (1988) obtained increased chlorophyll content of leaves in greengram, due to inoculation.

2.3.3. Yield and dry matter production.

Karyagin (1980) found that *Rhizobium* strains increased the fresh fodder, hay and seed yields in soybeans.

Sivaprasad and Shivappa shetty (1980) obtained Significant increase in yield of cowpea inoculated with *Rhizobium*. Bevanur *et al*. (1981) reported that the yield of fingermillet (*Eleusine-coracana*) grown in association with inoculated legumes was considerably higher compared to finger millet grown either as a pure crop or grown mixed with uninoculated legumes.

Yield improvement to the tune of 10 to 46 percent over control in *Rhizobium* inoculated redgram has been reported by Subba Rao (1981). *Rhizobium* inoculation resulted in significant increase in drymatter yield of greengram (Srivastava and Sharma, 1982).

Bhuiya *et al*. (1986) recorded the highest shoot, root and total drymatter yield in *Rhizobium* inoculated plants of black gram. Maiti *et al*. (1988) reported that seed inoculation increased the seed yield of greengram by 5 to 10 percent, but had no significant effect on lentil (*Lens esculenta*) seed yield.

Shaktawat (1988) reported that the cowpea seeds inoculated with Rhizobium produced significantly higher grain yield (758 kg ha^{-1}) over uninoculated cowpea (658 $kgha^{-1}$).

Seed inoculation with Rhizobium increased the drymatter content of cowpea. The dry matter yield was 5.14 and 4.10 t ha^{-1} with and without inoculation respectively. (Sairam et al., 1989) Significant increase in total dry matter yield was noted due to inoculation (Awonaike et al., 1990, Beena et al., 1990).

2.3.4. **Quality**

Deshmukh and Joshi (1973) found that inoculation of cowpea with Rhizobia increased the crude protein content. It was also seen that the inoculated plots yielded more than 400kg of protein per hectare.

Karyagin (1980) reported increase in crude protein in hay of soybeans due to Rhizobium inoculation. Similar increase has been noted in lucerne (Medicago sativa) by Johnson (1982) due to Rhizobium inoculation. Sudhakar et al. (1989) found that inoculation increased the protein content in blackgram, compared to control.

2.3.5. **Nodulation**

Gowda et al. (1979) found increased nodulation and nodule weight $plant^{-1}$ in Rhizobium inoculated cowpea plants.

Sivaprasad and Shivappa Shetty (1980) obtained significant increase in leghaemoglobin content of nodules in cowpea inoculated with Rhizobium. Bhuiya et al. (1986) obtained effective nodulation in terms of main root nodule counts relative to uninoculated controls in blackgram.

Kim et al. (1988) observed that Rhizobium inoculation increased the nodule number $plant^{-1}$, but had little effect on the nodule dry weight $plant^{-1}$. Nitrogen fixation was significantly increased by nodulation. Beneficial effect of inoculation in increasing nodulation and nodule dry weight $plant^{-1}$ has been reported by Prasad and Ram (1988).

Anthoniraj et al. (1989) obtained a positive correlation between nodule number and plant biomass due to inoculation. Ramdoss and Shivaprakasham (1989) reported that nodulation on cowpea roots was higher when the seeds were inoculated with Rhizobium, than the uninoculated control.

Sairam et al. (1989) indicated that inoculation with Rhizobium increased nodulation and nodule leghaemoglobin content of cowpea. Beena et al. (1990) and Singh (1994) also obtained

Significant increase in nodule number and nodule weight in inoculated plants.

2.3.6. **Uptake of nutrients**

2.3.6.1. **Nitrogen**

Nair *et al*. (1970) and Sahu and Behara (1972) obtained increased nitrogen content in cowpea inoculated with *Rhizobium*. Rao and Sharma (1980) also observed an increase in the nitrogen content of tops of soybean and blackgram as a result of *Rhizobium* inoculation.

Bevanur *et al*. (1981) reported that the nitrogen content of ragi grown in association with inoculated legumes was considerably higher when compared to ragi grown either as a pure crop or grown mixed with uninoculated ones.

Srivastava and Tewari (1981) observed that most of the strains of *Rhizobia* caused an increase in the nitrogen content in cowpea and greengram. Beneficial effect of inoculation in increasing nitrogen uptake has also been reported by Madhava Reddy (1986) and Sairam *et al*. (1989).

Beena *et al*. (1990) and Gregr (1990) observed increased nitrogen uptake by cowpea plants following *Rhizobial* inoculation.

2.3.6.2. **Phosphorus**

Inoculation of Rhizobium increased the phosphorus content of both straw and grain of mung bean (Raju and Verma, 1984). Similar increase in phosphorus content was reported by Yousef et al. (1989) in both shoots and seeds of mung bean due to inoculation.

2.3.6.3. **Other nutrients**

In mung, potassium concentration significantly increased in straw due to Rhizobium treatment (Raju and Verma, 1984). Prasad and Ram (1988) observed that Rhizobium inoculation increased calcium uptake and concentration in greengram.

2.3.7. **Fertilizer economy**

Gargantini and Wutke (1960) inoculated cowpea with Rhizobium and reported that the inoculated plants fixed nitrogen at the rate of 75 kg ha^{-1}. Chatterjee et al. (1972) observed that the variations in the amount of nitrogen fixed by different legumes are due to the differences in the Rhizobium strain associated with them.

Sahu (1973) reported that Rhizobium inoculation alone could enhance the nitrogen content of the soil by 20 to 38 percent in the case of bengalgram and by 7 to 19 percent in the case of horsegram.

Bergersen and Turner (1983) found significant differences between the ^{15}N concentrations in rye grass and clover wherein the nitrogen fixation rates were approximately 4kgNha^{-1} day^{-1}, during favourable conditions.

West and Wedin (1985) in their studies on seasonal trends in nitrogen fixation in alfalfa- orchard grass pastures observed that the total annual amount of nitrogen fixed averaged 70 kg ha^{-1}.

2.4. Effect of mycorrhiza

2.4.1. Occurrence

VAM (Vesicular arbuscular mycorrhiza) are known to occur on large number of agricultural crops and therefore it is of particular interest. The leguminosae (Jones, 1924; Samuel, 1926 and Asai, 1944) and Graminae (Asai, 1934; Winter, 1951 and Nicolson, 1959) are families of great importance in which VAM generally occurs. The following are the few crops that have VAM-maize (Gerdemann, 1964), soybean (Gerdemann, 1968 and Ross and Harper, 1970), sorghum and barley (Hayman, 1982), cowpea and other legumes (Godse et al., 1978, Bagyaraj and Manjunath, 1980; Islam et al., 1980 and Rao and Parvathi, 1982)

2.4.2. Growth and Growth Characters

Improved growth was reported by Islam and Ayanaba (1981) and Mathew and Johri (1989). Tinker (1982) reported the role of VAM in plant growth.

A significant increase in shoot length and root length of cowpea, greengram and blackgram was observed due to inoculation with VA mycorrhiza (Ramaraj and Shanmugham, 1986)

Hetrick and Wilson (1992) found that inoculation of wheat cultivars with mycorrhizal fungi increased the growth by 29 to 100 percent. Uma and Rao (1994) also reported an increase in shoot length of blackgram and greengram due to inoculation with VA mycorrhiza.

2.4.3. Yield and dry matter production

Improved yield was reported in mycorrhiza inoculated plants (Islam and Ayanaba, 1981). Champawat (1989) reported increase in fresh shoot weight and dry weight in chickpea due to VAM inoculation in unsterilized soil.

Inoculation of soybean with *Glomus fasciculatum* or indigenous VA mycorrhizal fungi increased the drymatter accumulation in plants (Singh, 1990).

Hetrick and Wilson (1992) observed improved plant dry weight in mycorrhizal inoculated wheat cultivars. Uma and Rao (1994) found that fresh and dry weights were higher in mycorrhizal plants than in control plants in blackgram and greengram.

2.4.4. **Quality**

Doss et al. (1988) reported that protein content of leaves of mycorrhizal inoculated finger millet was higher than that of non-mycorrhizal plants as indicated by an increase in size and number of proteinoplasts in the former.

2.4.5. **Root character and colonization**

Uninoculated plants of lucerne (Medicago sativa) reached 45 percent infection from indigenous endophytes and inoculated plants reached 70 percentage. Inoculation responses were not related to infection level. Lucerne responded most from inoculation with most available phosphorus (Owusu-Bennoah and Mosse, 1979).

Ocampo and Azcon (1985) found that VA mycorrhiza infected wheat varieties showed an increase of total and reducing sugars in their root extracts. However, no clear relationship between sugar concentration in the root and VA mycorrhizal infection level could be established.

Ramaraj and Shanmugham (1986) observed increased root length and root weight in cowpea, greengram and blackgram inoculated with VAM.

Champawat (1989) found that mycorrhizal treatment resulted in an increase in number of spores in the root zone soil.

Hetrick and Wilson (1992) reported that inoculation with mycorrhizal fungi improve the root characters with root colonization ranging from 18-45 percent.

2.4.6. **Nutrient uptake**

Mycorrhiza is known to influence the host growth through enhanced uptake of nutrients in general and phosphorus in particular. Mycorrhizal hyphae have the capacity to take up and deliver nutrients to the plant - P, NH_4^+, k, Ca, So_4^{2-}, Cu and Zn which can deliver upto 80 percent plant P, 25 percent plant N, 10 percent plant k, 25 percent plant Zinc and 60 percent plant copper (Marschner and Diel, 1994).

2.4.6.1. **Nitrogen**

A positive correlation between VA mycorrhizal infection and the amount of phosphorus and nitrogen in the tissues of cowpea and maize was reported by Sanni (1976) and also facilitated the transfer of labelled ^{15}N from legumes to non-legumes (Kessel et al., 1985)

Barea and Azcon Aguilar (1983) suggested that VA mycorrhiza may be of special significance in legumes, as the symbiotic nitrogen fixation is influenced by the phosphorus status of the host.

2.4.6.2 **Phosphorus**

Phosphorus has vital function in all biological systems because it is a major plant nutrient required in relatively larger amounts (Hayman, 1975; Tinker, 1980). Increased phosphorus uptake due to VA mycorrhizal association has been reported in many plants like finger millet (Bagyaraj and Manjunath, 1980; Raj et al., 1981), barley (Saif and Khan, 1977; Jensen, 1982), Paspalum notatum (Mosse et al., 1973), soybean (Asimi et al., 1980) and cowpea (Sanni, 1976; Bagyaraj and Manjunath, 1980).

Stribley et al. (1984) reported that shoots of plants infected with VA mycorrhiza contain higher internal concentrations of phosphorus than those of uninfected plants of equal size, over wide ranges of external phosphorus supply and of host plants.

Le Tacon (1985) generalised that VAM increased the traslocation of least soluble elements like phosphorus, zinc and copper. Phosphorus can be taken upto about 8 cm from the root.

VAM inoculation significantly increased the available phosphorus content of the soil, uptake of phosphorus and other nutrients in greengram (Santhi et al., 1988).

Champawat (1989) reported significant total phosphorus uptake in chickpea plants inoculated with mycorrhiza. Mycorrhizal plants not only are large but also have an increased concentration and/or content of phosphorus compared to nonmycorrhizal plants (Barea, 1991).

2.4.6.3 **Other nutrients**

Studies to ascertain the direct role of VAM in plant uptake of nutrients other than phosphate and nitrogen are very few. However the percentage content and/or concentration of major nutrients and trace elements in the shoots are reported and reviewed hereunder.

2.4.6.3.1. **Potassium**

Harley and Smith (1983) indicated that there was no conclusive support for the role of VAM in potassium uptake. But VAM aids in increased uptake of potassium. (Krishna et al., 1982; Yost and Fox, 1982; Blal and Gianiazzi - Pearson, 1989).

2.4.6.3.2. **Calcium and Magnesium**

Inoculation of VAM aids in the uptake of calcium (Rhodes and Gerdemann, 1978; Yost and Fox, 1982 and Krishna and Bagyaraj 1984) and magnesium (Krishna et al., 1982; Arines et al., 1989; Bikuochang and Kuoshiu chien, 1989).

2.4.6.3.3. **Micro nutrients**

Enhanced sulfur (S) uptake by VAM plants and hyphal translocation of sulfur have been demonstrated (Gray and Gerdemann, 1973; Cooper and Tinker, 1978; Rhodes and Gerdemann, 1978).

Direct uptake of zinc has been observed in VAM plants (Bowen et al., 1974, La Rue et al., 1975 and Blal and Giani nazzi - Pearson, 1989).

VAM aid in the uptake of other nutrients like copper and iron (Krishna et al., 1982; Krishna and Bagyaraj 1984; Pacovsky. 1986a and Blal and Gianinazzi - Pearson, 1989) and manganese (Krishna and Bagyaraj, 1984). Decreased manganese uptake was also reported (Pacovsky, 1986 and Arines et al., 1989).

The sum of the anion concentrations (Σc of chloride, sulfate, orthophosphate and nitrate ions) were increased strongly by mycorrhizal infection but not by P-additions. The concentrations of total cations (Σa of potassium, calcium, magnesium and sodium ions) was generally reduced by P-additions, hence P and VAM both reduced the cation excess ($\Sigma c - \Sigma a$) but by different mechanisms. (Buwalda et al., 1983). This suggests that uptake of anions by plants with VAM maybe a general phenomenon which would have important implications for the elemental composition of crops.

2.4.7. **Fertilizer economy**

Hall (1987) stressed the importance of VA mycorrhizal inoculation in replacing the fertilizer application to pastures.

Bazilinskaya (1988) stressed the use of VAM for conversion of phosphorus from unavailable to easily available forms. Therefore, attention has been concentrated on practical application of the Po_4 - mobilising capability of VAM on wasteland and also on soils extremely low in phosphorus and subject to pesticide treatment.

2.4.8. **Interaction of mycorrhiza with nitrogen fixing bacteria**

Some plant species which are able to from VA mycorrhiza are also mutualistically associated with nitrogen fixing prokaryotes, especially in the case of legumes and cereals. These plants with both nitrogen fixing bacteria like Azospirillum, Rhizobium and mycorrhiza, therefore possess ecological advantages to compensate for nutrient deficient situations (Hayman, 1982).

2.4.8.1. *Azospirillum* and VAM interation

Colonization by VAM fungi reduces root exudation (Graham *et al*., 1981) and may reduce the release of malate and other organic acids from Sorghum roots. These are preferred carbon sources for *Azospirillum brasilense* (Okon *et al*., 1976).

The increased formation of vesicles, arbuscles and spores have been reported in eight grasses after dual inoculation with *Azospirillum brasilense* and *Glomus macrocarpum* (Singh and Subba Rao, 1987).

Sreeramulu *et al.* (1988) reported that maize inoculated with both *Azospirillum* and VAM increased the growth and uptake of nutrients especially nitrogen and phosphorus.

2.4.8.2. *Rhizobium* and VAM interactions

VAM strongly stimulated nodulation by *Rhizobia* in some herbage legumes and nodulation was increased by increased phosphorus contents of host plants (Crush, 1974).

The average number of mycorrhizal vesicles developed per unit root length was more in leguminous hosts, than in non-leguminous hosts which may be due to the presence of *Rhizobium* in leguminous plants. (Rao and Parvathi, 1982). Similar results were reported by Packovsky (1986) and Ames and Bethlen Falvay (1987).

2.5. Effect of fertilizer application

In a sorghum - legume mixture, application of 120 kg N ha^{-1} increased total forage production, crude protein and mineral matter content. Potash application did not affect the green fodder yield (Kalra and Khokhar, 1979).

Accumalation curves for N, P, K, and Ca were determined for intercropped maize and cowpea given different fertilizer combinations (Wahua, 1983). Both species competed for these four elements, with cowpea suffering relatively more than maize. The highest fodder yield of the maize - legume mixture, was obtained when a fertilizer dose of 160:80:80 kg N,P_2O_5 and K_2O ha^{-1} was given and this dose was on par with the 140:70:70 kg levels. (Mercy George and Mohamed Kunju, 1983).

It was found that the maize-cowpea mixture gave the highest crude protein yield at 120:60:60 kg N,P_2O_5 and k_2O ha^{-1} while in the maize - velvet bean mixture, the crude protein yield was maximum at 160:80:80 kg N, P_2O_5 and K_2O ha^{-1} (Mercy George and Mohamed Kunju, 1984).

Kawamoto et al. (1988) reported that in a sorghum-soybean mixture, the content of nutrients (N,P,K, Ca and Mg) of sorghum tended to be higher than those in pure sorghum. Yield of these nutrients were higher in the mixed cropping than those in pure.

cropping even if the drymatter yield of sorghum in the mixed cropping was little less than that in pure sorghum cropping.

Rafee and Prasad (1992) based on an economic feasibility study on maize and pigeon pea intercropping at 100,75 and 50 percent levels of recommended dose of nutrients, reported that maximum gross and net return (Rs. 2728 ha^{-1}) were obtained from intercropping when both the crops were fertilized with 100 percent of the recommended dose. However, maximum net return per rupee investment was recorded under maize at 50 percent and pigeonpea at 100 percent nutrient level.

Thimmegowda and Shivaraj (1994) indicated that the recommended level of fertilizer dose for each fodder crop recorded higher fodder yield, nutrients uptake and protein yield in both maize and cowpea.

From an appraisal of the details stated above, it is seen that growth, yield, quality and uptake of nutrients in fodder crops and grain crops are improved by combined application of the major nutrients.

2.6. Interaction between inoculants and fertilizers

2.6.1. *Azospirillum* fertilizer interaction

Elango (1981) reported that the growth of fodder grass was significantly increased due to *Azospirillum* inoculation along with fertilizer nitrogen at the rate of 25 kg ha^{-1}.

Rai and Gaur (1982) studied the effect of inoculation on the yield and nitrogen uptake of wheat and reported that the treatment receiving 80 kg N ha^{-1} yielded 2.97t ha^{-1} against the yield of 4.15t ha^{-1} in the treatment receiving both inoculant and fertilizer.

Sanoria et al. (1982) reported that use of inoculant with no application of fertilizer nitrogen was more desirable. Increased numbers of Azospirillum brasilense became associated with Zea mays roots following the addition of low levels of combined nitrogen.

2.6.2. **Rhizobium - fertilizer interaction**

Maximum yield and nodulation of soybean without Rhizobium inoculation in field tests, where soybeans had been grown previously, was obtained with 40kg N ha^{-1}. Inoculation did not improve nodulation and crop yield. (Shahidullah and Hussain, 1980).

Soybeans inoculated with Rhizobium japonicum and given low rates of nitrogen and medium to high rates of phosphorus exhibited increased nodule number, dry weight and leghaemoglobin content (Dadson and Acquaah, 1984). Raju and Verma (1984) obtained significant increase in nodulation of mung due to Rhizobium alone or Rhizobium + 15 kg N ha^{-1}. Maximum dry weight plant^{-1}, protein yield and nitrogen uptake were recorded with Rhizobium + 15 kg N ha^{-1}.

Highest top dry matter and total nitrogen in two soils (infertile and medium fertile soils) were obtained with inoculation and phosphorus treatment (200 kg P_2O_5 ha^{-1}). The rate of increase was 116 percent in poor soils and 46 percent in fertile soils. (Garza et al., 1987).

Viteri et al. (1988) observed increased plant weight by inoculation with Rhizobium strains and increasing nitrogen rates, ie, with 0,75 and 150 ppm nitrogen the plant dry weight was 11.6, 26.1. and 29.9 mg and 6.8, 29.1 and 39.2 mg without inoculation.

In a trial with Vigna radiata Cv. Bl Basu et al. (1989) observed that seed inoculation with Rhizobium strains increased nodulation and shoot dry weight. Application of 20,30 or 40 kg N ha^{-1} gave 0.91, 0.98 and 0.90 t ha^{-1}, compared to 0.70 t without nitrogen.

Puspharaj et al. (1995), in a study to find out the effect of nitrogen and Rhizobium inoculations in sorghum - soybean intercropping inferred that the sorghum intercropped with soybean at 50 percent of the recommended level of nitrogen (45kg N ha^{-1}) in combination with the Rhizobium gave the highest yield of sorghum and soybean with a saving of 45 kg N ha^{-1}.

2.6.3. **Vesicular arbuscular mycorrhiza (VAM) - fertilizer interaction.**

Smith and Daft (1977) observed that application of phosphorus did not significantly reduce infection by VA mycorrhiza. But Asimi et al. (1980) reported that the levels of phosphorus application and infection by VAM fungi are inversely related.

Increase in phosphate fertilization considerably diminished mycorrhizal infection and, in particular, fungal spread within the roots, hence, the effect of VA mycorrhiza on *Rhizobium* is only through increased supply of phosphorus in soybean (Bethlenfalway and Yoder, 1981). Robson et al. (1981) suggests that effects of VA mycorrhiza on nodulation and nitrogen fixation operated through effects of P-nutrition of the host.

Santhi et al. (1988) reported that in green-gram, among the different sources of phosphorus tried, rock phosphate was more efficiently utilised when applied with VA mycorrhiza. VAM inoculation with 50 percent rock phosphate was as good as full dose of phosphorus alone.

Donds and Schenck (1990) found that plants receiving a balanced nutrient solution without phosphorus consistantly had the greatest percentage of root length, colonized by VA mycorrhizal fungi.

Diederichs (1991) found that root infection with VA mycorrhiza was always highest in the treatment with single super phosphate and in most cases correlated with plant growth of maize.

Mercy *et al*. (1991) reported that the mycorrhizal colonization and shoot phosphorus concentration were higher in inoculated plants with 11 kg P ha^{-1}. Application of phosphorus fertilizers increased the yield parameters and decreased mycorrhizal spore number in rhizosphere soil (Sasai, 1991).

Shen *et al*. (1994) found that mycorrhizal colonization of plant roots in maize reduced as the phosphorus nutrition of the plant was increased.

Mishra *et al*. (1995) reported that the conjunctive use of biofertilizers and half of the recommended nitrogen, phosphorus and potassium led to the additional yield in maize.

MATERIALS AND METHODS

MATERIALS AND METHODS

The present investigation envisaged the possibility of increasing the herbage production of fodder maize-cowpea intercropping system by microbial inoculation and thus to save fertilizer without affecting the productivity.

The field experiment was conducted during the period from July 1994 to September 1994. The materials used and the methods adopted for the study are detailed hereunder.

3.1. Materials

3.1.1. Experimental site

The experiment was conducted at the Instruction farm, attached to the College of Agriculture Vellayani.

3.1.2. Soil

The soil of the experimental area was sandy clay loam. The data on the physico-chemical properties of the soil of the experimental site are given below.

A) Physical properties

Mechanical composition

Constitute	Content in soils (%)	Method used
Coarse sand	14.20	International
Fine sand	33.30	Pipette method
Silt	27.50	(Piper, 1950)
Clay	25.60	

Textural class : Sandy clay loam

B. Chemical composition

Constituent	Content in Soil ($kg\ ha^{-1}$)	Rating	Method used
Available nitrogen	238.1	Low	Alkaline Potassium permanganate method (Subbiah and Asija, 1956)
Available P_2O_5	38.4	Medium	Bray Colorimetric method (Jackson,1973)
Available K_2O	67.12	Low	Ammonium acetate method (Jackson, 1973)
Available Calcium	412.32		Ammonium acetate method (Jackson, 1973)
Available magnesium	51.7		Ammonium acetate method (Jackson, 1973)
PH	5.1	Acidic	1:2.5 soil solution ratio using pHmeter

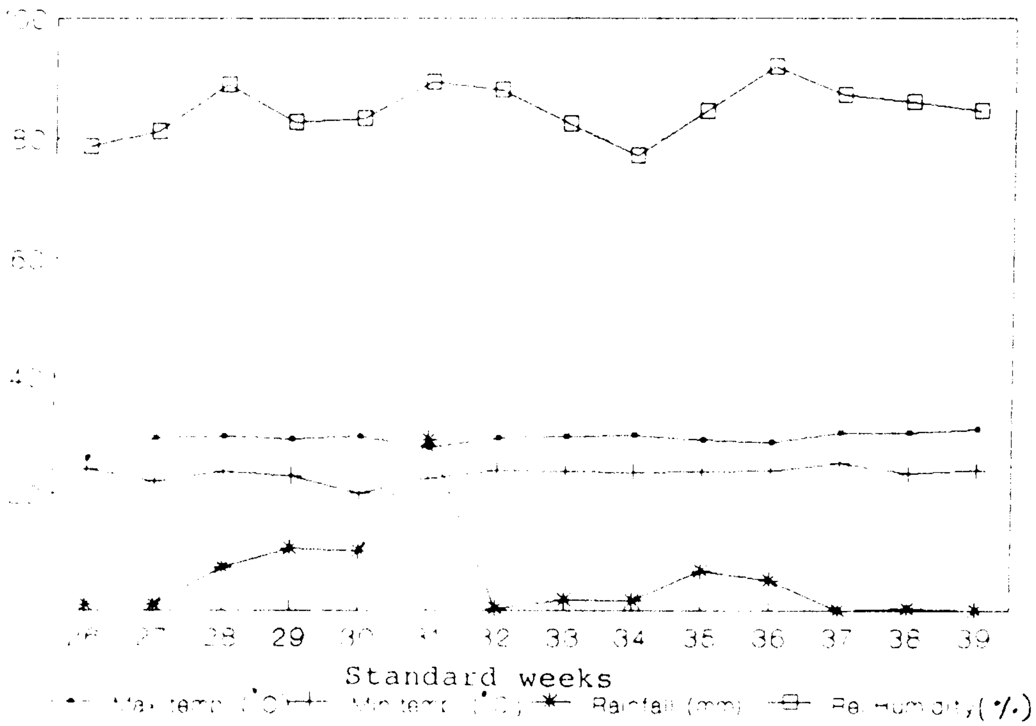

Fig.1. Weather condition during the cropping period

Cowpea: The fodder variety C - 152 was used. It gives 30 to 50 t ha^{-1} green fodder yield with 16 to 22 percent crude protein content.

3.1.7. Source of seed

The seeds were obtained from the National Seeds Corporation Ltd., (NSC), Branch Office, Karamana. The seeds were tested for viability and were found to give 99 to 100 percent germination.

3.1.8. Fertilizers

Fertilizers with the following analysis were used for the study.

Urea : 46 percent N

Mussoori Rock Phosphate : 20 percent P_2O_5

Muriate of Potash : 60 percent K_2O

3.1.9. Inoculants

3.1.9.1. *Azospirillum* culture

The *Azospirillum* culture for inoculation of maize seeds were obtained from M/s. The National Biofertilizers, Sasthamangalam.

3.1.9.2. <u>Rhizobium</u> culture

The *Rhizobium* culture for inoculation of cowpea seeds were obtained from M/s. The National Biofertilizers, Sasthamangalam.

3.1.9.3. **Mycorrhizal inoculum**

The mycorrhizal inoculum was obtained from the Division of Plant Pathology, College of Agriculture, Vellayani. The soil-sand culture containing infected root segments, mycorrhizal spores etc. served as mycorrhizal inoculum.

3.2 **Methods**

3.2.1. **Land preparation**

The field was dug twice, stubbles removed, clods broken and field was laid out into blocks and plots.

3.2.2. **Fertilizer application**

Fertilizers were applied to all the plots as per the treatment. Nitrogen, phosphorus and potassium were applied to the plots in the form of urea, musooriphos and muriate of potash respectively. The entire quantity of fertilizers were applied to the plot one day prior to sowing.

3.2.3. Seeds and Sowing

3.2.3.1. Seed rate

Seed rate of 40-60 kg ha^{-1} maize and 40-50 kg ha^{-1} for cowpea as recommended in the package of practices, KAU was adopted.

3.2.3.2. Seed treatment

1. ***Azospirillum***

Maize seeds were thoroughly mixed with the *Azospirillum* culture by using rice gruel of previous day, few hours before sowing. The inoculated seeds were dried under shade over a clean paper and sown immediately.

2. ***Rhizobium***

Cowpea seeds were thoroughly mixed with the *Rhizobium* culture, by using rice gruel of previous day, few hours before sowing. The inoculated seeds were dried under shade over a clean paper and sown immediately.

3. **Vesicular Arbuscular Mycorrhiza (VAM)**

For both maize and cowpea, approximately 10 g of soil and root debris from the pot cultures was placed at a depth of 3-5 cm and mixed with the soil, over which the seeds were sown so that all the developing roots passed through the inoculum.

3.2.3.3. **Method of sowing**

All the seeds were dibbled at the rate of two seeds per hole at a depth of 3-5 cm. One row of cowpea was sown in between two rows of maize.

3.2.4. **After cultivation**

Gap filling and thinning were done on the seventh day after sowing to secure a uniform stand of the crop.

3.2.5. **Irrigation**

One light irrigation was given immediately after sowing and then in alternate days.

3.2.6. **Plant protection**

Ekalux (0.05 percent) was sprayed against thrips attack, at 40 DAS.

3.2.7. **Harvest**

The crop was harvested on 17.9.1995 from above ground level, when maize crop was in the milk stage and cowpea at 50 percent flowering.

3.3. Technical programme

3.3.1. Design and layout

The experiment was laid out as strip plot experiment with 25 treatment combinations. The layout plan is shown in fig 2.

Gross plot size	:	3m x 3m
Net plot size	:	2.4 m x 1.8 m
Spacing	:	30x15 cm for maize and cowpea
Treatment combinations	:	25
Replications	:	3
Total number of plots	:	75

3.3.2. Treatments

a. **Inoculations : 5**

1. No biofertilizer (b_0)
2. Azospirillum - maize + Rhizobium - Cowpea (b_1)
3. Azospirillum - maize + VAM-cowpea (b_2)
4. VAM - maize + VAM - cowpea (b_3)
5. VAM - maize + Rhizobium - cowpea (b_4)

b. **Nutrient levels : 5**

1. No nutrients (f_0)
2. 25 percent of recommended dose (f_1)
3. 50 percent of recommended dose (f_2)
4. 75 percent of recommended dose (f_3)
5. 100 percent of recommended dose (f_4)

Fig.2. LAY OUT PLAN-FACTORIAL EXPERIMENT IN STRIP PLOT DESIGN

N <——

R I

T_3	T_1	T_5	T_4	T_2
T_{13}	T_{11}	T_{15}	T_{14}	T_{12}
T_8	T_6	T_{10}	T_9	T_7
T_{23}	T_{21}	T_{25}	T_{24}	T_{22}
T_{18}	T_{16}	T_{20}	T_{19}	T_{17}

R II

T_{24}	T_{25}	T_{21}	T_{22}	T_{23}
T_9	T_{10}	T_{11}	T_7	T_8
T_4	T_5	T_1	T_2	T_3
T_{14}	T_{15}	T_{11}	T_{12}	T_{13}
T_{19}	T_{20}	T_{16}	T_{17}	T_{18}

R III

T_{12}	T_{14}	T_{15}	T_{11}	T_{13}
T_{25}	T_{24}	T_{22}	T_{21}	T_{23}
T_{17}	T_{19}	T_{20}	T_{16}	T_{18}
T_7	T_9	T_{10}	T_6	T_8
T_2	T_4	T_5	[illegible]	T_3

Gross plot size : 3m x 3m
Net plot size : 2.4m x 1.8m

$T_1-b_0f_0$	$T_6-b_1f_0$	$T_{11}-b_2f_0$	$T_{16}-b_3f_0$	$T_{21}-b_4f_0$
$T_2-b_0f_1$	$T_7-b_1f_1$	$T_{12}-b_2f_1$	$T_{17}-b_3f_1$	$T_{22}-b_4f_1$
$T_3-b_0f_2$	$T_8-b_1f_2$	$T_{13}-b_2f_2$	$T_{18}-b_3f_2$	$T_{23}-b_4f_2$
$T_4-b_0f_3$	$T_9-b_1f_3$	$T_{14}-b_2f_3$	$T_{19}-b_3f_3$	$T_{24}-b_4f_3$
$T_5-b_0f_4$	$T_{10}-b_1f_4$	$T_{15}-b_2f_4$	$T_{20}-b_3f_4$	$T_{25}-b_4f_4$

Recommended nutrient dose :-

Fodder maize : 120:60:40 N, P_2O_5, K_2O, Kg ha^{-1}.

Fodder cowpea : 25:60:30 N, P_2O_5, K_2O Kg ha^{-1}.

3.3.3. **Treatment combinations-**

The treatment combinations are as follows:

T1 - b_0f_0

T2 - b_0f_1

T3 - b_0f_2

T4 - b_0f_3

T5 - b_0f_4

T6 - b_1f_0

T7 - b_1f_1

T8 - b_1f_2

T9 - b_1f_3

T10- b_1f_4

T11- b_2f_0

T12- b_2f_1

T13- b_2f_2

T14 - b_2 f_3

T15 - b_2 f_4

T16 - b_3 f_0

T17 - b_3 f_1

T18 - b_3 f_2

T19 - b_3 f_3

T20 - b_3 f_4

T21 - b_4 f_o

T22 - b_4 f_1

T23 - b_4 f_2

T24 - b_4 f_3

T25 - b_4 f_4

3.4. **Observations recorded**

The characters studied and the observations recorded are detailed below.

3.4.1. Biometric observations

3.4.1.1. Height of the plant

Five plants each of maize and cowpea were selected at random and tagged. The height from the base of the plant to the tip of the growing point was measured in centimetres at three stages of growth viz., 20th day, 40th day and 60th day (harvest) after sowing. The mean height of plants was worked out and recorded.

3.4.1.2. Number of leaves.

The total number of leaves in maize and cowpea were recorded on 20th day, 40th day and 60th day after sowing and mean number per plant was worked out.

3.4.1.3. Leaf Area Index (LAI)

The leaf area index of maize and cowpea were found out in a leaf area meter at the time of harvest.

3.4.1.4. Leaf - Stem Ratio

The samples taken for drymatter estimation were separated into leaf and stem for both crops and oven dried for three days The dry weight of leaves and stem of individual plants were recorded and ratio compared by dividing the leaf dry weight by the stem dry weight.

3.4.1.5. Green - matter yield

The green matter yield of maize and cowpea per hectare were calculated from the net plot area.

3.4.1.6. Dry - matter yield

The samples of maize and cowpea were air dried and then oven dried at 80 ± 5^{o}C till a constant weight was obtained and dry matter production per hectare was calculated.

3.4.1.7. Nodule number

The sample plants of cowpea were irrigated and carefully lifted on the following day with the help of a spade taking care to see that dislodging of nodules and damage to the root system didnot take place. The roots were washed free of adhering soil with a slow jet of water. The root nodules from each plant were separately collected with the help of a forceps and counted.

3.4.1.8. Nodule fresh weight

From the same plant samples after counting the nodule number, the nodules were separated, washed with cold distilled water and weighed in a sartorius balance after drying on a filter paper and recorded in milligrams.

3.4.1.9. **Nodule dry weight**

The same nodules were dried to a constant weight at 60°C in a drying oven and then dry weight was recorded.

3.4.1.10. **Root length**

The root length of the sample plants were taken from the base of the shoot to the maximum growing tip with the help of a meter scale.

3.4.1.11. **Root volume**

The root volume was recorded by water displacement method as stated below. The roots of sample plants were washed free of adhering soil with a slow jet of water. The roots were immersed in 1000 ml measuring cylinder containing water, and the rise in water level was recorded. Displacement in volume of water was taken as a measure of the volume of the root measured.

3.4.1.12. **Mycorrhizal colonization in the root**

The washed roots were taken and the VA-mycorrhizal infection in the root samples were observed by staining the root tissue (Phillips and Hayman, 1970).

3.4.2. **Analytical procedures**

3.4.2.1. **Plant analysis**

The whole plant was analysed for nitrogen, phosphorus, potassium, calcium, magnesium, fibre and protein content. The plant samples were dried in an oven at 70°C till constant weights were obtained. The samples were then ground to pass through a 0.5mm mesh in a Wiley mill. The required quantity of samples were then weighed out in an electronic balance and analysis was carried out.

3.4.2.1.1. **Nitrogen content**

Total nitrogen content was estimated by modified microkjeldhal method (Jackson, 1973) and the values were expressed as percentages.

3.4.2.1.2. **Phosphorus content**

Phosphorus content was estimated calorimetrically (Jackson, 1973) by developing colour by vanadomolybdo phosphoric yellow colour method and read in klett-summerson photo electric calorimeter.

3.4.2.1.3. **Potassium content**

The potassium content of samples were determined after extraction with neutral normal ammonium acetate extract and then reading in an EEL flame photometer.

3.4.2.1.4. **Calcium and magnesium content**

The total calcium and magnesium content of samples were determined after extraction and then determined using Atomic Absorption Spectrophotometer.

3.4.2.1.5. **Uptake studies**

The total uptake of nitrogen, phosphorus, potassium, calcium and magnesium were calculated based on the contents of these nutrients and the dry matter produced at these stages were expressed in kg ha^{-1}.

3.4.2.1.6. **Quality characteristics**

The crude protein content was calculated by multiplying the percentage of nitrogen by a factor 6.25 (Simpson et al, 1965). The crude protein yield was calculated by multiplying the crude protein content by dry matter production and expressed in kg ha^{-1}.

The crude fibre content was determined by A.O.A.C. method (1975) and multiplied by dry matter production to get the crude fibre yield.

3.4.2.2. **Soil analysis**

Soil samples were taken from the experimental area before and after the experiment. The air dried soil samples were analysed for the mechanical composition and chemical characteristics using the standard procedures.

3.5. Economics of cultivation

Net income was calculated as the difference between the gross income and cost of cultivation.

Net income = Gross income-Cost of cultivation.

Benefit-cost ratio was calculated as the ratio of the gross income and cost of cultivation.

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

3.6. Statistical analysis

The data generated from the experiment was subjected to analysis of variance technique (ANOVA) as applied to strip plot experiment in RBD as suggested by Cochran and Cox (1962). Analysis excluded data pertaining to nodule number, nodule weight and mycorrhizal colonization in the root, since observations were made only from a composite sample.

RESULTS

RESULTS

A field experiment was conducted in the Instructional farm, College of Agriculture, Vellayani to study the effect of different bioinoculants (Azospirillum, Rhizobium and Vesicular arbuscular mycorrhiza) in increasing the fodder productivity of maize-cowpea intercropping system and to find out the fertilizer economy due to biofertilizer inoculation. Observations were made on growth, yield, nutrient and quality characters. The data recorded were analysed statistically and the results are given below vide Tables 4.1 - 4.14

4.1 Growth characters

4.1.1. Height of plants

The influence of different chemical nutrients and inoculants on the height of plants at various growth stages are presented in Table 4.1.

(a) Maize

The main effects of biofertilizers, chemical fertilizers and their interactions were found to be significant except for the main effect of biofertilizer at 60 DAS.

Table 4.1. Effect of treatments on plant height (cm) of maize and cowpea at different stages.

CF / BF	Maize						Cowpea					
	f_0	f_1	f_2	f_3	f_4	BF	f_0	f_1	f_2	f_3	f_4	BF
20 DAS												
b_0	32 70	34.96	42.69	54.68	57.69	44.54	20.86	22.72	27.78	29.82	33.61	26.96
b_1	36.38	36.73	55.71	56.91	57.29	48.61	23.90	24.75	30.48	33.57	32.78	29.10
b_2	37.03	39.73	57.26	53.70	54.66	48.48	23.74	24.65	29.76	36.07	35.90	30.03
b_3	35.08	43.00	55.61	54.55	54.73	48.59	21.84	23.67	28.55	31.85	32.78	27.74
b_4	35.94	43.68	55.51	53.72	54.50	48.47	24.99	25.91	30.92	36.02	35.88	30.74
CF	35.42	39.42	53.36	54.71	55.77		23.07	24.34	29.50	33.47	34.19	
SEm ± = 0.752							0.146					
CD (BF, CF, BF x CF) = 1.231, 1.238, 2.174							0.348, 0.368, 0.423					
40 DAS												
b_0	38.18	44.43	82.17	91.78	125.61	76.64	46.74	60.62	70.47	87.84	90.78	71.29
b_1	42.10	46.78	117.40	118.41	119.84	89.11	61.59	65.74	79.80	90.98	90.38	77.70
b_2	44.35	56.88	127.48	134.70	128.8	98.85	53.16	64.70	75.56	89.51	90.88	74.76
b_3	40 18	57.06	121.44	126.36	127.10	94.63	52.68	62.82	75.45	89.10	89.48	73.91
b_4	44 90	58.77	121.36	123.92	126.18	95.23	60.58	68.47	79.90	91.55	91.85	78.47
CF	41.94	52.79	113.97	119.04	120.71		54.95	64.47	76.24	89.80	90.67	
SEm ± = 0.142							0.276					
CD (BF, CF, BF x CF) = 0.182, 0.182, 0.410							0.320, 0.595, 0.798					
60 DAS												
b_0	88.70	94.86	160.72	169.73	171.40	137.08	70.19	80.54	92.61	98.40	100.71	88.49
b_1	95.72	138.84	169.85	168.11	166.38	147.98	76.41	84.59	95.63	103.02	101.85	92.30
b_2	94.05	123.92	171.94	169.86	170.41	145.84	75.80	82.46	93.36	100.64	101.56	90.77
b_3	91.78	129.61	167.04	167.38	165.08	144.18	74.40	82.60	93.29	99.42	99.61	89.06
b_4	127.08	126.08	166.38	168.14	169.35	151.61	79.48	85.52	96.33	103.52	102.10	93.39
CF	99.47	122.66	167.19	168.05	169.32		75.26	83.14	94.24	101.00	101.17	
SEm ± = 6.808							0.184					
CD (BF, CF, BF x CF) = 9.278, 9.643, 19.675							0.182, 0.387, 0.531					

At 20DAS:

At 20 DAS no significant difference in plant height was observed among maize plants treated with different inoculants, though these treated plants recorded a significant increase in plant height compared to control. Biofertilizer b_3 was found to be inferior to b_1, b_2, b_4.

An increase in the dose of nutrients was found to increase the plant height. In the case of plants treated with above 75 percent package of practice recommendation (f_3) no positive effect was noted.

In the absence of nutrients, no significant difference in height was seen in plants treated with different inoculants. In combination with 25 percent and 50 percent recommended dose of chemical fertilisers b_1, b_2, b_4 treated plants grew taller than others. But biofertiliser in combination with 75 percent and 100 percent of recommended dose of chemical fertilisers produced differential response. b_2 & b_4 treated plants produced taller plants.

At 40 DAS

The plants inoculated with b_2 produced taller plants. At 40 DAS, more than 75 percent of package of practices recommendation of chemical fertilisers did not produce any positive response.

At 40 DAS, under all the dosage of fertilizers b_2 in combination with f_2, f_3, f_4 produced taller plants.

At 60 DAS

The effect of inoculants on plant height was not significantly higher.

Treatments above 50 percent of the recommended dose of chemical fertilisers did not show any positive response.

At later stages, no significant difference in plant height was observed with respect to inoculants in combination with fertiliser.

(b) **Cowpea**

At 20 DAS

Due to biofertilizer inoculation no significant difference in plant height was observed. b_4 treatment produced taller plants among all others.

It was further noted that there was no significant difference in height with respect to the dosage of chemical fertilizers above 75 percent of the recommended dose (f_3).

Where chemical fertilizers were not combined with biofertilizer, b_1 and b_2 treated plants showed more height. When combined with f_1, b_3, b_4 treated plants recorded more height. With 75 percent of recommended dose of nutrients b_1 treated plants recorded more height.

At 40 DAS

Biofertilizer b_1 & b_4 treated plants produced taller plants.

An increase in chemical fertilizers above 75 percent did not show any marked increase in plant height.

When biofertilizer was applied in combination with f_0, f_1, f_2, f_3, b_1 and b_4 were found to be superior, but with f_4, b_4 produced taller plants.

At 60 DAS

On an average b_4 treated plants recorded taller plants.

Here also, f_3 treated plants recorded taller plants. Doses above f_3 did not produce any positive response.

At this stage f_1, f_2, f_3 rates of chemical fertilizers with b_1 and b_4 treated plants were taller than others among which f_3 b_4 treated plants recorded more height.

4.1.2 **Number of leaves**

The mean number of leaves per plant at different growth stages of the crops are presented in Table 4.2.

Table 4.2. Effect of treatments on number of leaves of maize and cowpea at different stages.

CF / BF	Maize f_0	f_1	f_2	f_3	f_4	BF	Cowpea f_0	f_1	f_2	f_3	f_4	BF
20 DAS												
b_0	2.01	3.06	3.71	4.45	4.54	3.56	7.10	8.21	9.13	10.40	11.17	9.20
b_1	4.00	4.05	4.13	4.20	4.60	4.20	8.28	10.35	11.21	11.20	11.13	10.44
b_2	4.37	4.84	5.08	4.78	4.70	4.75	8.26	9.10	11.13	11.16	11.09	10.15
b_3	3.58	4.15	4.40	4.54	3.69	4.07	8.28	9.11	10.42	11.16	11.18	10.03
b_4	4.14	4.22	4.47	4.58	4.68	4.42	9.02	10.69	11.53	11.21	11.52	10.80
CF	3.62	4.06	4.36	4.51	4.44		8.19	9.49	10.69	11.03	11.32	
SEm ± = 0.019							0.178					
CD (BF, CF, BF x CF) = -, -, 0.055							0.371, 0.226, 0.513					
40 DAS												
b_0	3.15	3.43	4.56	5.56	7.07	4.76	22.78	28.71	34.41	34.18	35.59	31.13
b_1	4.65	5.10	8.17	8.22	8.52	6.93	26.60	31.33	35.45	35.66	35.29	33.06
b_2	4.74	5.76	8.07	7.77	7.76	6.82	24.61	30.45	34.41	34.60	34.71	31.76
b_3	4.38	5.19	7.50	6.43	6.50	6.00	24.44	30.45	32.70	33.15	34.37	31.02
b_4	4.84	5.25	7.62	7.40	7.75	6.57	27.48	32.48	36.73	34.76	35.60	33.21
CF	4.35	4.95	7.18	7.08	7.52		25.18	30.68	34.74	34.47	35.11	
SEm ± = 0.215							0.195					
CD (BF, CF, BF x CF) = 0.238, 0.290, 0.622							0.343, 0.318, 0.564					
60 DAS												
b_0	6.42	8.26	12.03	13.71	13.95	11.03	25.58	34.05	44.46	47.44	51.21	40.95
b_1	8.48	10.34	15.39	14.47	15.67	12.87	34.11	40.90	51.23	50.12	50.94	45.47
b_2	7.51	10.57	14.03	14.82	14.88	12.36	33.45	39.06	46.07	49.17	51.03	43.76
b_3	7.38	9.43	12.66	13.56	13.98	11.40	31.03	39.01	45.11	48.28	48.92	42.47
b_4	7.22	9.51	13.58	13.30	13.52	11.43	34.38	40.89	51.29	50.92	51.72	45.83
CF	7.40	9.62	13.70	13.97	14.40		32.11	38.78	47.63	49.69	50.00	
SEm ± = 0.196							0.222					
CD (BF, CF, BF x CF) = 0.313, 0.362, 0.565							0.390, 0.311, 0.642					

(a) **Maize**

At 20 DAS

On an average, b_2 treated plants produced more leaves.

There was no significant difference in the number of leaves among the different fertilizer levels but number of leaves was significantly higher in comparison to control.

The number of leaves in maize was influenced by the interaction effect of fertilizer and inoculants. At 20 DAS, the number of leaves were found to be less for b_2 and b_3 when combined with f_4.

At 40 DAS

Biofertiliizer b_1 and b_2 produced more leaves.

At this stage plants grown under package of practice recommendation of chemical fertilizer (f_4) recorded more number of leaves.

In the absence of chemical fertilizers, no significoant difference among biofertilizer was obtained. But when higher levels of chemical fertilizer was combined with inoculants, b_1 was found to be better.

At 60 DAS

On an average, b_1 was superior to other inoculants.

At this stage, recommended dose of fertilizer (f_4) resulted in better production of leaves.

When fertilizer was not combined with inoculants, b_1 was found to be better, but along with f_1 both b_1 and b_2 produced more leaves while where higher doses of fertilizers were combined, b_1 was superior to others.

(b) **Cowpea**

At 20 DAS

Biofertilizer b_4, recorded the maximum number of leaves.

Regarding the fertilizer dose, leaf production was more for the highest level of chemical fertilizers (f_4).

At higher doses of chemical fertilizers no significant difference with respect to biofertilizer was seen. At f_2 level, b_1 and b_4 level, there was no significant increase in leaf production, in combination with other inoculants.

At 40 DAS

Biofertilizer, b_1 and b_4 treated plants produced more leaves.

Among fertilizer levels higher number of leaves was recorded under the treatment package of practices recommendation.

At 40 DAS, significant increase in the number of leaves was noticed in b_4 treated plants. b_1 and b_4 in combination with f_2 level produced more number of leaves.

At 60 DAS

Here also, b_1 and b_4 produced the highest number of leaves.

Fertilizer levels after f_2 did not record any marked increase in leaf number.

Biofertilizer b_4 was found to be the best in combination with all levels of chemical fertilizers.

4.1.3. **Leaf Area Index**

The mean leaf area index of the crops are presented in Table 4.3.

(a) **Maize**

Both the main effect of biofertilizer and chemical fertilizers and their interactions were found to be significant. b_2 treated plants, recorded more leaf area index.

Table 4.3. Effect of treatments on Leaf Area Index (LAI) and Leaf-Stem Ratio (LSR) of maize and cowpea.

CF / BF	Maize f_0	Maize f_1	Maize f_2	Maize f_3	Maize f_4	Maize BF	Cowpea f_0	Cowpea f_1	Cowpea f_2	Cowpea f_3	Cowpea f_4	Cowpea BF
Leaf Area Index												
b_0	4.60	5.64	6.56	6.95	9.08	6.57	6.06	6.84	7.20	7.27	7.76	7.03
b_1	6.65	7.57	9.56	9.25	9.01	8.41	6.89	7.88	8.11	8.21	6.18	7.85
b_2	6.63	7.71	10.53	9.53	9.25	8.73	6.87	7.52	7.69	8.08	8.22	7.68
b_3	5.39	6.55	7.75	8.12	8.43	7.25	6.85	7.10	7.27	7.35	7.39	7.19
b_4	5.50	6.46	8.33	8.53	8.71	7.51	6.94	7.13	8.24	8.18	8.23	7.75
CF	5.76	6.79	8.55	8.48	8.90		6.72	7.30	7.70	7.82	7.96	
SEm ± = 0.111							0.079					
CD (BF, CF, BF x CF) = 0.113, 0.261, 0.321							0.071, 0.116, 0.227					
Leaf-Stem Ratio												
b_0	1.28	1.32	1.41	1.48	1.57	1.41	0.14	0.26	0.89	0.88	0.92	0.62
b_1	1.30	1.42	1.52	1.79	1.50	1.50	0.24	0.80	1.25	1.36	1.34	1.00
b_2	1.41	1.64	2.74	1.72	1.68	1.84	0.19	0.52	1.09	1.18	1.22	0.84
b_3	1.32	1.42	1.95	1.76	1.57	1.60	0.18	0.35	1.06	1.09	1.17	0.77
b_4	1.39	1.43	2.43	1.69	1.64	1.72	0.21	0.69	1.37	1.34	1.30	0.98
CF	1.34	1.44	2.01	1.69	1.59		0.19	0.52	1.13	1.17	1.19	
SEm ± = 0.073							0.007					
CD (BF, CF, BF x CF) = 0.107, 0.150, 0.210							0.012, 0.011, 0.021					

The effect of fertilization an leaf area index of maize was highest at recommended dose of fertilizers (f_4).

The interaction effect b_1 and b_2 were found to be better combiners and no significant differences was seen in leaf area index when mixed with f_3 and f_4.

(b) **Cowpea**

Maximum leaf area index of cowpea was noticed for b_1 inoculant.

The leaf area index of cowpea increased due to application of fertilizer. The highest level (f_4) recorded the maximum leaf area index.

b_1 and f_4 interaction were found to record more leaf area index of 8.22. When biofertilizers were applied alone, no significant difference in leaf area index was seen with respect to b_1, b_2, b_3, b_4. But in combination with chemical fertilizer, b_1, b_2 and b_4 produced more or less similar results at the doses f_3 and f_4.

4.1.4 Leaf stem Ratio

The mean leaf-stem ratio of the crops are presented in Table 4.3.

(a) **Maize**

The effect of chemical fertilizer, biofertilizer and their interaction was significant. Maximum ratio was observed for b_2 treated plants which was on par with b_4.

Leaf stem ratio was maximum at 50 percent recommended dose of fertilizer (f_2) which significantly differ from that noticed at other levels. A decrease in leaf stem ratio was noticed at highest level of fertilizer (f_4).

No significant difference was observed in plants when biofertilizer was applied alone, but in combination with f_2, b_2 was most effective in increasing the leaf-stem ratio of maize. It was also noted that at higher fertilizer level (f_4) under all the levels of inoculants a decrease in the value of leaf-stem ratio was noticed.

(b) **Cowpea**

The mean effect of inoculant b_1 showed significant influence on this character.

Significant response to increase in nutrient levels was observed on leaf-stem ratio of plants. The highest value of 1.19 was recorded by f_4 level.

Biofertilizer b_1, recorded maximum leaf-stem ratio with out combining chemical fertilizer and when combined with 25 percent chemical fertilizer with f_3, b_4 recorded higher ratio 061.37 followed by b_1 which when combined with f_3 and f_4, produced highest leaf-stem ratio.

4.2 Root characters

The mean values of root length, root-volume, nodule count, nodule weight and mycorrhizal colonization of crops are presented in Tables 4.4 & 4.5.

4.2.1 Root length

(a) Maize

The root length was found to be higher in all treatments with minimum fertilizer dose. Maximum root length (35.01cm) was observed for b_1 f_0, followed by b_3 f_0.

(b) Cowpea

The root length was affected in treatments with no inoculants and with high fertilizer levels. Root length was highest for b_2 f_4 (26.14cm) and lowest for b_0 f_0.

Table 4.4. Effect of treatments on root length (cm), root volume (cm^3) and mycorrhizal colonization percentage of maize

Treatment	Root length	Root volume	Mycorrhizal Colonization
b_0f_0	18.50	59.91	18.00
b_0f_1	17.20	55.12	25.00
b_0f_2	19.80	56.12	20.00
b_0f_3	19.90	58.15	23.00
b_0f_4	20.50	52.42	17.00
b_1f_0	35.01	78.72	40.00
b_1f_1	31.10	77.34	35.00
b_1f_2	29.52	75.45	38.00
b_1f_3	30.09	75.33	28.00
b_1f_4	31.52	74.54	45.00
b_2f_0	34.49	102.44	55.00
b_2f_1	32.08	101.33	50.00
b_2f_2	31.15	100.25	60.00
b_2f_3	31.21	99.23	55.00
b_2f_4	30.90	96.12	50.00
b_3f_0	34.98	88.99	75.00
b_3f_1	32.08	87.56	80.00
b_3f_2	30.12	86.01	90.00
b_3f_3	30.50	85.00	75.00
b_3f_4	30.09	83.73	70.00
b_4f_0	33.99	99.01	65.00
b_4f_1	31.01	98.72	70.00
b_4f_2	30.09	96.53	85.00
b_4f_3	31.12	94.73	80.00
b_4f_4	30.99	92.12	75.00

Table 4.5. Effect of treatments on root length (cm), number of nodules, nodule weight (mg) and mycorrhizal colonization percentage of cowpea.

Treatment	Root length	Number of nodules	Nodule fresh weight	Nodule dry weight	Mycorrhizal colonization
b_0f_0	14.81	0.17	0.52	0.23	32.00
b_0f_1	15.32	0.46	0.68	0.24	30.00
b_0f_2	17.12	0.68	0.61	0.28	31.00
b_0f_3	19.21	1.20	0.60	0.39	34.00
b_0f_4	19.11	1.30	0.92	0.31	29.00
b_1f_0	19.82	28.81	107.17	48.50	35.00
b_1f_1	20.91	29.81	109.00	48.17	32.00
b_1f_2	21.41	30.92	121.83	33.00	42.00
b_1f_3	21.82	30.96	158.00	67.83	39.00
b_1f_4	22.31	30.41	134.17	56.33	30.00
b_2f_0	20.67	27.62	1.35	0.61	92.00
b_2f_1	22.33	28.62	1.38	0.68	91.00
b_2f_2	27.21	29.69	1.41	0.72	85.00
b_2f_3	25.13	29.72	2.01	0.99	86.00
b_2f_4	26.14	29.52	1.58	0.76	72.00
b_3f_0	18.13	26.60	1.06	0.40	95.00
b_3f_1	20.67	26.61	1.08	0.48	96.00
b_3f_2	22.56	27.42	1.10	0.45	89.00
b_3f_3	22.56	27.61	1.17	0.53	88.00
b_3f_4	21.84	27.82	1.15	0.50	89.00
b_4f_0	17.95	31.48	87.83	27.83	72.00
b_4f_1	21.50	32.76	154.33	28.67	68.00
b_4f_2	26.33	33.91	136.83	48.83	65.00
b_4f_3	23.83	33.92	157.67	64.50	54.00
b_4f_4	25.81	33.42	87.83	58.11	50.00

4.2.2. Root volume for maize

Increase in root volume was observed only for maize. Higher values were recorded in the interaction having b_2 biofertilizer treatment, among which maximum value was for b_2 f_0 and minimum for b_0 f_4 treatment.

4.2.3 Nodule count for cowpea

In uninoculated plants, nodule number was very less and nodule number was higher for all b_4 inoculated plants. Highest value was noted for b_4f_3, followed by b_4f_2 and minimum for b_0f_0.

4.2.4 Weight of nodules

Low values of both fresh and dry weights were recorded in uninoculated plants and higher values observed for b_1 and b_4, at lower levels of fertilizer.

The value was found highest for b_1 f_3 treatments followed by b_4f_0 and lowest for b_0f_0.

4.2.5 Mycorrhizal colonization in the root

(a) Maize

The mean mycorrhizal colonization of maize roots, showed that the highest values was recorded by treatment combination b_3 f_2 (90%) followed by b_4f_2. The lowest value was recorded for the treatment b_0f_4. Although in uninoculated plants mycorrhizal colonization, was recorded the values were below 50 percent, and inoculated plants registered higher values even up to 90 percent.

(b) **Cowpea**

All the plants registered mycorrhizal colonization. Inoculated plants showed higher percentage values above 95. Highest value of mycorrhizal colonization was observed for b_3f_1 (96%) followed by b_3f_0 and lowest value for b_0f_4.

4.3 Yield Attributes

4.3.1. Green matter yield

The mean values on green matter yield of crops are presented in Tables 4.6

(a) **Maize**

Among the different inoculants, b_2 recorded the highest green-matter yield which significantly differed from all others.

The nutrient level f_2 registered the highest green-matter yield and thereafter at higher levels the yield started decreasing.

The green-matter yield was maximum(27.00 t ha^{-1}) for the interaction between b_2f_2, other inoculants did not show significant influence in increasing the production. Anyway, it was noted that under interaction the yield decreased at full recommended dose of fertilizer (f_4).

Table 4.6. Effect of treatments on green matter yield (t ha^{-1}) and dry matter yield (t ha^{-1}) of maize and cowpea.

CF / BF	Maize f_0	f_1	f_2	f_3	f_4	BF	Cowpea f_0	f_1	f_2	f_3	f_4	BF
Green matter yield												
b_0	7.71	11.11	16.87	21.71	23.38	16.15	3.59	6.63	8.42	10.56	12.48	8.34
b_1	10.02	14.20	19.82	21.31	21.59	17.39	6.30	8.31	10.38	11.52	12.09	9.72
b_2	16.11	17.00	27.00	25.35	24.37	21.96	5.45	7.48	8.48	10.24	10.32	9.40
b_3	14.24	15.07	21.59	17.82	16.68	17.08	5.13	6.68	9.33	9.27	10.31	8.14
b_4	14.67	16.00	23.00	18.98	17.00	17.93	6.34	8.73	13.31	13.27	12.69	10.87
CF	12.55	14.67	21.65	21.03	20.60		5.36	7.57	9.99	10.97	11.58	
SEm ± = 0.104							0.147					
CD (BF, CF, BF x CF) = 0.097, 0.151, 0.300							0.180, 0.289, 0.426					
Drymatter yield												
b_0	1.05	2.01	3.25	4.13	5.57	3.20	1.14	2.13	2.66	2.64	3.86	2.66
b_1	2.36	2.35	5.64	4.15	4.52	3.80	1.85	2.81	3.54	3.64	3.76	3.12
b_2	2.95	3.57	7.19	6.07	3.68	4.69	1.75	2.54	2.76	3.62	3.64	2.86
b_3	2.66	2.79	5.40	4.70	5.03	4.12	1.68	2.05	3.29	3.51	3.55	2.82
b_4	2.67	3.35	5.90	5.15	5.32	4.48	2.48	2.96	4.97	4.95	4.55	3.98
CF	2.34	2.81	5.48	4.84	4.82		1.78	2.50	3.44	3.87	3.87	
SEm ± = 0.213							0.092					
CD (BF, CF, BF x CF) = 0.313, 0.240, 0.617							0.128, 0.066, 0.266					

(b) **Cowpea**

The treatment b_4 recorded the maximum green matter yield which significantly differed from other treatments.

Maximum yield was produced by the highest level (f_4) and the effects due to different fertilizer levels differed significantly.

Inoculants b_1 and b_4 were on par when they were applied alone, but b_4 in combination with f_2 resulted in higher green-matter yield,(13.31t ha^{-1}) which was on par with b_4f_3. After f_2 level, the yield decreased. But with other inoculants, there was a slight increase in yield, with increase in nutrient levels.

4.3.2 **Dry matter** yield

The data on dry matter yield of maize and cowpea are given in Tables 4.6.

(a) **Maize**

The treatment b_2 produced more drymatter.

The fertilizer level f_2 was superior in increasing the drymatter yield of maize and at higher levels (f_3 & f_4), the yield started decreasing.

The interaction effect b_2f_2 was significant over f_2 and f_4 levels. At f_3 and f_4 levels decrease was noted for b_1 and b_4 inoculants.

(b) **Cowpea**

The dry matter production was highest for b_4 treatment.

Among the fertilizer levels 50 percent of recommended dose of fertilizer (f_2) was found to be sufficient.

The interaction effect b_4f_2 was significant.

4.4. **Chemical composition**

4.4.1 **Nitrogen content**

The mean value of nitrogen content of maize and cowpea expressed as percentage are presented in Table 4.7.

(a) **Maize**

The biofertilizer treated plants under b_2 recorded more nitrogen content.

The highest level of fertilization (f_4) gave the highest nitrogen content.

Maize plants grown with biofertilizer treatment b_2 and fertilizer level f_4 recorded the highest nitrogen content.

(b) **Cowpea**

The treatment inoculation b_1 recorded the highest nitrogen content which was followd by b_4.

The higher levels of fertilizer application (f_3 & f_4) were significantly superior to the lower levels.

Interaction effect b_4f_4 was significant. Under all combinations, f3 and f4 levels were on par.

4.4.2. **Phosphorus content**

The data on the phosphorus content of maize and cowpea are presented in Table 4.7.

(a) **Maize**

Among the biofertilizers, there was no significant difference in phosphorus content, the highest value was recorded for b_4.

No difference in phosphorus content was noted due to different chemical fertilizers.

Among all combinations of biofertilizers and fertilizers, b_4 under f_2 level recorded the highest phosphorus content in maize.

Table 4.7. Effect of treatments on nitrogen, phosphorus and potassium content (percentage) of maize and cowpea

CF / BF	Maize						Cowpea					
	f_0	f_1	f_2	f_3	f_4	BF	f_0	f_1	f_2	f_3	f_4	BF
Nitrogen												
b_0	0.90	0.91	0.99	1.13	1.21	1.03	0.92	1.12	1.34	2.41	2.82	1.72
b_1	1.21	1.23	1.63	1.65	1.68	1.48	2.94	2.89	3.02	3.05	3.04	2.99
b_2	1.24	1.26	1.76	1.75	1.76	1.56	2.13	2.39	2.75	2.95	2.93	2.63
b_3	1.17	1.21	1.39	1.42	1.37	1.31	1.94	2.11	2.69	2.81	2.75	2.46
b_4	1.23	1.23	1.38	1.38	1.38	1.32	2.85	2.88	2.97	3.07	3.10	2.97
CF	1.15	1.17	1.43	1.47	1.48		2.16	2.28	2.56	2.86	2.93	
SEm ± = 0.013							0.033					
CD (BF, CF, BF x CF) = 0.023, 0.018, 0.039							0.038, 0.056, 0.096					
Phosphorus												
b_0	0.10	0.18	0.15	0.20	0.21	0.17	0.09	0.13	0.12	0.15	0.20	0.14
b_1	0.12	0.13	0.14	0.20	0.22	0.16	0.11	0.12	0.15	0.17	0.20	0.15
b_2	0.11	0.13	0.14	0.20	0.22	0.16	0.11	0.12	0.15	0.17	0.20	0.15
b_3	0.19	0.20	0.25	0.22	0.23	0.22	0.17	0.20	0.23	0.24	0.24	0.22
b_4	0.20	0.24	0.27	0.26	0.26	0.25	0.15	0.17	0.18	0.20	0.21	0.18
CF	0.14	0.18	0.20	0.22	0.23		0.13	0.16	0.18	0.19	0.22	
							0.006					
CD (BF, CF, BF x CF) = -, -, -							0.009, 0.009, 0.017					
Potassium												
b_0	0.70	0.79	0.90	0.96	0.97	0.86	0.62	0.68	0.73	0.87	0.99	0.78
b_1	0.72	0.80	0.82	0.83	0.85	0.80	0.80	0.83	0.87	0.92	0.98	0.88
b_2	0.74	0.80	0.91	0.91	0.92	0.86	0.99	1.01	1.22	1.42	1.51	1.23
b_3	0.78	0.82	0.96	0.98	0.99	0.91	0.98	1.11	1.31	1.52	1.51	1.29
b_4	0.75	0.84	0.95	0.98	0.98	0.90	0.96	1.01	1.13	1.32	1.42	1.17
CF	0.74	0.81	0.91	0.93	0.94		0.37	0.93	1.05	1.21	1.28	
SEm ± = 0.002							0.017					
CD (BF, CF, BF x CF) = 0.003, 0.003, 0.005							0.065, 0.053, 0.049					

(b) **Cowpea**

Inoculant b_3 recorded the highest phosphorus content.

Fertilizer level f_4 registered the highest phosphorus content in cowpea.

Biofertilizer b_3 in combination with f_4 produced the highest phosphorus content.

4.4.3 **Potassium content**

The data on the potassium content of maize and coupea expressed in percentage are presented in Table 4.7.

(a) **Maize**

Potassium content in maize was highest for the treatment b_3.

As the fertilizer level increased from f_0 to f_4, the potassium content also increased.

Among the interaction effects, b_3f_4 showed the highest value.

(b) **Cowpea**

Biofertilizer treatment b_2 showed the highest value of potassium content in cowpea.

The potassium content increased as the level of fertilizer increased from f_0 to f_4.

Biofertilizer b_3 in combination with f_3 level recorded the highest potassium content.

4.4.4 Calcium content

The mean values of calcium content of maize and cowpea are presented in Table 4.8.

For both maize and cowpea the inoculation, nutrient levels and their interactions were not significant.

4.4.5 Magnesium content

Table 4.8 show the mean values of magnesium content of maize and cowpea.

For both maize and cowpea the inoculation, nutrient levels and their interactions were not significant.

4.5 Uptake studies

4.5.1 Uptake of nitrogen

The data on the uptake of nitrogen by maize and cowpea are presented in Table 4.9

Table 4.8. Effect of treatments on calcium and magnesium content (percentage) of maize and cowpea.

CF / BF	Maize f_0	f_1	f_2	f_3	f_4	BF	Cowpea f_0	f_1	f_2	f_3	f_4	BF
Calcium												
b_0	0.32	0.34	0.32	0.35	0.33	0.33	0.40	0.72	0.76	0.78	0.80	0.69
b_1	0.34	0.32	0.33	0.32	0.33	0.33	0.60	0.70	0.71	0.69	0.79	0.70
b_2	0.40	0.41	0.42	0.43	0.43	0.42	0.73	0.75	0.87	0.91	0.90	0.83
b_3	0.40	0.42	0.44	0.45	0.46	0.43	0.72	0.76	0.85	0.89	0.90	0.82
b_4	0.40	0.42	0.43	0.46	0.46	0.43	0.71	0.77	0.78	0.85	0.87	0.80
CF	0.37	0.38	0.39	0.40	0.40		0.63	0.74	0.79	0.82	0.85	
CD (BF, CF, BF x CF) = -,-,-							-,-,-					
Magnesium												
b_0	0.24	0.26	0.24	0.27	0.26	0.25	0.40	0.42	0.45	0.42	0.43	0.42
b_1	0.29	0.26	0.28	0.28	0.29	0.28	0.53	0.58	0.49	0.52	0.51	0.53
b_2	0.31	0.32	0.34	0.36	0.38	0.34	0.75	0.76	0.78	0.81	0.83	0.79
b_3	0.32	0.36	0.39	0.37	0.39	0.37	0.79	0.77	0.80	0.89	0.89	0.83
b_4	0.36	0.37	0.38	0.37	0.39	0.37	0.75	0.74	0.79	0.71	0.72	0.74
CF	0.30	0.31	0.33	0.33	0.34		0.64	0.65	0.66	0.67	0.68	
CD (BF, CF, BF x CF) = -,-,-							-,-,-					

Table 4.9. Effect of treatments on uptake of nitrogen, phosphorus and potassium ($Kgha^{-1}$) of maize and cowpea.

CF / BF	Maize f_0	Maize f_1	Maize f_2	Maize f_3	Maize f_4	Maize BF	Cowpea f_0	Cowpea f_1	Cowpea f_2	Cowpea f_3	Cowpea f_4	Cowpea BF
Nitrogen												
b_0	10.30	19.50	33.71	47.70	68.53	35.95	11.34	23.91	36.14	88.11	109.37	53.78
b_1	29.30	29.77	92.91	69.89	78.31	60.04	54.35	81.68	107.52	111.39	114.78	93.94
b_2	37.90	46.61	127.70	107.38	66.24	77.17	37.88	61.37	76.57	107.26	107.07	78.03
b_3	32.35	35.04	76.24	67.85	70.35	56.37	33.21	43.63	89.27	98.87	98.29	72.66
b_4	35.00	42.09	82.79	72.14	74.48	61.30	70.51	85.91	148.44	152.37	141.03	119.65
CF	28.97	34.60	82.67	72.99	71.58		41.46	59.30	91.59	111.60	114.11	
SEm ± = 3.013							2.537					
CD (BF,CF, BF x CF) = 7.774, 10.295, 8.708							5.398, 7.051, 7.331					
Phosporus												
b_0	1.03	3.59	4.83	8.22	11.68	5.87	1.03	2.74	3.21	5.47	5.14	3.52
b_1	2.82	3.04	7.88	8.27	9.91	6.38	2.05	3.39	5.33	6.20	7.54	4.90
b_2	3.21	4.59	13.63	13.31	8.78	8.71	3.73	5.06	8.97	9.93	9.57	7.45
b_3	5.02	5.53	13.46	10.31	11.49	9.16	2.88	4.12	7.59	8.44	8.64	6.34
b_4	4.74	8.03	15.90	13.36	13.82	11.17	2.64	4.85	5.81	7.50	8.38	5.84
CF	3.37	4.96	11.14	10.70	11.14		2.47	4.03	6.18	7.51	7.86	
SEm ± = 0.480							0.519					
CD (BF, CF, BF x CF)= 0.823, 1.058, 1.387							1.020, 0.707, 1.501					
Potassium												
b_0	7.33	15.91	29.30	39.77	54.06	29.28	34.02	14.46	19.37	31.62	38.05	27.5[illegible]
b_1	17.01	18.83	46.29	34.51	38.45	31.02	14.75	23.30	30.78	33.44	36.83	27.82
b_2	21.90	28.66	65.48	55.27	33.95	41.05	23.76	29.98	55.59	64.84	64.02	47.64
b_3	20.82	22.98	51.91	46.20	49.73	38.34	16.50	22.40	48.82	52.99	53.37	37.62
b_4	20.14	28.17	56.12	50.36	52.35	41.43	17.23	25.69	33.36	50.94	54.83	36.41
CF	17.44	22.91	49.82	45.24	45.71		21.25	23.17	36.38	46.77	49.42	
SEm ± = 1.771							2.457					
CD (BF, CF, BF x CF) = 2.952, 3.439, 5.117							5.083, 5.554, 7.101					

(a) **Maize**

The effect due to the inoculants on the nitrogen uptake by maize was significant. The highest value was for the inoculant b_2.

Different levels of nutrients also showed significant difference. The f_2 level of nutrient produced the maximum nitrogen uptake.

Among the interaction effects, the highest uptake value (12.70kg ha^{-1}) was noted by b_2f_2, which significantly differed from all other treatments.

(b) **Cowpea**

The inoculant b_4 treated plants recorded more nitrogen uptake.

With increasing nutrient levels, nitrogen uptake (152.37kg ha^{-1}) also increased. f_3 and f_4 levels were on par.

The b_4f_3 combination showed the maximum nitrogen uptake.

4.5.2 **Uptake of phosphorus**

The data on phosphorus uptake by maize and cowpea are presented in Table 4.9.

(a) **Maize**

The treatment inoculant b_4 recorded the highest uptake of phosphorus.

Maximum uptake was recorded by the treatment 50 percent of package of practices recommendation of chemical fertilizers.

Among the interaction effects b_4f_2 gave the highest uptake (15.90kg ha^{-1}). Different inoculants with f_2 level produced higher values.

(b) **Cowpea**

The inoculation had significant effect on phosphorus uptake. The treatment b_2 recorded the highest uptake value.

Progressive increase in phosphorus uptake was noted due to increasing nutrient levels, but f_3 and f_4 levels were on par.

Inoculation b_2, with f_3 nutrient level produced the highest (9.93kg ha^{-1}) phosphorus uptake among the different interactions.

4.5.3 **Uptake of potassium**

Data on uptake of potassium by maize and cowpea are presented in Table 4.9

(a) **Maize**

Maximum potassium uptake was for the treatment b_4.

The different fertilizer levels also significantly influenced the uptake of potassium by maize, the maximum was for the level f_2.

Among the interaction effects uptake was maximum in the b_2f_2 (65.48kg ha^{-1}) combination which differed significantly from other treatments. All the inoculants with f_3 and f_4 levels decreased the potassium uptake.

(b) **Cowpea**

Biofertilizer b_2 treated plants recorded more potassium uptake.

The uptake increased consistently with the increase in fertilizer levels but the difference was not significant. f_3 and f_4 levels recorded more or less similar values.

The interaction effect was significant and b_2 inoculant at higher two levels of fertilizers (f_3 & f_4) showed the maximum value(64.84kg ha^{-1}).

4.5.4 Uptake of calcium

The data on the uptake of calcium by maize and cowpea are presented in Table 4.10.

Table 4.10. Effect of treatments on uptake of calcium and magensium ($Kgha^{-1}$) of maize and cowpea.

CF / BF	Maize f_0	f_1	f_2	f_3	f_4	BF	Cowpea f_0	f_1	f_2	f_3	f_4	BF
Calcium												
b_0	3.34	6.79	10.35	14.42	18.37	10.65	4.58	15.31	20.21	28.39	30.87	19.87
b_1	8.02	7.50	18.60	13.25	14.88	12.45	11.10	19.69	25.15	25.11	29.72	22.16
b_2	11.76	14.59	30.17	26.05	15.78	19.67	17.60	22.84	38.79	42.13	39.57	32.19
b_3	10.61	11.67	23.72	21.12	23.05	18.04	12.12	15.72	28.02	31.26	21.97	23.82
b_4	10.62	14.05	25.34	23.66	24.46	19.62	12.77	19.07	24.03	32.96	32.75	24.32
CF	8.87	10.92	21.64	19.70	19.31		11.63	18.53	27.24	31.97	32.98	
SEm ± = 0.800							0.551					
CD (BF, CF, BF x CF) = 1.800, 0.974, 2.310							1.107, 1.419, 1.599					
Magnesium												
b_0	2.49	5.19	7.75	11.11	14.47	8.20	4.55	8.94	11.97	15.29	16.61	11.47
b_1	6.84	6.10	12.65	11.59	13.07	10.05	9.80	16.32	17.37	18.93	19.19	16.32
b_2	9.11	11.37	24.42	21.81	13.93	16.13	18.59	21.95	39.28	35.19	32.75	29.55
b_3	8.48	9.99	21.02	17.36	19.53	15.28	13.29	15.80	26.37	31.26	31.62	23.67
b_4	9.56	12.38	22.39	19.02	20.74	16.82	13.12	19.88	21.55	29.34	30.20	22.82
CF	7.29	9.01	17.65	16.18	16.35		11.87	16.58	23.31	26.00	26.08	
SEm ± = 0.896							0.581					
CD (BF, CF, BF x CF) = 1.426, 1.129, 2.590							1.900, 0.747, 1.680					

(a) **Maize**

Inoculation and the different nutrient levels significantly influenced the calcium uptake. Maximum uptake was for the treatment b_2 which was on par with b_4.

The nutrient level of f_2 showed highest uptake of calcium and differed significantly from other levels. At higher fertilizer levels, the calcium content of plants decreased.

Among the interactions, b_2f_2 recorded the maximum calcium (30.17Kg ha^{-1}) uptake and it differ significantly from other interactions.

(b) **Cowpea**

The uptake of calcium by different inoculants varied significantly where b_2 recorded the maximum value.

The higher three levels of fertilizer were equally efficient in increasing the uptake.

Cowpea with b_2 biofertilizer and f_3 fertilizer (35.19kg ha^{-1}) level was significantly superior to all other interactions. But it was also noted that the interaction effect decreased the uptake at f_4 levels.

4.5.5 **Uptake of magnesium**

The data on the uptake of magnesium by maize and cowpea are given in Table 4.10.

(a) **Maize**

Inoculant b_4 was significantly superior to other treatments

The nutrient level f_2 recorded maximum magnesium uptake by maize.

The interaction effect b_2f_2 produced significant uptake (24.42kg ha^{-1}). All inoculations in combination with f_2 level of nutrition produced higher uptake.

(b) **Cowpea**

Cowpea plants inoculated with b_2 increased the uptake of magnesium.

The higher two levels of fertilizers (f_3 & f_4) were on par in increasing the uptake of magnesium.

Among the interactions, b_2f_2 produced the maximum magnesium (39.28kg ha^{-1}) uptake, which was significantly superior to other treatments. Inoculation b_3 in combination with f_3 & f_4 levels of nutrients also increased the uptake of magnesium.

4.6 Quality Aspects

4.6.1 Crude protein content

The data on crude protein content of maize and cowpea expressed in percentage are presented in Tab. 4.11.

(a) **Maize**

Crude protein content of maize was maximum for the inoculant b_2.

The highest level of fertilizer application (f_4) gave the maximum crude protein content.

Maize with inoculant b_2 at f_4, f_3, f_2 gave the highest crude protein content b_1 and b_2 at fertilizer levels above 50 percent of recommended dose increased the crude protein content.

(b) **Cowpea**

Inoculant b_1 registered the maximum crude protein content.

The fertilizer level f_4 gave higher crude protein content.

Among the interaction effects, b_4f_4 produced maximum crude protein content, but it was on par with other treatments, b_4f_3 and b_1f_3. In the absence of nutrients significant difference in protein content was seen in plants treated with different inoculants.

4.6.2 **Crude protein yield**

The data on crude protein yield of maize and cowpea are presented in Table 4.11

Table 4.11. Effect of treatments on crude protein content (percentage) and crude protein yield ($Kgha^{-1}$) of maize and cowpea.

CF / BF	Maize f_0	f_1	f_2	f_3	f_4	BF	Cowpea f_0	f_1	f_2	f_3	f_4	BF
Crude protein content												
b_0	5.63	5.71	6.19	7.07	7.58	6.44	5.77	6.98	8.40	15.06	17.65	10.77
b_1	7.56	7.67	9.50	10.33	10.50	9.11	18.36	18.06	18.90	19.06	19.00	18.68
b_2	7.75	7.90	11.00	10.94	11.00	9.72	13.31	14.91	17.19	18.36	18.34	16.43
b_3	7.33	7.54	8.67	8.90	8.56	8.20	12.15	13.21	16.81	17.59	17.19	15.39
b_4	7.69	7.71	8.63	8.61	8.65	8.26	17.79	17.98	18.58	19.19	19.35	18.58
CF	7.19	7.31	8.80	9.17	9.26		13.48	14.23	15.98	17.85	18.31	
SEm ± = 0.170							0.210					
CD (BF, CF, BF x CF) = 0.212, 0.176, 0.490							0.257, 0.317, 0.608					
Crude protein yield												
b_0	64.41	121.91	210.80	298.31	428.32	224.75	70.86	149.44	225.98	550.73	683.63	336.13
b_1	183.16	186.16	543.17	436.79	489.40	367.74	339.72	510.54	672.01	696.20	717.36	587.17
b_2	236.92	291.33	789.12	671.27	414.11	482.35	236.69	383.64	478.61	667.25	669.29	487.10
b_3	202.17	219.03	476.68	424.16	439.68	352.34	207.57	272.68	557.86	618.03	614.31	454.09
b_4	212.31	263.03	517.54	453.63	465.56	382.41	440.64	536.96	927.77	951.59	881.40	747.67
CF	179.79	216.29	509.26	456.83	447.42		259.10	370.65	572.45	696.76	713.20	
SEm ± = 19.567							15.841					
CD (BF, CF, BF x CF) = 53.801, 64.914, 56.549							33.949, 44.227, 45.781					

(a) **Maize**

b_2 inoculant showed the maximum effect on increasing the crude protein yield of maize.

The fertilizer at f_2 level gave the maximum crude protein yield.

Interaction of b_2f_2 produced the maximum crude protein [illegible] and was superior to all other interactions. Under all levels of inoculations, the crude protein yield was maximum, in combination with 50 percent of the recommended dose of fertilizer.

(b) **Cowpea**

Inoculant b_4 gave the highest crude protein yield.

Fertilizer level f_4 recorded the highest value.

Among the different treatment combinations biofertilizer b_4 [illegible] at f_3 level produced the maximum crude protein yield with all inoculations, the fertilizer level f_3 and f_4 were on par.

4.6.3 Crude fibre content

The table 4.12 shows the mean values on crude fibre content of maize and cowpea.

For both maize and cowpea the inoculation, nutrient levels and their interaction were not significant.

Table 4.12. Effect of treatments on crude fibre content (percentage) and crude fibre yield (tha^{-1}) of maize and cowpea.

CF / BF	Maize f_0	f_1	f_2	f_3	f_4	BF	Cowpea f_0	f_1	f_2	f_3	f_4	BF
Crude fibre content												
b_0	32.29	28.20	26.38	21.51	32.31	28.14	30.39	24.70	28.69	28.61	28.70	28.22
b_1	23.54	26.30	28.61	21.64	31.51	26.32	21.52	22.27	24.49	27.21	27.40	24.58
b_2	26.24	28.46	20.17	23.27	31.55	25.94	22.47	21.33	22.10	26.59	26.47	23.79
b_3	25.59	27.53	19.54	22.51	31.52	25.34	21.52	22.46	25.54	27.73	27.47	24.94
b_4	25.54	27.49	19.64	22.39	31.61	25.34	21.54	22.46	25.85	27.64	27.52	25.01
CF	26.64	27.59	22.87	22.26	31.70		23.49	22.64	25.34	27.56	27.52	
CD (BF, CF, BF x CF) = -,-,-							-,-,-					
Crude fibre yield												
b_0	0.34	0.57	0.86	0.89	1.17	0.77	0.34	0.52	0.76	1.04	1.11	0.76
b_1	0.56	0.62	1.61	0.90	1.42	1.02	0.40	0.63	0.87	0.99	1.03	0.79
b_2	0.78	1.02	1.46	1.41	1.80	1.29	0.40	0.54	0.61	0.96	0.96	0.70
b_3	0.68	0.77	1.06	1.06	1.59	1.03	0.36	0.46	0.84	0.98	0.98	0.73
b_4	0.69	0.92	1.16	1.15	1.68	1.12	0.54	0.66	1.10	1.37	1.25	0.99
CF	0.61	0.78	1.23	1.08	1.53		0.41	0.57	0.84	1.07	1.07	
SEm ± = 0.178							0.039					
CD (BF, CF, BF x CF) = 0.091, 0.133, 0.178							0.070, 0.088, 0.112					

4.6.4 Crude fibre yield

Data on crude fibre yield of maize and cowpea are presented in Table 4.12.

(a) Maize

Crude fibre yield was maximum for b_2 treatment.

The highest fertilizer level f_4 gave the maximum crude fibre yield.

Maximum crude fibre yield due to interaction was recorded by b_2f_4 (1.80t ha^{-1}).

(b) Cowpea

b_4 recorded the maximum crude fibre yield.

The highest level of fertilization (f_4) gave the maximum crude fibre yield which was on par with f_3.

Among the interaction effects, b_4f_3 recorded the maximum crude fibre yield (1.37t ha^{-1}).

4.7 Chemical composition of soil after the experiment

The mean value of available nitrogen, phosphorus, potassium, calcium and magnesium contents of the soil as affected by the different biofertilizers at various fertilizer levels are presented in Table 4.13.

Table 4.13. Effect of treatment on soil nitrogen, phosphorus, potassium, calcium and magnesium content ($Kg ha^{-1}$) after the experiment.

CF / BF	f_0	f_1	f_2	f_3	f_4	BF	f_0	f_1	f_2	f_3	f_4	BF
Nitrogen							**Calcium**					
b_0	110.01	132.46	142.36	143.50	230.59	151.79	337.34	342.29	346.62	348.57	397.68	354.50
b_1	128.17	134.26	142.42	170.34	248.26	164.69	338.34	340.39	342.57	346.73	357.43	345.09
b_2	123.78	135.42	141.29	145.51	240.49	157.30	243.59	259.40	278.30	279.38	292.45	270.62
b_3	125.38	139.35	145.39	141.32	231.36	156.56	222.88	228.31	229.47	229.60	269.46	235.95
b_4	121.25	139.55	140.15	148.12	241.29	158.07	233.53	233.63	231.56	236.51	281.25	243.30
CF	121.72	136.21	142.32	149.76	238.40		275.14	280.81	285.71	288.16	319.65	
SEm ± = 0.338												
CD (BF, CF, BF x CF) = 0.471, 0.258, 0.977							-,-,-					
Phosphorus							**Magnesium**					
b_0	33.77	38.97	38.05	37.15	31.02	35.79	40.27	41.35	45.44	45.52	45.65	43.65
b_1	31.98	34.94	30.80	34.14	32.94	31.96	39.32	39.61	37.45	33.51	35.33	37.05
b_2	32.15	33.96	35.01	36.04	29.93	33.41	29.45	29.46	30.55	31.43	31.03	30.39
b_3	29.76	29.05	29.33	27.13	28.02	28.66	28.25	29.55	29.36	30.30	32.49	29.99
b_4	32.26	36.02	31.98	33.93	30.07	32.86	30.60	31.30	33.90	33.65	32.80	32.45
CF	31.99	34.59	33.04	33.68	30.40		33.58	34.25	35.34	34.88	35.47	
SEm ± = 0.127												
CD (BF, CF, BF x CF) = 0.237, 0.209, 0.367							-,-,-					
Potassium												
b_0	42.55	40.22	39.43	36.22	38.10	38.50						
b_1	33.44	33.42	31.44	36.42	36.36	34.22						
b_2	30.31	34.14	36.20	37.62	31.20	33.89						
b_3	32.38	35.58	32.42	34.61	37.56	34.51						
b_4	30.47	33.46	35.40	30.34	33.34	32.60						
CF	33.83	35.36	34.98	35.04	35.31							
CD (BF, CF, BF x CF) = -,-,-												

4.7.1 **Available nitrogen content**

It was observed that biofertilizer treatment did not significantly influence the available nitrogen status in the soil.

The different levels of nutrients significantly increased the available nitrogen status of soil. The highest value of 238. 40kg ha-1 was recorded by the treatment f_4 which was significantly superior to other treatments.

It was seen that b_1f_4 interaction effect, increased the available nitrogen status (248.26 kg ha-1) after the experiment. With all inoculations, f_4 level gave higher residual nitrogen in the soil.

4.7.2 **Available Phosphorus content**

Biofertilizers significantly decreased the available phosphorus content in the soil. Highest available phosphorus content in the soil was recorded under control.

There was significant increase in available phosphorus content of the soil, due to different nutrient levels. The treatment f_1 recorded the highest available phosphorus content of 34.59 kg ha^{-1}.

Among the interaction effect, one with no biofertilizer and highest fertilizer level (b_0f_4) recorded the highest residual phosphorus content (38.97 kg ha^{-1}) of soil.

4.7.3 **Available potassium content**

Treatment with no biofertilizer (b_0) recorded the highest available potassium content of 38.50 kg ha^{-1}.

The different nutrient levels did not significantly influence the potassium content of the soils. The treatment f_0 recorded the highest available potassium content in the soil, followed by f_3 and f_2.

Fertilizer level f_0 in combination with no biofertilizer recorded the highest potassium content (42.55 kg ha^{-1}) and lowest value under b_2f_0.

4.7.4 **Available calcium content**

There was no significant difference in the available calcium content in the soil due to biofertilizers. However the highest content was recorded by the treatment b_0 and lowest by the treatment b_3.

The different nutrient levels tried had no significant influence on available calcium content in the soil. The calcium content in the soil was maximum for the highest dose of fertilizer level (f_4).

4.7.5 Available magnesium content

Biofertilizer did not significantly increase the available magnesium content in the soil. However the highest value was recorded for the treatment b_0 and lowest for b_3.

The nutrient levels also did not have any significant influence on the available magnesium content in the soil.

4.8 Economics of cultivation

The results on the economics of fodder production by maize - cowpea intercropping system under different biofertilizer and nutrients treatment is presented in Table 4.14.

It was found that all treatment combinations were able to give more profit than control except b_0f_1, b_1f_0 and b_3f_0. The treatment combination, b_4f_2 (VAM - maize + Rhizobium - cowpea + 50 percent recommended dose) recorded the highest net returns of Rs. 8110.00 and Benefit - cost ratio of 1.502. This was followed by the treatment b_2f_2 (Azospirillum - maize + VAM - cowpea + 75 percent recommended dose) with a net income of Rs. 7504 and benefit - cost ratio of 1.464 and b_2f_3 (Azospirillum - maize + VAM - cowpea + 75 percent recommended dose) with a net profit of Rs. 7097 and benefit-cost ratio of 1.420. The control treatment b_0f_0 registered a loss of Rs. 5217 and benefit - cost ratio of 0.643.

Table 4.14. Economics of cultivation

Treatment	Cost of cultivation excluding treatment Rs.	Cost of treatment Rs.	Total Cost of cultiva-tion Rs.(y)	Total yield tha^{-1}	Gross income Rs.(x)	Net income Rs x-y	B/C ratio x/y
b_0f_0	14,625	-	14,625	15.68	9408	-5217	0.643
b_0f_1		443.69	15,342	21.77	13,062	-2280	0.851
b_0f_2		887.43	16,060	29.28	17,568	1508	1.094
b_0f_3		1331.10	16,779	36.60	21,960	5181	1.309
b_0f_4		1774.86	17,496	39.74	23,844	6348	1.363
b_1f_0		200.00	14,825	20.49	12,294	-2531	0.829
b_1f_1		643.69	15,542	26.49	15,894	352	1.023
b_1f_2		1087.43	16,260	34.25	20,550	4290	1.264
b_1f_3		1531.10	16,979	37.30	22,380	5401	1.318
b_1f_4		1974.86	17,696	37.90	22,740	5044	1.285
b_2f_0		100.00	14,725	25.72	15,432	707	1.048
b_2f_1		843.69	15,442	28.41	17,046	1604	1.104
b_2f_2		987.43	16,160	39.44	23,664	7504	1.464
b_2f_3		1431.10	16,879	39.96	23,976	7097	1.420
b_2f_4		1874.86	17,596	39.17	23,502	5806	1.336
b_3f_0		-	14,625	23.50	14,100	-525	0.964
b_3f_1		443.69	15,342	26.41	15,846	144	1.033
b_3f_2		887.43	16,060	34.91	20,946	4886	1.304
b_3f_3		1331.10	16,779	31.54	18,924	2145	1.128
b_3f_4		1774.86	17,496	31.16	18,696	1200	1.069
b_4f_0		100.00	14,725	25.11	15,066	341	1.023
b_4f_1		843.69	15,442	28.92	17,352	1910	1.124
b_4f_2		987.43	16,160	40.45	24,270	8110	1.502
b_4f_3		1431.10	16,879	36.58	21,948	5069	1.300
b_4f_4		1874.86	17,596	34.24	20,544	2948	1.168

1 Kg urea : Rs.3.50, 1 Kg mussoriphos:Rs.2.00. 1 Kg Muriate of potash:Rs.5.00

1 Kg fodder:Rs.0.60. Labour Charge: Rs.72 per head.

DISCUSSION

DISCUSSION

A field experiment was conducted in the Instructional farm, College of Agriculture,Vellayani to study the effect of different bioinoculants (Azospirillum, Rhizobium and Vesicular arbuscular mycorrhiza) in increasing the fodder productivity of maize-cowpea intercropping system and to find out the fertilizer economy due to inoculation. Observations were made on growth, yield, nutrient and quality characters. The results obtained from the study are discussed below:

5.1. Growth characters

(a) Maize

It could be seen from Table 4.1 - 4.3 that the inoculants, chemical fertilizers and their interaction produced significant differences on growth characters like plant height, number of leaves, leaf area index and leaf-stem ratio.

At 20 DAS, the growth characters especially plant height and number of leaves were not affected due to inoculation. This is in agreement with the observations of Gallo et al. (1989) in Zea mays, where the effect due to inoculation with biofertilizers was seen only after 22 days after sowing. But at 40 DAS, plants inoculated with Azospirillum recorded maximum height and number of leaves. Tien et al. (1979) reported that Azospirillum inoculation produced growth hormones like IAA, Indole lactic acid, giberellin and cytokinins like substances which increase the growth of host plants. Kapulnik et al. (1981) also showed increased growth in wheat due to Azospirillum inoculation. However at 60DAS, both Azospirillum and mycorrhiza were found to have a beneficial role in plant growth. Jeeva (1988) obtained increase in plant height, leaf production, and leaf area of banana cultivar poovan by Azospirillum inoculation. Mycorrhiza have a beneficial role in increasing the growth characters - shoot length, leaf area index and leaf-stem ratio through the uptake of nutrients (Mosse et al., 1973). The inoculation effect of companion crop-cowpea, also have a favourable effect on the growth of maize. Nitrogen fixation, transfer to the associated grass and its significant effect on growth have been studied by various workers (Whitney and Kanchiro, 1967 and Chan, 1971). Thus the results obtained in the present investigation are in agreement with the above findings.

The different levels of fertilizers also showed significant differences in plant growth characters at all stages of growth. The maximum response was recorded by the higher level of fertilization and was on par with 50 percent of the recommended dose of fertilizer, showing that this dose could be economically used. The nutrients especially nitrogen influenced all the phases of crop growth as reported by Garg and Kayande (1962) and Chand (1977). At 72.50: 60.00: 35.00 kg N, P_2O_5 and K_2Oha^{-1}, the nitrogen released from the nodules of cowpea might have also contributed towards more growth such a stimulation of growth in maize by excretion from the root nodules of legumes was reported by Tiwana et al. (1978).

There was significant effect in the growth of maize due to the interaction effect of fertilizer and inoculants. In all stages, it can be seen that due to interaction effect, 50 percent of recommended dose of fertilizer could produce the same growth when 75 and 100 percent levels were used. Azospirillum inoculation with fertilizers in both lower and higher levels had resulted in increased plant growth. This might be due to nitrogen fixation and growth hormones produced by the bacteria. (Barea and Brown, 1974). Therefore at 50 percent level of the recommended dose of chemical fertilizer itself, the maize plants would have got the amount of nutrients required for their growth. Also fertilizers at a limited quantity increases the availability of root exudates which might have accelerated the activity of inoculated Azospirillum which would have resulted in higher nitrogen fixation and secretion of growth promoting substances. This is in conformity with the findings of Gill et al. (1970) and Dart and Day (1975).

(b) Cowpea

Result presented in Tables 4.1 - 4.3 showed that growth characters were better at all stages for the treatments, VAM - maize + Rhizobium - Cowpea. Rhizobium inoculation increases the nitrogen status of the soil, through atmospheric nitrogen fixation and thus promotes the vegetative growth of plants. Similar results were reported by Karyagin (1980) in soybeans and Srivastava and Sharma (1982) in greengram. Rhizobium and mycorrhizal fungi associated with the companion crop-maize were found to be synergistic which would have helped it for greater utilization of environmental resources and which in turn might have increased the plant height and number of leaves (Srivastava and Sharma, 1982).

The different levels of fertilizers also showed significant differences in plant growth, at all stages of growth. The highest level of fertilization produced the tallest plants. The plants in unfertilized plots recorded the lowest value of all growth characters. As the level of NPK increased from 0 Kg ha^{-1} to 145: 120 : 70 Kg ha^{-1} the growth increased progressively. The influence of nitrogen in promoting the vegetative growth of plants is well established and as such the increase in growth with incremental doses of nitrogen is quite natural (Tisdale *et al*., 1985). Phosphorus promotes root growth which in turn would enhance the uptake of nutrients resulting in rapid growth

(Tisdale et al., 1985). Potassium is important in the photosynthetic process, thus leading to greater CO_2 assimilation and growth (Russell, 1973). Similar increases in plant growth due to increased NPK application was reported in cowpea by Thimmegowda and Shivaraj (1994). The fertilizer dose of 75 percent and 100 percent of the recommended doses were found to be on par. This might be due to the comparitively better fertility status of the experimental soil due to biofertilizer inoculation.

It was seen that the treatment VAM-maize + Rhizobium cowpea at 50 percent recommended dose was the best. But above the 50 percent of recommended dose there was no significant increase in growth in combination with other inoculants. This may be due to the reduction in the effectiveness of Rhizobium, as higher levels of NPK create salts and antagonists of Rhizobium (Subba Rao, 1981a).

5.2. Root characters

The results presented in Tables 4.4 & 4.5 revealed that there was significant different in the root characteristics of maize and cowpea.

(a) Maize

In maize, it can be seen that the root length and root volume were considerably increased due to Azospirillum inoculation and under low levels of fertilizer. It has been shown that *Azospirillum brasilense* enhances root branching and root hair formation (Tien *et al*., 1979). This effect on the root system is probably due to growth hormones secreted by the bacteria. (Kapulnik *et* al., 1981). Following inoculation, *Azospirillum* adsorbs to and proliferates on the roots and apparently invades root internal parts. There it promotes root hair development and branching (Umali - Garcia *et al*., 1980). Increase in the concentrations of nutrients inhibits the *Azospirillum* population and therefore its effectiveness was decreased (Taylor, 1979).

(b) **Cowpea**

It can be seen that the root length was found to be higher in mycorrhiza inoculated plants, provided with 50 percent of the recommended dose of fertilizers. This might be due to the effect of mycorrhiza in stimulating phosphate uptake, which might have increased root growth parameters. Number of nodules and nodule weight were higher under *Rhizobium* inoculated and under 75 percent of recommended dose of fertilizers. This is in conformity with the findings of Sairam *et al*. (1989) that inoculation with *Rhizobium* increased the nodulation and nodule leghaemoglobin of cowpea. High doses of phosphorus and potassium are known to increase nodulation (Russell, 1973). The increase in nodule number might have increased the nodule weight also.

5.3 **Mycorrhizal colonization**

The results presented in Table 4.4 & 4.5 and Fig.2b showed that at the time of harvest, mycorrhizal colonization in VAM inoculated plants were higher under lower fertilizer levels, in both maize and cowpea. Saif (1986) also reported stimulated mycorrhizal infection wih low levels of applied phosphorus. Addition of combined nitrogen decreased mycorrhizal development in Young Clover roots (Chambers et al., 1980). Elias and Safir (1987) found that the preference of VAM fungi to low phosphorus concentration is because, at low levels, the exudates from plants stimulate hyphal elongation of VAM fungi.

The lowest value was reported for the treatment, no inoculant + 100 percent recommended dose. This indicates that native VAM is suppressed at higher doses of fertilizer application VAM fungi are especially affected by soil fertility factors. Limonnard and Ruissen (1989) found that the effect of nitrogen on VAM development was even more significant than that of phosphorus. Even at high phosphorus levels, much VAM could be formed, provided the soil nitrogen level was low.

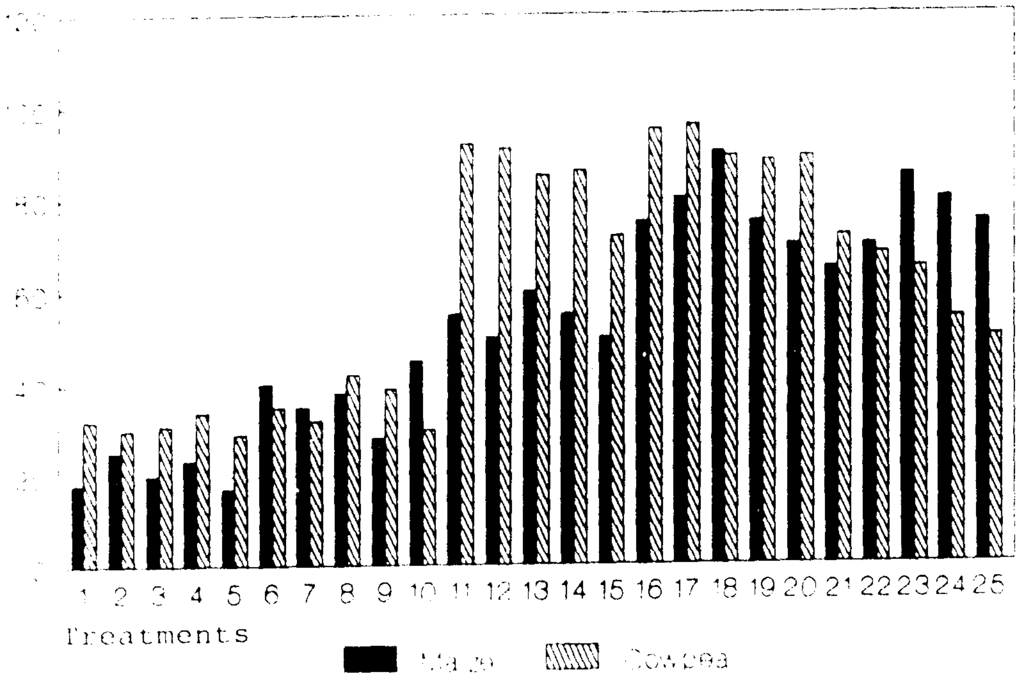

Fig.2b Effect of treatments on mycorrhizal colonization (%) of maize & cowpea

5.4. Yield attributes

(a) Maize

The results on green matter yield and dry matter yield presented in Table 4.5 and fig.34 showed that there was significant difference between the treatments.

The treatments Azospirillum - maize + VAM - cowpea was significantly superior to other treatments. Similar increase in oats fodder yield due to Azospirillum inoculation was obtained by Tanwar et al. (1985). As a result of the combination of improved nitrogen nutrition from fixation by the bacterium, increased root surface area, and improved nutrient and water uptake by plants often show yield response (Sumner, 1990). The increase in yield might also be due to the benefits received from the companion crop inoculated with VAM.

The nutrient level at 50 percent of the recommended dose of fertilizer was enough for high yield, above which the yield was not significant. It can be seen that all the growth characters were found to be high at 50 percent level and thereby the yield, which might be due to comparitively better fertility status of the soil brought about by biofertilizer.

It can be seen that both green matter yield and drymatter yield were highest for the treatment, Azospirillum - maize +

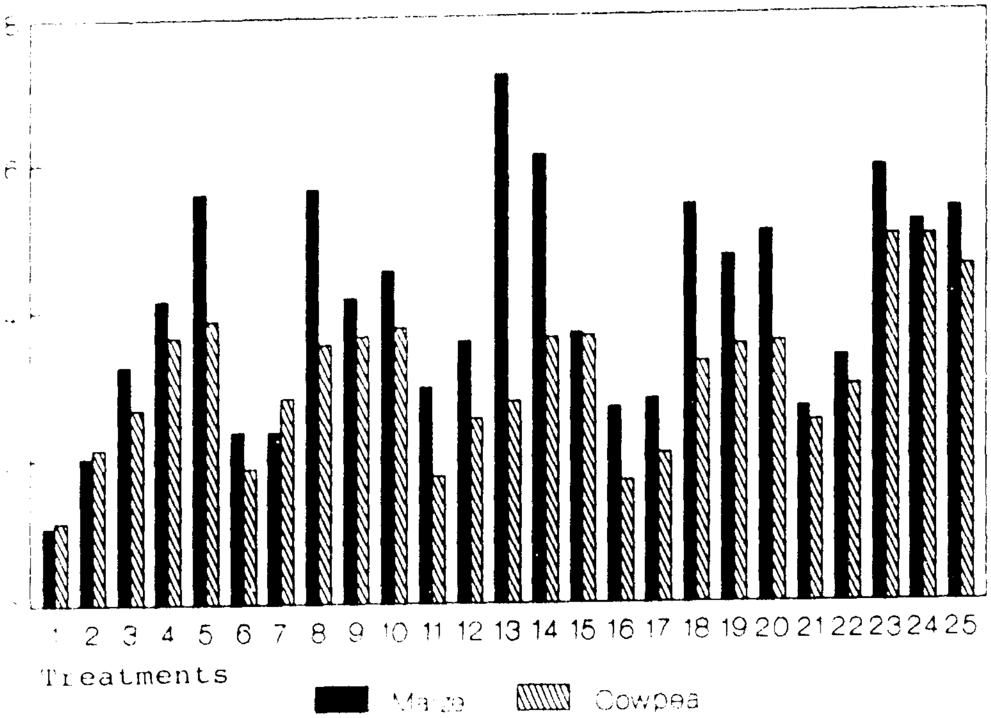

Fig.4. Effect of treatments on dry matter (t ha^{-1}) of maize and cowpea

VAM - cowpea with 50 percent of the recommended dose of fertilizers. It can be seen that under interaction the yield tend to decrease at full recommended dose of fertilizer. Fertilizer dose of 50 percent level with Azospirillum inoculation was found to have significant influence over higher doses of fertilizers with Azospirillum inoculation in increasing the yield. This might be attributed to the increased growth characters and photosynthate accumalation. This is in conformity with the findings of Dhanapal *et al*. (1978) in Sorghum and in pearl millet, Hegazi *et al*. (1981) in wheat. Arunachalam and Venkatesan (1984) reported the possibility of reducing 50 percent fertilizer nitrogen of sesamum without adversely affecting the yield by the use of Azospirillum. The results obtained by Pahwa and Patil (1984) also indicated the possibility of saving 15-20 kg inorganic N ha^{-1} by inoculating forage crops with *Azospirillum lipoferum*.

(b) **Cowpea**

The results on green matter yield and dry matter yield presented in Table 4.6 and Fig 3&4 showed that the treatment *Rhizobium* gave higher yield. Similar results were reported in cowpea by Sivaprasad and Shivappashetty (1980) and in redgram by Subba Rao (1981). The enhanced vegetative growth could be the reason for higher green-matter yield which might also have contributed to greater dry matter yield. The increase in yield of cowpea may also be due to the effect of VAM due to the inoculation of the companion crop.

The fertilizer level 100 percent of the recommended dose recorded the highest yield-both green matter and dry matter yield which was on par with 50 percent of the recommended dose. As the level of nitrogen increases, the carbohydrates synthesised in the leaves are converted to amino acids mainly in the leaf. The extra protein allows the leaves to grow larger and have more photosynthetic area, leading to higher yield (Russell,1973). Gill et al. (1972) also reported an increase in green matter yield with increasing phosphorus levels in greengram. Potassium has been shown to increase yields in *Trifolium alexandrinum* (Robinson and Savoy,1989). In general, increasing dose of fertilizers have increased the green matter yield, reflecting in higher dry matter yield also. The treatments 50 percent recommended dose and full fertilizer dose were on par suggesting that 50 percent recommended dose was sufficient beyond which no significant yield increase occurred.

Inoculation with *Rhizobium* in combination with 50 percent of recommended dose of chemical fertilizers resulted in higher yield. The *Rhizobium* along with high fertilizer dose applied in this trial might have increased the overall vegetative growth of the plant and this could be the reason for higher green matter yield, reflecting in higher dry matter yield. Yields obtained in this study showed that 50 percent of recommended dose was as efficient as 100 percent of recommended dose in producing both green matter and dry matter yields.

5.5. **Chemical Composition**

(a) **Maize**

The nutrient content of maize - nitrogen, phosphorus, potassium, calcium and magnesium presented in Tables 4.7 & 4.8 showed that there was not much difference between the various treatments. The nitrogen content was maximum for the treatment with Azospirillum. This might be due to the nitrogen fixation by inoculated plants and subsequently its availability to the crop plants. The phosphorus and potassium contents were higher for mycorrhiza inoculated plants. The VAM hyphae can take advantage of their geometry and better distribution than roots to acquire phosphate from transistory localised and diluted sources of the elements (Harley and Smith, 1983) Mycorrhizal infection has been found to improve the potassium nutrition of Trifolium Subterraneum when internal potassium concentrations were generally low (Robinson and Savoy, 1989).

The nitrogen, phosphorus and potassium contents were found to be higher at higher doses of fertilizer. Maize would have taken up more nitrogen for its growth and development. Increased nitrogen content due to increased doses of fertilizers might have resulted in increased absorption of phosphorus and potassium which in turn increased the phosphorus content (Tisdale and Nelson,1975 and Grant and Maclean, 1966).

The nitrogen content was higher for the combination - Azospirillum and full recommended dose of fertilizer. Phosphorus and potassium for the mycorrhizal treatment in combination with 50 percent of the recommended dose of fertilizer. Plants require nitrogen from the early stages of its growth since mycorrhizae can make use of the unavailable phosphorus and phosphorus beyond the depletion zone in the soil,Only 50 percent of recommended fertilizer dose is necessary as high levels will affect the mycorrhizal population as reported by Tisdale and Nelson (1975).

(b) **Cowpea**

There was no significant difference between the treatments,as shown in Tables 4.7 & 4.8. The nitrogen content was maximum for Rhizobium inoculated plants.As cowpea plants have heavy vegetative growth,it requires nitrogen in large quantities which is supplied well by the Rhizobium. The phosphorus and potassium were higher for mycorrhizal inoculated plants, since VAM can act as extensions of roots and hence are able to absorb the unavailable sources of phosphorus and to a certain extent potassium,their absorption and content will be higher in VAM treated plants as reported by Young et al. (1986).

Fertilizer levels influenced the nitrogen, phosphorus and potassium contents. Similar increase in NPK content with the increased application of fertilizer was reported by Gill et al.(1972) and Faroda and Tomer (1975).

Rhizobium with full recommended dose of fertilizer recorded the maximum nitrogen content and there was no significant difference between 75 percent and 100 percent of the recommended dose of fertilizer dose recorded the highest phosphorus and potassium contents. But here also no significant difference was noticed between 75 and 100 percent of the recommended dose of fertilizer which means that about 25 percent of fertilizer can be saved due to mycorrhizal inoculation as reported by Rajapakse et al. (1989) in cowpea.

5.6. **Uptake Studies**

(a) **Maize**

The result presented in Table 4.9 & 4.10 and fig.5 revealed that the nitrogen uptake was enhanced due to Azospirillum and phosphorus, potassium and magnesium due to mycorrhizal inoculation. The enhanced nitrogen uptake due to Azospirillum inoculation may be attributed to the enzymatic action as reported earlier by Umali - Garcia et al. (1980). They reported that Azospirillum "Softens"the middle lamellae through the action of

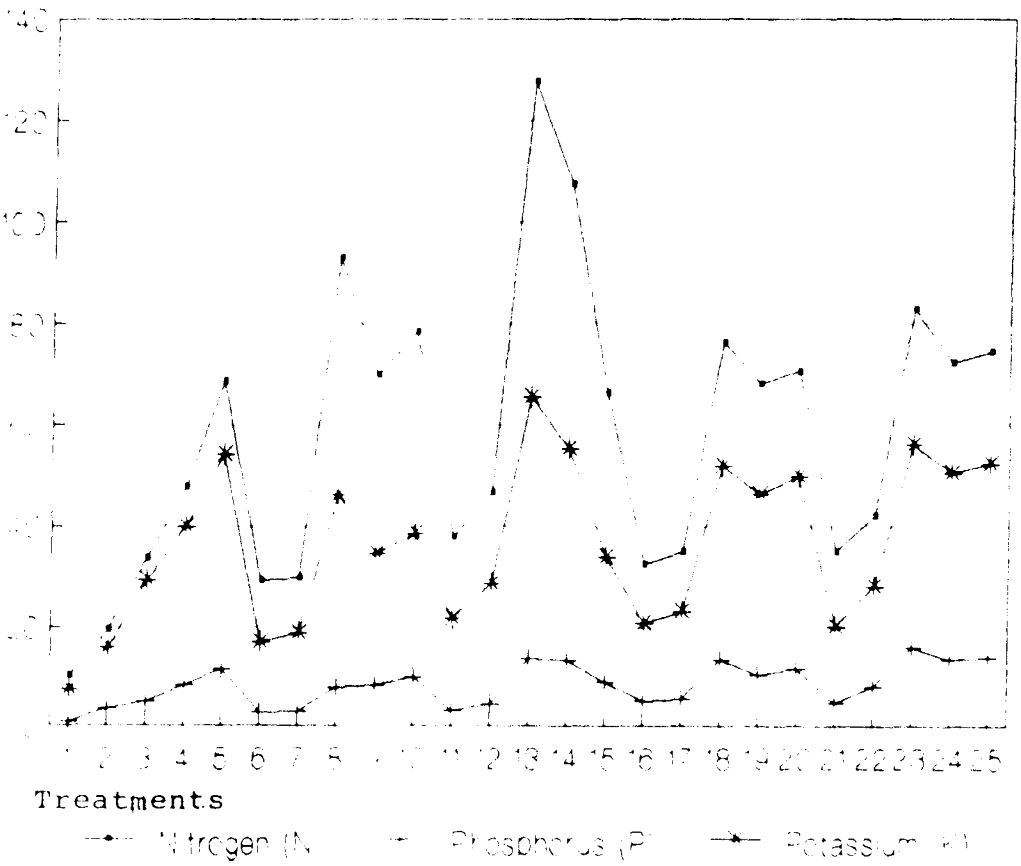

Fig.5. Effect of treatments on uptake of N,P and K (kg ha^{-1}) of maize

pectinolytic enzymes thus enhancing the mineral absorption surface of cortex cells in a kind of "sponge" effect. Increased nitrogen content was also reported by Cohen et al. (1980) in maize and Boddey et al. (1986).

In general nutrients uptake was higher due to mycorrhizal inoculation. The development of an extensive net work of extramatrical hyphae by the VAM in soil surrounding the root, together with the capacity of these hyphae for nutrient absorption and transport to the cortical root cells, indicate that VAM modify the nutrient uptake properties of a root system. (Harely and smith, 1983). VAM represents a complement of the root system, being more critical when the latter is less developed or when the environment is stressed, nutrient - poor or competitive (Mosse et al., 1981). Thus VAM acts as a modified root system which greatly improves nutrient uptake. Increase in uptake of these nutrients was also reported by Krishna et al. (1982) and Yost and Fox (1982).

Fertilizer levels were found to increase the nitrogen, phosphorus and potassium uptake, which was found to be high at 50 percent of the recommended dose of fertilizer. Higher levels of fertilizers increase the calcium and magnesium uptake also in maize. This might be due to the influence of higher doses of nitrogen and phosphorus fertilizers in increasing the calcium and magnesium uptake. Stewart and Reed (1969) reported such an increase in calcium uptake with increase in nitrogen and phosphorus application. Olofsson (1964) and Anderson and Schjelderup (1973) reported that there was a significant increase in the magnesium content of the crop, by doubling the amount of nitrogen fertilization.

Nitrogen, potassium, calcium and magnesium uptake was maximum for the treatment *Azospirillum* in combination with 50 percent of the recommended dose of fertilizers. Similar results were reported by Rai and Gaur (1982) and Boddey *et al*. (1986) in wheat. Lin *et al*. (1983) reported enhancement in the uptake of calcium and magnesium by roots of *Zea mays* and *Sorghum bicolor* inoculated with *Azospirillum brasilense*. Bashan *et al*.(1990) also reported the capacity of *Azospirillum* strains to enhance the accumulation of K^+, Ca^{2+}, Mg^{2+}, Mn^{2+}, Na^+ and Zn^{2+} in inoculated wheat and soybean plants.Phosphorus uptake was maximum with mycorrhiza in combination with 50 percent recommended dose of fertilizers. The reason is that soil reduces the overall percentage of VAM colonization as reported by Amijee *et al*. (1989) and Rajapakse *et al*. (1989).

(b) **Cowpea**

It is evident from the results presented in Tables 4.9 & 4.10 and Fig.6 that inoculation significantly differ in the uptake of nitrogen, phosphorus, potassium, calcium and magnesium. The

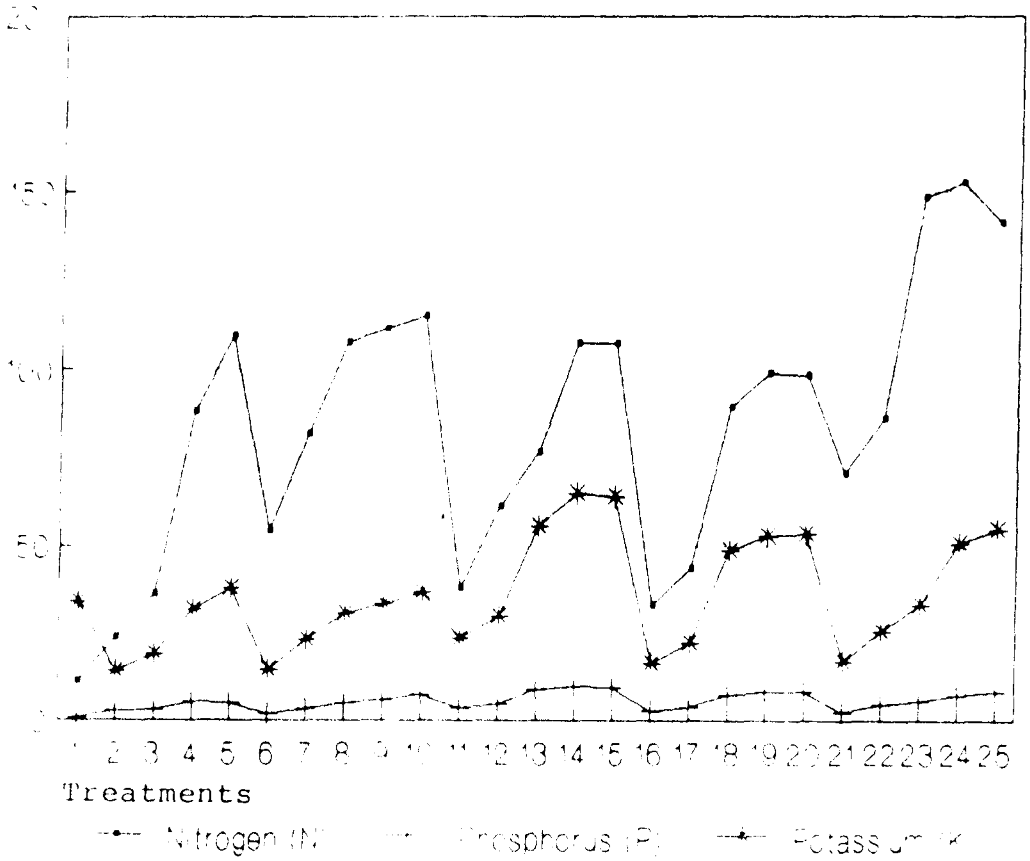

Fig.6. Effect of treatments on uptake of N,P and K (kg ha^{-1}) of cowpea

treatment Rhizobium recorded the highest nitrogen uptake , as the higher nodule number and nodule weight was noted for this treatment.

Higher uptake of other nutrients ie phosphorus, potassium, calcium and magnesium were recorded for VAM treatment. There are indications that VAM hyphae are able to take up phosphate from soil solutions with low phosphate concentrations more efficiently than simple roots (Barea, 1991). Mycorrhizal infection has been found to improve the potassium nutrition of Trifolium subterraneum when internal potassium concentrations are generally low. The increased potassium uptake might also be the result of improved phosphorus nutrition (Smith et al.,1981) Increase in uptake of calcium due to VAM inoculation was reported by Huang et al. (1983) in Leucaena leucocephala. Smith and Gianinazzi-pearson (1988) suggest an association of Ca^{2+} distribution in plants with the synthesis and breakdown of polyphosphate granules since the cation is a secondary constituent of these granules. Mycorrhizal inoculation was shown to significantly increase magnesium uptake of lucerne by Nielson (1990). The enhanced magnesium uptake may be an effect of the extensive mycelial net work and increased drymatter production of plants.

The different nutrient levels had significant effect on the uptake of nutrients-nitrogen, phosphorus, potassium , calcium and magnesium when compared to control, due to the poor fertility status of the soil.The increasing nutrient levels showed an increasing trend in the nitrogen uptake,as cowpea had a heavy vegetative growth, for which nitrogen is required. In the uptake pattern of phosphorus also, increase was noticed from the lowest dose to the highest dose of fertilizers. Increasing the rate of phosphorus applied in the soil might have increased its availability and consequent assimilation by plants which results in higher phosphorus uptake values for the plant. Similar results have been reported by Dhar (1978) and Mariyappan (1978) in the case of various legumes tried. Higher levels of fertilizer application might have resulted in better proliferation of root system and increased intake efficiency of plants. Similar results with increasing potassium concentration was reported by Robinson and Savoy (1989) in Trifolium repens with increasing fertilizer doses. The nutrient levels did not affect the uptake of calcium and magnesium. However with increasing nutrient doses, an increasing trend was noticed in the uptake value. Similar increase in the uptake of cations with increase in the dose of phosphorus applied to stylosanthes was reported by Balachandran Nair (1989). The indirect effect of enhanced uptake may be due to the higher nutrient levels.

Nitrogen uptake was maximum for the interaction effect between Rhizobium and 50 percent of the recommended dose of fertilizer. Other nutrients uptake - phosphorus, potassium, calcium and magnesium was noted for the interaction between VAM and 50 percent of the recommended dose of fertilizer. Under high phosphate levels, the extent of extramatrical mycelium (Abbott and Robinson, 1984) and the number of arbuscles formed (Smith and Gianinazzi - pearson,1988) will be decreased. Therefore the fungal metabolism will be affected.

5.7. Quality aspects

(a) Maize

Results (Table 4.11 & 4.12) showed that crude protein content, crude protein yield and crude fibre yield was maximum for the treatment Azospirillum. Since the nitrogen content was higher in Azospirillum treated plants, crude protein content as well as crude protein yield was also found to be maximum. Tanwar et al (1985) also reported 41 percent increase in crude protein content of oat fodder inoculated with Azospirillum. There was no marked difference in crude fibre content and crude fibre yield due to inoculation in the present study.

The protein content and yield was increased at higher level of fertilizer the readily available fertilizer nitrogen might have increased the protein content. Increased doses of nitrogen influenced the quantity of crude protein in maize as shown by Sharma and Singh (1973) and Ahmed and Gunasena (1979). The crude fibre content of maize did not differ significantly by the different fertilizer levels. Rajagopal *et al.* (1974) also reported that nitrogen levels failed to influence the crude fibre content. The higher levels of fertilizer were also found to be significantly superior to lower levels in increasing the crude fibre yield. Increased dry matter yield at higher rates of fertilizer application could be considered as the main reason for higher crude fibre yield in maize. Such an increase in crude fibre yield with increase in nitrogen application was reported by Sharma and Singh (1973).

The crude protein content and yield as well as crude fibre content and yield were found to be high, for the interaction between *Azospirillum* and at higher level of fertilizers. But there was no significant difference between the treatments.

(b) **Cowpea**

It can be seen from Table. 4.11 & 4.12 that crude protein content and yield was higher for *Rhizobium* treated plots. This might be due to the higher nitrogen content in the plant due to better assimilation of nitrogen. Increase in crude protein was noticed with *Rhizobium* inoculation in soybean hay by Karyagin (1980). The crude fibre content and yield was highest for *Rhizobium* treatment, which did not show any significant difference with other treatments.

The crude protein content and yield varied with increasing nutrient levels. Increase in nitrogen content in the plant had a positive effect on the crude protein content (Russell 1973). The influence of higher doses of fertilizers in increasing the crude protein content and the dry matter yield might have resulted in the higher crude protein yield. Application of NPK fertilizers also increased the crude protein content in soybean (Girenko and Levenskii, 1974). Higher levels of fertilizers also increased the crude fibre yield. This was also due to the influence of higher drymatter yield produced by higher rates of fertilizer application, which resulted in higher crude fibre yield from them.

Interaction effect due to different biofertilizers and chemical fertilizers were not significant. However, the highest quality parameters were observed for Rhizobium and higher level of fertilizer. Due to the higher nitrogen uptake, the crude protein content and yield might have increased and due to the higher dry matter production, crude fibre content and yield were increased.

5.8. Chemical composition of the soil after the experiment

5.8.1. Nitrogen content in the soil

The result presented in Table 4.13 showed that the biofertilizer treatment significantly influence the available nitrogen status of the soil. Due to the high level of nitrogen fixation, when inoculated with Azospirillum - maize + Rhizobium - cowpea, nitrogen status of the soil might have been improved to a great extent, which have led to a high value of residual nitrogen. But in the case of no inoculation treatment, in addition to the poor nitrogen status of the soil, at the beginning of experiment, the crop uses a certain amount for its growth from this limited pool, leading to a lower residual nitrogen in the soil.

However, with increasing fertilizer levels from control to 100 percent recommended dose, there was significant increase in the soil nitrogen status. The moderately high (238.40Kg ha^{-1}) nitrogen status of the soil might have enhanced the drymatter production of the plant, resulting in less utilization of applied nitrogen. The increased soil nitrogen status might also be attributed to the utilization of fixed nitrogen by the crop leading to the increase in residual nitrogen status. Increase in soil nitrogen status with increased application of nitrogenous fertilizers had been reported by Lee *et al*. (1990).

Interaction which produced highest residual nitrogen status was the *Azospirillum* - maize + *Rhizobium* - cowpea with 100 percent of the recommended dose of fertilizers. This, as already, explained, would have increased the nitrogen status of the soil through fixation as well as through inorganic sources by which a large amount of residual nitrogen remained in the soil after the experiment.

5.8.2. **Phosphorus content in the soil**

The results presented in Table 4.13 showed that the control treatment (no inoculation) recorded the highest available phosphorus content in the soil. This could be attributed to less uptake of phosphorus by the plant and hence less utilization of native and applied phosphorus. The lowest value was recorded by the treatment VAM-maize + VAM - cowpea, of 28.66 kg ha^{-1} in the soil. Inoculation with mycorrhiza increases the phosphorus uptake by way of extensive mycelial net work. However the higher green matter yield due to acquisition of nutrients like phosphorus would have resulted in low available phosphorus in the soil (Barea,1991).

Significant increase was observed in available phosphorus content due to different fertilizer levels.The treatment 25 percent of the recommended dose recorded the highest available phosphorus content followed by 75 percent fertilizer dose.

Similar increase in phosphorus content of soil was reported by Garg *et al*. (1970).

It can be seen that the treatment no inoculation in combination with 25 percent fertilizer dose produced the highest phosphorus content in the soil.This might be due to the less utilization of phosphorus.

5.8.3. **Potassium content**

The results presented in Table 4.13 showed that no biofertilizer recorded the highest available potassium content in the soil This might be due to the less utilization of potassium, for growth and as a result green matter yield also decreased.

Among the different nutrient levels, the control treatment registered the highest potassium content probably due to limited utilization of the element for green matter production by the plants. Interaction under no biofertilizer and no fertilizer produced the maximum potassium content in the soil.

5.8.4. **Calcium and magnesium content**

It can be seen from the Table 4.13 that there was no sigificant difference in the available calcium and magnesium content in the soil due to inoculation. This might be due to increased uptake of these nutrients with inocuiation.

The different nutrient levels also did not influence the available calcium and magnesium status of the soil. This showed that there was no additional benefit due to the application of NPK fertilizers on the calcium and magnesium contents in the soil. But the increasing trend shown by the increasing nutrient levels seems to suggest the influence of phosphorus in increasing the available calcium and magnesium contents in soil. Increase in CEC with increase in dose of phosphorus was reported by Singh and Singh (1975).

5.9. **Economics**

From the data presented in Table 4.14 and Fig.7 it was seen that the maximum net return was obtained from the combination of VAM - maize + Rhizobium - cowpea with 50 percent of the recommended dose of fertilizer application. This was followed by Azospirillum - maize + VAM - cowpea with 75 percent of the recommended dose of fertilizer application.

When the crops were grown under control there was a loss of Rs. 5217. Thus it can be seen that through the use of biofertilizers, about 50 percent of the recommended dose of fertilizer can be saved, thereby reducing the cost of cultivation.

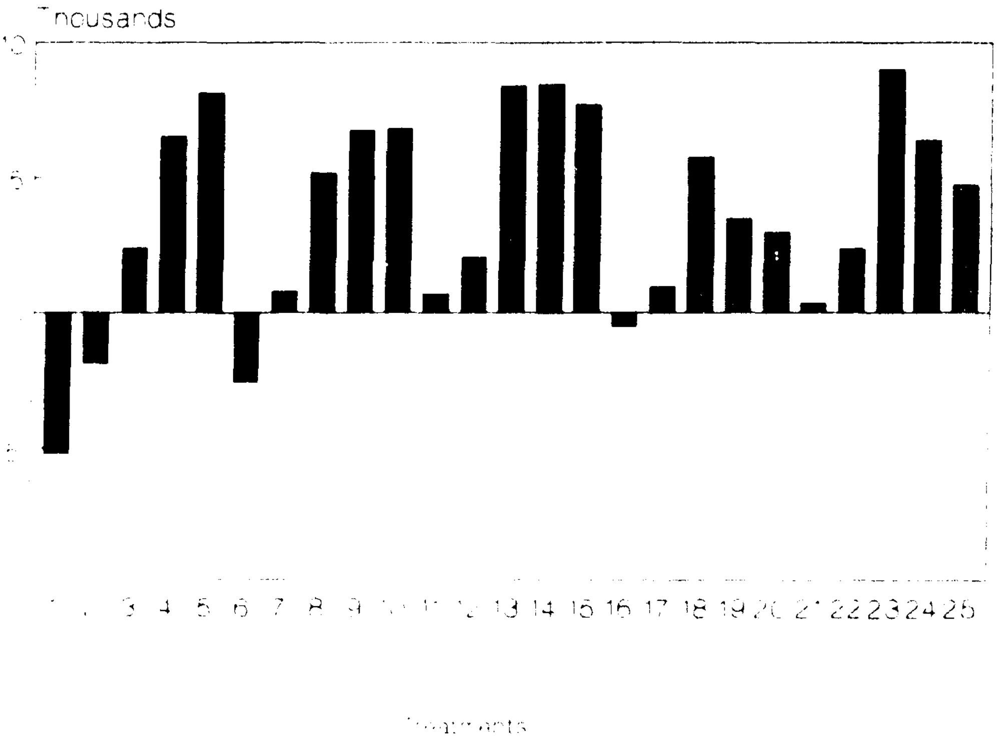

Fig.7. Net Profit of different treatments (Rs ha^{-1})

SUMMARY

SUMMARY

An investigation was conducted to study the effect of different microbial inoculants (*Azospirillum*, *Rhizobium*, vesicular arbuscular mycorrhiza (VAM) as well as different levels of nutrients ie control, 25 percent, 50 percent, 75 percent and 100 percent of the recommended dose of fertilizer and their interaction on increasing the forage production of maize-cowpea intercropping system. The experiment was laid out in strip-plot design with three replications The important results of the study are summarised below.

1. The height of maize was not influenced significantly with respect to inoculates in combination with fertilizer. Plant height of cowpea ,significantly increased with treatment VAM - maize + *Rhizobium* - cowpea + 75 percent recommended dose of fertilizer.

2. The treatment *Azospirillum* - maize + *Rhizobium* - cowpea with 75 percent recommended dose of fertilizer recorded the maximum number of leaves and leaf area index in maize. In cowpea the interaction between the treatment VAM - maize + *Rhizobium* - cowpea and 50 percent recommended dose of fertilizer produced maximum number of leaves and leaf area index.

3. In maize, interaction effect of _Azospirillum_ - maize + VAM - cowpea with 50 percent recommended dose of fertilizer produced maximum leaf-stem ratio. It was also noted that at higher fertilizer levels, whatever may be the inoculant there was a decrease in the value of leaf stem ratio For cowpea, again the same treatment VAM - maize + _Rhizobium_ - cowpea with 75 percent recommended dose of fertilizer produced maximum leaf-stem ratio.

4. In maize, the root length was maximum for the treatment _Azospirillum_ - maize + _Rhizobium_ - cowpea and root volume for the treatment _Azospirillum_ - maize + VAM - cowpea, both under no fertilizer application. The root length of cowpea was highest for the treatment _Azospirillum_ - maize + VAM - cowpea and nodule number,and nodule weight for the treatment VAM - maize + _Rhizobium_ - cowpea, all these under no fertilizer application.

5. The mycorrhizal colonization of maize roots was highest for the treatment VAM - maize + VAM - cowpea.Highest value of mycorrhizal colonization in cowpea was noted for the treatment VAM - maize + VAM - cowpea, all in combination with no fertilizer application. Here although in uninoculated plants, mycorrhizal colonization was recorded, the values were below 50 percent, and inoculated plants registered higher values even up to 90 percent.

6. Both green - matter dry matter yield maize were highest for the treatment combination between _Azospirillum_ - maize + VAM - cowpea and 50 percent of the recommended dose of fertilizer. In cowpea, both green - matter and dry matter yield were highest for the interaction between VAM - maize + _Rhizobium_ - cowpea and 50 percent of the recommended dose of fertilizer.

7. For maize, the interaction effect between the treatment _Azospirillum_ - maize + VAM - cowpea with 50 percent of the recommended dose of fertilizer produced maximum nitrogen, potassium, calcium and magnesium uptake.The prosperous uptake was maximum for the treatment, VAM - maize + _Rhizobium_ - cowpea with 50 percent of the recommended dose of fertilizer. In cowpea, highest nitrogen content waS for the combination between VAM - maize + _Rhizobium_ cowpea with 75 percent of the recommended dose of fertilizer. For other nutrients uptake, interaction between _Azospirillum_ - maize + VAM - cowpea with 75 percent of the recommended dose of fertilizer produced highest value.

8. The highest crude protein content and crude protein yield of maize were recorded for the combination between _Azospirillum_ - maize + VAM - cowpea with 50 percent of the recommended dose of fertilizer. Crude fibre yield was maximum

for the treatment, Azospirillum - maize + ,VAM - cowpea, with full recommended dose of fertilizer. In cowpea, crude protein content, was highest for the treatment, VAM - maize + Rhizobium - cowpea with full recommended dose of fertilizer. The crude protein yield and crude fibre yield were maximum for the same biofertilizer treatment as above with 75 percent of the recommended dose of fertilizer.

9. The available nitrogen, phosphorus, potassium, calcium and magnesium status of the soil varied significantly due to interaction between biofertilizer and chemical fertilizer. But it was noticed that with increase in nutrient doses, there was corresponding increase in the available nitrogen and phosphorus status of the soil.

10. The treatment combination, VAM - maize + Rhizobium - cowpea + 50 percent of the recommended dose registered the highest net profit of Rs 8110.00 and Benefit cost ratio of 1.502.

11. The treatment combination, VAM-maize+ Rhizobium cowpea +50 percent of the recommended dose can be given as the final recommendation in fodder maize- cowpea intercropping system.

Future line of work

The effect of biofertilizer treatment with *Azospirillum*, *Rhizobium* and VAM on other-maize legumes has to be investigated. The effect on other cereal legumes [illegible] should also be tried out and the fertilizer economy due to this should also be worked out.

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APPENDIX

NUTRIENT MANAGEMENT WITH BIOFERTILIZERS IN A FODDER MAIZE-COWPEA INTERCROPPING SYSTEM

BY

KAVITHA, P. K.

ABSTRACT OF THE THESIS
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Faculty of Agriculture
Kerala Agricultural University

Department of Agronomy
COLLEGE OF AGRICULTURE
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ABSTRACT

An experiment was conducted in the Instructional farm attached to the College of Agriculture, Vellayani during the Kharif season in 1994. The object was to study the effect of different bioinoculants (Azospirillum, Rhizobium, Vesicular arbuscular mycorrhiza (VAM) as well as different levels of nutrients ie control,25,50, 75 and 100 percent of the recommended dose of fertilizer and their interaction on increasing the forage production of maize - cowpea intercropping system.

The height of maize plant, number of leaves, and leaf area index were maximum for the treatment, Azospirillum - maize + Rhizobium - cowpea but the maximum leaf-stem ratio was observed for Azospirillum - maize + VAM - cowpea.In cowpea, all the growth characters were maximum for the treatment, VAM - maize + Rhizobium-cowpea. It was also seen that fertilizer level above 50 percent didn't produce any significant increase in these characters.

In maize, highest root length was observed for Azospirillum - maize + Rhizobium - cowpea treated plants and highest root volume for, Azospirillum - maize + VAM - cowpea treated plants. Maximum nodulation in cowpea was observed for the treatment, VAM -maize + Rhizobium - cowpea and maximum root

length for Azospirillum - maize + VAM - cowpea. Mycorrhizal colonization percentage was found to be higher in the roots of inoculated plants for both crops. All these character were found to be maximum under no fertilizer application.

Maximum green matter and drymatter yield of maize occurred for the treatment, Azospirillum - maize + VAM - cowpea and for cowpea, the treatment VAM - maize + Rhizobium - cowpea. It was also noted that 50 percent of the recommended dose of fertilizer was enough for producing maximum yield.

The treatment Azospirillum - maize + VAM cowpea produced maximum uptake of nitrogen in maize, phosphorus in cowpea and potassium, calcium and magnesium uptake in both the crops. The treatment VAM - maize + Rhizobium - cowpea produced the maximum uptake of phosphorus in maize and nitrogen in cowpea. The uptake of nutrients do not differ significantly after 50 percent of recommended dose of fertilizer.

In maize, crude protein yield and crude fibre yield were maximum for the treatment, Azospirillum - maize + VAM-cowpea under high levels of fertilizer. In cowpea, the treatment VAM - maize + Rhizobium - cowpea at high levels of fertilizer produced maximum value.

The available nitrogen, phosphorus, potassium, calcium and magnesium status of the soil varied significantly due to the interaction between biofertilizer and chemical fertilizers.

The treatment combination, VAM - maize + Rhizobium - cowpea + 50 percent of the recommended dose registered the highest net profit of Rs. 8110.00 and Benefit-cost ratio of 1.502.

The treatment combination, VAM-maize+ Rhizobium-cowpea+ 50 percent of the recommended dose can be given as the final recommendation in fodder maize-cowpea intercropping system.