EFFECT OF BIOFERTILIZERS ON N AND P ECONOMY IN PALMAROSA (*Cymbopogon martinii*)

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THESIS

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DECLARATION

I hereby declare that this thesis entitled 'Effect of biofertilizers on N and P economy in palmarosa (Cymbopogon martinii)' is a bonafide record of research work done by me during the course of research work and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society

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CERTIFICATE

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REGIMOL THOMAS

DEDICATED

TO

MY LOVING PARENTS

Introduction

INTRODUCTION

Palmarosa (*Cymbopogon martinii* Stapf var Motia) is an important perennial aromatic grass indigenous to India The foliage and flowering tops of this grass on steam distillation yield an essential oil rich in geraniol with typical rosaceous odour The oil is extensively used in perfumery, cosmetics, soaps and detergents, medicines, flavouring, synthesis of aromatic compounds and in mosquito repellants The studies conducted so far on various aspects have clearly indicated that it is a suitable crop under the agroclimatic conditions of Kerala and at present, it is the main geraniol yielding aromatic plant under tropical conditions

Indian palmarosa oil is valued at Rs 759 kg^{-1} in the international market and in the domestic markets the palmarosa oil costs Rs 450 kg^{-1} (CIMAP, 1995) The high cost of cultivation makes the farmers reluctant to take up its largescale cultivation The escalating prices and periodic shortages of chemical fertilizers add to it Moreover, the continuous use of chemical fertilizers is not advisable as far as the long term soil productivity is concerned So future research efforts should be oriented to maintain soil health without reducing the economic return from the limited land area available The use of biofertilizers to supplement partially the costly synthetic fertilizers thus assumes importance Above all, the use of biofertilizers is environmentally friendly in addition to saving the huge amount spent for inorganic fertilizers

There is virtually no report on the use of biofertilizers in palmarosa to economise N and P fertilization for getting economic yield and hence the present study was planned with the following objectives -

1 To assess the possibility of using biofertilizers so as to replace or minimise the expensive synthetic nitrogen fertilizers for palmarosa

2 To find out the effect of phosphorus solubilizing bacteria (Bacillus megatherium var phosphaticum) in increasing the availability of fixed soil phosphorus

3 To find out the effect of combination of chemical and biofertilizers on the growth and yield of palmarosa

4 To work out the N and P economy due to the integration of chemical and biofertilizers

Review of Literature

REVIEW OF LITERATURE

The available literature on the effect of chemical and biofertilizers on the growth, yield nutrient uptake and soil fertility status of palmarosa are given below -

2 1 Mineral nutrition in palmarosa

2 1 1 Growth characters

2 1.1 1 Plant height

A few reports are available showing that application of N and P resulted in significant increase in plant height in palmarosa

In an experiment conducted at Delhi, application of different levels of N and P (0,40, and 80 kg ha^{-1} for both) increased the plant height in the crop (Gupta et al , 1978) Pareek et al (1981) at New Delhi observed that application of 80 kg N ha^{-1} increased the height of plants significantly over control in two out of three cuttings Maheshwari et al (1984) also observed that N application significantly increased the plant height in palmarosa Similar results were obtained by Singh et al (1992) at Assam Experiments conducted at NBPGR New Delhi also showed that application of 25 kg N ha^{-1} brought about a significant increase in plant height as compared to those without any N application (Pareek and Maheshwari, 1995)

Also there are reports that N and P application did not affect plant height in palmarosa Experiments conducted at Assam by Singh *et al* (1981) showed that application of different levels of N (0,50 and 100 kg ha^{-1}) and P (0,40 and 80 kg ha^{-1}) did not show any significant effect on the plant height in palmarosa Also Pareek *et al* (1981), Maheshwari *et al* (1984) and Singh *et al* (1992) did not observe any significant effect of P application to palmarosa

2 1.1 2 Number of tillers

Pareek *et al* (1981) and Pareek and Maheshwari (1995) observed that the application of N showed a significant increase in the number of tillers

Significant effect of N and P on the number of tillers was reported by Gupta *et al* (1978) and Singh *et al* (1992)

There are also reports that application of N and P (Singh *et al* , 1981 and Maheshwari *et al* , 1984), P (Pareek *et al* , 1984) and N (Maheshwari *et al* , 1991) did not affect the tiller production in palmarosa

2 1 1 3 Length of inflorescence

Experiments conducted by Gupta *et al* (1978) showed a significant increase in the length of inflorescence with the application of N @ 40 kg ha^{-1} Pareek *et al* (1981) also observed that out of three harvests taken application of N significantly influenced the length of inflorescence in the second and third harvests

At the same time, Maheshwari *et al* (1984), Maheshwari *et al* (1991) and Pareek and Maheshwari (1995) reported that the length of inflorescence in palmarosa was not affected by N application and also by the application of P (Gupta *et al*, 1978 and Maheshwari *et al*, 1984)

2 1.2 Yield characters

2 1 2 1 Herbage yield

According to Hazarika and Bora (1977) herbage yield of palmarosa increased significantly with the application of N from 0 to 60 kg ha^{-1}, whereas Sarma *et al* (1977) obtained similar results with the application of N upto 75 kg ha^{-1} Sharma *et al* (1980) observed that N at 150 kg ha^{-1} significantly raised the herbage yield in two out of four harvests Similar results were obtained by Pareek *et al* (1981) with the application of N upto 80 kg ha^{-1} Also Maheshwari *et al* (1984) and Yadav *et al* (1985) observed that nitrogen application increased the herbage yield significantly Rao *et al* (1989) observed that application of N @ 50 kg ha^{-1} produced significantly higher yield over control, whereas Singh et al (1992) reported similar effect with the application of N upto 80 kg ha^{-1} With the application of N @ 0,25, 50 and 75 kg ha^{-1} Pareek and Maheshwari (1995) observed that the treatment 25 kg N ha^{-1} resulted in maximum herbage yield

Application of phosphorus showed a significant effect on herbage yield of palmarosa as reported by Sharma et al (1980) and Singh et al (1981)

Also there are reports that P application did not affect the herbage yield of palmarosa (Sarma et al ,1977, Pareek et al , 1981, Maheshwari et al ,1984, Rao et al ,1991 and Singh et al ,1992)

Gupta et al (1978) reported that combined application of N and P resulted in an increase in herbage yield in palmarosa

The highest fresh herbage yield of 47 t ha^{-1} was obtained with N_{100} P_{100} K_{50} as against 25 t ha^{-1} from control (Dutta and Paul, 1976) The combination of P and K with N showed a direct effect in increasing the herbage yield and the best combination was N_{60} P_{40} K_{40} (Hazarika and Bora, 1977)

2 1 2 2 Oil content

Most of the reports show that N and P application did not significantly influence the oil content in palmarosa

Increasing N application from 75 to 150 kg ha^{-1} significantly reduced the oil content in Java citronella (Bommegowda, 1978), whereas Rao et al (1989) and Maheshwari et al (1992) observed that nitrogen application did not affect the oil content in palmarosa

Nitrogen and phosphorus produced no effect on the oil content of palmarosa (Dutta and Paul, 1976, Pareek et al , 1981, Singh et al , 1981, Pareek et al , 1983 and Maheshwari et al , 1984)

Hazarika et al (1978) observed that N_{120} P_{40} K_0 and N_{60} P_{40} K_{40} yielded maximum percentage of oil which were highly significant over most of the other combinations

2 1 2 3 Oil yield

Application of N could significantly increase the oil yield in palmarosa (Sharma et al , 1980, Munsi and Mukherjee, 1982, Yadav et al , 1985, Rao et al , 1989, Singh et al , 1992 and Pareek and Maheshwari, 1995)

There are a few reports showing no influence of N application on oil yield (Singh *et al*, 1981, Maheshwari *et al*, 1991 and Maheshwari *et al*, 1992)

Significant influence of P application in increasing oil yield of palmarosa was reported by many workers (Sharma *et al*, 1980, Singh *et al*, 1981 and Munsi and Mukherjee, 1982)

The effect of P on oil yield was found non-significant (Sarma *et al*, 1977, Sharma *et al*, 1980, Pareek *et al*, 1981 and Singh *et al*, 1992)

Maheshwari *et al* (1984) also found that the effect of N and P on oil yield was not significant

2.1.2.4 Geraniol

Non-significant influence of N on geraniol content of palmarosa oil was observed by several researchers (Singh *et al*, 1981, Chinnamma, 1985, Yadav *et al*, 1985, Maheshwari *et al*, 1991, Maheshwari *et al*, 1992 and Pareek and Maheshwari, 1995)

Singh *et al* (1981) observed that P application brought about a positive significant difference in geraniol over control, whereas Chinnamma(1985) observed that P application did not influence the geraniol content in palmarosa

The effect of N and P on the quality of oil was also not significant (Pareek *et al* 1981)

2 1 3 **Content and uptake of nutrients**

There are reports that application of N and P increased the concentrations of these nutrients in the plant Munsi and Mukherjee (1982) observed a higher concentration of N in plants grown under increased levels of N and P Pareek *et al* (1983) observed that N application resulted in significantly higher K content in plant while it did not influence the contents of N and P They also found that application of P did not bring about any significant change in the content of N, P and K

With regard to uptake, Pareek *et al* (1983) observed that application of 40 kg N ha^{-1} resulted in significantly higher uptake of N, P and K by 35 3, 24 6 and 42 8 per cent respectively over control Rao *et al* (1989) reported that N application significantly increased the uptake of N P and K N application increased its uptake in palmarosa (Yadav *et al* , 1985) Application of 150 kg N ha^{-1} significantly increased the N and K uptake (Rao *et al* , 1991)

There are also a few reports that application of P did not influence the uptake of N, P and K in palmarosa (Pareek *et al* , 1983 and Rao *et al* , 1991)

2 2 Biofertilizers on growth and yield of crops

The survey of literature showed that there are few reports on the effect of biofertilizers in palmarosa Hence reports that are available on the effect of inoculation in field crops are given below

2.2.1 *Azotobacter*

Azotobacter is a heterotrophic, aerobic,free-living nitrogen fixing bacteria which are not usually present in the rhizoplane but are abundant in the rhizosphere Inoculation with ***Azotobacter*** is well known to improve the growth and yield of crops Besides nitrogen fixation, it has the ability to produce considerable quantity of biologically active substances like vitamins of B group, nicotinic acid, pantothenic acid, biotin, heteroauxin, giberellins and antifungal antibiotics and fungistatic compounds against pathogens like Fusarium, Alternaria and Trichoderma (Mishustin and Shillinkova, 1972) ***Azotobacter*** also secretes certain growth promoting substances like auxins, giberellins, and cytokinins (Rosario and Barea 1975)

2 2 1.1 Rice

Rangarajan and Muthukrishnan (1976) observed that in the main field, seedling root dip with ***Azotobacter*** alone significantly increased rice grain yield over uninoculated control They also observed that seed treatment with *Azotobacter* resulted in significant increase in shoot length and drymatter production over uninoculated seeds Prasad and Singh (1984) reported a significant increase in plant height, panicle length and number of grains panicle $^{-1}$ due to inoculation as compared to control

Mehrotra and Lehri (1971) observed not much effect of *Azotobacter* inoculation in increasing rice grain yield Prasad and Singh (1984) also did not observe any significant effect of *Azotobacter* with respect to number of tillers plant^{-1} and grain yield plant^{-1}

2 2 1 2 **Wheat**

A positive influence of *Azotobacter* inoculation on wheat crop was reported by several workers An increase in grain yield was observed due to *Azotobacter* inoculation (Rao et al , 1963) Badgire and Bindu (1976) reported that *Azotobacter* inoculation with 2 out of 3 strains resulted in a significant increase in drymatter production Palarpwar (1983) obtained an increase of 16-33 per cent in grain yield due to inoculation Experiments conducted in Maharashtra by Zambre et al (1984) revealed that the number of tillers, drymatter production and grain yield of wheat were more when inoculated with *Azotobacter* at all levels of N (0,30,60,90 and 120 kg ha^{-1}) compared to the corresponding control Sharma et al (1987) found that *Azotobacter* could markedly increase plant height, number of tillers, ear length and grain yield of wheat over no inoculation in the sandy loam soils of Maharashtra Badiyala and Verma (1991) also obtained significantly higher grain yield under the agroclimatic conditions of Himachal Pradesh with *Azotobacter* inoculation *Azotobacter* inoculation increased the grain yield as well as drymatter production significantly as reported by Tomar et al (1995)

Mehrotra and Lehri (1971) observed that *Azotobacter* inoculation did not increase the grain yield conspicuously Badgire and Bindu (1976) obtained almost similar results with respect to number of tillers, plant height and grain yield Singh et al (1993) found that *Azotobacter* inoculation did not affect the grain and straw yields in wheat Tomar et al (1995) also observed that *Azotobacter* inoculation did not affect the number of tillers and straw yield in wheat

2 2 1.3 Sorghum

There are a few reports showing the superiority of *Azotobacter* inoculation on green fodder and drymatter production in sorghum such as that by Wani and Rai (1980) who observed that dry weight of jowar plant increased significantly when inoculated with *Azotobacter* as a seed inoculant or foliar spray Katiyar and Shrivastava (1986) reported significantly higher green fodder and drymatter in forage sorghum varieties due to *Azotobacter* seed treatment They also observed that *Azotobacter* inoculation along with varying levels of N increased green fodder yield over N levels alone Nagre et al (1990) reported a significant increase (12 8 per cent) in drymatter production of sorghum plants at harvest due to *Azotobacter* seed treatment. Raghuwanshi et al (1991) reported that seed inoculation with *Azotobacter* had increased jowar yields

Dey (1972) did not observe any effect of *Azotobacter* inoculation on growth and drymatter production of sorghum

2 2.1 4 Maize

Inoculation with *Azotobacter* significantly increased plant height, drymatter production and grain yield in maize as reported by Karthikeyan (1981) Badiyala and Verma (1991) also reported significant improvement in maize grain yield due to inoculation, whereas Singh et al (1993) observed that seed inoculation with *Azotobacter* had a significant effect on green fodder yield and drymatter production of forage maize

According to Singh et al (1981) *Azotobacter* inoculation did not result in any significant increase in grain yield in maize

2 2 1 5 Millets

Seed inoculation with *Azotobacter* significantly increased grain and straw yields in bajra over no inoculation (Bhargava et al , 1981) Reddy (1981) observed a significant increase in plant height due to *Azotobacter* inoculation in bajra Raghuwanshi et al (1991) also observed that seed inoculation with *Azotobacter* along with the recommended dose of 50 kg N ha^{-1} has helped to increase the grain yield in bajra by 38 per cent

In a growth chamber experiment Yahalom et al (1984) observed that *Azotobacter* inoculation significantly increased plant dry weight and panicle length in foxtail millet over control, but this did not result in conspicuous increase in forage yield of the crop

In an experiment conducted at Madhya Pradesh, Naik and Dhagat (1987) found that application of FYM and *Azotobacter* culture alone or in combination have not shown appreciable effect on both grain and straw yields of kodo and kutki millets

2 2 1.6 Other members of Gramineae

Studies conducted in sugarcane on the effect of *Azotobacter* inoculation by Singh (1984) revealed that inoculation resulted in significantly higher drymatter as compared to control Also Misra and Naidu (1990) reported that *Azotobacter* inoculation improved the plant height, number of tillers and cane yield in sugarcane

Supplementing 45 kg N ha^{-1} with *Azotobacter* recorded maximum plant height in guinea grass (KAU 1991)

2 2 1 7. Oil seeds

Arunachalam and Venkatesan (1984) reported increase in grain yield in sesame due to *Azotobacter* seed inoculation, whereas Subbian and Chamy (1984) did not see any effect of *Azotobacter* inoculation alone or in combination with FYM in the plant height and 1000 seed weight of sesame

Azotobacter application in sunflower resulted in 2-8 per cent increase in seed yield as reported by Oblisami et al (1976)

Azotobacter inoculation in Brassica napus significantly increased the number of primary branches and drymatter production over control with an increase of 52 per cent in seed yield (Singh and Bhargava, 1994)

2 2 1 8 Vegetables

There are a few reports showing beneficial effect of *Azotobacter* inoculation on the yield of vegetables

Mehrotra and Lehri (1971) reported that *Azotobacter* inoculation resulted in significantly higher yield in cabbage to a level of 50 per cent and 62 per cent in brinjal (Lehri and Mehrotra 1972) In brinjal Sivakumar et al (1991) reported that 30 kg N acre^{1} plus *Azotobacter* inoculation recorded an increase of 7 21 per cent in yield over 40 kg N acre^{1} without inoculation

But Mehrotra and Lehri (1971) did not obtain any significant increase in the yield of brinjal and tomato due to *Azotobacter* inoculation

2 2 1 9 Cotton

The survey of literature showed that *Azotobacter* inoculation resulted in an increase in yield components and yield in cotton In an experiment conducted by Pothiraj(1979) at Tamil Nadu showed that application of *Azotobacter* alone or in combination with FYM under rainfed conditions to cotton in black cotton soils resulted in an increase in yield Shende etal(1988)observed that seed inoculation with *Azotobacter* increased the number of bolls plant^{-1} compared to control An average increase of 29-39 per cent was observed in seed cotton yield due to inoculation (Malik et al , 1994) Inoculation resulted in a significant increase in seed cotton yield (Prasad and Prasad, 1994)

2 2 2 *Azospirillum*

Azospirillum is a common soil and root inhabiting bacterium in the tropics Inoculation of crop plants with ***Azospirillum*** exerts a beneficial effect on growth and yield The increased yield due to inoculation has been postulated as fixation of atmospheric nitrogen, protection from pathogenic plant microorganisms and production of plant growth promoting substances (Okon and Kapulnik, 1986) The N fixing capacity of ***Azospirillum*** has been associated with soil types, environmental factors, nitrogen status of soil and crop genotype The reports available on the effect of ***Azospirillum*** on growth and yield of different crops are summarised below -

2.2 2 1. Rice

There are reports that ***Azospirillum*** inoculation resulted in a significant increase in the growth and yield in rice

Increase in rice grain yield due to *Azospirillum* inoculation was reported by many workers (Subba Rao et al 1979 and Subba Rao et al , 1980) The plant height in rice increased significantly with *Azospirillum* inoculation as reported by Sanoria et al (1982) Prasad and Singh (1984) also observed significant increase in plant height, number of tillers and grain yield plant^{-1} Jeyaraman and Ramiah (1986) reported that application of 75 kg N ha^{-1} in combination with root dipping with *Azospirillum* recorded significantly higher grain yield as compared to 100 kg N ha^{-1} alone Both grain and straw yields were increased significantly due to inoculation (Purushothaman 1988) Gopalaswamy et al (1989) found significant increase in grain and straw yields at 75 kg N ha^{-1} along with *Azospirillum* inoculation Kandasamy et al (1991) observed that the beneficial effect of *Azospirillum* in increasing rice grain yield was more pronounced at 75 kg N ha^{-1} Lakshminarasimhan and Pannerselvam (1991) also observed increased grain yields due to inoculation along with fertilizer nitrogen

There are also a few reports that the inoculation did not affect the growth characters in rice Watanabe and Lin (1984) observed that the effect of *Azospirillum* inoculation on total dry weight was non-significant Similar effect on plant height and number of productive tillers was reported by Gopalaswamy et al (1989)

2 2 2 2 **Wheat**

There are a few reports that ***Azospirillum*** inoculation resulted in an increase in the grain yield of wheat (Subba Rao et al , 1979), grain yield and drymatter production (Kapulnik et al , 1979) Application of FYM plus ***Azospirillum*** increased the wheat yield significantly (Lal and De, 1980) An increase in grain yield (Subba Rao et al , 1980) and drymatter production, height and number of tillers (Hegazi et al , 1981) were noticed in wheat due to ***Azospirillum*** inoculation Significant increase in plant height (Kapulnik et al , 1981), grain yield (Rai and Gaur, 1982) and number of fertile tillers per unit area (Kapulnik et al , 1983) were noticed due to ***Azospirillum*** inoculation Dreessen and Vlassak (1984) observed an increase in grain yield due to inoculation Millet and Feldman (1984) obtained a significant average increase of 0 17 fertile spikelets spike^{-1} due to ***Azospirillum*** inoculation Zambre et al (1984) reported that grain yield, drymatter production and number of tillers were more when inoculated with ***Azospirillum*** at all levels of N (0,30,60, 90 and 120 kg ha^{-1}) compared to the corresponding uninoculated control

2 2 2 3 Sorghum

Azospirillum inoculation along with 75 per cent recommended dose of fertilizer nitrogen increased the drymatter yield in sorghum (Smith et al , 1978) Kapulnik et al (1979) observed that *Azospirillum* inoculation increased the grain yield and drymatter production whereas Subba Rao et al (1980) observed a 28 3 per cent increase in grain yield due to *Azospirillum* inoculation Also the treatment had ‿ ⌒ shown to increase the plant height, number of panicles plant^{-1} and 1000 grain weight of sorghum significantly (Kapulnik et al , 1981) Okon et al (1981) also observed that *Azospirillum* inoculation resulted in an increase in grain yield and 1000 grain weight of sorghum *Azospirillum* inoculation resulted in an increase in drymatter production and a 12 per cent increase in grain yield (Sarig et al , 1981) The treatment also increased drymatter production (Tilak et al , 1982 and Pacovsky et al , 1985) and grain yield (Prabakaran, 1991 and Raghuwanshi et al , 1991) in sorghum

2 2 2 4 Maize

Azospirillum inoculation resulted in an increase in dry weight (Okon et al , 1981, Kapulnik et al , 1979 and Nur et al , 1980) in maize Hegazi et al (1983) reported that *Azospirillum* inoculation resulted in 200 per cent increase in plant dry weight and that straw amendment with *Azospirillum* recorded an increase of 343 per cent in plant drymatter Experiments conducted at Tamil Nadu by Srinivasan et al (1991) revealed an increase of 10 4 per cent in grain yield of maize due to *Azospirillum* inoculation over control In a study conducted at Bihar, Yadav et al (1992) observed that application of different levels of N in conjunction with *Azospirillum* brought about a significant increase in yield of maize over its corresponding control of fertilizer nitrogen alone Fulchieri and Frioni (1994) reported that *Azospirillum* inoculation resulted in 71 per cent more stubble dry weight, which was significantly higher than that in the control plot This was also on par with plots in which N @ 80 kg urea ha^{-1} alone was applied

2 2 2 5 Other members of Gramineae

Azospirillum inoculation to pearl millet resulted in significant increase in grain yield (Smith et al , 1977), dry weight (Taylor 1979 Govindan, 1982 and Venkateswarlu and Rao 1983), grain and straw yields (Purushothaman and Gunasekaran 1980) and drymatter production, height and earhead length (Reddy, 1981) as compared to that in control Gautam et al (1985) in the experiments conducted at New Delhi, reported that *Azospirillum* inoculation along with all levels of N (0 40 and 80 kg ha^{-1}) resulted in an increase in plant height, number of tillers, length of ear, and drymatter production and a significant increase in grain yield of pearl millet in the first year while in second year significant effect of inoculation was noticed only at 40 kg N ha^{-1} They also observed that the effect of ***Azospirillum*** inoculation did not improve the stover yield in pearl millet Similar effect on grain yield was reported by Pareek and Shaktawat (1988) and Raghuwanshi et al (1991) in pearl millet

Studies conducted in growth chamber by Yahalom et al (1984) revealed that ***Azospirillum*** inoculation resulted in significant increase in plant dry weight and panicle length in foxtail millet

2 2 2 6 Pulses

In the studies conducted in Israel by Sarig et al (1986) it was observed that ***Azospirillum*** inoculation significantly increased the seed yield of chick pea and garden pea over control whereas the shoot dry weight and 1000 seed weight of chick pea and garden pea was not affected Inoculation of cowpea with ***Azospirillum*** resulted in 111 2 per cent increase in total dry weight (Menon and Pillai 1994)

2 2 2 7 Oilseeds

Purushothaman and Gunasekaran (1981) obtained significant increase in drymatter yields of cotton as a result of *Azospirillum* inoculation Arunachalam and Venkatesan (1984) reported increased yield of sesamum due to inoculation In mustard Saha et al (1985) reported significant increase in yield due to *Azospirillum* inoculation Saravanan and Sundaram (1991) obtained a yield of 1490 kg ha^{-1} in *Azospirillum* inoculated plots as against 950 kg ha^{-1} in the control plots in sunflower Prasad and Prasad (1994) observed that *Azospirillum* inoculation resulted in significant increase in seed cotton yield as compared to that in the control

2 2 3 **Phosphate Solubilising Bacteria (PSB)**

2 2.3 1. Cereals and millets

Inoculation of PSB along with rock phosphate resulted in an increase in grain yield of rice as compared to that in uninoculated control (Anthoniraj et al , 1994) Inoculation with Bacillus megatherium var phosphaticum along with mussorie rock phosphate (MRP) in rice did not cause any significant increase in the number of productive tillers $hill^{-1}$, panicle length and grain and straw yields as compared to MRP alone (Paulraj and Velayudham, 1995)

Inoculation of wheat plant with PSB, resulted in increase in grain yield (Kundashev, 1956) Similar results were obtained by Smallii (1958) and Sundara Rao (1968) Also Taha <u>et al</u> (1969) observed an increase in grain yield and drymatter production in wheat Under pot culture conditions Bajpai and Rao (1971) obtained increased yield in wheat due to PSB inoculation Tiwari <u>et al</u> (1993) reported that PSB inoculation resulted in a significant increase in the grain yield of wheat as compared to that in the uninoculated control

Increase in the yield of maize due to PSB inoculation was reported by Kundashev (1956), Sundara Rao (1968) and Kavimandan and Gaur (1971)

Inoculation with PSB resulted in an increase in grain yield of sorghum (Rangaswamy and Morachan, 1974 and Pharande and Patil, 1991)

Application of compost or decomposing sugarcane trash along with phosphate solubilising bacteria resulted in an increase in the grain yield of pearlmillet (Rasal and Patil 1991)

2 2 3 2 Pulses

Kundashev (1956) obtained higher yield of soybean due to PSB application so also Bajpai and Rao (1971) obtained increased yield in cowpea due to PSB inoculation Patil *et al* (1979) observed that a combination of PSB plus rock phosphate plus FYM on cowpea gave a drymatter yield of 67 g pot^{-1} as against the same treatment without inoculation which yielded 53 9 g pot^{-1} Ahmad and Jha (1982) obtained increase in yield of soybean due to inoculation with PSB Alagawadi and Gaur (1988) observed that combined inoculation of Rhizobium and PSB significantly increased the drymatter content and grain yield in chick pea Kuppuswamy *et al* (1991) reported significant increase in grain and haulm yield of blackgram due to seed coating with diammonium phosphate and PSB Seed inoculation with phosphate solubilising microorganisms did not show any response to grain yield of gram (Veer *et al* , 1991) Tomar *et al* (1993) observed that PSB inoculation resulted in a significant increase in the number of pods $plant^{-1}$, seeds pod^{-1} and seed yield of black gram, whereas the treatment did not affect the plant height in the crop

2 2.3 3. Vegetables

PSB inoculation resulted in an increase in tomato yield (Sundara Rao and Sinha, 1963) and it enhanced the yield and drymatter production in broadbean (Taha *et al* , 1969) Vinayak and Patil (1978) obtained 33 per cent increase in the yield of tomato due to the combined inoculation of PSB and *Azotobacter*

2 3 Biofertilizers on content and uptake of nutrients

2 3 1 *Azotobacter*

In wheat *Azotobacter* inoculation resulted in significantly higher N content in the plant as compared to that in the uninoculated control (Badgire and Bindu 1976) Singh (1984) observed similar results in sugarcane Yahalom et al (1984) observed higher N content in Setaria italica due to inoculation with *Azotobacter* while Sharma et al (1987) reported similar results in wheat Nagre et al (1990) reported that the concentration of N increased due to *Azotobacter* inoculation in sorghum

There are also reports that *Azotobacter* inoculation did not show any effect in increasing N content in sorghum (Wani and Rai 1980) and that of N P and K contents in rice as indicated by Prasad and Singh (1984)

Rao et al (1963) observed increased N and P uptake by wheat while Karthikeyan (1981) reported increase in N and P uptake in maize due to *Azotobacter* inoculation Prasad and Singh (1984) found that the uptake of N P and K was increased significantly in rice

The effect of *Azotobacter* in increasing the N uptake by wheat (Gai et al 1976) and N P and K uptake in rice (Prasad and Singh 1984) was not significant

2 3 2 *Azospirillum*

Inoculation of ***Azospirillum*** resulted in an increase in plant N content in corn (Okon et al 1976) bajra (Bouton et al, 1979) and of maize and foxtail millet (Cohen et al, 1980) Significant increase in plant N content was observed due to ***Azospirillum*** inoculation in wheat and sorghum (Kapulnik et al 1981) and of sorghum seeds (Okon et al 1981) ***Azospirillum*** inoculation could increase the N content in sorghum (Sarig et al 1981) maize (Hegazi et al 1983) wheat (Dreessen and Vlassak 1984) and Setaria italica (Yahalom et al 1984) Konde and Patil (1993) reported that ***Azospirillum*** inoculation significantly enhanced P content in green chillies Menon and Pillai (1994) observed an increase of 33 1 per cent in shoot N content in cowpea due to ***Azospirillum*** inoculation

Nur et al (1980) observed that N content in maize and Setaria italica was not affected by ***Azospirillum*** inoculation Also ***Azospirillum*** inoculation did not affect the N content of rice (Watanabe and Lin 1984) N P and K contents in rice (Prasad and Singh 1984) and N content of mustard (Saha et al 1985)

N uptake of sorghum increased due to ***Azospirillum*** inoculation (Pal and Malik, 1981) Significant increase in N uptake in wheat (Kapulnik et al, 1983) and N, P and K uptake in rice (Prasad and Singh, 1984) was observed due to inoculation P uptake by sorghum in inoculated plot was greater than that in control (Pacovsky et al, 1985) ***Azospirillum*** inoculation exerted a significant influence in increasing N uptake in mustard (Saha et al, 1985) and N and P uptake by green chillies (Konde and Patil, 1993)

2 3 3 Phosphate Solubilising Bacteria (PSB)

An increase in P content was observed at all stages of crop growth in sorghum due to PSB inoculation (Rangaswamy and Morachan, 1974)

Gerretsen (1948) observed an increase in the P assimilated by oats, mustard, rape and sunflower with phosphobacterium PSB inoculation resulted in increased P uptake in oats (Pikovskaya, 1948) and wheat (Smallii, 1958) Both N and P uptake of berseem were significantly greater with the treatment FYM + rock phosphate + Bacillus megatherium var phosphaticum than with FYM and rock phosphate (Bajpai and Rao, 1971) N and P uptake in rice (Sharma and Singh, 1971 and Asanuma et al 1978) and P uptake in bengal gram (Subramanian and Purushothaman, 1974) and potato (Kundu and Gaur, 1980) increased due to PSB inoculation Alagawadi and Gaur (1988) observed that combined inoculation of Rhizobium and PSB resulted in a significantly higher N and P uptake over uninoculated control in chick pea

2.4. Biofertilizers in soil fertility improvement

2 4 1 *Azotobacter*

Most reports show a beneficial effect of biofertilizers in improving the organic C and available N status of soil

Azotobacter inoculation to maize crop resulted in an increase in the available N and organic C of soil (Karthikeyan, 1981) Sharma et al (1987) reported that ***Azotobacter*** inoculation in wheat improved the total available N status of soil

2 4 2. *Azospirillum*

Ram et al (1992) observed an increase in available N in soil due to ***Azospirillum*** inoculation in sunflower Addition of organic manures and ***Azospirillum*** singly or in combination to rice crop gave higher organic carbon content of soil (Rangarajan and Subramanian, 1993)

Saha et al (1985) reported that the total N content of rhizosphere soil of mustard at 40 days and at maturity recorded significant increase due to inoculation The available N and P was significantly increased with the application of organic manures and *Azospirillum* in rice (Rangarajan and Subramanian, 1993)

Yahalom et al (1984) did not observe any difference in the N content of soil due to *Azospirillum* inoculation over control in foxtail millet Also Subramaniam (1987) reported that *Azospirillum* inoculation in rice did not influence the available N, P and K of soil

2 4.3 Phosphate Solubilising Bacteria (PSB)

Samoilov (1953) stated that application of PSB increased the content of available P in soil Rangaswamy and Morachan (1974) found that inoculation of PSB in sorghum increased the available P in soil Similar observations were reported in chickpea by Alagawadi and Gaur (1988) Application of PSB along with rock phosphate in maize increased the available P in soil at all stages of growth (Singaram and Kothandaraman 1994)

Thus microbial inoculation of *Azotobacter Azospirillum* and PSB has been shown to be beneficial by way of increasing the level of available nutrients in soil

2 5 Biofertilizers in N and P economy

2 5 1 *Azotobacter*

Oblisami <u>et al</u> (1976) reported that ***Azotobacter*** could compensate 25 per cent of fertilizer N giving similar yield of rice as that of 100 per cent fertilizer N alone ***Azotobacter*** can reduce the N requirement of sunflower from 60 kg ha^{-1} to 45 kg ha^{-1} without affecting seed yield (Oblisami <u>et al</u> , 1976) ***Azotobacter*** reduced the N requirement to the tune of 10-20 kg ha^{-1} $season^{-1}$ in sweetpotato (Oblisami <u>et al</u> 1976) Arunachalam and Venkatesan (1984) reported the possibility of reducing 50 per cent fertilizer N by ***Azotobacter*** in sesamum Durai and Mohan (1991) observed that application of 22 kg N ha^{-1} along with ***Azotobacter*** gave superior cane yields than when 275 kg N ha^{-1} was applied alone Raghuwanshi <u>et al</u> (1991) reported that ***Azotobacter*** increased the yield of jowar and can save 20 kg N ha^{-1} Sivakumar <u>et al</u> (1991) observed that in brinjal, application of 30 kg N $acre^{-1}$ plus ***Azotobacter*** was superior to 40 kg N $acre^{-1}$ alone Lakshminarayana <u>et al</u> (1992) recorded a saving of fertilizer N equal to 30 kg N ha^{-1} by ***Azotobacter*** inoculation in wheat

2 5 2 *Azospirillum*

In pearl millet, ***Azospirillum*** inoculation along with 75 per cent fertilizer N recorded a grain yield of 7968 kg ha^{-1} as compared to 6586 kg ha^{-1} obtained with the application of 100 per cent N alone (Purushothaman et al , 1979), whereas, the treatments gave similar grain yield in finger millet (Muthukrishnan et al , 1981) Purushothaman and Gunasekaran (1981) found that ***Azospirillum*** can save 25-30 kg ha^{-1} fertilizer N in cotton Desale and Konde (1984) reported that grain yield of sorghum when applied with 66 kg N ha^{-1} plus ***Azospirillum*** was almost equal to that with 100 kg ha^{-1} alone Application of 75 kg N ha^{-1} along with ***Azospirillum*** recorded significantly higher grain yield in rice compared to that with the application of 100 kg N ha^{-1} (Jeyaraman and Ramiah, 1986) Misra and Naidu (1990) found that in sugarcane similar yields were obtained with the application of 75 per cent N plus ***Azospirillum*** and 100 per cent N alone Raghuwanshi et al (1991) reported that seed inoculation with ***Azospirillum*** increased the grain yield of sorghum and could save 20 kg N ha^{-1}

Thus inoculation of crop plants with ***Azotobacter*** and ***Azospirillum*** could save 25 per cent of their N requirement without reducing the yield

2 5 3 Phosphate Solubilising Bacteria (PSB)

Inoculating pigeon pea with PSB gave higher net return over control and the highest net return was obtained at 1/4 dose of NPK kg ha^{-1} along with PSB (Mohammad, 1984) Alagawadi and Gaur (1988) reported that combined inoculation of Rhizobium and PSB along with rock phosphate in chickpea could save 10 kg N and replace entire superphosphate with rockphosphate and PSB inoculation Prabhakara and Rai (1991) reported the possibility of replacing single super phosphate with rock phosphate by the dual inoculation of *Azospirillum* and PSB in maize

Materials and Methoc

MATERIALS AND METHODS

A field experiment was conducted from July 1994 to June 1995 to evaluate the effect of chemical and biofertilizers on palmarosa The details of the materials used and the methods followed are presented in this chapter

3 1 Field culture

3 1 1 Site, climate and soil

The project work was carried out at the experimental site of the College of Horticulture, Kerala Agricultural University Vellanikkara, Trichur It is located at 10° 31 N latitude and 76°13 E longitude at an altitude of 40 29 m above MSL This area enjoys a typical humid tropical climate The meteorological data for the period of investigation are given in Fig 1 and Appendix 1 During the period of investigation a total rainfall of 3228 2 mm was received in 119 rainy days The cumulative pan evaporation value for the period was 1634 2 mm The mean maximum and mean minimum temperature during the period ranged from 28 6°C - 37 6°C and 22 2°C - 24°9 C respectively The mean sunshine hours during the experimentation ranged from 1 4 to 10 6 with a mean RH of 58 - 91%

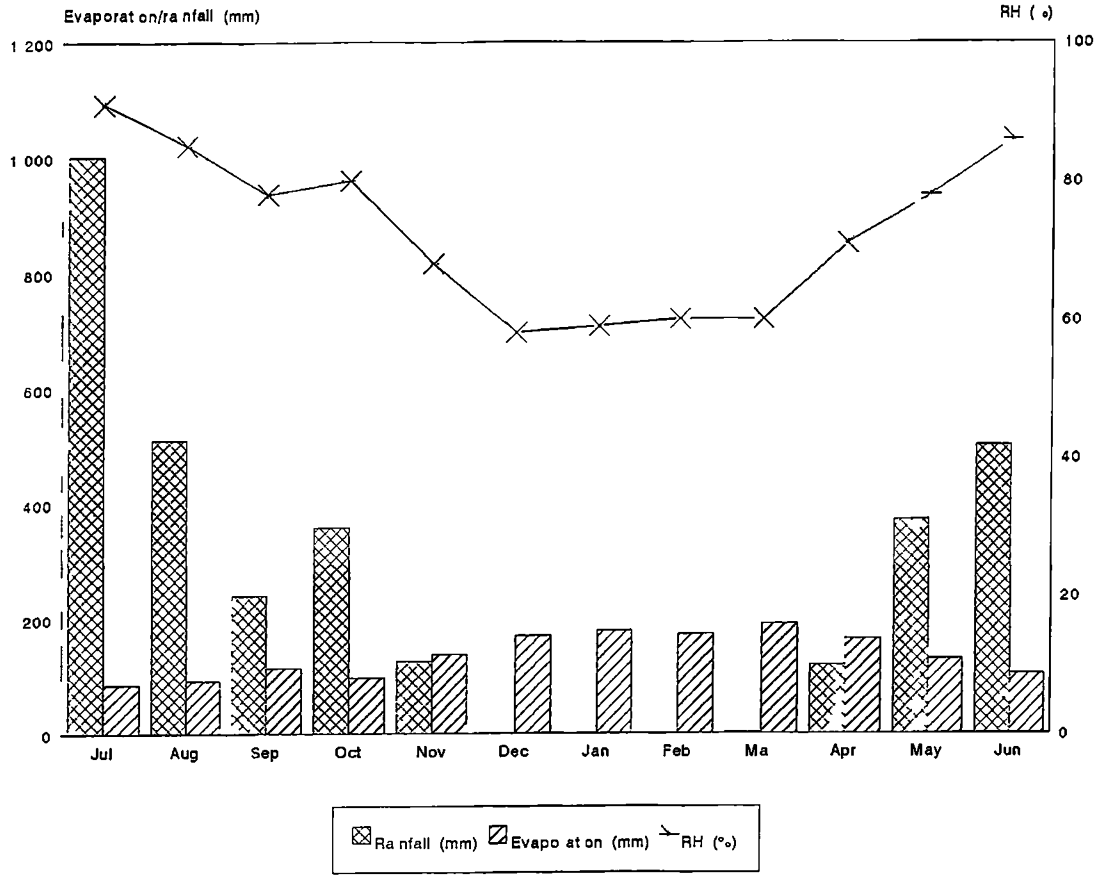


Fig 1a Meteorological data (monthly average) at Vellanikkara Trichur for the period of July 1994 to June 1995

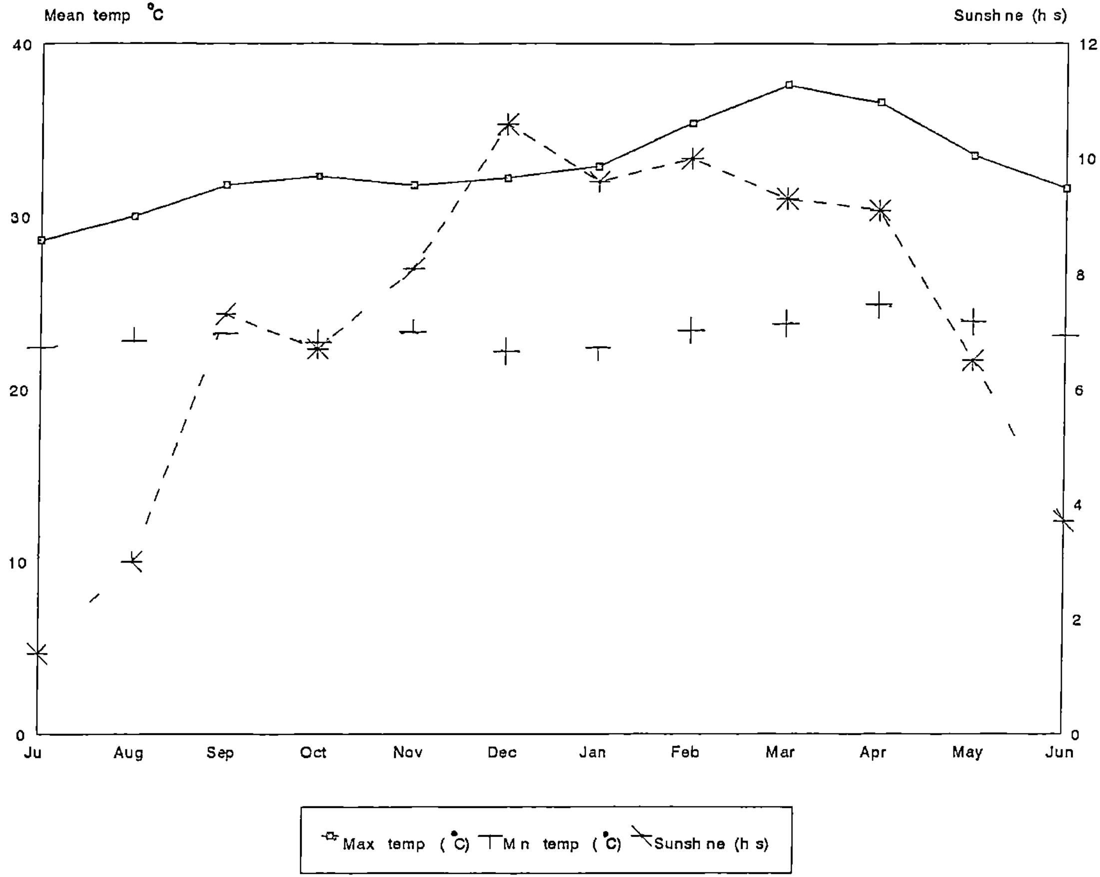


Fig 1b Meteorological data (monthly average) at Vellanikkara Trichur for the period of July 1994 to June 1995

The soil of the experimental site was sandy clay loam in texture with medium fertility status The physical and chemical properties of the experimental site are presented in Table 1

3 1 2 Design and treatments

The experiment was laid out in a randomised block design with three replications The plan of lay out is presented in Fig 2 There was 18 treatments which was factorial combinations of 3 levels of chemical fertilizers and 6 levels of biofertilizers

A. Levels of chemical fertilizers

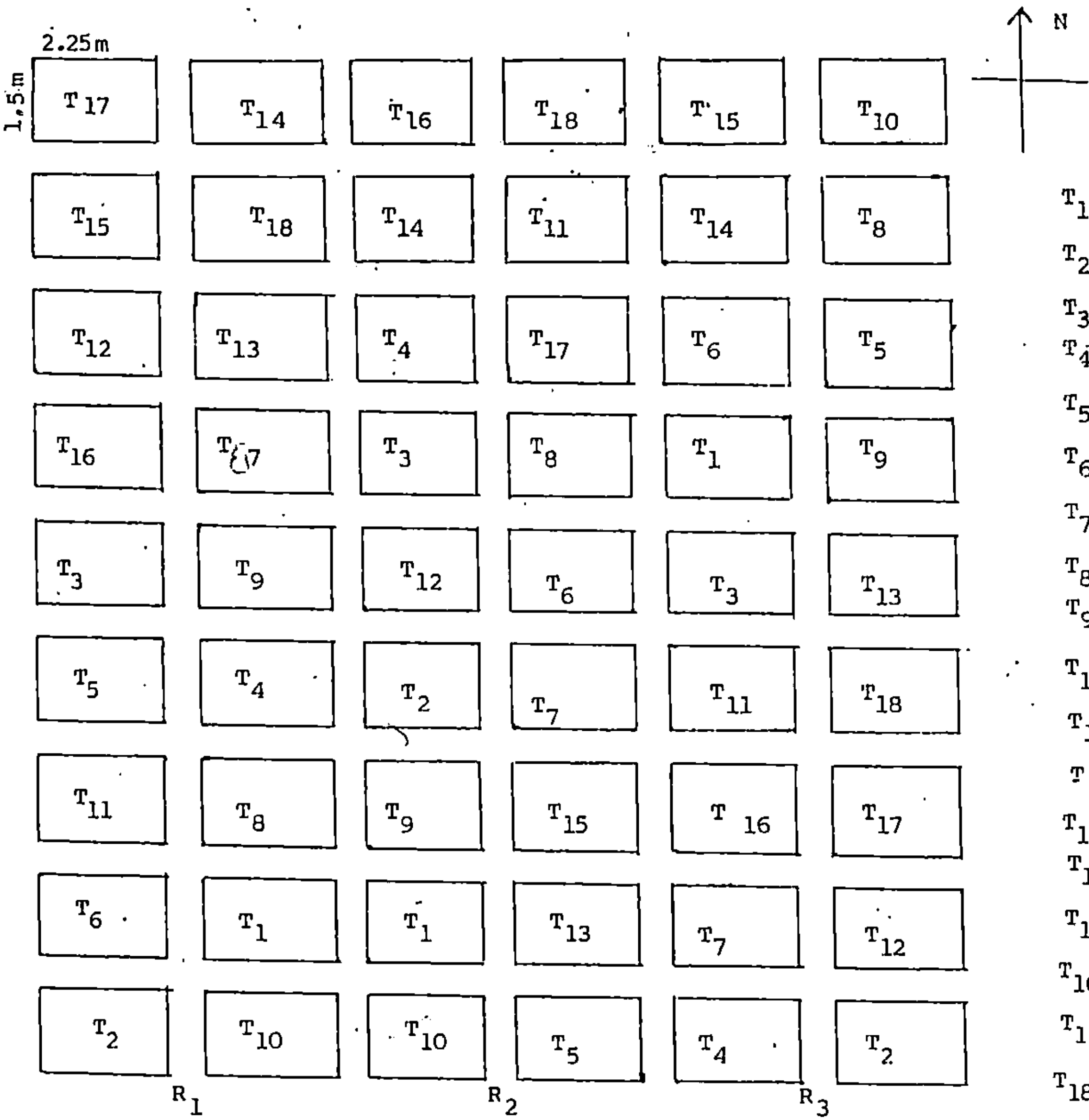
1 N_0P_0 (0 kg each of N and P_2O_5 ha^{-1})
2 $N_{20}P_{20}$ (20 kg each of N and P_2O_5 ha^{-1})
3 $N_{40}P_{40}$ (40 kg each of N and P_2O_5 ha^{-1})

B Levels of biofertilizers

1 Control (No biofertilizer)
2 Azoto (*Azotobacter* @ 2 kg ha^{-1})
3 Azosp (*Azospirillum* @ 2 kg ha^{-1})
4 PSB (Phosphorous solubilising bacteria(PSB) @ 3 kg ha^{-1})
5 Azoto + PSB (*Azotobacter* @ 2 kg ha^{-1} and PSB @ 3 kg ha^{-1})
6 Azosp + PSB (*Azospirillum* @ 2 kg ha^{-1} and PSB @ 3 kg ha^{-1})

Table 1 Physico-chemical characteristics of the soil in the experimental site

Sl No	Particulars	Value	Method employed
1	Mechanical analysis		
	Sand	40 6 %	
	Silt	26 8 %	Robinson s International Pipette method
	Clay	32 6 %	(Piper, 1942)
Soil texture		Sandy clay loam	
2	CEC	7 4 C mol m 2	Jackson, 1973
3	Available N	211 kg ha^{-1}	Alkaline permanganate method (Jackson 1973)
4	Available P	23 36 kg ha 1	Bray I extract, Ascorbic acid blue colour method (Watanabe and Olsen, 1965)
5	Available K	100 5 kg ha^{-1}	Neutral normal ammonium acetate extract, Flame photometry (Jackson, 1973)
6	Organic C	0 84 %	Walkely - Black method (Jackson, 1973)
7	Total N	2206 kg ha^{-1}	Microkjeldahl method (Jackson, 1973)
8	Soil pH	5 2	1 2 5 soil water suspension, pH meter (Jackson, 1973)



T_1 – $N_0 P_0$ + Control

T_2 – $N_0 P_0$ + Azoto.

T_3 – $N_0 P_0$ + Azosp.

T_4 – $N_0 P_0$ + PSB

T_5 – $N_0 P_0$ + Azoto. + PSB

T_6 – $N_0 P_0$ + Azosp. + PSB

T_7 – $N_{20} P_{20}$ + Control

T_8 – $N_{20} P_{20}$ + Azoto.

T_9 – $N_{20} P_{20}$ + Azosp.

T_{10} – $N_{20} P_{20}$ + PSB

T_{11} – $N_{20} P_{20}$ + Azoto. + PSB

T_{12} – $N_{20} P_{20}$ + Azosp. + PSB

T_{13} – $N_{40} P_{40}$ + Control

T_{14} – $N_{40} P_{40}$ + Azoto.

T_{15} – $N_{40} P_{40}$ + Azosp.

T_{16} – $N_{40} P_{40}$ + PSB

T_{17} – $N_{40} P_{40}$ + Azoto. + PSB

T_{18} – $N_{40} P_{40}$ + Azosp. + PSB

Fig.2 Plan of lay-out

3 1 3 Plot size

2 25 m x 1 50 m

3 1 4 Variety

The palmarosa type ODP-2 was used for the trial It is a superior selection of Cymbopogon martinii Stapf var Motia made at the Aromatic and Medicinal Plants Research Station Odakkali under the Kerala Agricultural University This is also very popular among the palmarosa cultivators of Kerala

3 1 5 Preparatory cultivation

The experimental field was thoroughly dug to uniform tilth and laid out into 3 blocks each with 18 plots The individual plots were once again dug and levelled

3 1 6 Planting

The palmarosa type ODP-2 was used for the trial Slips were used for planting These were planted @ 3 slips hill^{-1} at a spacing of 45 cm x 15 cm

3 1 7 Fertilizer application

The chemical fertilizers used in this experiment were urea (46% N) mussoriephos (22% P_2O_5) and muriate of potash (60% K_2O) Whole of P_2O_5 and half of N were applied as basal dose as per the treatments Uniform quantity of 20 kg ha $^{-1}$ K_2O and 2 5 t ha $^{-1}$ FYM were also applied basally Half of N was applied 20 days after planting

The biofertilizers ***Azotobacter*** (acid tolerant strain) obtained from the College of Agriculture Vellayani ***Azospirillum*** (acid tolerant strain) and PSB obtained from the Division of Microbiology Tamil Nadu Agricultural University Coimbatore were made use of for the experimentation These were applied in rows 20 days after the topdressing of N after mixing with solarised cowdung

Application of chemical and biofertilizers was completed before the first harvest Neither of these were applied after subsequent harvests

3 1 8 Intercultural operations

The intercultural operations mainly weeding was done just before topdressing of fertilizers and biofertilizer application Weeding was also done after each harvest of the crop

3 1 9 Irrigation

Life saving irrigation was given during the summer months using sprinklers

3 1 10 Plant protection

The crop was absolutely free of any disease or pest problems Hence no plant protection operation had to be taken up

3 1 11 Harvest

The first harvest of herbage was done 135 days after planting when the crop was in the early seed formation stage and subsequent harvests were made at intervals of 90 days The herbage was cut at a height of 30 cm from the ground level

3 2 Observations

3 2 1 Biometric characters

For recording growth characters, four plants were tagged from each plot at random and observations were recorded before each harvest and the mean value of each of these characters was worked out

3 2 1 1 Plant height

Height of the plant from the ground level to the tip of the longest tiller was measured and recorded as the plant height

3.2.1.2 Number of tillers

The total number of tillers $hill^{-1}$ of the selected plants were counted and recorded as the number of tillers $hill^{-1}$.

3.2.1.3 Number of tillers with inflorescence

The number of tillers which bear inflorescence in a hill were recorded separately and noted as the number of inflorescences $hill^{-1}$

3.2.1.4 Length of inflorescence

The length of the inflorescence of the observation plants was measured from the point of sheath union of boot leaf to the tip of the inflorescence and recorded as the length of the inflorescence

3.2.1.5 Plant spread

The spread of plants in a hill was measured to East - West direction and North -South direction using a metre scale and expressed as plant spread in East - West (E- W) and North - South (N - S) direction respectively

3 2 2 Yield characters

3 2 2 1 Herbage yield plant^{-1}

The weight of fresh herbage from the tagged plants were recorded by harvesting them separately and noting the fresh weight immediately after harvest and expressed as g hill $^{-1}$

3 2.2 2. Herbage yield hectare^{-1}

The fresh herbage yield from the net plot was noted immediately after harvest and expressed as fresh herbage yield t ha $^{-1}$

3 2.2.3. Drymatter yield

The samples from each harvest of tagged plants meant for chemical analysis were oven dried at 80°C to constant weight The drymatter yield from each plot was computed for each harvest using this drymatter percentage and expressed as t ha $^{-1}$

3 2.2 4 Essential oil content

Oil content of palmarosa was estimated by steam distillation using clevenger apparatus For this 80g of finely chopped fresh herbage of palmarosa was taken in a round bottom flask (1 litre capacity) with a high neck, to which was added 100ml of distilled water The contents were distilled for 3 hours and the volume of volatile oil condensed was collected and noted

The oil obtained using clevenger apparatus from a sample of fresh herbage from each treatment was used for working out the oil content (v/w) on fresh weight basis This was converted to dry weight basis using drymatter percentage

3 2 2 5 Oil yield

The oil yield was calculated using the oil content and the fresh herbage yield and expressed as $l\ ha^{-1}$

3 3 Chemical analysis

3 3 1 Plant samples

3 3 1 1 Content of N, P and K

The dried plant samples were analysed for total N by microkjeldahl digestion and distillation method (Jackson, 1973) For the estimation of total phosphorus and potassium, the plant material was first digested with triacid (HNO_3 H_2SO_4 $HClO_4$ in the ratio 10 1 4) mixture Phosphorus content of the digested plant material was determined by vanado-molybdo-phosphoric acid yellow colour method (Jackson, 1973) and potassium content of the triacid extract was estimated using EEL flame photometer (Jackson, 1973)

3 3 1 2 Uptake of N, P and K

Nitrogen, phosphorus, and potassium uptake by the crop at different harvests were computed from the content of each of these elements and the drymatter production and expressed as kg ha $^{-1}$

3 3 2 Soil samples

Soil samples were collected after each harvest and were analysed for available nitrogen by alkaline permanganate method (Jackson, 1973) Available P was determined in Bray I extract using ascorbic acid blue colour method (Watanabe and Olsen, 1965) and available K was estimated in neutral normal ammonium acetate extract using EEL flame photometer (Jackson, 1973)

3 4 Statistical analysis

The data were subjected to analysis of variance and the significance was tested by F-test (Panse and Sukhatme, 1985)

Results

RESULTS

The results obtained during the course of investigation are presented in this chapter

4 1 Growth characters

4 1.1 Plant height

Data on the effect of chemical and biofertilizers on height of plants are presented in Table 2

The data revealed that application of chemical fertilizers resulted in a significant increase in plant height in palmarosa in all the three harvests and that height increased with increasing level of chemical fertilizers The plant height in the treatments $N_{20}P_{20}$ and $N_{40}P_{40}$ was almost similar in all the three harvests

Effect of different biofertilizers on plant height in palmarosa showed that it affected significantly the height of plants in the second and third harvests and that the plants in plots receiving combined application of ***Azospirillum*** and PSB were the tallest which was significantly superior to that in the control plot without any biofertilizer application In the first harvest different biofertilizer levels did not affect the height of plants and the values ranged from 176 7 to 180 2 cm

Table 2 Effect of chemical and biofertilizers on plant height (cm) in palmarosa in different harvests

Treatments	Harvest No 1	Harvest No 2	Harvest No 3
A Chemical fertilizers			
N_0P_0	174 45	176 43	126 39
$N_{20}P_{20}$	178 05	180 45	131 62
$N_{40}P_{40}$	180 87	183 45	132 76
SEM+	1 20	1 13	0 40
CD (0 05)	3 45	3 24	1 16
B Biofertilizers			
Control	176 73	178 96	126 71
Azoto	177 40	176 06	129 09
Azosp	177 03	178 22	131 11
PSB	177 70	180 69	132 92
Azoto + PSB	177 70	182 42	127 70
Azosp + PSB	180 23	184 32	133 99
SEM±	1 70	1 60	0 57
CD (0 05)	NS	4 60	1 64

The interaction effect of chemical x biofertilizers was significant only in the second harvest (Table 3) and the treatment combination $N_{40}P_{40}$ along with ***Azospirillum*** plus PSB recorded the maximum height

4 1 2 Number of tillers

The effect of chemical and biofertilizers on tiller production in palmarosa are presented in Table 4

Tiller production varied significantly with different levels of chemical fertilizers and it increased with increasing levels of fertilizers in all the three harvests In the first and third harvests, all the treatments varied significantly from one another In the second harvest tiller production at $N_{20}P_{20}$ and $N_{40}P_{40}$ were statistically similar

The effect of various biofertilizers on tiller production in palmarosa showed that the treatment varied significantly in all the three harvests and that more number of tillers were produced by the combined application of ***Azospirillum*** and PSB which was significantly superior to all the other levels in first and third harvests and to uninoculated control in second harvest Maximum number of tillers (59 3 $hill^{-1}$) were produced in the second harvest

Table 3 Effect of various treatments on plant height (cm) in palmarosa at second harvest

Treatments	Chemical fertilizers		
	N_0P_0	$N_{20}P_{20}$	$N_{40}P_{40}$
Biofertilizers			
Control	174 36	176 13	186 40
Azoto	172 40	175 51	180 28
Azosp	174 52	180 14	180 00
PSB	179 16	180 00	182 92
Azoto + PSB	178 76	186 30	182 19
Azosp + PSB	179 40	184 64	188 91
SEM ±		2 77	
CD (0 05)		7 96	

Table 4 Effect of chemical and biofertilizers on the number of tillers $hill^{-1}$ in palmarosa in different harvests

Treatments	Harvest No		
	1	2	3
A Chemical fertilizers			
N_0P_0	33 88	48 83	28 45
$N_{20}P_{20}$	38 29	55 27	31 54
$N_{40}P_{40}$	40 55	57 84	34 87
SEM+	0 75	1 43	0 49
CD (0 05)	2 16	4 11	1 42
B Biofertilizers			
Control	33 25	49 41	30 28
Azoto	37 93	53 19	29 81
Azosp	35 60	54 82	30 00
PSB	39 40	55 45	32 10
Azoto + PSB	36 01	51 72	32 70
Azosp + PSB	43 24	59 31	34 82
SEM±	1 06	2 02	0 69
CD (0 05)	3 05	5 81	1 98

The interaction effect was significant only in the second harvest (Table 5) The combined application of $N_{40}P_{40}$ and *Azospirillum* plus PSB as well as $N_{20}P_{20}$ and *Azospirillum* plus PSB recorded the highest number of tillers

4 1 3 Plant spread

a East - West

The data on the effect of chemical and biofertilizers on the spread of plant in E-W direction are presented in Table 6

The data showed that the application of different levels of chemical fertilizers affected the plant spread in palmarosa significantly and the value increased with increasing levels of chemical fertilizers Maximum E-W spread was recorded in the treatment $N_{40}P_{40}$ which was significantly superior to that at $N_{20}P_{20}$ in all the three harvests The plants in control plots were of least spreading nature

Effect of different biofertilizer treatments on the spread of plants were significant in all the three harvests The treatment *Azospirillum* plus PSB recorded the maximum plant spread in two out of three harvests and was

Table 5 Tiller production in palmarosa under various treatments in the second harvest

Treatments	Chemical fertilizers		
	N_0P_0	$N_{20}P_{20}$	$N_{40}P_{40}$
Biofertilizers			
Control	44 20	50 36	53 67
Azoto	52 35	54 98	52 24
Azosp	48 12	56 18	60 17
PSB	50 39	52 18	63 77
Azoto + PSB	47 70	54 14	53 31
Azosp + PSB	50 26	63 78	63 89
SEM+		3 50	
CD (0 05)		10 07	

Table 6 Effect of chemical and biofertilizers on plant spread (E-W) in palmarosa (cm) in different harvests

Treatments	Harvest No		
	1	2	3
A Chemical fertilizers			
N_0P_0	25 79	42 40	37 64
$N_{20}P_{20}$	26 34	44 12	38 90
$N_{40}P_{40}$	28 46	46 96	42 55
SEM±	0 53	0 49	0 35
CD (0 05)	1 52	1 41	1 01
B Biofertilizers			
Control	24 31	42 34	37 81
Azoto	26 58	42 84	40 06
Azosp	27 43	43 99	38 63
PSB	28 33	45 40	40 91
Azoto + PSB	26 59	44 04	38 46
Azosp + PSB	27 92	48 34	42 32
SEM±	0 75	0 69	0 50
CD (0 05)	2 16	1 98	1 44

significantly superior to uninoculated control in all the three harvests

The interaction effect of chemical and biofertilizers was significant only in the second harvest and the treatment combination $N_{40}P_{40}$ along with PSB recorded the highest value (Table 7) and was at par with $N_{40}P_{40}$ along with *Azospirillum* plus PSB and $N_{20}P_{20}$ along with *Azospirillum* plus PSB

b North-South

The data on the effect of chemical and biofertilizers on the spread of plants in the N-S direction are presented in Table 8

The data showed that application of different levels of chemical fertilizers influenced the character significantly Higher spread of plants was noticed at increasing levels of fertilizers which in turn was significantly superior to that in the control

The effect of biofertilizers also showed variation in the character in all the three stages of harvest and that the treatment *Azospirillum* plus PSB recorded the highest value which alone was significantly different from that in the uninoculated control in the first harvest In the second and third harvests the plants in the plots receiving PSB alone and *Azospirillum* plus PSB were having

Table 7 Plant spread (E-W) in palmarosa (cm) as influenced by the various treatments in the second harvest

Treatments	Chemical fertilizers		
	N_0P_0	$N_{20}P_{20}$	$N_{40}P_{40}$
Biofertilizers			
Control	40 13	40 84	46 04
Azoto	44 68	42 48	41 35
Azosp	42 80	47 13	42 04
PSB	41 76	41 16	53 28
Azoto + PSB	42 84	43 20	46 08
Azosp + PSB	42 16	49 90	52 96
SEM ±		1 20	
CD (0 05)		3 45	

Table 8 Effect of chemical and biofertilizers on plant spread (N-S) in palmarosa (cm) in different harvests

Treatments	Harvest No		
	1	2	3
A Chemical fertilizers			
N_0P_0	12 14	19 25	15 55
$N_{20}P_{20}$	13 43	21 48	17 42
$N_{40}P_{40}$	15 53	22 36	17 46
SEM±	0 48	0 34	0 49
CD (0 05)	1 38	0 98	1 42
B Biofertilizers			
Control	12 49	19 72	16 20
Azoto	13 38	19 85	15 63
Azosp	12 92	21 15	15 25
PSB	13 88	22 35	18 45
Azoto + PSB	14 36	20 67	17 00
Azosp + PSB	15 17	22 43	18 33
SEM+	0 68	0 48	0 69
CD (0 05)	1 96	1 38	1 98

significantly higher plant spread (N-S) compared to that in uninoculated control

The interaction effect of chemical x biofertilizers was significant only in the second harvest (Table 9) and the treatment combination of $N_{20}P_{20}$ along with ***Azospirillum*** plus PSB recorded the highest value

4 1 4 Number of inflorescences

The data on the effect of chemical and biofertilizers on the number of inflorescences $hill^{-1}$ are presented in Table 10

The application of different levels of chemical fertilizers resulted in a significant increase in the number of inflorescence $plant^{-1}$ and that it increased with increasing levels of fertilizer application The treatment $N_{40}P_{40}$ recorded the highest value which was significantly superior to that in the control in all the three harvests In the first and second harvests, the treatments $N_{20}P_{20}$ and $N_{40}P_{40}$ were significantly different

The effect of biofertilizers on the number of inflorescences $hill^{-1}$ was also significant in all the three harvests and in the first harvest the treatment ***Azospirillum*** plus PSB recorded the maximum number of inflorescences and the treatment uninoculated control the

Table 9 Plant spread (N-S) in palmarosa (cm) as influenced by various treatments in the second harvest

Treatments	Chemical fertilizers		
	N_0P_0	$N_{20}P_{20}$	$N_{40}P_{40}$
Biofertilizers			
Control	16 45	20 85	21 85
Azoto	16 41	22 95	20 20
Azosp	19 80	20 35	23 30
PSB	21 40	22 15	23 50
Azoto + PSB	20 70	18 90	22 41
Azosp + PSB	20 74	23 65	22 90
SEM±		0 83	
CD (0 05)		2 39	

Table 10 Effect of chemical and biofertilizers on the number of inflorescences $hill^{-1}$ in palmarosa at different harvests

Treatments	Harvest No 1	Harvest No 2	Harvest No 3
A Chemical fertilizers			
N_0P_0	30 72	47 33	2 77
$N_{20}P_{20}$	35 02	47 95	3 12
$N_{40}P_{40}$	38 05	48 98	3 27
SEM+	1 03	0 21	0 06
CD (0 05)	2 96	0 60	0 17
B Biofertilizers			
Control	31 62	45 92	2 83
Azoto	36 37	47 13	2 96
Azosp	34 13	46 98	2 94
PSB	36 07	51 29	3 11
Azoto + PSB	32 90	46 62	3 27
Azosp + PSB	36 50	50 59	3 22
SEM+	1 46	0 30	0 08
CD (0 05)	4 20	0 86	0 23

lowest which were significantly different from each other, whereas in the second harvest, the treatment PSB recorded the largest number of inflorescence which was statistically similar to that in the treatment *Azospirillum* plus PSB In the third harvest, the treatments PSB alone, *Azotobacter* plus PSB and *Azospirillum* plus PSB recorded significantly higher number of inflorescences as compared to that in the uninoculated control

The interaction effect of chemical x biofertilizers was significant only in the second harvest (Table 11) The treatment $N_{40}P_{40}$ along with PSB recorded the largest number of inflorescences which was on par with that in the treatment $N_{20}P_{20}$ along with PSB and *Azospirillum* plus PSB and N_0P_0 along with PSB This was also statistically similar to that in the treatment $N_{40}P_{40}$ along with *Azospirillum* plus PSB and that at $N_{40}P_{40}$ alone without any biofertilizer application

4.1 5 Length of inflorescence

The data on the effect of chemical and biofertilizers on the length of inflorescence are given in Table 12

The results showed that application of different levels of chemical fertilizers affected the length of inflorescence significantly in the first harvest and that

Table 11 Number of inflorescences $hill^{-1}$ in palmarosa as as influenced by various treatments at second harvest

Treatments	Chemical fertilizers		
	N_0P_0	$N_{20}P_{20}$	$N_{40}P_{40}$
Biofertilizers			
Control	39 41	47 71	50 63
Azoto	46 22	46 55	48 63
Azosp	47 64	47 58	45 71
PSB	51 25	50 88	51 76
Azoto + PSB	49 72	43 75	46 38
Azosp + PSB	49 73	51 25	50 78
SEM±		0 51	
CD (0 05)		1 47	

Table 12 Effect of chemical and biofertilizers on the length of inflorescence (cm) in palmarosa in different harvests

Treatments	Harvest No		
	1	2	3
A Chemical fertilizers			
N_0P_0	32 33	33 06	22 72
$N_{20}P_{20}$	34 00	34 57	26 04
$N_{40}P_{40}$	34 08	36 74	25 20
SEM±	0 60	0 24	0 32
CD (0 05)	1 73	NS	NS
B Biofertilizers			
Control	31 85	32 33	24 18
Azoto	32 25	34 57	23 79
Azosp	33 91	32 53	23 43
PSB	35 75	38 12	26 35
Azoto + PSB	31 88	34 23	23 75
Azosp + PSB	35 17	36 96	26 40
SEM+	0 85	0 34	0 45
CD (0 05)	2 44	NS	NS

the treatment $N_{40}P_{40}$ resulted in an increase in the length of inflorescence which was superior to that in the control In the second and third harvests application of chemical fertilizers did not affect the length of inflorescence significantly

Application of different combinations of biofertilizers showed that the length of inflorescence was affected significantly only in first harvest, where the treatments PSB inoculation and ***Azospirillum*** plus PSB recorded the longest inflorescence which were significantly superior to that in the uninoculated control In the second and third harvests, the length of inflorescence was not affected by the biofertilizer application and the values ranged from 32 33 to 38 12 cm and 23 43 to 26 40 cm respectively

The interaction affect of chemical x biofertilizers on the length of inflorescence was not significant in all the three harvests

4 1 6 Fresh herbage yield per plant

Data on the effect of chemical and biofertilizers on the herbage yield plant^{-1} are presented in Table 13

Application of chemical fertilizers resulted in an increase in the fresh herbage yield in all the three harvests and it increased with increase in the level of

Table 13 Effect of chemical and biofertilizers on fresh herbage yield (g $plant^{-1}$) of palmarosa in different harvests

Treatments	Harvest No 1	Harvest No 2	Harvest No 3
A Chemical fertilizers			
N_0P_0	94 33	158 63	41 94
$N_{20}P_{20}$	113 69	187 61	48 50
$N_{40}P_{40}$	127 40	202 69	53 59
SEM±	1 91	5 19	0 99
CD (0 05)	5 49	14 93	2 85
B Biofertilizers			
Control	101 45	168 30	44 29
Azoto	110 72	198 97	45 85
Azosp	117 40	155 63	43 45
PSB	110 92	195 92	49 61
Azoto + PSB	113 69	155 18	49 77
Azosp + PSB	117 40	223 85	55 07
SEM+	2 70	7 34	1 39
CD (0 05)	7 77	21 11	4 00

chemical fertilizers The treatment $N_{40}P_{40}$ recorded the highest value which was significantly superior to that at $N_{20}P_{20}$ which in turn was significantly superior to that in the control without any fertilizer application The percentage increase in yield at $N_{20}P_{20}$ and $N_{40}P_{40}$ over control were 20 5 and 35 1, 18 3 and 27 8 and 15 6 and 27 8 respectively in the first, second and third harvests

Inoculation of various combinations of biofertilizers on fresh herbage yield resulted in a significant effect in all the three harvests The treatment *Azospirillum* plus PSB recorded the highest yield which was significantly superior to all the other treatments in second and third harvests and to uninoculated control in the first harvest In the first harvest the yield of all the inoculation treatments were significantly superior to that in the control

The interaction effect of chemical x biofertilizers on yield per plant was significant in the second and third harvests (Table 14) In both the harvests the treatment combination $N_{40}P_{40}$ along with *Azospirillum* plus PSB recorded the highest value In the third harvest the treatments $N_{40}P_{40}$ along with PSB and $N_{20}P_{20}$ along with *Azospirillum* plus PSB were on par with that of $N_{40}P_{40}$ along with *Azospirillum* plus PSB

Table 14 Interaction effect of chemical x biofertilizers on fresh herbage yield (g $plant^{-1}$) of palmarosa in the second and third harvests

Treatments	Chemical fertilizers					
	Second harvest			Third harvest		
	N_0P_0	$N_{20}P_{20}$	$N_{40}P_{40}$	N_0P_0	$N_{20}P_{20}$	$N_{40}P_{40}$
Biofertilizers						
Control	113 18	196 65	195 08	37 6	50 20	45 07
Azoto	211 27	180 67	204 98	37 31	43 13	57 13
Azosp	173 93	130 95	162 00	44 26	37 57	48 53
PSB	153 45	185 18	249 14	40 50	50 22	58 12
Azoto + PSB	110 70	206 55	148 22	42 73	52 29	54 29
Azosp + PSB	189 23	225 68	256 66	49 25	57 56	58 41
SEM+		5 19			2 41	
CD (0 05)		14 93			6 93	

4 1 7 Drymatter production

The data on the effect of chemical and biofertilizers on the drymatter production of palmarosa are presented in Table 15

Application of chemical fertilizers showed that it affected the drymatter yield of palmarosa significantly in all the three harvests and it increased with increasing levels of chemical fertilizers and that the highest value was recorded by the treatment $N_{40}P_{40}$ and the lowest in the control plot In the first and second harvests, the treatment $N_{40}P_{40}$ was significantly superior to that at $N_{20}P_{20}$ which in turn was significantly superior to that in the control In the third harvest, the treatments $N_{20}P_{20}$ and $N_{40}P_{40}$ registered almost similar yields

The effect of chemical fertilizers on total drymatter production over one year (Table 15) showed that the application of chemical fertilizers affected the character significantly and 40 kg ha^{-1} each of N and P_2O_5 produced the highest drymatter which was statistically superior to that $N_{20}P_{20}$

The effect of different biofertilizer levels on the the drymatter production of palmarosa showed that the values varied significantly in all the three harvests In the

Table 15 Effect of chemical and biofertilizers on drymatter production (t ha^{-1}) in palmarosa in different harvests

Treatments	Harvest No 1	2	3	Total drymatter (t ha^{-1} yr^{-1})
A Chemical fertilizers				
N_0P_0	5 62	10 01	2 18	17 67
$N_{20}P_{20}$	6 82	11 80	2 62	21 24
$N_{40}P_{40}$	7 68	12 76	2 78	23 23
SEM±	0 12	0 33	0 07	0 39
CD (0 05)	0 35	0 95	0 20	1 12
B Biofertilizers				
Control	6 07	10 56	2 33	18 96
Azoto	6 64	12 53	2 42	21 59
Azosp	7 05	9 58	2 26	18 83
PSB	6 64	12 32	2 62	21 58
Azoto + PSB	6 85	9 76	2 59	19 20
Azosp + PSB	7 00	14 18	2 94	24 12
SEM±	0 17	0 47	0 10	0 55
CD (0 05)	0 49	1 35	0 29	1 58

second and third harvests, the treatment ***Azospirillum*** plus PSB recorded significantly higher drymatter than all other biofertilizer levels whereas in the first harvest, the treatment ***Azospirillum*** produced the highest drymatter which was statistically similar to that at ***Azospirillum*** plus PSB, which in turn were statistically superior to that in the uninoculated control

Application of different levels of biofertilizer affected the total drymatter production significantly and the data showed that inoculation with ***Azospirillum*** plus PSB resulted in significantly higher total drymatter than all the other biofertilizer treatments Inoculation with ***Azotobacter*** alone and PSB alone were statistically superior to uninoculated control with regard to the total drymatter production

The interaction effect of chemical x biofertilizers on drymatter production was significant only in the second harvest (Table 16) where the combinations, $N_{40}P_{40}$ along with ***Azospirillum*** plus PSB, $N_{40}P_{40}$ along with PSB and $N_{20}P_{20}$ along with ***Azospirillum*** plus PSB were the best

The interaction effect of chemical x biofertilizers on total drymatter production (Table 16) showed that the treatment combination $N_{40}P_{40}$ along with ***Azospirillum*** plus

Table 16 Drymatter production in palmarosa at second harvest (t ha^{-1}) and total drymatter (t ha^{-1} yr^{-1}) as influenced by various treatments

Treatments	Chemical fertilizers					
	Second harvest			Total		
	N_0P_0	$N_{20}P_{20}$	$N_{40}P_{40}$	N_0P_0	$N_{20}P_{20}$	$N_{40}P_{40}$
Biofertilizers						
Control	7 11	12 35	12 23	14 11	21 02	21 76
Azoto	13 31	11 35	12 93	20 87	20 45	23 45
Azosp	10 99	8 20	10 16	18 50	17 49	20 49
PSB	9 57	11 64	15 76	17 27	20 96	26 51
Azoto + PSB	6 99	12 98	9 30	14 91	22 79	19 89
Azosp + PSB	12 08	14 27	16 19	20 34	24 75	27 26
SEM+		0 82			0 95	
CD (0 05)		2 33			2 73	

PSB recorded the highest value which was on par with the treatments $N_{40}P_{40}$ along with PSB and $N_{20}P_{20}$ along with *Azospirillum* plus PSB

4 2 Yield characters

4 2 1 Fresh herbage yield

The data on the effect of chemical and biofertilizers on fresh herbage yield of palmarosa are presented in Table 17 and Fig 3 and 4

The effect of different levels of chemical fertilizers showed that herbage yield increased with increasing levels of fertilizer applications and that yield at higher level was significantly different from its immediate lower level in all the three harvests Thus, by the application of 20 kg ha^{-1} each of N and P_2O_5, the herbage yield was increased by 20 5, 18 3 and 18 9 per cent respectively in the first second and third harvests, whereas it was to the tune of 35 1, 27 8 and 27 4 per cent respectively with the application of 40 kg ha^{-1} each of N and P_2O_5 as compared to that in the control

The data revealed that application of different levels of chemical fertilizers showed significant effect on herbage yield production within a period of one year Here the yield increased with increase in the level of

Table 17 Effect of chemical and biofertilizers on fresh herbage yield (t ha^{-1}) in palmarosa in different harvests

Treatments	Harvest No 1	Harvest No 2	Harvest No 3	Total herbage (t ha^{-1} yr^{-1})
A Chemical fertilizers				
N_0P_0	13 98	23 50	6 19	43 61
$N_{20}P_{20}$	16 84	27 79	7 36	51 98
$N_{40}P_{40}$	18 87	30 03	7 87	56 77
SEM±	0 28	0 77	0 17	0 80
CD (0 05)	0 81	2 21	0 49	2 30
B Biofertilizers				
Control	15 03	24 93	6 56	46 52
Azoto	16 40	29 48	6 82	52 70
Azosp	17 39	23 06	6 37	46 82
PSB	16 43	29 03	7 41	52 73
Azoto + PSB	16 84	22 99	7 39	47 22
Azosp + PSB	17 28	33 16	8 28	58 73
SEM±	0 40	1 09	0 25	1 13
CD (0 05)	1 15	3 13	0 72	3 25

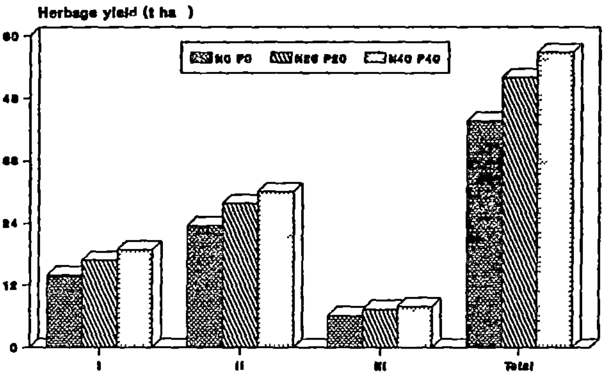


Fig 3 Fresh herbage yield of palmarosa as influenced by chemcial fertilizers in different harvests

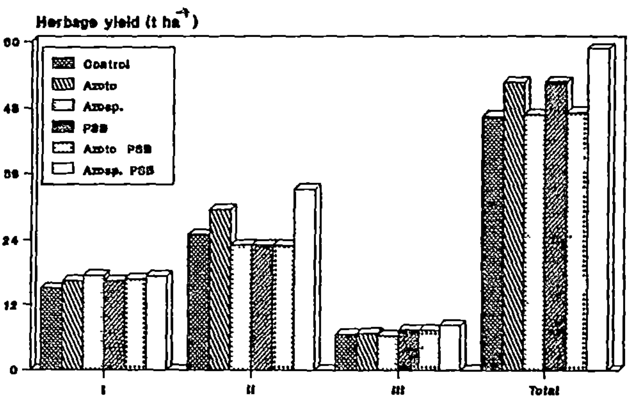


Fig 4 Fresh herbage yield of palmarosa as influenced by biofertilizers in different harvests

chemical fertilizers and the yield at low level of fertilizer application was significantly superior to that in the control The yield at $N_{40}P_{40}$ was significantly superior to that at $N_{20}P_{20}$ also The increase in yield due to the application of low and high level of fertilizers over control were 19 2 and 30 2 per cent respectively

The effect of different levels of biofertilizers on herbage yield of palmarosa showed that the treatment ***Azospirillum*** plus PSB resulted in significantly higher yield as compared to other combinations in the second and third harvests In the first harvest, this treatment was on par with other biofertilizer treatments, but significantly superior to uninoculated control The increase in herbage yield due to this treatment was to the tune of 15, 33 and 26 2 per cent respectively over that in the uninoculated control, in the first, second and third harvests

Among the different levels of biofertilizers the treatment ***Azospirillum*** plus PSB recorded the highest total herbage yield which was significantly superior to that in all the other treatments Also, the treatments PSB alone and ***Azotobacter*** alone were found to be significantly superior to that in the uninoculated control which recorded the lowest yield

The interaction effect of chemical x biofertilizers was significant in the second and third harvests (Table 18) and the treatment combinations $N_{40}P_{40}$ along with PSB, $N_{40}P_{40}$ along with ***Azospirillum*** plus PSB and $N_{20}P_{20}$ along with ***Azospirillum*** plus PSB were found to be good in deriving higher herbage yields

The interaction effect of chemical x biofertilizers on total herbage yield was found to be significant (Table 19) The treatment combination $N_{40}P_{40}$ along with ***Azospirillum*** plus PSB recorded the highest herbage yield which was on par with that in the treatment $N_{40}P_{40}$ along with PSB

4.2.2 Oil content

a Fresh weight basis

The data on the effect of different levels of chemical and biofertilizers on fresh herbage oil content in palmarosa are presented in Table 20

The results showed that barring the treatment $N_{40}P_{40}$ in the first harvest application of different levels of chemical fertilizers resulted in an increase in the oil content of palmarosa The oil content at both the levels of chemical fertilizer application were significantly

Table 18 Fresh herbage yield (t ha $^{-1}$) in palmarosa [illegible]
and third harvests as influenced by various treatments

Treatments	Chemical fertilizers					
	Second harvest			Third harvest		
	N_0P_0	$N_{20}P_{20}$	$N_{40}P_{40}$	N_0P_0	$N_{20}P_{20}$	$N_{40}P_{40}$
Biofertilizers						
Control	16 77	29 13	28 90	5 43	7 71	6 53
Azoto	31 30	26 77	30 37	5 49	6 60	8 38
Azosp	25 77	19 40	24 00	6 35	5 79	6 97
PSB	22 73	27 43	36 91	5 98	7 61	8 63
Azoto + PSB	16 40	30 60	21 97	6 41	7 89	7 86
Azosp + PSB	28 03	33 43	38 02	7 46	8 57	8 82
SEM+		1 88			0 43	
CD (0 05)		5 42			1 24	

Table 19 Total herbage yield (t ha^{-1} $year^{-1}$) in palmarosa as influenced by various treatments

Treatments	Chemical fertilizers		
	N_0P_0	$N_{20}P_{20}$	$N_{40}P_{40}$
Biofertilizers			
Control	34 87	51 48	53 21
Azoto	50 77	49 99	57 35
Azosp	47 26	42 97	50 23
PSB	42 29	51 42	64 47
Azoto + PSB	36 80	55 77	49 09
Azosp + PSB	49 65	60 27	66 25
SEM±		1 96	
CD (0 05)		5 64	

Table 20 Effect of chemical and biofertilizers on fresh herbage oil content (%) in palmarosa in different harvests

Treatments	Harvest No		
	1	2	3
A Chemical fertilizers			
N_0P_0	0 45	0 74	0 38
$N_{20}P_{20}$	0 49	0 79	0 52
$N_{40}P_{40}$	0 39	0 79	0 58
SEM+	0 03	0 01	0 03
CD (0 05)	0 09	0 03	0 09
B Biofertilizers			
Control	0 47	0 76	0 50
Azoto	0 46	0 77	0 44
Azosp	0 46	0 77	0 49
PSB	0 41	0 78	0 46
Azoto + PSB	0 41	0 79	0 54
Azosp + PSB	0 46	0 78	0 52
SEM+	0 04	0 01	0 04
CD (0 05)	NS	NS	NS

superior to that in the absolute control without any fertilizer addition

Inoculation of different biofertilizers did not change the fresh herbage oil content in palmarosa in any of the harvests and the values ranged from 0 41 to 0 47, 0 76 to 0 79 and 0 44 to 0 52 per cent respectively in the first second and third harvests

The interaction effect of chemical x biofertilizers on fresh herbage oil content was not significant in all the three harvests

b Dry weight basis

The data on the influence of different levels of chemical and biofertilizers on the dry herbage oil content of palmarosa are presented Table 21

Application of chemical fertilizers resulted in a significant increase in dry herbage oil content in palmarosa in the second and third harvests The data showed that application of N and P_2O_5 @ 40 kg ha^{-1} each as well as the same at 20 kg ha^{-1} were as par and resulted in a significantly higher oil content in palmarosa as compared to that in the control Maximum oil content of 1 87 per cent was noticed at the second harvest

Table 21 Effect of chemical and biofertilizers on dry herbage oil content (%) in palmarosa in different harvests

Treatments	Harvest No		
	1	2	3
A Chemical fertilizers			
N_0P_0	1 12	1 73	1 07
$N_{20}P_{20}$	1 22	1 87	1 44
$N_{40}P_{40}$	0 96	1 86	1 63
SEM+	0 07	0 03	0 07
CD (0 05)	NS	0 09	0 20
B Biofertilizers			
Control	1 17	1 79	1 40
Azoto	1 12	1 79	1 25
Azosp	1 13	1 82	1 34
PSB	1 02	1 84	1 29
Azoto + PSB	1 02	1 85	1 53
Azosp + PSB	1 15	1 82	1 46
SEM+	0 11	0 04	0 10
CD (0 05)	NS	NS	NS

As in the case of fresh herbage oil content, application of different combinations of biofertilizer did not change the dry herbage oil content of palmarosa and the values ranged from 1 02 to 1 17, 1 79 to 1 85 and 1 25 to 1 53 per cent in the first, second and third harvests respectively

The interaction effect of chemical x biofertilizers on dry herbage oil content was not significant in all the three harvests

4 2 3 Oil yield

The data on the effect of chemical and biofertilizers on the oil yield in palmarosa are presented in Table 22 and Fig 5 and 6

Application of different levels of chemical fertilizers resulted in a significant increase in oil yield over control In the third harvest, the treatment $N_{40}P_{40}$ resulted in significantly higher oil yield as compared to that obtained with the application of $N_{20}P_{20}$ which in turn was significantly superior to that in the control In the first and second harvest the oil yields at $N_{20}P_{20}$ and $N_{40}P_{40}$ were statistically similar and were superior to that obtained in control without any fertilizer application The increase in oil yield over control due

Table 22 Effect of chemical and biofertilizers on oil yield (l ha^{-1}) in palmarosa in different harvests

Treatments	Harvest No 1	2	3	Total oil yield (l ha^{-1} yr^{-1})
A Chemical fertilizers				
N_0P_0	64 04	173 33	23 36	260 74
$N_{20}P_{20}$	83 54	219 27	37 25	340 07
$N_{40}P_{40}$	73 54	236 99	44 90	355 53
SEM+	5 19	7 58	1 82	10 27
CD (0 05)	14 93	21 80	5 23	29 54
B Biofertilizers				
Control	71 91	189 65	32 91	294 47
Azoto	74 86	224 14	31 03	330 03
Azosp	78 94	178 66	30 14	287 74
PSB	68 07	227 08	34 50	329 65
Azoto + PSB	66 41	180 49	39 52	286 42
Azosp + PSB	82 04	259 16	43 14	384 35
SEM+	7 35	10 73	2 57	14 52
CD (0 05)	NS	30 86	7 39	41 76

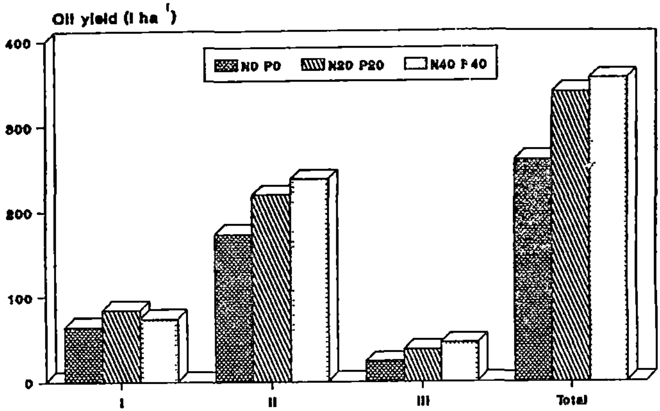


Fig.5 Oil yield of palmarosa as influenced by chemical fertilizers in different harvests

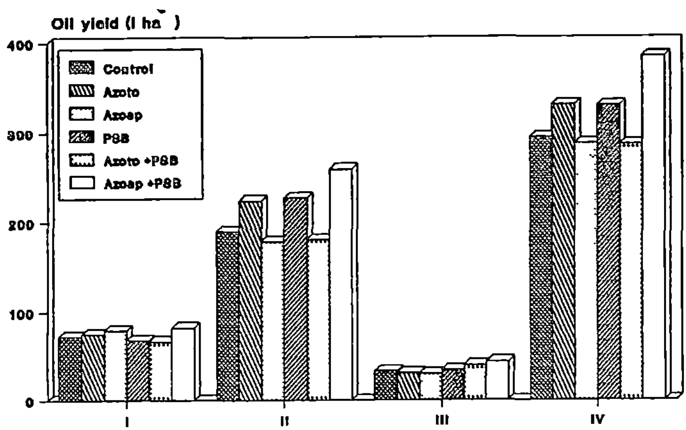


Fig 6 Oil yield of palmarosa as influenced by biofertilizers in different harvests

to the application of 20 kg ha^{-1} each of N and P_2O_5 were 30 4, 26 5 and 59 5 per cent in the first, second and third harvests respectively, whereas the corresponding values were 14 8, 36 7 and 92 2 per cent respectivelv with the application of 40 kg ha^{-1} each of N and P_2O_5

Application of chemical fertilizers resulted in a significant increase in the oil yield of the crop in a period of one year The treatments $N_{20}P_{20}$ and $N_{40}P_{40}$ recorded significantly higher oil yield as compared to that in the control plot which in turn were statistically similar even though highest oil yield of 355 53 l ha^{-1} yr^{-1} was noticed by the application of 40 kg ha^{-1} each of N and P_2O_5

The effect of different combinations of biofertilizers showed that it affected the oil yield significantly in the second and third harvests and the treatment ***Azospirillum*** plus PSB recorded maximum oil yield Application of different biofertilizers did not affect the oil yield in the first harvest However, the maximum oil yield of 82 04 l ha^{-1} was recorded by the treatment ***Azospirillum*** plus PSB which was 14 4 per cent more than that in the control plot

Application of different combinations of biofertilizers showed a significant effect on total oil yield of palmarosa The treatment ***Azospirillum*** plus PSB recorded the highest total oil yield which was significantly superior to that in all the other treatments which themselves were statistically similar in oil production

The interaction effect of chemical x biofertilizers was significant only in the second harvest (Table 23) The best treatment combinations were $N_{40}P_{40}$ along with *Azospirillum* plus PSB $N_{40}P_{40}$ along with PSB and $N_{20}P_{20}$ along with *Azospirillum* plus PSB

The interaction effect of chemical x biofertilizers on total oil yield over one year was significant (Table 24) and the treatment combination $N_{40}P_{40}$ along with *Azospirillum* plus PSB recorded the highest oil yield of 461 3 l ha^{-1} which was on par with that in the treatment $N_{40}P_{40}$ along with PSB alone and $N_{20}P_{20}$ along with *Azospirillum* plus PSB

4 3 Content and uptake of nutrients

4 3 1 Nutrient content

20a Nitrogen

The data on the effect of chemical and biofertilizers on the N content of palmarosa are presented in Table 25

Table 23 Oil yield (l ha^{-1}) of palmarosa in the second harvest as influenced by various treatments

Treatments	Chemical fertilizers		
	N_0P_0	$N_{20}P_{20}$	$N_{40}P_{40}$
Biofertilizers			
Control	121 15	225 25	222 57
Azoto	232 84	206 09	233 49
Azosp	200 12	156 54	179 31
PSB	160 18	229 90	291 14
Azoto + PSB	119 88	234 36	187 24
Azosp + PSB	205 81	263 48	308 20
SEM±		18 58	
CD (0 05)		53 43	

Table 24 Total oil yield (l ha^{-1} $year^{-1}$) in palmarosa as influenced by various treatments

Treatments	Chemical fertilizers		
	N_0P_0	$N_{20}P_{20}$	$N_{40}P_{40}$
Biofertilizers			
Control	195 45	342 18	345 78
Azoto	318 39	331 99	339 71
Azosp	292 54	276 22	294 46
PSB	237 24	330 78	420 94
Azoto + PSB	229 85	358 38	271 04
Azosp + PSB	290 95	400 85	461 25
SEM±		25 16	
CD (0 05)		72 36	

Table 25 Effect of chemical and biofertilizers on the N content (%) of palmarosa in different harvests

Treatments	Harvest No 1	2	3
A Chemical fertilizers			
N_0P_0	1 56	1 54	1 58
$N_{20}P_{20}$	1 72	1 71	1 72
$N_{40}P_{40}$	1 66	1 68	1 68
SEM+	0 03	0 02	0 007
CD (0 05)	0 09	0 06	NS
B Biofertilizers			
Control	1 67	1 69	1 64
Azoto	1 70	1 62	1 69
Azosp	1 65	1 65	1 70
PSB	1 62	1 63	1 64
Azoto + PSB	1 60	1 66	1 66
Azosp + PSB	1 64	1 62	1 63
SEM±	0 04	0 03	0 01
CD (0 05)	NS	NS	NS

The data revealed that application of different levels of chemical fertilizers resulted in a significant increase in the content of N in the plant in the first and second harvests and a higher content was noticed in the treatments receiving N and P_2O_5 as compared to that in the control In the third harvest, application of chemical fertilizers did not significantly influence the N content but a higher concentration was noticed in the treatments receiving chemical fertilizers

Application of different combinations of biofertilizers did not affect the N concentration in the plant, in all the three harvests In general it was observed that the N concentration in the plant was lower in the biofertilizer treatments with higher herbage yields

The interaction effect of chemical x biofertilizers was not significant in all the harvests

b Phosphorus The data on the P content of palmarosa as influenced by chemical and biofertilizers are presented in Table 26

Application of chemical fertilizers significantly influenced the P content in the first harvest only even though the contents were higher in the treatments

Table 26 Effect of chemical and biofertilizers on the P content (%) of palmarosa in different harvests

Treatments	Harvest No		
	1	2	3
A Chemical fertilizers			
N_0P_0	0 272	0 271	0 272
$N_{20}P_{20}$	0 308	0 307	0 309
$N_{40}P_{40}$	0 295	0 295	0 296
SEM+	0 007	0 007	0 006
CD (0 05)	0 02	NS	NS
B Biofertilizers			
Control	0 296	0 286	0 290
Azoto	0 297	0 297	0 295
Azosp	0 292	0 292	0 30
PSB	0 288	0 290	0 289
Azoto + PSB	0 286	0 297	0 293
Azosp + PSB	0 291	0 286	0 285
SEM+	0 06	0 01	0 008
CD (0 05)	NS	NS	NS

which received chemical fertilizers as compared to that in the control in all the three harvests

The use of different combinations of biofertilizers did not affect the P content of palmarosa in any of the harvests, and the content in general varied from 0 285 to 0 300 per cent

Also the interaction effect of chemical x biofertilizers on P content of palmarosa was not significant

c Potassium

The data on the effect of chemical and biofertilizers on K content in palmarosa are presented in Table 27

Application of chemical fertilizers increased significantly the K content in plant only in the first harvest The K contents in general varied from 1 42 to 1 60 per cent when all the harvests taken together

Application of different combinations of biofertilizers did not influence the K content of palmarosa in any of the harvests

The interaction effect of chemical x biofertilizers was also not significant in all the harvests

Table 27 Effect of chemical and biofertilizers on the K content (%) of palmarosa in different harvests

Treatments	Harvest No		
	1	2	3
A Chemical fertilizers			
N_0P_0	1 43	1 42	1 43
$N_{20}P_{20}$	1 60	1 55	1 60
$N_{40}P_{40}$	1 51	1 51	1 51
SEM±	0 03	0 01	0 02
CD (0 05)	0 1	NS	NS
B Biofertilizers			
Control	1 52	1 46	1 50
Azoto	1 55	1 47	1 54
Azosp	1 48	1 50	1 56
PSB	1 51	1 49	1 48
Azoto + PSB	1 49	1 55	1 52
Azosp + PSB	1 50	1 47	1 47
SEM±	0 04	0 01	0 03
CD (0 05)	NS	NS	NS

4 3 2 Nutrient uptake

a Nitrogen

The data on the effect of different levels of chemical and biofertilizers on N uptake by palmarosa are presented in Table 28 and Fig 7 and 8

Application of increasing levels of chemical fertilizers resulted in an increase in the nitrogen uptake by the crop in all the three harvests and that the uptake increased with increase in the level of chemical fertilizers In the first and second harvests, the treatment $N_{40}P_{40}$ resulted in highest N uptake which was significantly superior to that in the treatment $N_{20}P_{20}$ In the third harvest, N uptake in the treatments $N_{20}P_{20}$ and $N_{40}P_{40}$ were significantly superior to that in the control, which themselves were statistically similar

Application of chemical fertilizers increased the total N uptake by the crop significantly and it increased with increase in the level of chemical fertilizers There were significant difference in uptake at each level of fertilizer application

Use of different combinations of biofertilizers significantly affected the N uptake by palmarosa plants in

Table 28 Effect of chemical and biofertilizers on N uptake ($kg\ ha^{-1}$) by palmarosa in different harvests

Treatments	Harvest No 1	2	3	Total N uptake ($Kg\ ha^{-1}\ yr^{-1}$)
A Chemical fertilizers				
N_0P_0	87 47	154 15	34 44	275 78
$N_{20}P_{20}$	117 35	201 78	45 06	364 12
$N_{40}P_{40}$	129 03	214 37	46 70	389 58
SEM+	3 34	4 36	0 58	8 07
CD (0 05)	9 60	12 56	1 66	23 24
B Biofertilizers				
Control	101 83	178 46	38 21	319 77
Azoto	111 23	202 99	40 89	356 97
Azosp	119 50	161 37	38 42	318 29
PSB	107 67	200 82	42 97	353 22
Azoto + PSB	110 00	162 02	42 99	316 83
Azosp + PSB	115 47	229 72	47 92	393 86
SEM+	4 72	6 17	0 82	11 41
CD (0 05)	13 60	17 75	2 36	32 82

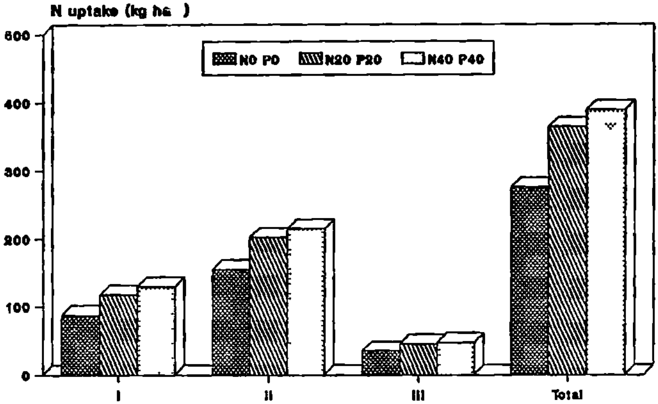


Fig 7 N uptake of palmarosa as influenced by chemcial fertilizers in different harvests

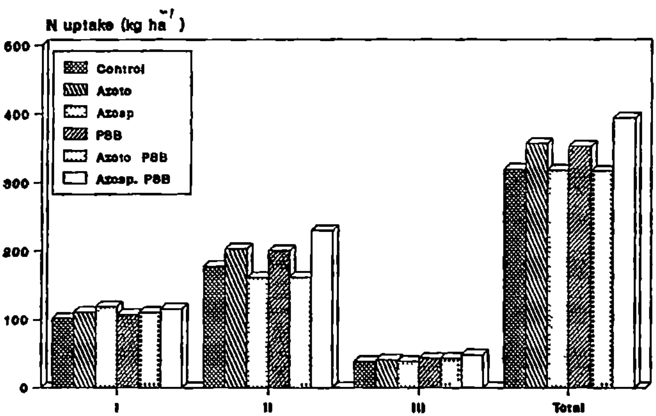


Fig 8 N uptake of palmarosa as influenced by biofertilizers in different harvests

all the three harvests In the second and third harvests the treatment, *Azospirillum* plus PSB removed the maximum amount of nitrogen from the soil and was significantly different from that in all the other treatments In the first harvest, the highest N uptake was noticed due to inoculation with *Azospirillum* alone which was statistically similar to that with *Azospirillum* plus PSB and these were superior to that in the uninoculated control

Application of different combinations of biofertilizers resulted in a significant effect on total N uptake by the crop and the treatment *Azospirillum* plus PSB recorded significantly higher N uptake than all others The values in the treatments *Azotobacter* alone and PSB alone were also significantly superior to that in the control

The interaction effect of chemical x biofertilizers on N uptake was significant only in the second harvest (Table 29) Higher amount of N was removed by the plants in the treatment combination $N_{40}P_{40}$ along with PSB, $N_{40}P_{40}$ along with *Azospirillum* plus PSB and $N_{20}P_{20}$ along with *Azospirillum* plus PSB

The interaction effect of chemical x biofertilizers on total N uptake was significant (Table 29) and that the treatment combination $N_{40}P_{40}$ along with *Azospirillum* plus

Table 29 The N uptake by palmarosa in the second harvest (kg ha^{-1}) and total N uptake (kg ha^{-1} yr^{-1}) as influenced by various treatments

Treatments	Chemical fertilizers					
	Second harvest			Total		
	N_0P_0	$N_{20}P_{20}$	$N_{40}P_{40}$	N_0P_0	$N_{20}P_{20}$	$N_{40}P_{40}$
Biofertilizers						
Control	114 47	214 89	209 13	223 67	364 28	371 37
Azoto	202 31	192 95	213 35	325 38	351 86	393 67
Azosp	169 25	140 20	171 70	300 42	301 33	353 11
PSB	146 42	197 88	263 19	264 68	354 62	440 36
Azoto + PSB	108 35	224 55	158 10	230 67	391 80	328 02
Azosp + PSB	182 41	241 16	267 14	309 86	420 81	450 90
SEM±		10 68			19 77	
CD (0 05)		30 72			56 86	

PSB recorded the highest uptake value which was similar to that in $N_{40}P_{40}$ along with PSB and $N_{20}P_{20}$ along with *Azospirillum* plus PSB

b Phosphorus

The data on the effect of different levels of chemical and biofertilizers on P uptake in palmarosa are presented in Table 30 and Fig 9 and 10

Application of different levels of chemical fertilizers resulted in a significant variation in the P uptake by the crop and that the values increased with increasing levels of chemical fertilizers In the first and second harvest P uptake at $N_{40}P_{40}$ level was significantly higher than that at $N_{20}P_{20}$ level which in turn was significantly more than that in the control plots In the third harvest application of $N_{20}P_{20}$ and $N_{40}P_{40}$ resulted in significantly higher uptake than in the control which themselves were at par

Chemical fertilizers brought about significant increase in the total P uptake by the crop over a period of one year and that the total P uptake at $N_{20}P_{20}$ and $N_{40}P_{40}$ were statistically similar but were significantly superior to that in the control

Table 30 Effect of chemical and biofertilizers on P uptake ($kg\ ha^{-1}$) by palmarosa in different harvests

Treatments	Harvest No 1	Harvest No 2	Harvest No 3	Total P uptake ($kg\ ha^{-1}\ yr^{-1}$)
A Chemical fertilizers				
N_0P_0	15 25	27 13	5 93	48 18
$N_{20}P_{20}$	21 01	36 23	8 10	65 28
$N_{40}P_{40}$	22 67	37 64	8 23	68 48
SEM+	0 49	0 48	0 29	2 83
CD (0 05)	1 42	1 39	0 83	8 16
B Biofertilizers				
Control	17 97	31 36	6 76	56 53
Azoto	19 77	35 84	7 14	62 70
Azosp	20 65	28 56	6 78	55 77
PSB	19 24	35 73	7 57	62 71
Azoto + PSB	19 64	28 99	7 59	56 62
Azosp + PSB	20 53	40 55	8 38	69 56
SEM+	0 69	0 68	0 41	4 00
CD (0 05)	1 98	1 96	1 18	11 50

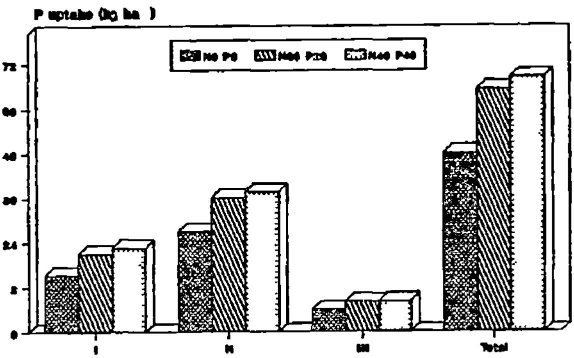


Fig 9 P uptake of palmarosa as influenced by chemcial fertilizers in different harvests

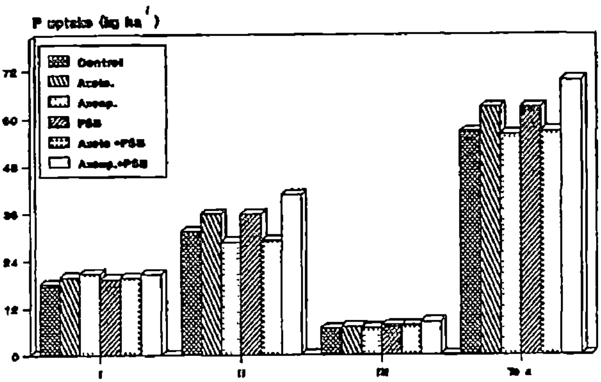


Fig 10 P uptake of palmarosa as influenced by biofertilizers in different harvests

Application of different combinations of biofertilizers also showed significant differences with regard to P uptake and the treatment, *Azospirillum* plus PSB recorded maximum uptake values in all the three harvests In the second harvest, *Azospirillum* plus PSB was significantly superior to all other biofertilizer combinations, whereas the treatment was significantly superior to that in the control in the first and third harvests

Comparing the different biofertilizer levels for total P uptake, it was observed that the highest value was recorded by the treatment *Azospirillum* plus PSB which was significantly superior to that with uninoculated control

The interaction effect of chemical x biofertilizers was significant in the second harvest only (Table 31) The treatment combination $N_{40}P_{40}$ along with *Azospirillum* plus PSB recorded the highest P uptake value which was on par with $N_{40}P_{40}$ along with PSB

The interaction effect of chemical x biofertilizers on total P uptake was significant (Table 31) and the treatment combination $N_{40}P_{40}$ along with *Azospirillum* plus PSB recorded the highest value which was closely followed by

Table 31 The P uptake by palmarosa at second harvest (kg ha $^{-1}$) and total P uptake (kg ha $^{-1}$ yr^{-1}) as influenced by various treatments

Treatments	Chemical fertilizers					
	Second harvest			Total		
	N_0P_0	$N_{20}P_{20}$	$N_{40}P_{40}$	N_0P_0	$N_{20}P_{20}$	$N_{40}P_{40}$
Biofertilizers						
Control	19 69	38 53	36 81	38 55	65 51	65 55
Azoto	35 67	34 16	37 50	56 61	62 61	68 88
Azosp	29 67	25 42	29 97	52 54	54 54	60 23
PSB	25 74	35 85	46 02	46 32	64 07	77 74
Azoto + PSB	19 08	40 63	28 27	40 49	70 19	59 17
Azosp + PSB	32 37	42 67	46 95	54 59	74 79	79 29
SEM+		1 18			6 93	
CD (0 05)		3 39			19 93	

$N_{40}P_{40}$ along with PSB and $N_{20}P_{20}$ along with *Azospirillum* plus PSB

c Potassium

The data on the effect of chemical and biofertilizers on K uptake in palmarosa are presented in Table 32 and Fig 11 and 12

As in the case of N and P, application of different levels of chemical fertilizers increased the uptake of K which increased with increasing levels of fertilizers In the first two harvests the uptake at high level of fertilizer application was significantly superior to that in the low level of fertilizer application which was significantly different from that in the control

Application of chemical fertilizers resulted in significant effect on the total potassium uptake Application of $N_{20}P_{20}$ and $N_{40}P_{40}$ recorded comparable total potassium uptake but were significantly superior to control

The effect of application of different combination of biofertilizers showed that it affected the K uptake in palmarosa significantly The treatment *Azospirillum* plus PSB recorded the highest K uptake, significantly superior to that in control in all the three harvests

Table 32 Effect of chemical and biofertilizers on K uptake (kg ha^{-1}) by palmarosa at different harvests

Treatments	Harvest No 1	2	3	Total K uptake (kg ha^{-1} yr^{-1})
A Chemical fertilizers				
N_0P_0	80 36	142 10	31 17	252 98
$N_{20}P_{20}$	109 12	182 90	41 92	333 25
$N_{40}P_{40}$	115 97	192 68	41 98	349 38
SEM±	1 95	2 15	1 83	7 48
CD (0 05)	5 62	6 2	5 26	21 37
B Biofertilizers				
Control	93 03	154 18	34 95	283 22
Azoto	103 57	184 19	37 27	325 08
Azosp	104 45	146 70	35 26	285 75
PSB	100 39	183 57	38 78	323 98
Azoto + PSB	102 28	151 28	39 37	295 38
Azosp + PSB	105 52	208 45	43 22	357 72
SEM±	2 76	3 04	2 59	10 50
CD (0 05)	7 94	8 74	7 45	30 25

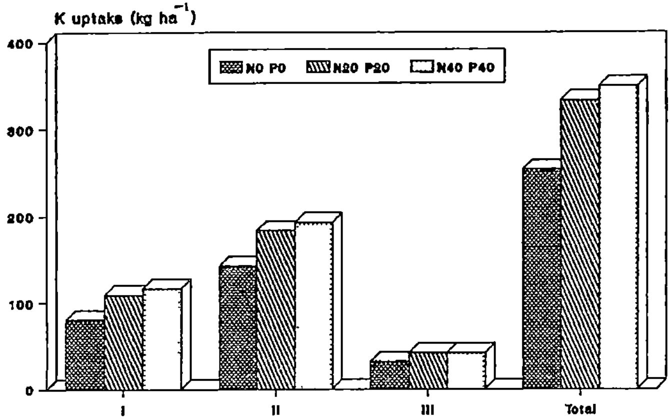


Fig 11 K uptake of palmarosa
as influenced by chemcial fertilizers
in different harvests

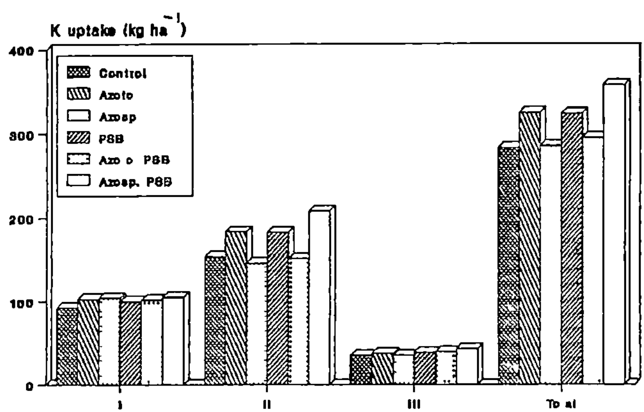


Fig 12 K uptake of palmarosa
as influenced by biofertilizers in
different harvests

The data on the effect of biofertilizers showed that the application of ***Azospirillum*** plus PSB resulted in significantly higher total potassium uptake than all others The biofertilizer levels ***Azotobacter*** and PSB were also significantly superior to control

The interaction effect of chemical x biofertilizers was significant only in the second harvest (Table 33) The treatment combination $N_{40}P_{40}$ along with PSB recorded highest K uptake value

The interaction effect of chemical x biofertilizers on total K uptake was significant (Table 33) It showed that the highest value was recorded by the treatment combination $N_{40}P_{40}$ along with ***Azospirillum*** plus PSB which was closely followed by that at $N_{40}P_{40}$ along with PSB and $N_{20}P_{20}$ along with ***Azospirillum*** plus PSB

4 4 Soil Analysis

4 4 1 Available Nitrogen

The data on the effect of chemical and biofertilizers on the residual available soil nitrogen after each harvest are presented in Table 34

The data showed that application of different levels of chemical fertilizers significantly influenced the residual

Table 33 The K uptake by palmarosa at second harvest (kg ha^{-1}) and total K uptake (kg ha^{-1} yr^{-1}) as influenced by various treatments

Treatments	Chemical fertilizers					
	Second harvest			Total		
	N_0P_0	$N_{20}P_{20}$	$N_{40}P_{40}$	N_0P_0	$N_{20}P_{20}$	$N_{40}P_{40}$
Biofertilizers						
Control	102 38	172 90	189 57	200 25	311 94	337 49
Azoto	186 34	175 93	190 07	295 97	326 04	353 43
Azosp	156 06	129 56	152 40	274 02	275 63	307 61
PSB	134 94	182 75	236 40	246 30	328 14	397 50
Azoto + PSB	101 36	214 17	145 08	213 71	371 13	301 31
Azosp + PSB	169 12	221 19	236 30	287 60	386 61	398 95
SEM±		5 27			18 19	
CD (0 05)		15 16			52 32	

Table 34 Effect of chemical and biofertilizers on the available N (kg ha^{-1}) in soil after different harvests

Treatments	Harvest No 1	2	3
A Chemical fertilizers			
N_0P_0	240 14	243 67	231 92
$N_{20}P_{20}$	247 79	244 84	232 09
$N_{40}P_{40}$	254 93	251 17	237 58
SEM±	2 15	1 13	1 94
CD (0 05)	6 18	3 25	5 58
B Biofertilizers			
Control	241 96	238 53	230 88
Azoto	245 47	245 23	239 92
Azosp	248 06	238 55	234 09
PSB	252 43	251 37	231 34
Azoto + PSB	240 98	248 54	234 80
Azosp + PSB	256 83	257 16	239 14
SEM±	3 04	1 60	2 74
CD (0 05)	8 74	4 60	NS

available soil nitrogen and that the content increased with increase in the level of application of chemical fertilizers The highest soil N level was noticed in the treatment receiving 40 kg each of N and P_2O_5 ha^{-1} which was significantly more than that in the treatment receiving 20 kg ha^{-1} each of N and P_2O_5 which in turn was significantly superior to that in the control in the first harvest In the second harvest the available N status in the treatment $N_{40}P_{40}$ was significantly superior to that in the treatment $N_{20}P_{20}$ and in the control plots In the thirdharvest i e after the experimentation the soil N status in the treatments $N_{20}P_{20}$ and $N_{40}P_{40}$ were statistically similar but was significantly superior to that in the control plots

Use of different combinations of biofertilizers showed that combined application of *Azospirillum* and PSB registered the highest available N in soil after the first and second harvests which was on par with treatment PSB in the first harvest and these in turn were significantly superior to that in the control After the third harvest, the different biofertilizer levels did not show any significant difference in the status of available N in soil The interaction of chemical x biofertilizers on residual soil N was significant in all the harvests (Table 35) and the treatments $N_{40}P_{40}$ in combination with PSB $N_{40}P_{40}$ alongwith *Azospirillum* plus

Table 35 The available N (kg ha ^{1}) of soil after different harvests as influenced by various treatments

Treatments	Chemical fertilizers								
	Harvest No								
	1			2			3		
	N_0P_0	$N_{20}P_{20}$	$N_{40}P_{40}$	N_0P_0	$N_{20}P_{20}$	$N_{40}P_{40}$	N_0P_0	$N_{20}P_{20}$	$N_{40}P_{40}$
Biofertilizers									
Control	237 87	240 80	247 20	230 40	236 11	249 07	226 60	228 53	237 50
Azoto	234 82	245 33	256 26	250 93	243 90	240 86	231 45	225 70	241 60
Azosp	243 47	242 30	258 40	248 42	234 12	238 12	232 26	237 80	232 20
PSB	236 75	256 53	264 00	242 91	247 20	264 00	234 13	220 20	239 70
Azoto + PSB	239 73	241 60	241 60	239 70	251 20	254 71	234 80	233 10	236 50
Azosp + PSB	248 20	260 15	262 13	254 67	256 53	260 27	232 28	247 20	237 95
SEM+		5 27			2 77			4 75	
CD (0 05)		15 16			7 97			13 66	

PSB and $N_{20}P_{20}$ along with *Azospirillum* plus PSB recorded higher available N in soil

4 4 2 Available P

The data on the effect of chemical and biofertilizers on available P content of soil after each harvest are presented in Table 36

Application of different levels of chemical fertilizers resulted in a significant increase in the available P status of soil as evidenced by the higher available P contents after each harvest where the contents increased with increase in the levels of fertilizer application

Effect of different levels of biofertilizers on the available P content of soil after each harvest also showed significant effect on the character and the treatment *Azospirillum* plus PSB recorded significant increase in available P as compared to that in the uninoculated control, in all the three harvests

The interaction effect of chemical x biofertilizers was also significant in all the three harvests (Table 37) The treatment combinations $N_{40}P_{40}$ along with PSB, $N_{40}P_{40}$ along with *Azospirillum* plus PSB and $N_{20}P_{20}$ along with *Azospirillum* plus PSB recorded higher values after each of the three harvests

Table 36 Effect of chemical and biofertilizers [illegible]

available P (kg ha^{-1}) in soil after different harvests

Treatments	Harvest No 1	Harvest No 2	Harvest No 3
A Chemical fertilizers			
N_0P_0	20 17	19 24	19 [illegible]
$N_{20}P_{20}$	20 63	19 96	20 34
$N_{40}P_{40}$	21 08	20 54	20 84
SEM+	0 13	0 12	0 18
CD (0 05)	0 37	0 34	0 50
B Biofertilizers			
Control	20 23	19 56	20 01
Azoto	20 55	20 09	20 15
Azosp	20 43	19 77	19 89
PSB	20 90	19 79	20 36
Azoto + PSB	20 65	19 78	20 30
Azosp + PSB	21 05	20 23	20 76
SEM+	0 18	0 17	0 25
CD (0 05)	0 52	0 48	0 71

Table 37 The available P (kg ha⁻¹) status of soil after different harvests as influenced by various treatments

Treatments	Chemical fertilizers / Harvest No 1			2			3		
	N_0P_0	$N_{20}P_{20}$	$N_{40}P_{40}$	N_0P_0	$N_{20}P_{20}$	$N_{40}P_{40}$	N_0P_0	$N_{20}P_{20}$	$N_{40}P_{40}$
Biofertilizers									
Control	19 47	20 54	20 67	18 53	19 67	20 48	19 08	20 05	20 90
Azoto	20 07	20 92	20 67	19 90	20 08	20 74	20 09	20 25	20 09
Azosp	20 29	20 10	20 90	18 92	20 09	20 64	18 92	20 07	20 68
PSB	20 58	20 58	21 56	19 09	19 88	20 41	19 46	20 29	21 33
Azoto + PSB	20 10	20 49	21 36	19 52	19 74	20 07	19 88	20 30	20 70
Azosp + PSB	20 48	21 16	21 35	19 47	20 32	20 89	19 84	21 10	21 32
SEM±		0 31			0 29			0 43	
CD (0 05)		0 89			0 82			1 24	

Available K

The data on the effect of different levels of chemical and biofertilizers on available soil K are presented in Table 38

Application of different levels of chemical fertilizers resulted in a significant increase in the available K content of soil after each harvest As in the case of available N and P contents, the available K content of soil was also significantly higher in fertilizer applied plots than in the control after each harvest

Use of different combinations of biofertilizers also showed significant variation among the treatments In the first and third harvests application of combination of *Azospirillum* plus PSB resulted in significantly higher available K content over that in the control In the second harvest, inoculation with PSB was the only treatment which registered significance over control

The interaction effect of chemical x biofertilizers on available K content of soil was significant in all the three harvests (Table 39) The treatment combinations $N_{40}P_{40}$ along with PSB, $N_{40}P_{40}$ along with *Azospirillum* plus PSB and $N_{20}P_{20}$ along with *Azospirillum* plus PSB recorded higher available K content in soil after each harvest

Table 38 Effect of chemical and biofertilizers on the available K (kg ha^{-1}) in soil after different harvests

Treatments	Harvest No		
	1	2	3
A Chemical fertilizers			
N_0P_0	124 67	122 58	120 94
$N_{20}P_{20}$	127 17	124 88	123 33
$N_{40}P_{40}$	128 32	125 06	123 99
SEM±	0 37	0 23	0 24
CD (0 05)	1 06	0 66	0 69
B Biofertilizers			
Control	125 56	123 98	122 17
Azoto	125 75	123 36	123 04
Azosp	125 49	123 11	122 43
PSB	128 20	125 82	122 66
Azoto + PSB	126 29	124 02	122 57
Azosp + PSB	129 03	124 76	123 61
SEM+	0 52	0 33	0 34
CD (0 05)	1 48	0 94	0 98

Table 39 The available K (kg ha^{-1}) status of soil after different harvests as influenced by various treatments

Treatments	Chemical fertilizers								
	Harvest No								
	1			2			3		
	$N P_0$	$N_{20} P_{20}$	N_4 P_4	$N_0 P$	N_2 P_2	$N_{40} P_{40}$	$N_0 P_0$	N_2 P_{20}	N_4 P_4
Biofertilizers									
Control	122 50	127 50	126 67	121 12	124 99	125 84	120 00	123 09	123 32
Azoto	125 50	125 25	126 49	123 34	122 56	2 18	122 0	172 59	17 12
Azosp	123 48	125 84	127 18	122 49	122 83	124 02	120 84	122 96	123 49
PSB	126 26	128 34	130 00	124 49	126 80	126 15	121 19	121 68	125 10
Azoto + PSB	124 36	126 50	128 05	122 40	124 59	125 08	120 43	122 99	124 30
Azosp + PSB	125 94	129 61	131 55	121 67	127 50	125 10	120 65	126 57	123 63
SEM±	0 90			0 57			0 59		
CD (0 05)	2 58			1 63			1 70		

4 5 Correlation studies

Correlations of different characters to herbage and oil yields in each of the harvests are presented in Table 40

4.5.1. Correlations to herbage yield

All the growth characters were positively correlated to herbage yield Among these, the number of tillers, number of inflorescences and the drymatter production registered significant positive correlation to herbage yield in all the three harvests

The oil contents (both fresh weight and dry weight basis) showed a slight negative correlation to herbage yield in the first harvest while it was positive in the second and third harvests The oil yield was significantly and positively correlated to herbage yield in the second and third harvests

The content and uptake of N, P and K were positively correlated to herbage yield in all the three harvests and the correlations between uptakes and herbage yield was significant

Table 40 Correlations of different characters to herbage and oil yields

Character	Harvest No					
	Herbage yield			Oil yield		
	1	2	3	1	2	3
Plant height	0 458	0 432	0 388	0 356	0 182	0 271
Number of tillers hill [1]	0 580*	0 471*	0 475*	0 410	0 472*	0 398
Plant spread (E W)	0 476*	0 398	0 472*	0 014	0 213	0 098
Plant spread (N S)	0 321	0 319	0 298	0 059	0 132	0 192
Number of inflorescence hill [1]	0 592*	0 600*	0 473*	0 422	0 398	0 470*
Length of inflorescence	0 358	0 272	0 301	0 518*	0 402	0 387
Drymatter production	0 921*	0 918*	0 897*	0 340	0 693*	0 701*
Herbage yield				0 351	0 848*	0 807*
Oil content (FWB)	0 278	0 292	0 525*	0 786*	0 692*	0 718*
Oil content (DWB)	0 258	0 228	0 580*	0 803*	0 726*	0 682*
Oil yield	0 351	0 852*	0 803*			-
N content	0 289	0 216	0 238	0 386	0 441	0 418
P content	0 406	0 385	0 192	0 400	0 318	0 302
K content	0 395	0 402	0 368	0 511*	0 278	0 311
N uptake	0 861*	0 762*	0 698*	0 450	0 419	0 301
P uptake	0 773*	0 819*	0 803*	0 430	0 398	0 412
K uptake	0 759*	0 782*	0 800*	0 451	0 443	0 295
Available soil N	0 614*	0 562*	0 600*	0 240	0 413	0 312
Available soil P	0 582*	0 538*	0 492*	0 406	0 396	0 204
Available soil K	0 438	0 501*	0 394	0 355	0 201	0 232

* Significant at 5% level

The available N, P and K in soil after different harvests were also positively correlated to herbage yield in all the three harvests

Correlations to oil yield

All the growth characters were positively correlated to oil yield

The herbage yield had significant positive correlation to oil yield in the second and third harvests

The correlation of oil contents (both fresh weight and dry weight basis) to oil yield was positively significant in all the three harvests

The content and uptake of nutrients and the available soil nutrients were also positively correlated to oil yield

Discussion

DISCUSSION

The results obtained during the course of investigation are discussed in this chapter in the light of available literature with explanations on the cause-effect relationship as far as possible

Growth and yield

From the results it can be seen that application of 20 kg ha^{-1} each of N and P_2O_5 resulted in significantly higher oil yield over a period of one year (Table 22) compared to no fertilizer application Also this particular treatment gave superior oil yield in two out of three harvests (Table 22) The results are in agreement with those reported by Sharma et al (1980), Munsi and Mukherjee (1982), Yadav et al (1985), Rao et al (1989) Singh et al (1992) and Pareek and Maheshwari (1995) on the effect on N in increasing the oil yield in palmarosa Also the increased oil yield may be due to the effect of phosphorus application as reported by Sharma et al (1980), Singh et al (1981) and Munsi and Mukherjee (1982) Under Kerala conditions, Chinnamma (1985) has reported an increase in the oil yield in palmarosa with the application of P up to 50 kg ha^{-1}

When compared to control the treatment $N_{20}P_{20}$ recorded significantly high total herbage yield over a period of one year and the herbage yield from all the three harvests considered separately (Table 17) Similar observations were made by Rao _et al_ (1989) with the application of N @ 50 kg ha^{-1} and Singh _et al_ (1992) upto 80 kg N ha^{-1} and also by Sharma _et al_ (1980) and Singh _et al_ (1981)

Application of N and P_2O_5 each at 20 kg ha^{-1} resulted in significantly higher oil content in two out of three harvests compared to that in the control (Tables 20 and 21) In the first harvest application of chemical fertilizers did not affect the oil content on dry weight basis The results are in conformity with those reported by Dutta and Paul (1976) Pareek _et al_ (1981), Singh _et al_ (1981), Pareek _et al_ (1983) and Maheswari _et al_ (1984) that N and P application did not result in any effect on the oil content of palmarosa

With regard to the growth and yield attributes like plant height (Table 2), number of tillers (Table 4) plant spread (Table 6 and 8), number of inflorescences (Table 10), fresh herbage yield $plant^{-1}$ (Table 13) and drymatter production (Table 15), the treatment $N_{20}P_{20}$ was significantly superior to that in the control This is in conformity with that reported by Pareek _et al_ (1981) and

Pareek and Maheshwari (1995) on the effect of N in increasing plant height and number of tillers Singh et al (1992) on the effect of N and P on the number of tillers and Chinnamma (1985) on the drymatter production

Thus application of N and P_2O_5 each at 20 kg ha^{-1} could improve the growth of palmarosa and thus resulting in higher oil yield Since the soil of the experimental site was medium in available N and P and low in available K, the application of N and P_2O_5 might have resulted in increased availability of N, P and K in soil The plants might have utilised the available nutrients as evidenced from the increased uptake (Tables 28, 30 and 32) of these nutrients Since the crop was irrigated during summer months, there was probably no apparent dearth of soil moisture throughout the growing period which might have enhanced the nutrient absorption All these might have resulted in an increase in growth and yield attributing characters due to the application of 20 kg ha^{-1} each of N and P_2O_5 which ultimately might have resulted in higher herbage yield as evidenced from the positive significant correlation of these characters to herbage yield (Table 40) The increased oil yield obtained at this level of fertilizer application might be due to an increase in herbage yield as well as oil content in the crop in this particular treatment

The data on the effect of biofertilizers total oil yield over a period of one year (Table 22) showed that the treatment Azospirillum plus PSB was the best recording highest oil yield which was significantly superior to that obtained at all the other biofertilizer levels The same treatment recorded the highest oil yield in all the three harvests (Table 22) when considered separately eventhough the data on the first harvest was non significant

The total herbage yield over a period of one year (Table 17) was maximum with the inoculation of *Azospirillum* plus PSB and was significantly superior to all the other biofertiliser levels Also it recorded the highest herbage yield is two out of three harvests (Table 17)

The influence of biofertilizers on growth and yield characters (Tables 2 4 6 8 10 13 and 15) showed that all these attributes were influenced favourably due to the combined inoculation of Azospirillum plus PSB

Similar reports showing beneficial effect of *Azospirillum* inoculation in improving the growth and yield in many field crops are available viz plant height in rice (Sanoria et al 1982) plant height in wheat (Kapulnik et al 1981) wheat grain yield (Rai and Gaur 1982) and number of fertile tillers per unit area in wheat (Kapulnik et al 1983) Also similar reports on the effect of PSB

Effect of PSB

inoculation in increasing grain yield of wheat (Tiwari et al 1993) and yield of maize (Kundashev 1956 Sundara Rao 1968 and Kavimandan and Gaur 1971) are available The results are in conformity with that reported by Gautam and Kaushik (1988) on the grain yield of pearl millet which was improved significantly due to the combined inoculation of Azospirillum and VAM

Application of organic manures has been found to be beneficial to microorganisms and that straw incorporation along with ***Azospirillum*** inoculation have been found to induce the multiplication of ***Azospirillum*** in maize plants as compared to the application of ***Azospirillum*** alone (Hegazi et al 1983) In the present experiment application of FYM along with the inoculation of Azospirillum plus PSB might have resulted in the proliferation of both the microorganisms Also addition of organic manures might have enhanced their activity PSB being chaemoheterotrophic (Dey et al 1976)

Azospirillum have been found to influence plant growth by several ways like fixation of atmospheric nitrogen protection from plant pathogenic microorganisms and production of plant growth promoting substances (Okon and Kapulnik 1986) Also Azospirillum inoculation resulted in better water and nutrient uptake by way of promoting the root growth It *softens the middle lamellae through the action of pectinolytic enzymes, thus enhancing the mineral absorption surface of the cortical cells of roots (Konde and Patil 1993)*

Inoculation with PSB might have solubilised unavailable forms of soil P besides secreting plant hormones Even the native phosphorus of the soil was well mobilised by PSB inoculation (Anthoniraj et al 1994) Phosphate Solubilising Bacteria affected plant growth by the production of plant hormones so that more actively growing roots are able to explore more soil zones and the solubilisation of insoluble phosphate by the production of organic acids upon inoculation with PSB (Azcon et al , 1976)

Thus the benefit due to the combined inoculation of ***Azospirillum*** plus PSB might be due to the cumulative effects such as supply of N and P to the crop in addition to the production of growth promoting substances and the better root growth which helped the plant to utilise the water and nutrients thus resulting in better growth and yield characters and finally in higher herbage yield The increase in oil yield might be due to the increase in herbage yield since the oil content did not vary significantly due to different biofertilizer combinations (Tables 20 and 21)

The interaction effect of chemical x biofertilizers on total oil yield over one year (Table 24) showed that the treatment combination $N_{40}P_{40}$ along with **Azospirillum** *plus PSB produced the maximum oil yield which was statistically similar to that at $N_{40}P_{40}$ along with PSB and $N_{20}P_{20}$ along with* ***Azospirillum*** plus PSB Considering individual harvests, the interaction was significant only in the second harvest (Table 23) In that case too, the same treatment combinations resulted in higher oil yield and were at par Therefore $N_{20}P_{20}$ along with **Azospirillum** *plus PSB would be the most economic combination The increased oil yield obtained at $N_{20}P_{20}$ along with* ***Azospirillum*** plus PSB might be due to the increased herbage yield (Table 18 & 19) which might be the result of increase in growth and yield characters (Tables 3, 5, 7, 9, 11, 14 and 16) since the oil content did not vary significantly Application of chemical fertilizers along with the inoculation of **Azospirillum** *plus PSB might have resulted in a better availability of nutrients in the soil Better root growth of plants inoculated with* ***Azospirillum*** plus PSB coupled with the adequate soil moisture might have resulted in an increase in the uptake of available nutrients from soil thus improving the growth and ultimately higher herbage yield and oil yield The increased yield obtained as a result of inoculation with Azospirillum plus PSB along with higher level of fertilizers showed that the beneficial effect of inoculation is pronounced even at 40 kg ha^{-1} each of N and P_2O_5. This may be due to the fact that application of nitrogen fertilizer might be increasing the efficiency and growth of ***Azospirillum*** in soil (Lee and Gaskin 1982)

Nutrient content and uptake

It can be seen that the application of chemical fertilizers increased the content of N P and K in the plant in all the harvests except third harvest for N second and third harvest for P and K (Table 25 26 and 27) Application of 20 kg ha^{-1} each of N and P_2O_5 resulted in a significant increased in the P and K content of palmarosa in the first harvest and the N content in the first and second harvests compared to control A higher concentration of N in palmarosa with high levels of N and P (Munsi and Mukherjee 1982) and high K content due to N application (Pareek et al 1983) were noticed

The results showed that application of biofertilizers could not bring about any significant change in the content of N P and K in palmarosa (Table 25 26 and 27) This is in conformity with that reported by Nur et al (1980) on the N content in maize and Setaria italica and on the N P and K contents in rice (Prasad and Singh 1984) The inability of biofertilizers to bring about significant

Among different biofertilizer levels, ***Azospirillum*** plus PSB recorded higher uptake of N P and K in all the harvests (Table 28, 30 and 32) when considered separately and also in the total value over a period of one year (Table 28, 30 and 32) Similar observations on the significant increase in N,P and K uptake in rice (Prasad and Singh, 1984), N uptake in mustard (Saha et al , 1985) and N and P uptake by green chillies (Konde and Patil, 1993) were reported due to **Azospirillum** *inoculation Likewise, PSB inoculation increased N and P uptake in rice (Sharma and Singh, 1971 and Asanuma et al , 1978) and P uptake in bengal gram (Subramanian and Purushothaman, 1974) and potato (Kundu and Gaur, 1980) Combined inoculation of nitrogen fixing and phosphate solubilising bacteria was also found beneficial as reported by Alagawadi and Gaur (1988) on the N and P uptake by chickpea The benefit obtained due to the combined inoculation of* ***Azospirillum*** and PSB in terms of the increased uptake of nutrients might be due to the increased supply of these nutrients along with better root growth which resulted in increased absorption of nutrients and ultimately higher drymatter production

The interaction effect of chemical x biofertilizers showed that the total N,P and K uptake over a period of one year (Table 29 31 and 33) was higher in the treatment combination $N_{20}P_{20}$ along with **Azospirillum** *plus PSB*

*Considering individual harvests the interaction effect was significant only in the second harvest (Table 29, 31 and 33) in which case too the same treatment combination recorded higher value Application of chemical fertilizers along with the inoculation of **Azospirillum*** plus PSB might have helped the plant in deriving the benefits of both chemical and biofertilizers This showed that chemical fertilizers did not inhibit the efficiency of biofertilizers This is in agreement with that of Lee and Gaskin (1982) who observed an increase in the efficiency and growth of **Azospirillum** *due to nitrogenous fertilizer application The increased availability and absorption of nutrients might have resulted in increased drymatter production and thus higher nutrient uptake*

Soil fertility parameters

Application of chemical fertilizers was found to increase the available N,P and K contents in soil after different harvests (Table 34,36 & 38) and barring the N content after second and third harvest application of 20 kg ha^{-1} each of N and P_2O_5 resulted significantly higher values for all the nutrients after all the harvest compared to control This is in conformity with that obtained by Chinnamma (1985) who reported a significant increase in the available P_2O_5 content of soil due to P application

The different biofertilizer levels influenced significantly the available N P and K contents in soil after different harvests (Table 34 36 and 38) and the treatment ***Azospirillum*** plus PSB recorded higher values in all the cases Inoculation with PSB might have helped in the solubilisation of fixed soil phosphorus Similar results on the increase in available soil P due to PSB inoculation were reported in sorghum (Rangaswamy and Morachan, 1974) and chickpea (Alagawadi and Gaur, 1988) Also **Azospirillum** *inoculation increased the available N in soil cropped with sunflower (Ram et al , 1992)*

The interaction effect of chemical x biofertilizers showed that the treatment combination $N_{20}P_{20}$ along with ***Azospirillum*** plus PSB recorded higher values of available N, P and K contents in soil after all the harvests (Table 35, 37 and 39) Thus the combination of chemical and biofertilizers improved the soil nutrient status Similar results on the available P status of soil due to the application of rock phosphate along with PSB inoculation in maize was reported by Singaram and Kothandaraman (1994)

Correlation studies

All the growth characters were positively correlated to herbage yield and oil yield The number of tillers, number of inflorescences and the drymatter production were highly and positively correlated to herbage yield The results are in agreement with that of Punia et al (1988) who observed positive significant correlations of tiller per clump and plant height to herbage and oil yields

In all the three harvests, significantly high positive correlations of oil yield to oil content, both fresh weight and dry weight basis was obtained These are in conformity to that reported by Punia et al (1988) who observed a positive correlation of 0 335 between the fresh herbage oil content and oil yield

Here a very strong positive correlation was obtained between herbage and oil yields Similarly Punia et al (1988) had also reported a significant positive correlation of 0 995 between herbage and oil yields

The content and uptake of nutrients as well as the available nutrients in soil were positively correlated to herbage yield and oil yield

N and P economy

The data on the total oil yield over a period of one year (Table 24) showed that the oil yield obtained with the application of 20 kg ha^{-1} each of N and P_2O_5 was on par with that obtained with the application of *Azotobacter* alone Azospirillum alone and *Azospirillum* plus PSB This shows that the biofertilizers *Azotobacter* Azospirillum and the combination of *Azospirillum* and PSB could substitute chemical fertilizers to the level of 20 kg ha^{-1} each of N and P_2O_5 Eventhough there was no significant enhancement in oil yield from $N_{20}P_{20}$ alone to $N_{40}P_{40}$ alone the application of N and P_2O_5 each at 40 kg ha^{-1} along with Azospirillum plus PSB which resulted in the maximum oil yield of 461 25 l ha^{-1} $year^{-1}$ and this was significantly superior to that obtained with the application of 40 kg ha^{-1} each of N and P_2O_5 alone Also the total oil yield at $N_{20}P_{20}$ along with *Azospirillum* plus PSB was on par with that at $N_{40}P_{40}$ along with Azospirillum with PSB which recorded the highest value Thus addition of 20 kg ha^{-1} each of N and P_2O_5 along with *Azospirillum* plus PSB could be adopted to palmarosa in producing economical yields The maximum benefit cost ratio was with the treatment $N_{40}P_{40}$ along with *Azospirillum* plus PSB (2 84) followed by $N_{40}P_{40}$ along with PSB (2 59) and $N_{20}P_{20}$ along with *Azospirillum* plus PSB (2 48) Considering the soil health at long sight (fertility and productivity) it is now recommended $N_{20}P_{20}$ along with *Azospirillum* plus PSB for palmarosa However being a perennial crop the response of palmarosa to either chemical or biofertilizers should be studied for more than one year

Future line of work

For obtaining the contribution of different biofertilizers in palmarosa towards the requirement of N and

Table 41 Economics of use of chemical and biofertilizers in palmarosa

Sl No	Treatment	Cost involved for the particular treatment (Rs)	Total cost of culti vation (Rs)	Total returns (Rs)	Net returns (Rs)	Benefit cost ratio (Rs)
1	N_0P_0 + Control	0 00	57621	70362	12741	1 22
2	N_0P_0 + Azoto	12 00	57633	114620	56987	1 98
3	N_0P_0 + Azosp	12 00	57633	105314	47681	1 82
4	N_0P_0 + PSB	18 00	57639	85406	27767	1 48
5	N_0P_0 + Azoto + PSB	30 00	57651	82746	25095	1 43
6	N_0P_0 + Azosp + PSB	30 00	57651	104742	47091	1 81
7	$N_{20}P_{20}$ + Control	408 45	58029	123185	65155	2 12
8	$N_{20}P_{20}$ + Azoto	420 45	58041	119516	67475	2 05
9	$N_{20}P_{20}$ + Azosp	420 45	58041	99439	41398	1 71
10	$N_{20}P_{20}$ + PSB	426 45	58047	119081	61034	2 05
11	$N_{20}P_{20}$ + Azoto + PSB	438 45	58059	129017	70958	2 22
12	$N_{20}P_{20}$ + Azosp + PSB	438 45	58059	144306	86247	2 48
13	$N_{40}P_{40}$ + Control	816 90	58438	124481	66043	2 13
14	$N_{40}P_{40}$ + Azoto	828 90	58450	122296	63846	2 09
15	$N_{40}P_{40}$ + Azosp	828 90	58450	106006	47556	1 81
16	$N_{40}P_{40}$ + PSB	834 90	58456	151538	93083	2 59
17	$N_{40}P_{40}$ + Azoto + PSB	846 90	58468	97574	39107	1 66
18	$N_{40}P_{40}$ + Azosp + PSB	846 90	58468	166050	107582	2 84

* Cost of cultivation excluding the treatment is Rs 57 621/ (See Appendix IV)

** 1 kg palmarosa oil costs Rs 450/

P separately individual application of different rates of N should be compared to **Azotobacter** *and* ***Azospirillum*** and that of P should be compared to PSB Also there is possibility that addition of more nutrients may result in further enhancement in the yield of palmarosa and hence enhanced doses of fertilizers may be tried

Summary

SUMMARY

A study was conducted at the College of Horticulture Vellanikkara, during 1994- 95 to assess the effect of biofertilizers on N and P economy in palmarosa The main objectives were to assess the possibility of using biofertilizers so as to replace or minimise the expensive synthetic nitrogen fertilizers, the effect of phosphorus solubilising bacteria (*Bacillus megatherium* var *phosphaticum*) in increasing the availability of fixed soil phosphorus, the effect of combination of chemical and biofertilizers on the growth and yield of palmarosa and the N and P economy due to the intergration of chemical and bioferilizers The important results of the study are summarised below

A Chemical fertilizers affected the growth and yield of palmarosa

Plant height increased significantly due to the application of chemical fertilizers compared to control but $N_{20}P_{20}$ and $N_{40}P_{40}$ were at par

Tiller production varied significantly due to the application of chemical fertilizers and the treatment $N_{40}P_{40}$ was significantly superior to $N_{20}P_{20}$ in the first and third harvests

The plant spread (E-W) in the treatment $N_{40}P_{40}$ was significantly superior to that at $N_{20}P_{20}$ in all the harvests

The plant spread (N-S) in the treatments $N_{20}P_{20}$ and $N_{40}P_{40}$ were at par and significantly superior to control in two out of three harvests

The numbers of inflorescences $hill^{-1}$ increased with increasing level of chemical fertilizers and $N_{20}P_{20}$ and $N_{40}P_{40}$ were significantly different in the first and second harvests

Application of chemical fertilizers affected the length of inflorescence only in the first harvest where the treatment $N_{40}P_{40}$ was significantly superior to control

With regard to the herbage yield per plant, the treatment $N_{40}P_{40}$ recorded the highest value which was significantly superior to that at $N_{20}P_{20}$ which in turn was significantly superior to control

The effect of chemical fertilizers on drymatter production showed that in two out of three harvests the treatment $N_{40}P_{40}$ was significantly superior to that at $N_{20}P_{20}$ which in turn was significantly superior to that in the control

In all the three harvests, the fresh herbage yield at $N_{40}P_{40}$ was significantly different from that at $N_{20}P_{20}$ which in turn was significantly superior to control This was true in the total herbage production over one year also

Application of 20 kg ha^{-1} each of N and P_2O_5 resulted in a higher oil content (fwb) which was significantly superior to that in the control plots in the second and third harvest

The treatment $N_{20}P_{20}$ resulted in significantly higher oil content on dry weight basis compared to control in the second and third harvests, whereas the application of chemical fertilizers didnot affect the character in the first harvest

The treatment $N_{20}P_{20}$ resulted in a higher oil yield which was significantly superior to that in the control plots in the first and second harvests

Also the treatment $N_{20}P_{20}$ registered higher N content in the plant in the first and second harvests and higher P and K contents in the first harvest which were significantly more than that in the control plots The N content in the third harvest and P and K contents in the second and third harvests were not affected by chemical fertilization

The uptake of N P and K in all the three harvests as well as the total N P and K uptake over a period of one year were significantly higher in the treatment $N_{20}P_{20}$ as compared to that in the control

Application of chemical fertilizers affected the available nutrient contents in the soil after different harvests The available N status of soil in the treatment N_{20} P_{20} after the first, second and third harvests were significantly superior to that in the control plots without any chemical fertilizer application

B Application of biofertilizers affected the growth and yield of palmarosa

The combined inoculation of *Azospirillum* and PSB resulted in a significant increase in plant height as compared to uninoculated control in the second and third harvests Biofertilizer application did not affect the plant height in the first harvest

The treatment *Azospirillum* plus PSB recorded the maximum plant spread in the East-West direction in two out of three harvests which was significantly superior to that in uninoculated control in all the three harvests

Also in the North South direction, the treatment *Azospirillum* plus PSB recorded the maximum plant spread which alone was significantly superior to uninoculated control in the first harvest, whereas in the second and third harvests, the treatments *Azospirillum* plus PSB and PSB alone recorded significantly higher plant spread as compared to that in the control

In all the three harvests, significantly higher number of inflorescences $hill^{-1}$ was recorded by the treatment *Azospirillum* plus PSB as compared to that in the control

Biofertilizers affected the length of inflorescence only in the first harvest and the treatment *Azospirillum* plus PSB recorded the longest inflorescence which was statistically superior to that in the uninoculated control

The treatment *Azospirillum* plus PSB recorded the highest total herbage yield as well as drymatter production over a period of one year which was significantly superior to that in the other biofertilizer treatments Also inoculation of palmarosa with PSB alone and *Azotobacter* alone resulted in increased fresh and dry herbage yield which were statistically higher than that in the uninoculated control

Inoculation of different biofertilizers did not affect the oil content of palmarosa Inoculating palmarosa with a combination of ***Azospirillum*** and PSB resulted in the highest total oil yield within a period of one year which was significantly superior to that in all the other biofertilizers levels

The content of N,P and K in the crop was not affected by biofertilizer application The total N and K uptake by the crop in the treatment ***Azospirillum*** plus PSB was significantly higher than that in all the other bio-fertilizer levels and the above treatment was significantly superior to the uninoculated control with regard to total P uptake

The available N status of soil after the experimentation was not affected by biofertilizer application The treatment ***Azospirillum*** plus PSB increased signficantly the available soil P and K status after the experimentation as compared to control

C Interaction effect of chemical X biofertilizers was found to be significant for many of the parameters studied

The treatment combination $N_{40}P_{40}$ along with ***Azospirillum*** plus PSB recorded the maximum plant height in the second harvest

The combined application of $N_{40}P_{40}$ along with Azospirillum plus PSB $N_{20}P_{20}$ along with PSB and $N_{40}P_{40}$ along with PSB recorded the highest number of tillers hill^{-1} in the second harvest

In the second harvest, the maximum plant spread in the East-West direction was noticed in the plants which received 40 kg ha^{-1} each of N and P_2O_5 along with PSB whereas the maximum plant spread in the N-S direction was recorded by the treatment $N_{20}P_{20}$ along with ***Azozpirillum*** plus PSB

Inoculating the plants with phosphate solubilising bacteria resulted in almost equal number of inflorescences hill^{-1} as that of the treatment N_{40} P_{40} along with PSB which recorded the largest number of inflorescences hill^{-1} in the second harvest

The total herbage yield over one year was maximum in the treatment combination $N_{40}P_{40}$ along with ***Azospirillum*** plus PSB

The treatment combination $N_{20}P_{20}$ along with ***Azospirillum*** plus PSB was the best with regard to the total drymatter production within a period of one year

The treatment combination N_{20} P_{20} along with *Azospirillum* plus PSB was the best regarding the total N P and K uptake by the crop as well as the available N P and K status of soil

The total oil yield over one year showed that the treatment combination $N_{20}P_{20}$ along with *Azospirillum* plus PSB would be more economical It also resulted in comparable total returns net returns and benefit-cost ratio as that of $N_{40}P_{40}$ along with *Azospirillum* plus PSB which recorded the highest value The data on total oil yield also revealed that the biofertilizers *Azotobacter* alone, *Azospirillum* alone and *Azospirillum* plus PSB could substitute chemical fertilizers to the level of 20 kg ha^{-1} each of N and P_2O_5

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* Originals not seen

Appendices

APPENDIX - I

Meteorological data at vellanikkara, Trichur for the period July 1994 to June 1995

Month & year		Mean sunshine (hrs)	Mean temp (C) Max	Min	Mean relative humidity (%)	Total rainfall (mm)	No of rainy days	Cumulati pan evapo ration (m
1994	July	1 4	28 6	22 4	91 0	1002 1	29 0	86 1
	August	3 0	30 0	22 8	85 0	509 2	20 0	91 4
	September	7 3	31 8	23 2	78 0	240 5	8 0	113 9
	October	6 7	32 3	22 7	80 0	358 2	20 0	97 1
	November	8 1	31 8	23 3	68 0	125 3	5 0	137 9
	December	10 6	32 2	22 2	58 0	0 0	0 0	169 6
1995	January	9 6	32 9	22 4	59 0	0 0	0 0	178 5
	February	10 0	35 4	23 4	60 0	0 5	0 0	172 2
	March	9 3	37 6	23 8	60 0	2 8	0 0	190 2
	April	9 1	36 6	24 9	71 0	118 7	5 0	164 3
	May	6 5	33 5	23 9	78 0	370 5	13 0	129 3
	June	3 7	31 6	23 1	86 0	500 4	19 0	103 7

ISI specification for palmarosa oil (Anon , 1968)

Colour	- Light yellow to yellow
Odour	- Rosaceous with a characteristic grassy background
Specific gravity at 30°C	- 0 8740 to 0 8860
Optical rotation	- −2° to + 3°
Refractive index at 30°C	- 1 4690 to 1 4735
Acid value	- Maximum 3
Ester value	- 9 to 36 (geranyl acetate 3 1 to 12 5 per cent)
Saponification value after acetylation	- 266 to 284
Total alcohol calculated as geraniol	- Minimum 90 per cent
Solubility	- Soluble in 2 volume of 70 per cent alcohol

Analyses of variance for herbage yield and oil yield

Source	d f	Mean squares						
		Herbage yield				Oil yield		
		First harvest	Second harvest	Third harvest	Total herbage	First harvest	Second harvest	T[illegible] h[illegible]
Chemical fertilizers	2	109 05*	198 13*	13 36*	798 68*	1712 38*	19431 78*	2
Biofertilizers	5	6 63*	151 34*	4 45*	210 85*	335 41	9315 98*	
Chemical X biofertilizers	10	0 63	77 32*	1 41*	92 11*	777 93	4801 61*	
Error	34	1 44	10 63	0 55	11 52	485 77	1035 35	

Significant at 5 per cent level

Cost of cultivation of palmarosa (1 ha*)

A Cost of inputs

Item	Quantity	Rate (Rs)	Cost (Rs.)
Slips	444444	3/100 Nos	13333 30
FYM	2 5 t	300/t	750 00
Chemical fertilizers			
Urea	87 kg	3 5/kg	304 50
Mussoriephos	182 kg	1 8/kg	327 60
MOP	33 kg	5 6/kg	184 80
Biofertilizers			
Azotobacter/ Azospirillum	2 kg	3/500 g	12 00
PSB	3 kg	3/500 g	18 00

B Labour cost

Particulars	Men @70	Women @70	Amount(Rs)
Tractor ploughing (Rs 80/hr, 5 hrs/ha)	-	-	400 00
Removal of stubbles and weeds	-	30	2100 00
Taking beds	30	-	2100 00
Planting	-	35	2450 00

Particulars	Men 70	Women 70	Amount (Rs)
Transportation & application of			
FYM	3	10	910 00
Chemical Fertilizers	2	10	840 00
Biofertilizers	-	5	350 00
Weeding & earthing up	50	50	7000 00
Harvesting	15	45	4200 00
Distillation charges 35 ps/kg	-	-	23187 50
Grand total			58467 70

* Based on the treatment combination $N_{40}P_{40}$ along with Azospirillum plus PSB which recorded the highest yield

EFFECT OF BIOFERTILIZERS ON N AND P ECONOMY IN PALMAROSA (*Cymbopogon martinii*)

By

REGIMOL THOMAS

ABSTRACT OF A THESIS

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VELLANIKKARA THRISSUR

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ABSTRACT

An investigation was undertaken at the College of Horticulture, Kerala Agricultural University, Vellanikkara, during 1994- 95 to study the effect of biofertilizers on N and P economy in palmarosa (Cymbopogon martinii Stapf var Motia)

The main objective of the study was to assess the possibility of using biofertilizers so as to replace or minimise the expensive synthetic nitrogen fertilizers for palmarosa The study also aimed to find out the effect of phosphorus solubilising bacteria (Bacillus megatherium var phosphaticum) in increasing the availability of fixed soil phosphorus, the effect of combination of chemical and biofertilizers on the growth and yield of palmarosa and to work out the N and P economy due to the integration of chemical and biofertilizers The experiment was carried out using the palmarosa selection ODP- 2 The salient findings are abstracted below

The application of chemical fertilizers increased the available N,P and K contents in soil after different harvests, resulted in increased nutrient uptake and thus improved the growth and yield of palmarosa The oil yield obtained with the application of 20 kg ha^{-1} each of N and P_2O_5 was significantly superior to that in the control plot

The different biofertilizer levels were compared with regard to their effect on palmarosa and it was observed that the combined inoculation of ***Azospirillum*** and PSB was the best in increasing the available N,P and K contents in soil and the nutrient uptake by the crop Hence this particular treatment resulted in the highest oil yield which was significantly superior to that in the uninoculated control

The interaction effect of chemical X biofertilizers showed that the oil yield over a period of one year obtained with the application of 20 kg ha^{-1} each of N and P_2O_5 was on par with that obtained with the applications of either ***Azotobacter*** alone or ***Azospirillum*** alone and also the combined inoculation of ***Azospirillum*** and PSB Thus the biofertilizers ***Azotobacter*** alone, ***Azospirillum*** alone and the combined inoculation of ***Azospirillum*** and PSB could substitute chemical fertilizers to the level of 20 kg ha^{-1} each of N and P_2O_5 The data again showed that the combined application of chemical and biofertilizers ie, N and P_2O_5 each at 20 kg ha^{-1} along with ***Azospirillum*** plus PSB resulted in camparable total oil yield, total returns, net returns and benefit - cost ratio as that obtained with the application of N_{40} P_{40} along with ***Azospirillum*** plus PSB which recorded the highest value