INTEGRATED NUTRIENT MANAGEMENT IN HEDGE LUCERNE (*Desmanthus virgatus* (L.) WILLD.) UNDER RAINFED CONDITION

BY

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THESIS

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CERTIFICATE

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DEDICATED TO MY
LOVING PARENTS
AND SISTER

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Kavitha

KAVITHA. G.V.

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LIST OF ABBREVIATIONS

@	at the rate of
AMF	arbuscular mycorrhizal fungi
°C	degree Celsius
cc	Cubic centimetre
cm	centimetre
cv	cultivar
DFY	dry fodder yield
FYM	farm yard manure
Fig.	Figure
g	gram
ha	hectare
KAU	Kerala Agricultural University
kg	kilogram
kg ha^{-1}	kilogram per hectare
m	metre
m^2	square metre
%	per cent
mg	milligram
N	nitrogen
K	potassium
P	Phosphorus
t	tonnes
t ha^{-1}	tonnes per hectare

INTRODUCTION

1. INTRODUCTION

Modern agriculture has been heavily depending on the fossil fuel based inputs such as inorganic fertilizers, pesticides, herbicides and energy intensive farm machinery. The indiscriminate use of pesticides and chemical fertilizers has resulted in serious damage to ecosystem. With almost twice the quantity of plant nutrients being removed from soil than what is added through fertilizers, the growing nutrient imbalance posses a major threat to soil health and crop productivity. It has therefore become imperative to go for Integrated nutrient management system (INMS) which involves the use of different nutrient sources in a judicious manner.

In Kerala, fodder grasses yield well under open and shaded conditions. The growth and yield of grasses is optimum during the monsoon months. During summer season, the dairy farmers depend on low quality roughages like paddy straw, crop wastes and weeds for feeding the animals. Hence there is drastic reduction in milk production during summer months. To overcome this situation, cultivation of leguminous fodder trees or shrubs, which can be lopped during the summer season for cattle feeding is the alternative solution. Hedge lucerne (*Desmanthus virgatus* (L.) Willd.) is an ideal legume fodder tree crop suitable for this purpose.

Despite the large cattle population of 3.4 million heads in Kerala, there is a perpetual shortage of milk and other animal products. Low productivity is mainly due to poor nourishment. Adequate nutrition is essential for ensuring sufficient production. Forage plants are heavy feeders of nutrients, but are often raised under non-fertilized or residual fertility situations. With exorbitant hike in prices of chemical fertilizers, it becomes highly demanding for farmers to use them even for food crops. At this juncture, any alternative means to fully or partially substitute the use of inorganic fertilizers is a welcome boon to farmers and here comes the importance of biofertilizers.

The role of legume inoculants in increasing nitrogen fixation and yield of leguminous crops is well established. *Rhizobium* is a nitrogen fixing microorganism in symbiotic association with the roots of legume crops. In addition to economizing nitrogen fertilization, *Rhizobium* inoculation serves to enrich soil fertility by augmenting nitrogen fixation.

In Kerala with predominantly acid soils, phosphorus fixation is a major problem. Phosphorus is a vital element in almost all biological systems (Westheimer, 1987) and is required in large quantities. Arbuscular mycorrhizal fungi (AMF) which is a fungus in symbiotic association with the roots of crops have the ability to harvest even the unavailable and sparingly soluble forms of soil phosphorus and absorb it more readily than roots (Young *et al.*, 1986). In addition to phosphorus, AMF fungi are known to increase the availability of micronutrients. Hence it could be beneficial if the potential of these organisms to enhance the acquisition of nutrients and there by the increase in productivity is exploited to our advantage.

With this background, the present investigation was undertaken with the following objectives,

- To assess the nutrient requirement of *Desmanthus virgatus* under rainfed condition
- To study the influence of biofertilizers on the growth and yield of *Desmanthus virgatus*
- To find out the extent to which nitrogen can be substituted with biofertilizers
- To work out the economics of fodder production

REVIEW
OF LITERATURE

2. REVIEW OF LITERATURE

The present investigation entitled "Integrated nutrient management in Hedge lucerne (*Desmanthus Virgatus* (L.) Willd.) under rainfed condition" involves the application of bioinoculants like *Rhizobium* and Arbuscular mycorrhizal fungi along with chemical fertilizers. A perusal of the literature pertaining to the investigation revealed a dearth of specific information on the influence of these bioagents on *Desmanthus*. Hence relevant works on other crops are also considered and reviewed here under.

2.1. Effect of *Rhizobium* on growth, yield and quality

2.1.1. Effect of *Rhizobium* on growth and yield

Karyagin (1980) observed that *Rhizobium* strains increased plant height, root weight, fresh fodder yield and hay yield in soyabean.

Rhizobium inoculation resulted in significant increase in number of leaves and branches of green gram (Srivastava and Sharma, 1982). In *Acacia mangium*, Umali-Garcia *et al.* (1988) observed an increase of 13.22 per cent in plant height consequent to *Rhizobium* inoculation. Plant height of *Glyricidia sepium* was increased from 16.9 cm to 18.8 cm due to *Rhizobium* inoculation (Ngulube, 1989).

Ardeshna *et al.* (1993) reported significantly higher plant height, number of branches per plant and dry matter production in green gram (*Phaseolus radiatus*) inoculated with *Rhizobium*. Kumar and Agarwal (1993) observed significantly higher plant height, number of branches and number of leaves per plant in lentil (*Lens esculentus*) plants inoculated with *Rhizobium*. Height of inoculated plants of *Acacia mangium* showed significant increase of 9 to 26 per cent compared to that of uninoculated trees (Galiana *et al.*,1994). Totey *et al.* (2000) reported that application of 2g of *Rhizobium* culture per plant increased the relative height and growth of one year old plantation of forest legume *Dalbergia sissoo* by 1.5 times as against control.

Gupta *et al.* (1980) reported increase in green fodder yield of lucerne due to inoculation with *Rhizobium*. Stover yield improvement to the tune of 10 to 46 per cent over control in *Rhizobium* inoculated red gram has been reported by Rao (1981). Johnson (1982) found that *Rhizobium* inoculation increased dry matter production in Lucerne.

Bhuiya *et al.* (1986) recorded highest shoot yield and total dry matter yield in *Rhizobium* inoculated plants of black gram compared to uninoculated plants. Barnett (1986) reported significantly increased nursery growth of indigenous legume tree species inoculated with specific *Rhizobium* strains. Chang *et al.* (1986) observed greater shoot dry weight in *Rhizobium* inoculated *Acacia* seedlings compared to uninoculated plants. According to Balaji and Rangarajan (1987) there was 21.8 per cent increase in shoot dry weight of *Acacia nilotica* by *Rhizobium* inoculation.

Daroy *et al.* (1987) observed that inoculation of *Sesbania rostrata* with *Rhizobium* significantly influenced plant biomass positively in pot and jar experiments. Investigations by Manguiat *et al.* (1987) revealed that inoculation increased the biomass production of *Sesbania rostrata* by as much as 93 per cent. In

Leucaena leucocephala (K-8), Mohammed (1988) noticed an increase in shoot dry weight from 1.41 to 3.88 gram per plant by *Rhizobium* inoculation. Seed inoculation with *Rhizobium* increased the dry matter content of cowpea. The dry matter yield was 5.14 and 4.10 t ha^{-1} with and without inoculation respectively (Sairam *et al.*, 1989).

Medicago sativa inoculated with *Rhizobium melilotii* strains have higher fresh fodder yields compared to uninoculated controls (Kots, 1989). Nursery and short term field trials with *Acacia nilotica* and *Leucaena leucocephala* (Khanna *et al.*, 1992; Lal and Khanna, 1993) revealed that inoculation of these tree legumes with specific and effective strains of *Rhizobium* spp had a positive effect on tree biomass

Hazra (1994) reported the results of detailed studies in which the effect of *Rhizobium* inoculation to all important cultivated legume fodder crops, pasture legumes and shrubs was evaluated. The increased fodder yields were observed to be 28 per cent in *Medicago sativa*, 21 per cent in berseem (*Trifolium alexandrinum)*, 26 per cent in *Stylosanthes hamata*, 13 per cent in siratro, 25 per cent in *Centrocema pubescens*, 14 per cent in hedge lucerne (*Desmanthus virgatus*), 11 per cent in subabul (*Leucaena leucocephala*) and 12 per cent is shevri (*Sesbania sesban*) over respective controls. The green forage yields of *Desmanthus virgatus* were 235 q ha^{-1} and 269 q ha^{-1} for uninoculated and inoculated plants respectively.

Lal and Khanna (1996) reported that dry matter yields of all *Rhizobium* inoculated plants of *Leucaena leucocephala* and *Acacia nilotica* demonstrated a significant increase over that of uninoculated plants at the end of five years after transplanting.

Chellamuthu *et al.* (1998 a) reported that in *Desmanthus virgatus* plant height increased from 74.8 cm to 80.1 cm when *Rhizobium* inoculation was done. The green fodder yield increased from 20.1 t ha^{-1} to 35.3 t ha^{-1} and dry fodder yield increased from 5 t ha^{-1} to 8.6 t ha^{-1}. In lucerne (*Medicago sativa*) plant height increased from 58.1cm to 68.9 cm, green matter yield increased from 47.9 t ha^{-1} to 53.8 t ha^{-1} and dry matter yield from 11.7 t ha^{-1} to 13.3 t ha^{-1} in uninoculated and *Rhizobium* inoculated plants respectively (Chellamuthu *et al.*, 1998 b).

Mezni and Sifi (1998) found that inoculation of annual medicago with *Rhizobium meliloti* increased dry matter yield. Rajput and Singh (1998) reported that seed inoculation with *Rhizobium* increased fodder yield by 10.85 per cent compared with no inoculation in cowpea (*Vigna unguiculata*).

Biswas *et al.* (2001) reported that in terms of green fodder yield, response of *Rhizobium* to winter season legumes like berseem, lucerne and peas ranged from 12 to 35 per cent.

2.1.2. Effect of *Rhizobium* on the content and uptake of nutrients

2.1.2.1. Nitrogen

Nair *et al.* (1970) and Sahu and Behara (1972) obtained increased nitrogen content in cowpea inoculated with *Rhizobium*. Rao and Sharma (1980) also observed an increase in the nitrogen content of tops of soyabean and black gram as a result of *Rhizobium* inoculation. Srivastava and Tewari (1981) observed that most of the strains of *Rhizobium* improved the nitrogen content in cowpea and green gram.

Beneficial effect of *Rhizobium* inoculation in increasing nitrogen uptake has been reported in green gram and cowpea by Reddy (1986) and Sairam *et al.* (1989). Mohammed (1988) noted an increase in nitrogen uptake from 27.72 mg per plant to 96.23 mg per plant in lucerne due to application of *Rhizobium.* Pahwa (1989) observed that nitrogen uptake in *Leucaena leucocephala* was increased to 444.9 mg per plant from 336.7 mg per plant by *Rhizobium* inoculation. Murali (1989) reported that *Rhizobium* inoculation had significant positive influence on uptake of nitrogen in *Sesbania rostrata*. Beena *et al.* (1990) and Gregr (1990) observed increased nitrogen uptake by cowpea plants following rhizobial inoculation. Mezni and Sifi (1988) reported that inoculation of annual medicago with *Rhizobium meliloti* increased the nitrogen content in plants.

No significant difference in plant nitrogen content was noted by Tang *et al.* (1982) on inoculation with *Rhizobium* in *Macroptylum atropurpureum*.

2.1.2.2. Phosphorus

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

Mohammed (1988) noticed an increase in phosphorus uptake in *Leucaena* from 2.84 mg per plant to 5.13 mg per plant by *Rhizobium* inoculation. Murali (1989) observed that inoculation with *Rhizobium* had significant positive influence on the uptake of phosphorus by *Sesbania rostrata*. Rajput and Singh (1998) reported that seed inoculation with *Rhizobium* increased total nitrogen and phosphorus uptake in cowpea (*Vigna unguiculata).*

2.1.2.3. Potassium

In mung bean, potassium concentration significantly increased in straw consequent to *Rhizobium* inoculation (Raju and Verma, 1984). Murali (1989) reported that *Rhizobium* inoculation had significant positive influence on the uptake of potassium by *Sesbania rostrata*.

Sreedurga (1993) reported significant increase in potassium uptake in *Stylosanthes guianensis* cv Schofield with *Rhizobium* inoculation. The uptake of potassium was 16.48 kg ha^{-1} in inoculated plants as against 12.32 kg ha^{-1} in uninoculated plants.

2.1.3. Effect of *Rhizobium* on forage quality

2.1.3.1. Effect of *Rhizobium* on crude protein content

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

Karyagin (1980) reported increase in crude protein in hay of soybean as a result of *Rhizobium* inoculation. Similar increase has been noted in lucerne (*Medicago sativa*) by Johnson (1982) due to *Rhizobium* inoculation.

In field trials with *Medicago sativa*, it was observed that inoculation with *Rhizobium* strains increased the crude protein content in third and fourth cuts (Ponte *et al.*, 1988). Sudhakar *et al.* (1989) found that inoculation increased the crude protein content in black gram compared to control.

2.1.3.2. Effect of *Rhizobium* and crude fibre content

Parashar *et al.* (1999) reported that in broad bean (*Vicia faba* L.), *Rhizobium* inoculation reduced the crude fibre content significantly.

2.2. Effect of arbuscular mycorrhizal fungi (AMF) on growth, yield and quality

2.2.1. Effect of AMF on growth

Association of mycorrhizae is known to improve the growth and general condition of crop plants (Mosse, 1957., Bayalis, 1959). It is well established that mycorrhizal association improve growth in a wide range of plants (Hayman, 1983., Jeffries, 1987). The importance of AMF associations in agricultural crops is well documented (Bagyaraj, 1990).

Hayman and Mosse (1979) got improved growth in white clover under field conditions subsequent to mycorrhizal inoculation. Powell and Daniel (1979) reported that when clover seedlings were inoculated with indigenous or F_3 strains of mycorrhizal fungi, an increased shoot growth from 16 to 17 per cent was observed. A four fold increase in growth of lucerne was noticed by Owusu-Bennoah and Mosse (1979) due to inoculation with *Glomus caledonium*. Saterlee *et al.* (1983) reported an enhanced top growth of lucerne with mycorrhizal inoculation in pot trials on a clay loam soil. Inoculated cowpea plants had significantly higher plant height and higher yield than non-mycorrhizal plant (Rosalus *et al.*, 1987).

Koffa *et al.* (1995) reported that in *Leucaena leucocephala*, mycorrhizal plants out performed their non-mycorrhizal counterparts in all respects especially plant height, root length and nodulation. Significant increase in growth of soybean crop when inoculated with AMF was reported by Plinchette and Morel (1996).

2.2.2. Effect of AMF on yield

Champawat (1989) observed increased shoot and root dry weight in chick pea with AMF inoculation in unfertilized soil. He reported that inoculation of soybeans with *Glomus fasciculatum* increased the dry matter accumulation in plants.

Plant height and fresh shoot weight of eight species of *Medicago* increased significantly by inoculation with AMF (IGFRI, 1993). Dry matter production of cluster bean was significantly improved by AMF inoculation (Rao and Tarafdar, 1993). Sreedurga (1993) has reported significantly higher green matter yield and dry matter yield in *Stylosanthes guianensis* cv Schofield consequent to inoculation with *Glomus fasciculatum*.

Hazra (1994) conducted studies under All India Co-ordinated Research Project on Fodder Crops in different parts of the country on response of forage legumes to AMF inoculation. He concluded that AMF increased green forage yield of berseem by 18 per cent, lucerne by 22 per cent, Indian clover by 5 per cent, stylo (*Stylosanthes hamata*) by 16 per cent, centro (*Centrocema pubescens*) by 19 per cent and siratro (*Macroptilium atropurpureum*) by 13 per cent as compared to uninoculated control.

Uma and Rao (1994) observed that fresh and dry weights were higher in mycorrhizal plants than in control plants in black gram and green gram. Pande and Tarafdar (1999) reported that mycorrhizal inoculation increased plant height and dry matter yield in moth bean (*Vigna aconitifolia*) and mung bean (*Vigna radiata*). In berseem, an yield increase of 18 per cent was registered with AMF inoculation, (Biswas *et al.*, 2001).

2.2.3. Effect of AMF on the content and uptake of nutrients

Mycorrhizae is known to influence the shoot growth through enhanced uptake of nutrients in general and phosphorus in particular. Mycorrhizal hyphae have the capacity to take up and deliver nutrients like P, NH^{+}, K, Ca, So_4^{2-}, Cu and Zn to the plant. It can deliver upto 80 per cent P, 25 per cent N, 10 per cent plant K, 25 per cent plant Zn and 60 per cent plant Cu (Marschner and Dell, 1994).

2.2.3.1. Nitrogen

A positive correlation between AMF and the amount of nitrogen in the tissues of cowpea, tomato and maize was reported by Sanni (1976). Smith and Daft (1977) recorded a higher percentage of nitrogen concentration in shoots of mycorrhizal *Medicago sativa* at harvest.

Barea *et al.* (1980) reported that in *Medicago sativa* grown in soil inoculated with *Glomus mossae*, the plant dry weight and total uptake of nitrogen was significantly higher than in uninoculated plants.

The field experiments by Barea *et al.* (1987) and Kucey and Bonetti (1988) confirmed by using ^{15}N labeled fertilizer that AMF hyphae took up nitrogen from soil there by increasing nitrogen content in the AMF plant in comparison with controls receiving phosphorus.

Increase in nitrogen uptake of shoot and root of ground nut plants inoculated with AMF was observed by Champawat (1990) and increase in the nitrogen content in the dry matter of lucerne inoculated with AMF was reported by Nielson (1990) Goicoechea *et al.* (1997) reported an enhancement in the content of macronutrients in mycorrhizal alfalfa plants which were under drought stress.

2.2.3.2. Phosphorus

AMF played a significant role in improving plant growth and productivity through increased uptake of water, phosphorus and other minerals (Bagyaraj *et al.*, 1979). Mycorrhizal plants not only are large but also usually have increased concentration and / or content of phosphorus compared to non-mycorrhizal plants (Barea, 1991).

In pot trials, with *Leucaena leucocephala* higher phosphorus concentration was observed in mycorrhizal plants by Huang *et al.* (1983) and it was suggested that significant difference in nutrient uptake was because of increase in growth. Saterlee *et al.* (1983) observed an increase in herbage phosphorus content with mycorrhizal inoculation and phosphorus fertilization in lucerne cv Mesilla. Similar results were obtained by Jensen and Nielson (1984) in lucerne and in chickpea by Rao *et al.* (1986).

Stribley *et al.* (1984) reported that shoots of plants infected with AMF contained higher internal concentration of phosphorus than those of uninfected plants of equal size over wide ranges of external phosphorus supply and of host plants. In chickpea, soil application of *Glomus fasciculatum* alone increased the phosphorus concentration in the shoots (Rao *et al.*, 1986).

Evaluation of the influence of phosphorus concentration on the symbiotic interaction between *Leucaena leucocephala* and AMF – *Glomus fasciculatum* revealed that mycorrhizal inoculation significantly increased phosphorus uptake (Habte and Manjunath, 1987). Sattar and Gaur (1989) obtained the highest hay yield and mean phosphorus uptake in lentil cv – L-5-9 inoculated with *Glomus fasciculatum*.

Significant increase in phosphorus content in dry matter was reported in lucerne by Nielson (1990), Champawat (1990) in groundnut and Sreedurga (1993) in *Stylosanthes guianensis* cv Schofield due to AMF inoculation. Eranna and Parama (1994) reported that in soybean plants, mycorrhizal association increased phosphorus uptake. Lu and Koide (1994) reported that foliar concentration of phosphorus in mycorrhizal plants was generally significantly higher and this difference was smaller at higher levels of P amendment. Total phosphorus uptake was significantly enhanced in AMF inoculated plants than in uninoculated plants in sunflower (Chandrasekhara *et al.*, 1995).

Contrary to the above, Smith and Daft (1977) recorded no significant difference in the phosphate content of mycorrhizal and non-myeorrhizal clover plants.

2.2.2.3. Potassium

Rosendahl (1943) reported enhanced uptake of potassium in mycorrhizal plants when compared to the non-mycorrhizal controls. Smith *et al.* (1981) observed that mycorrhizal infection can improve the potassium nutrition of *Trifolium subterraneum* when internal potassium concentration are generally low. It was also suggested that increased potassium uptake may be an indirect result of improved phosphorus nutrition.

According to Bethenfalvay and Franson (1989) the remarkable difference in growth response of soybean to AMF inoculation seemed to be more related to improved potassium rather than phosphorus nutrition of host plant.

Sreedurga (1993) reported enhanced potassium uptake in *Stylosanthes guianensis* cv Schofield due to AMF inoculation. Mycorrhizae improved K, Ca, Mg, Zn, Cu, Fe and Mn uptake in white clover (Urzua *et al.*, 1993). AMF inoculated sorghum plants had higher S, K, Ca, Mg, Zn and Cu concentration than uninoculated plants (Medeiros *et al.*, 1995).

Potassium concentration of lucerne was not affected by AMF inoculation (Nielson, 1990). Marschner and Dell (1994) obtained lower concentration of potassium in mycorrhizal plants.

2.2.3. Effect of AMF on forage quality

2.2.3.1. Effect of AMF on crude protein content

Doss *et al.* (1983) reported that protein content of leaves of mycorrhizal inoculated finger millet was higher than that of non-mycorrhizal plants as indicated by an increase in the size and number of proteinoplasts in the former.

2.2.3.2. Effect of AMF on crude fibre content

Significantly lower crude fibre content was obtained in guinea grass and congosignal grass inoculated with AMF (George, 1996).

2.3. Effect of dual inoculation with *Rhizobium* and AMF on growth, yield and quality

2.3.1. Effect of dual inoculation on growth and yield

Legumes have the unique ability to form symbiosis with both arbuscular mycorrhizal fungi and root nodule bacteria. This tripartite symbiosis helps the plants with two vital elements, nitrogen and phosphorus (Hayman, 1982).

Daft and Giahmi (1974) found that infection of *Phaseolus* with *Endogone* and *Rhizobium* in comparison to *Rhizobium* alone, significantly increased the growth of the plant. Inoculation with *Rhizobium* and mycorrhizal fungi increased growth and nodulation of *Leucaena leucocephala* (Sivaprasad *et al.*, 1983). Rinj *et al.* (1987) observed that dual inoculation with *Rhizobium* and *Glomus fasciculatum* significantly increased the growth in *Leucaena leucocephala* when compared to single inoculation with either organism. Combined inoculation with AMF and *Rhizobium* sp produced better crop growth and seed yield in legumes (Hoque and Sattar, 1989).

Barea *et al.* (1980) reported increase in dry weight of lucerne by dual inoculation with *Rhizobium* and AMF *Glycine max* plants were grown in a green house sand medium low in available nitrogen and phosphorus and inoculated either with AMF alone or a strain of *Rhizobium japonicum* alone or both endophytes together or left uninoculated to serve as control. Nodulated plants contained 4-5 times the phytomass of non-inoculated controls and plants inoculated with AMF and *Rhizobium* were 18 per cent higher in dry weight than nodulated non-mycorrhizal plants. This was as a result of positive AMF-*Rhizobium* interaction (Pacovsky *et al.*,1986).

Devi *et al.* (1993) reported that green fodder yields of *Stylosanthes hamata* was positively influenced by dual inoculation with AMF and *Rhizobium*. The green fodder yields were 52.6 t ha^{-1}, 52.3 t ha^{-1}, 62.4 t ha^{-1} and 39.2 t ha^{-1} in the case of AMF inoculated, Rhizobium inoculated, dual inoculated and uninoculated plants respectively thus indicating the significant positive effect of dual inoculation. Herrera *et al.* (1993) found that inoculation of woody legumes with selected Rhizobia and AMF improved out planting performance, plant survival and biomass development. Green matter yield of *Stylosanthes guianensis* cv Schofield was significantly increased consequent to dual *inoculation* (Sreedurga, 1993).

Pahwa (1998) reported that in a pot experiment with *Leucaena leucocephala*, plants inoculated with *Rhizobium* and *Glomus* registered best yields and nodulation. Rajithkumar and Potty (1998) reported that in Yam bean (*Pachyrhizus erosus* L.) co-inoculation of *Bradyrhizobium* and AMF increased biomass production by more than three times than individual inoculation and uninoculated controls.

2.3.2. Effects of dual inoculation on the content and uptake of nutrients

2.3.2.1. Nitrogen

An increase in nitrogen uptake due to dual inoculation was obtained in pot culture experiments with lucerne. Inoculation with either *Glomus mossae* or *Rhizobium meliloti* alone, influenced nutrient uptake only slightly (Barea *et al.*, 1980). Chang *et al.* (1986) reported higher uptake of nitrogen and phosphorus due to dual inoculation with *Rhizobium* and *Glomus fasciculatum* in *Acacia* sp, compared to uninoculated control and *Rhizobium* or AMF alone.

Karunaratne *et al.* (1987) reported increased tissue nitrogen content of soyabean due to dual inoculation with *Glomus mosseae* and *Rhizobium japonicum*. Increase in nitrogen uptake was observed in plants inoculated with *Rhizobium trifolii* and mycorrhiza compared to non-mycorrhizal plants (Morton *et al.*, 1990). Thiagarajan *et al.* (1992) suggested that dual inoculation of cowpea with *Rhizobium* and AMF increased shoot nitrogen content significantly.

2.3.2.2. Phosphorus

AMF strongly stimulated nodulation by *Rhizobium* in some herbage legumes and nodulation was increased by increased phosphorus content of host plants (Crush, 1974).

Daft and Giahmi (1974) reported an increase in phophorus content of plants due to inoculation with *Endogone* and *Rhizobium* compared to *Rhizobium* alone in *Phaseolus*. Asimi *et al.* (1980) while studying the influence of soil phosphorus levels on the interaction between mycorrhiza and *Rhizobium* in soybean observed an enhanced uptake of phosphorus in plants inoculated with AMF and *Rhizobium*.

Morton *et al.* (1990) reported that in legumes, phosphorus concentration, phosphorus uptake and number of nodules were greater with dual inoculation compared to non-mycorrhizal plants. Dual inoculation with *Rhizobium* and AMF registered increased shoot phosphorus content in cowpea (Thiagarajan *et al.*, 1992).

2.3.2.3. Potassium

Uptake of potassium was significantly increased due to dual inoculation of *Rhizobium* and AMF on *Stylosanthes guianensis* cv Schofied (Sreedurga, 1993). Plants inoculated with both *Rhizobium* and AMF registered a potassium uptake of 18.26 kg ha^{-1} against 16.48 kg ha^{-1} in plants inoculated with *Rhizobium* alone and 16.51 kg ha^{-1} in plants inoculated with AMF.

2.3.3. Effect of dual inoculation on forage quality

2.3.3.1. Effect of dual inoculation on crude protein content

Daft and Giahmi (1974) reported an increase in protein content of plants due to inoculation with *Endogone* and *Rhizobium* compared to *Rhizobium* alone in *Phaseolus*.

2.4. Effect of major nutrients on growth, yield and quality

2.4.1. Nitrogen

2.4.1.1. Effect of nitrogen on growth

Mc lean *et al.* (1974) reported that in field beans, application of nitrogen increased plant weight. Edge *et al.* (1975) reported that leaf area index, plant height and size were related to application of nitrogen in snap beans.

Moursi *et al.* (1976) found that application of nitrogen increased vegetative growth of lupin as reflected in its plant height and number of branches per plant. Agboola (1978) observed that top growth of cowpea was increased with increasing nitrogen levels.

Ragini and Nair (1996) opined that nitrogen application increased the growth characters namely plant height and dry weight favourably in *Acacia catechu* and *Paraserianthes falcataria*. Akter *et al.* (1998) reported that dry weight of cowpea plants increased significantly with increase in level of nitrogen upto 40 kg ha^{-1}. In (*Phaseolus vulgaris* L.) french bean increasing levels of nitrogen increased plant height and number of branches per plant (Singh and Singh, 2000).

Posjpanov and Knyaseva (1974) stated that different levels of mineral nitrogen supply had practically no effect on plant growth and development in peas.

In general, it could be observed that increase in nitrogen supply increased the vegetative growth.

2.4.1.2. Effect of nitrogen on fodder yield

In *Medicago sativa*, dry forage yield was found to increase with increasing nitrogen rate (Zeedan *et al.*, 1988). Application of nitrogen has been found to increase the fodder yield of cereal forages and grass-legume mixture. (Verma *et al.*, 1993).

Sharma *et al.* (1992) reported that lucerne responded significantly well to applied nitrogen and increased the forage yield by 64.5 q ha^{-1} over 0 kg nitrogen per hectare. Barik and Tiwari (1998) reported that crop receiving 30 kg N ha^{-1} recorded significantly higher green fodder yield and dry fodder yield in berseem – 37 than those at lower levels.

Patel (1998) observed that effect of nitrogen on green fodder yield of berseem was significant. Application of each higher level of nitrogen produced significantly more green forage yield as compared to their preceeding level. Sharma *et al.* (1998) revealed that in lucerne application of nitrogen at 20 kg ha^{-1} recorded significantly higher green forage yield (918.06 q ha^{-1}) over no nitrogen application (866.6 q ha^{-1}).

Chellamuthu *et al.* (1998.a) reported that in hedge lucerne (*Desmanthus virgatus*) green fodder yield increased from 20.1 to 37.8 t ha^{-1} and dry fodder yield from 5 to 9.2 t ha^{-1} when 25 kg nitrogen was applied. Chellamuthu *et al.* (1998 b) found an increase in green fodder yield from 47.9 t ha^{-1} to 64.3 t ha^{-1} and dry fodder yield from 11.7 t ha^{-1} to 15.9 t ha^{-1} in hedge lucerne consequent to the application of 25 kg N per hectare.

Desale *et al.* (1999) reported that increasing levels of nitrogen from 0 to 40, 60, 80, 100 and 120 kg ha^{-1} progressively increased the green forage and dry matter yields of fodder sorghum.

2.4.2. Phosphorus

2.4.2.1. Effect of phosphorus on growth

Mariyappan (1978) observed that phosphorus levels upto 120 kg ha^{-1} increased the plant height in *Stylosanthes gracilis*. Geethakumari (1981) reported increased plant height with phosphorus application in cowpea. Increasing the level of phosphorus from 40 to 120 kg P_2O_5 ha^{-1} significantly increased the plant height, spread, nodule weight and nodule number of *Stylosanthes gracilis* (Sreekantan, 1981). Application of phosphorus @ 180 kg ha^{-1} recorded the maximum number and length of branches in *Stylosanthes gracilis*. Maximum spread and height of *Stylosanthes* sp was achieved at 60 Kg P_2O_5 ha^{-1} (Nair, 1989).

Jain *et al.* (1999) reported in chick pea (*Cicer arietinum* L.) that each successive increase of phosphorus levels from 30-60 Kg ha^{-1} increased the plant height and protein content of the plants. Singh and Singh (2000) observed that in *Phaseolus vulgaris* L. (french bean) increasing levels of phosphorus increased plant height, number of branches per plant and protein content.

Singh *et al.* (1998 a) reported that application of phosphorus did not have any significant effect on various growth attributes like plant height, branching and dry matter accumulation per plant in pigeon pea (*Cajanus cajan*).

2.4.2.2. Effect of phosphorus on yield

Increase in dry matter was reported in *Stylosanthes gracilis* at 120 kg P_2O_5 ha^{-1} (Mariyappan, 1978). Bajpai and Gupta (1979) reported that phosphorus fertilization significantly increased the green matter yield and nitrogen uptake of berseem (*Trifolium alexandrinum*); Manguiat *et al.* (1987) observed that phosphorus fertilization significantly improved the biomass production of *Sesbania rostrata*.

Taneja *et al.* (1987) and Rana *et al.* (1992) reported that application of phosphorus significantly increased the green fodder yield of Egyptian clover (*Trifolium alexandrinum*). Increased forage production of lucerne with phosphorus application was observed by Shah *et al.* (1991) and Munegowda *et al.* (1988).

Application of phosphorus fertilizers (Chand *et al.*, 1993) has been found to increase the fodder yield of cereal forages and grass-legume mixtures. Patel (1998) reported significant increase in fodder yield in berseem as the rate of phosphorus application was increased from 0 to 90 kg P_2O_5 ha^{-1} at all stages of growth. Sheoran and Rana (1998) found that application of phosphorus had a marked effect on forage yield of lucerne. Increasing phosphorus levels upto 100 kg ha^{-1} brought a significant increase in green matter and dry matter yields over their lower doses. Green fodder yield increased by 31.6 per cent and dry fodder yield by 28.5 per cent.

2.4.3. Potassium

2.4.3.1. Effect of potassium on growth

El leboudi *et al.* (1974) observed an increase in growth in beans when 250 kg potassium per hectare was applied. Peck and Buren (1975) concluded that snap bean grown with high rates of potassium made excessive vegetative growth.

Camper and Lutz (1977) reported that the application of potassium increased plant height in soyabean.

Groneman (1974) observed that potash fertilizers had little effect on growth in a three year trial with soyabean.

2.4.3.2. Effect of potassium on yield

Chandrababu *et al.* (1975) reported that total biomass of black gram was increased by 26 per cent over control by 1% K_2So_4 spray. Mengel and Kirkby (1981) proved that more dry matter can be produced by a plant supplied with potassium.

In soils with high potassium and medium phosphorus, application of 40 kg K_2O ha^{-1} increased average fresh and dry fodder yield of alfalfa by 4 per cent. Further increase in potassium rates were not effective (Collins *et al.*, 1986).

Singh *et al.* (1993) reported higher dry matter production in soybean with increasing potassium application. Application of 37.8 kg K_2O ha^{-1} gave maximum green fodder yield in hedge luceme (*Desmanthus virgatus*) with an increase of 65.2 per cent compared with control. (Vasanthi *et al.*, 1994).

2.4.4. Effect of major nutrients on the content and uptake of nutrients

2.4.4.1. Nitrogen

El Bakry *et al.* (1980) reported that nitrogen application in beans increased the nitrogen content in plant parts.

Enikov and Velchov (1976) observed that nitrogen application increased the nitrogen content and decreased phosphorus and potassium content in plant parts.

2.4.4.2. Phosphorus

From trails on red loam soils, Sasidhar and George (1972) reported that increasing levels of P_2O_5 application enhanced the nitrogen content in lablab. Sreekantan (1981) obtained significant increase in nitrogen content in the dry matter of *Stylosanthes* with increase in the dose of phosphorus applied to the soil.

While increasing rates of P_2O_5 from 0 to 180 kg ha^{-1} in three berseem cultivars, Dhar (1978) found that phosphorus content of the herbage increased with incremental doses of phosphorus. Phosphorus content of the herbage in *Stylosanthes* was enhanced consequent to increased phosphorus application (Sreekantan, 1981 and Nair, 1989).

Falade (1973) reported that phosphorus had no effect on the nitrogen content in *Stylosanthes gracilis*.

On increasing the phosphorus level, significant increase in the potassium content of *Stylosanthes gracilis* was reported by Mariyappan (1978).

2.4.4.3. Potassium

Yuan *et al.* (1970) obtained increased potassium content in leaf when soil application of potassium was done in soybean.

Johnson and Evans (1975) obtained higher potassium content in leaf when potassium was applied to southern bean.

2.4.5. Effect of major nutrients on forage quality

2.4.5.1. Nitrogen

Substantial increase in protein content of legume due to nitrogen application has been observed by various authors. Solomko and Rudin (1977) reported that in lucerne addition of 60 Kg N ha^{-1} along with phosphorus and potassium increased crude protein yield.

Shanmugasundaram (1985) reported an increase in crude protein content in lucerne on addition of nitrogen. Lee *et al.* (1990) reported an increase in dry matter yield and crude protein content with addition of nitrogen in *Medicago sativa*.

Pradhan and Mishra (1994) reported in Oat (*Avena sativa*) that increase in levels of nitrogen application increased the crude protein yield also. Vasanthi *et al.* (1994) revealed that application of 26.4 kg P_2O_5 ha^{-1} and 37.8 kg K_2O ha^{-1} to hedge lucerne (*Desmanthus virgatus*) gave the maximum crude protein content of 19.13 per cent.

2.4.5.2. Phosphorus

A significant increase is protein content in *Stylosanthes gracilis* was reported by Mariyappan (1978) when phosphorus was applied at a rate of 120 Kg ha^{-1}.

Crude protein content and yield of lucerne increased significantly by increasing levels of phosphorus to 60 kg P_2O_5 ha^{-1}. The crude protein content increased from 15.1 per cent to 16.5 per cent and yield from 0.25 t ha^{-1} to 0.42 t ha^{-1} (Singh *et al.*, 1998 b). Sreekantan (1981) observed that increasing the dose of phosphorus applied to the soil, enhanced the crude protein content in *Stylosanthes gracilis* significantly.

2.4.5.3 Potassium

Johnson and Evans (1975) reported higher crude protein content in leaf when K was applied in southern peas.

Rai and Patel (1985) found that there was no significant response to potassium in terms of crude protein yield in *Stylosanthes hamata.*

Patel *et al.* (1990) found that application of 50 kg K_2O ha^{-1} to alfalfa cv Anand-2 gave highest crude protein yield of 1.76 t ha^{-1}.

2.5. Interaction between inoculants and fertilizers

2.5.1. *Rhizobium* – Fertilizer Interaction

Soybean inoculated with *Rhizobium japonicum* and supplied with low rates of nitrogen and medium to high rates of phosphorus exhibited increased nodule number, dry weight and leg haemoglobin content (Dadson and Sequaah, 1984).

In a trial with *Vigna radiata* cv B_1, Basu *et al.* (1989) observed that seed inoculation with *Rhizobium* strains increased nodulation and shoot dry weight. Application of 20, 30 and 40 Kg N ha^{-1} gave 0.91, 0.98 and 0.9 t ha^{-1} compared to 0.70 t with *Rhizobium* inoculation alone.

Hazra (1994) while working in *Rhizobium* inoculation to Rabi legume forages viz. Indian clover and lucerne found that application of *Rhizobium* +20 kg N ha^{-1} gave green fodder yield of 450 t ha^{-1} against 385 t ha^{-1} when 25 kg N ha^{-1} alone was applied and 370 q ha^{-1} when *Rhizobium* alone was applied in white clover (*Trifolium repens*). In lucerne, *Rhizobium* +20 kg N ha^{-1} gave green fodder yield of 350 q ha^{-1} against 292 q ha^{-1} for 25 kg N ha^{-1} alone and 325 q ha^{-1} when *Rhizobium* alone was applied.

Rhizobium inoculation with application of phosphorus significantly increased the crude protein content in pea (*Pisum sativun*). The crude protein content was 16.14 per cent without application of phosphorus and increased to 21.39 per cent when phosphours was applied (Phookan and Shadeque, 1994).

Chellamuthu *et al.* (1998 a) found that in hedge lucerne, *Rhizobium* inoculation with application of 25 kg N ha^{-1} resulted in plants with significantly more height, which increased from 80.1 cm to 85.9 cm. The green fodder yield increased from 35.3 t ha^{-1} to 51.9 t ha^{-1} and dry fodder yield from 8.6 t ha^{-1} to 12.6 t ha^{-1}. Chellamuthu *et al.* (1998 b) reported increase in plant height in lucerne from 68.9 cm to 91.6 cm when 25 kg nitrogen was applied along with *Rhizobium* inoculation. Green fodder yield increased from 53.8 t ha^{-1} to 74.9 t ha^{-1} and dry fodder yield increased from 13.3 t ha^{-1} to 18.5 t ha^{-1}.

Rana *et al.* (1998) reported that in pigeon pea (*Cajanus cajan)*) root length, nodules per plant and dry matter production showed significant increase owing to nitrogen and *Rhizobium* inoculation. According to Singh *et al.*, 1998 a, in pigeon pea inoculation with *Rhizobia* along with 15 Kg N ha^{-1} significantly increased the plant height, branching and dry matter accumulation over control.

Raychaudhuri *et al.* (1997) reported that *Rhizobium* and phosphorus interaction was significant for nitrogen and phosphorus uptake in soybean. Upadhyay *et al.* (1999) opined that application of phosphorus and *Rhizobium* inoculation significantly increased plant height, number of branches and dry matter accumulation of green gram. Application of 20 Kg N ha^{-1} and *Rhizobium* inoculation significantly increased the plant height and dry matter accumulation in black gram (*Vigna mungo*) (Sharma *et al.*, 2000).

Vargas and Suhet (1989) reported increased total nitrogen, dry weight and nodulation in *Centrosema pubescens* by inoculation with *Rhizobium* strains compared to combination of inoculation and 75 kg N ha^{-1}. Homachen *et al.* (1989) observed no significant interaction between inoculation treatment and fertilizer application in *Stylosanthes humilis*.

2.5.2. Arbuscular Mycorrhizal Fungi (AMF) – Fertilizer Interaction

Mosse *et al.* (1976) found that the combination of rock phosphate and AMF acted significantly in increasing the plant dry weight in several crop plants.

Mosse (1979) reported that in some soils, rock phosphate application particularly when coupled with mycorrhizal inoculation served as a better source of phosphorus than the more soluble forms of phosphates.

Waidyanatha *et al.* (1979) found that in mycorrhizal *Pueraria* and *Stylosanthes*, the application of rock phosphate greatly stimulated nodulation and nodule activity.

Bagyaraj and Manjunath (1980) got significant increase in shoot dry weights of cowpea inoculated with *Glomus fasciculatum*. The growth parameters were higher in plants inoculated with AMF in combination with rock phosphate application.

Nielson and Jensen (1983) reported increased uptake of fertilizer phosphorus with mycorrhizal inoculation in lucerne.

Paulino *et al.* (1986) showed increased uptake of phosphorus by mycorrhizal *Centrosema* and *Macroptylium* plants over uninouculated plants when tested with rock phosphate and soluble form of phosphorus.

Santhi *et al.* (1988) reported that in green gram, among the different sources of phosphorus tried, rock phosphate was more efficiently utilized when applied with AMF. AMF inoculation with 50 per cent rock phosphate was as good as full dose of phosphorus alone.

Jalid (1991) also found that AMF inoculation in combination with rock phosphate application gave the highest total dry matter and nutrient uptake in corn.

Hazra (1994) reported that in forage sorghum green forage yield was increased by 17 per cent and dry fodder yield by 16 per cent when AMF and 40 kg N was applied.

Interactive effects between the AMF (*Glomus fasciculatum*) and phosphorus levels on three forage legumes (*Trifolium alexandrinum*, *Medicago sativa* and *Vigna unguiculata*) were studied by Jain *et al.* (1998). Biomass and phosphorus uptake was greatest in inoculated plants when soil was applied with 80 kg P_2O_5 ha^{-1}.

Trials on response of berseem to AMF and levels of phosphorus revealed an increase in both fresh weight (32.85 per cent) and dry weight (42.04 per cent) when plants were inoculated with AMF and supplemented with 40 kg P_2O_5 ha^{-1} (IGFRI, 1998).

2.5.3. Dual Inoculation – Fertilizer Interaction

The response of pigeon pea and cowpea to dual inoculation with *Rhizobium* and AMF and / or rock phosphate was studied in phosphorus deficient non-sterile soil. Plants inoculated with both mycorrhizae and *Rhizobium* and supplemented with phosphorus recorded the highest shoot dry weight, nitrogen and phosphorus content indicating the need for addition of small amounts of phosphorus to derive maximum benefit from dual inoculation with *Rhizobium* and AMF (Manjunath and Bagyaraj, 1984).

Dual inoculation with *Glomus fasciculatum* and *Rhizobium* spp registered the highest phosphorus status in the plants at N_{20} P_{20} level of fertilizer application in chick pea (Rao *et al*., 1986).

In pot trials with *Vigna radiata* grown in a phosphorus deficient soil, soil inoculation with mycorrhizal fungus (*Glomus fasciculatum*) or 15 kg N ha^{-1} increased the plant nodule dry weight and yields. Inoculation with *Rhizobium* and / or mycorrhizal fungus in combination with phosphorus gave highest yields (Gupta *et al*., 1988).

Meenakumari and Nair (1991) reported increase in number of nodules, shoot dry weight and nitrogen content of cowpea with dual inoculation of *Rhizobium* and AMF along with rock phosphate.

Moawad *et al*. (1998) reported that application of rock phosphate significantly increased plant growth parameters and green fodder yield when *Trifolium alexandrinum* was inoculated with AMF and *Rhizobium*.

Balachandar and Nagarajan (1999) observed that dual inoculation with *Glomus mossea* and *Rhizobium* with 50 per cent of recommended nitrogen and phosphorus fertilization recorded the maximum plant height and biomass in green gram.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present investigation was taken up to find out an integrated nutrient management technique for *Desmanthus Virgatus* (L.) Willd. under rainfed condition. *Desmanthus virgatus* or Hedge lucerne is now gaining importance all over India as a dry land crop in view of its drought resistance and perennial habit. The materials used and methods adopted for the study are detailed here under.

3.1. Materials

3.1.1 Experiment site

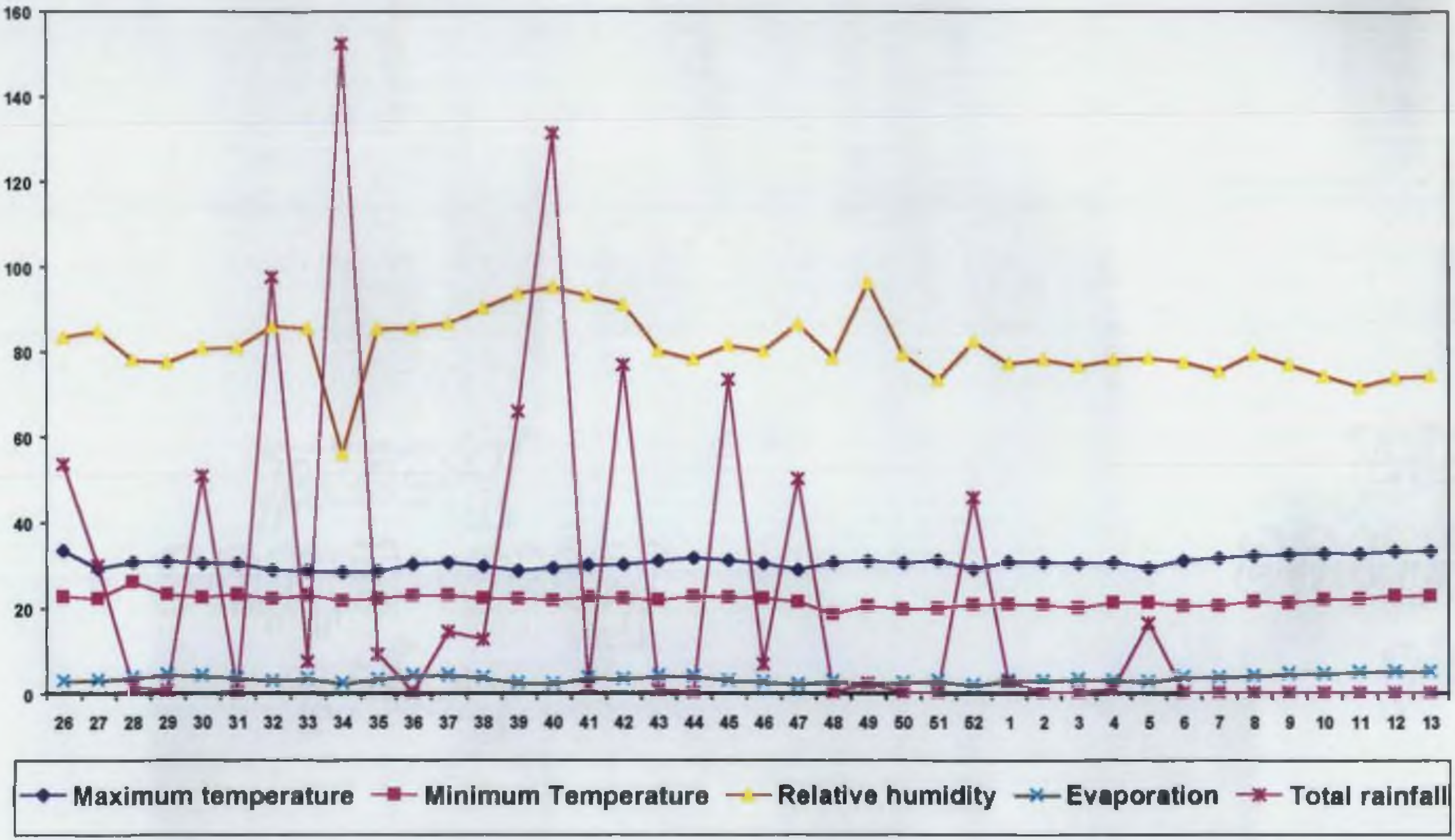
The experiment was conducted at the Instructional farm attached to the College of Agriculture, Vellayani located at 8.5°N latitude and 76.9°E longitude at an altitude of 29 m above Mean sea level.

3.1.2. Climate and season

A humid tropical climate prevails in the area of the experimental site. The experiment was started in June 2000 and investigations were continued upto April 2001. The meteorological parameters viz. rainfall, maximum and minimum temperature, relative humidity and evaporation during the cropping period were recorded. The average values of the weather parameters are presented in appendix I and represented graphically in Fig. 1.

3.1.3. Soil

The soil of the experimental site was red sandy clay loam belonging to the order oxisol and taxonomic class, loamy kaolinitic isohyperthermic rhodic hapulstox



Standard weeks

Fig. 1 Weather data for the cropping period (June 23. 2000 to April 2. 2001) –Weekly averages

(Vellayani series). The data on important physical and chemical properties of soil are represented in Table 1.

Table 1. Soil characteristics of the experimental site

A. Physical properties

Mechanical Composition

SL. No.	PARAMETER	CONTENT IN SOIL	METHOD USED
1	Coarse sand	16.7%	Bouyoucos Hydrometer (Bouyoucos, 1962)
2	Fine sand	31.3%	
3	Silt	25.5%	
4	Clay	26.5%	

B. Chemical properties

SL. No.	PARAMETER	VALUE	RATING	METHOD USED
1	P^H	5.00	Acidic	P^H meter with glass electrode (Jackson, 1973)
2	Available nitrogen (kg ha^{-1})	197.80	Low	Alkaline potassium permanganate method (Subbiah and Asija, 1956)
3	Available P_2O_5 (kg ha^{-1})	27.5	Medium	Bray extraction and Klett summerson photoelectric colorimeter (Jackson, 1973)
4	Available K_2O (kg ha^{-1})	51.5	Low	Neutral normal ammonium acetate method (Jackson, 1973)

3.1.4. Cropping history of the experimental site

The experiment area was under bulk cultivation of fodder crops for past one year.

3.1.5. Test crop used

Hedge Lucerne or *Desmanthus virgatus* (L.) Willd. which is a tree fodder was the test crop. This shrub regrow vigorously after the harvesting of shoots at intervals of 30 to 60 days. Variety TNDV– 9 released from Tamil Nadu Agricultural University was used for the study.

3.1.6. Source of seed

Seeds were obtained from Department of Forage Crops, Tamil Nadu Agricultural University, Coimbatore.

3.1.7. Fertilizers

Fertilizers of the following analysis were used as sources of N, P and K respectively.

Urea   46 per cent nitrogen
Mussoriephos – 20 per cent P_2O_5.
Muriate of potash – 60 per cent K_2O.

3.1.8. Biofertilizers

(a) *Rhizobium* culture

The *Rhizobium* culture was obtained from Agro-Bio-Tech Research Centre, Poovanthuruthu, Kottayam, Kerala.

Plate – 1 General view of the experimental site

(b) Arbuscular mycorrhizal fungi

Mixed culture containing spores of *Glomus* sp infected sorghum root pieces and infected medium (Perlite vermiculite) were obtained from Agro-Bio-Tech Research Centre, Poovanthuruthu, Kottayam, Kerala.

3.2. Methods

3.2.1.1. Experimental design and layout

The field experiment was laid out in split plot design with three replications. The layout plan is given in Fig. 2.

Replication	-	3
Plot size (gross)	-	3 x 1 m
(Net)	-	1.5 m x 60 cm
Spacing	-	75 x 20 cm

3.2.1.2. Treatment details

A. Main plot treatments

A.1. Nitrogen levels – 3

1. 0 kg ha^{-1} - n_0
2. 15 kg ha^{-1} - n_1
3. 30 kg ha^{-1} - n_2

A.2. Potassium levels – 3

1. 0 kg ha^{-1} - k_0
2. 20 kg ha^{-1} - k_1
3. 40 kg ha^{-1} - k_2

B. Sub plot treatments

Biofertilizers – 3

1. *Rhizobium* - b_1
2. AMF - b_2
3. *Rhizobium* + AMF - b_3

3.2.1.3. Treatment combinations – 27

(Combinations of three levels of nitrogen, three levels of potassium and biofertilizers formed 27 treatment combinations)

$n_0 k_0 b_1$	$n_1 k_0 b_1$	$n_2 k_0 b_1$
$n_0 k_0 b_2$	$n_1 k_0 b_2$	$n_2 k_0 b_2$
$n_0 k_0 b_3$	$n_1 k_0 b_3$	$n_2 k_0 b_3$
$n_0 k_1 b_1$	$n_1 k_1 b_1$	$n_2 k_1 b_1$
$n_0 k_1 b_2$	$n_1 k_1 b_2$	$n_2 k_1 b_2$
$n_0 k_1 b_3$	$n_1 k_1 b_3$	$n_2 k_1 b_3$
$n_0 k_2 b_1$	$n_1 k_2 b_1$	$n_2 k_2 b_1$
$n_0 k_2 b_2$	$n_1 k_2 b_2$	$n_2 k_2 b_2$
$n_0 k_2 b_3$	$n_1 k_2 b_3$	$n_2 k_2 b_3$

3.2.2. Field cultivation

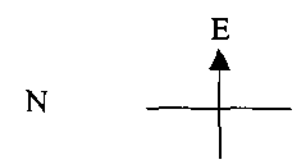
3.2.2.1. Land preparation

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

$n_0 k_2 b_1$	$n_1 k_1 b_3$	$n_2 k_1 b_3$	$n_1 k_2 b_1$	$n_1 k_0 b_1$	$n_0 k_1 b_3$	$n_2 k_2 b_1$	$n_0 k_0 b_1$	$n_2 k_0 b_3$	
$n_0 k_2 b_3$	$n_1 k_1 b_1$	$n_2 k_1 b_2$	$n_1 k_2 b_3$	$n_1 k_0 b_2$	$n_0 k_1 b_1$	$n_2 k_2 b_3$	$n_0 k_0 b_2$	$n_2 k_0 b_2$	Replication I
$n_0 k_2 b_2$	$n_1 k_1 b_2$	$n_2 k_1 b_1$	$n_1 k_2 b_2$	$n_1 k_0 b_3$	$n_0 k_1 b_2$	$n_2 k_2 b_2$	$n_0 k_0 b_3$	$n_2 k_0 b_1$	
$n_0 k_1 b_2$	$n_1 k_0 b_3$	$n_0 k_2 b_2$	$n_1 k_1 b_1$	$n_2 k_2 b_2$	$n_2 k_0 b_3$	$n_0 k_0 b_2$	$n_1 k_2 b_3$	$n_2 k_1 b_1$	
$n_0 k_1 b_3$	$n_1 k_0 b_1$	$n_0 k_2 b_1$	$n_1 k_1 b_3$	$n_2 k_2 b_1$	$n_2 k_0 b_2$	$n_0 k_0 b_1$	$n_1 k_2 b_2$	$n_2 k_1 b_3$	Replication II
$n_0 k_1 b_1$	$n_1 k_0 b_2$	$n_0 k_2 b_3$	$n_1 k_1 b_2$	$n_2 k_2 b_3$	$n_2 k_0 b_1$	$n_0 k_0 b_3$	$n_1 k_2 b_1$	$n_2 k_1 b_2$	
$n_2 k_2 b_2$	$n_0 k_2 b_1$	$n_1 k_0 b_2$	$n_0 k_0 b_1$	$n_2 k_1 b_1$	$n_2 k_0 b_3$	$n_1 k_2 b_2$	$n_1 k_1 b_2$	$n_0 k_1 b_3$	
$n_2 k_2 b_1$	$n_0 k_2 b_2$	$n_1 k_0 b_1$	$n_0 k_0 b_3$	$n_2 k_1 b_2$	$n_2 k_0 b_2$	$n_1 k_2 b_1$	$n_1 k_1 b_1$	$n_0 k_1 b_2$	Replication III
$n_2 k_2 b_3$	$n_0 k_2 b_3$	$n_1 k_0 b_3$	$n_0 k_0 b_2$	$n_2 k_1 b_3$	$n_2 k_0 b_1$	$n_1 k_2 b_3$	$n_1 k_1 b_3$	$n_0 k_1 b_1$	

FIG 2. LAYOUT PLAN OF EXPERIMENT

Plot Size : 3 x 1 m
Design : Split plot design



3.2.2.2. Application of fertilizers and manures

Farm yard manure at the rate of 10 t ha^{-1} was applied uniformly to all the plots and mixed well with top soil. A common dose of 25 kg P_2O_5 ha^{-1} was given to all the plots 15 days after sowing. Half dose of nitrogen and full dose of potassium were applied 15 days after sowing. The remaining half dose of nitrogen was applied after the first cut.

3.2.2.3. Application of biofertilizers

Rhizobium was applied at a rate of 375 g ha^{-1}. The AMF culture was placed 2 cm below the surface soil and seeds were sown on the same day itself.

3.2.2.4. Sowing

Seeds were dibbled in furrows taken in the prepared plots at a spacing of 75 cm between rows and 20 cm between plants. Sowing was done on 23-06-2000.

3.2.2.5. After cultivation

Gap filling was done 20 days after sowing. The crop was given regular weedings throughout the cropping period.

3.2.2.6. Irrigation

Protective irrigation was given as and when necessary.

3.2.2.7. Plant protection

Necessary plant protection measures were taken against soil grub.

3.2.2.8. Harvest

The first harvest of green fodder was taken at three months after sowing and subsequent harvests at two months interval. All together four harvests were taken. The plants were cut with sickle at a height of 25 cm from the ground.

3.3. Biometric observations

In each plot, two rows all around were left as border rows. Biometric observations were recorded from five sample plants selected randomly from the net plot area of each plot and the averages worked out.

3.3.1. Plant height

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

3.2.2. Number of branches

The total number of branches of the sample plants in each plot were counted, average worked out and was recorded as mean branch number.

3.3.3. Length of branches

Length of all branches of the sample plants were measured and mean length of branches was worked out.

3.3.4. Leaf: stem ratio

From the observational rows in each plot, sample plants were cut at the base. The leaves and the stem were separated and oven dried for 5 days till constant weight was obtained. The dry weight of leaves and stem of individual plants were recorded and the ratio computed by dividing leaf dry weight by the stem dry weight.

3.3.5. Yield and yield attributes

3.3.5.1. Green fodder yield

The green matter yield from the net plot area was recorded immediately after each harvest and total green matter produced per hectare was worked out.

3.3.5.2. Dry fodder yield

The sample plants collected from each net plot on the day prior to each harvest was weighed to determine the fresh weight, sun dried and then oven dried to a constant weight at 70°c. The dry matter content of each sample plant was computed and the dry matter yield worked out from the respective green matter yield.

3.4. Plant analysis

The plant samples were analysed for N, P and K at each harvests. The plant samples were dried in an oven at 70°c till constant weights were achieved. The samples were then ground to pass through a 0.5 mm mesh in a Willey mill. The required quantity of samples were then weighed out in an electronic balance and analysis carried out.

3.4.1. Uptake of nitrogen

The nitrogen content was estimated by Modified Microkjeldhal method (Jackson, 1973) and the uptake of nitrogen was calculated based on the content of this nutrient in plants and the dry matter produced. The values were expressed in kg ha^{-1}.

3.4.2. Uptake of phosphorus

Phosphorus content was determined by Vanado-molybdo-phosphoric yellow colour method using spectrophotometer (Jackson, 1973). Phosphorus uptake was calculated by multiplying the phosphorus content and dry weight of plants. The values were expressed in kg ha^{-1}.

3.4.3. Uptake of potassium

The potassium content in the plant samples were estimated using Flame photometry (Jackson, 1973). The uptake was calculated based on potassium content in plants and dry matter produced and expressed in kg ha^{-1}.

3.4.4. Crude protein content

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

3.4.5. Crude fibre content

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

3.5. Soil analysis

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

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

3.6. Economic analysis

The economics of cultivation was worked out based on cost of cultivation and prevailing market price of the fodder.

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

$$\text{Net income (Rs ha}^{-1}\text{)} = \text{Gross income} - \text{total expenditure}$$

$$\text{Benefit: cost ratio} = \frac{\text{Gross income}}{\text{Total expenditure}}$$

3.7. Statistical analysis

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

RESULTS

4. RESULTS

Field experiment was conducted at the Instructional Farm. College of Agriculture, Vellayani, Thiruvananthapuram, Kerala State during the period from June 2000 to April 2001 to find out an integrated nutrient management technique for *Desmanthus virgatus* (L.) Willd. under rainfed condition. The results obtained during the cropping period are presented here in.

4.1. Growth characters

Observations on growth characters like plant height, length of branches, number of branches and leaf: stem ratio were recorded and the results are presented to Tables 4.1.1 and 4.1.2.

4.1.1. Plant height [Table 4.1.1 (a), (b) and (c)]

Plant height was significantly influenced by increasing nitrogen application from 0 to 30 kg ha^{-1} in all the harvests.

Application of potassium also recorded a significant influence on the height of the plants at all four harvests. The highest dose of potassium (40 kg ha^{-1}) recorded highest plant height and was significantly superior to the lower potassium levels.

Biofertilizers have influenced the plant height significantly at all harvests. Among the biofertilizers tested, dual inoculation with AMF and *Rhizobium* significantly increased the plant height in all four harvests.

The N×K interaction effect was also significant. At the lower levels of nitrogen ie., at n_0 and n_1 when combined with K resulted in an increase in plant height. But at the highest dose of nitrogen ie., at n_2 (30 kg ha $^{-1}$) when combined with K resulted in differential response. The n_2k_2 combination (30 kg N ha $^{-1}$ + 40 kg K_2O ha $^{-1}$) was found to be significantly varied at second and fourth harvests, while it was on par with n_2k_1 (30 kg N ha $^{-1}$ + 20 kg K_2O ha $^{-1}$) in the first harvest. Application of highest dose of nitrogen and potassium produced tallest plants in the second cut and was significantly superior to that obtained from other treatments.

Interaction effect of nitrogen with biofertilizers was significant in fourth harvest. In fourth cut, the highest plant height (204.08 cm) was noticed for treatment n_2b_3 (30 kg N + dual inoculation) which was significantly superior to the height recorded in all other treatments. The treatment n_0b_1 (0 kg N+ *Rhizobium*) which recorded the lowest plant height (176.8 cm) was on par with n_0b_2 (0 kg N ha $^{-1}$)+ AMF).

K×B interaction was not significant.

4.1.2. Length of branches [Table 4.1.1 (a), (b) and (c)]

An increasing trend in length of branches was noticed with an increase in nitrogen levels in all the harvests. The length of branches was the highest at the highest dose of nitrogen (30 kg ha^{-1}) which was significantly superior to the lower doses.

An enhancement of potassium levels also resulted in an increase in the length of branches in all cuts. Length was maximum for k_2 (40 kg K_2O ha^{-1}) and was significantly superior.

However, combined application of biofertilizers significantly influenced the length of branches in all four harvests in comparison with their application alone.

N×K interaction had significant influence on the length of branches in all four harvests. Highest dose of N combined with K did not result in a significant positive response on the length of branches except in the second cut. N×K interaction on length of branches followed the same trend as that of plant height.

The interaction effect of nitrogen (N) and potassium (K) with biofertilizers were not significant.

4.1.3. Number of branches [Table 4.1.2 (a), (b) and (c)]

Nitrogen and potassium application significantly influenced the number of branches. The highest level of nitrogen and potassium and the combined application of biofertilizers resulted in an enhancement in number of branches.

N×K interaction on the number of braches was significant. However the rate of increase was inconsistent when highest dose of nitrogen was combined with potassium.

Table 4.1.1 (a) Effects of chemical fertilizers and biofertilizers on plant height and length of branches of *Desmanthus* (cm)

Main effects of factors	Plant height (cm)				Length of branches (cm)			
	I cut	II cut	III cut	IV cut	I cut	II cut	III cut	IV cut
n_0	171.62	176.37	179.32	178.31	169.67	174.28	177.41	176.12
n_1	189.76	192.67	195.50	196.30	187.82	190.65	193.48	194.20
n_2	199.63	199.04	201.38	202.83	197.39	196.87	198.77	200.32
$F_{2,16}$	3711.40**	4216.72**	5009.60**	5685.23**	2635.32**	6921.41**	2814.42**	3110.82**
k_0	184.15	185.66	188.77	189.61	182.10	183.57	186.77	187.08
k_1	187.26	188.61	192.44	192.39	185.29	186.54	189.88	190.37
k_2	189.60	193.81	195.01	195.44	187.49	191.69	193.01	193.19
$F_{2,16}$	137.12**	526.43**	378.13**	300.57**	97.48**	857.88**	221.47**	183.73**
SEm	0.233	0.180	0.161	0.168	0.274	0.140	0.210	0.226
CD	0.699	0.540	0.484	0.505	0.822	0.421	0.629	0.677
b_1	185.95	188.01	190.80	191.53	183.92	185.91	188.74	189.24
b_2	185.88	187.90	190.70	191.20	183.81	185.81	188.92	188.90
b_3	189.18	192.17	194.71	194.72	187.15	190.08	192.00	192.51
$F_{2,36}$	56.95**	167.35**	168.40**	150.06**	111.89**	140.07**	74.05**	120.38**
SEm	0.251	0.188	0.176	0.159	0.179	0.206	0.213	0.181
CD	0.719	0.541	0.506	0.456	0.515	0.591	0.611	0.521

* Significant at 5% level

** Significant at 1% level

Table 4.1.1 (b) Interaction effects of nitrogen (N) with potassium (K) on plant height and length of branches of *Desmanthus* (cm)

Interaction effects of factors	Plant height (cm)				Length of branches (cm)			
	I cut	II cut	III cut	IV cut	I cut	II cut	III cut	IV cut
n_0k_0	168.06	171.66	174.72	173.76	166.27	169.41	173.33	171.46
n_0k_1	171.27	175.69	179.88	178.26	169.40	173.55	177.34	176.10
n_0k_2	175.53	181.76	183.38	182.92	173.34	179.88	181.56	180.79
n_1k_0	185.98	187.87	191.77	192.41	183.66	185.82	189.38	190.14
n_1k_1	189.79	192.01	195.19	196.51	187.95	190.00	193.20	194.51
n_1k_2	193.52	198.14	199.54	199.98	191.85	196.13	197.86	197.96
n_2k_0	198.42	197.44	199.80	202.65	196.39	195.48	197.60	199.65
n_2k_1	200.73	198.13	202.25	202.42	198.51	196.08	199.10	200.50
n_2k_2	199.74	201.53	202.10	203.43	197.28	199.05	199.62	200.82
$F_{4, 16}$	22.09*	31.93*	41.24*	59.18*	18.89*	65.41*	25.95**	31.00*
SE	0.404	0.312	0.280	0.292	0.475	0.243	0.363	0.391
CD	1.211	0.935	0.838	0.874	1.424	0.728	1.089	1.172

* Significant at 5% level

** Significant at 1% level

Table 4.1.1 (c) Interaction effects of nitrogen (N) and potassium (K) with biofertilizers (B) on plant height and length of branches of *Desmanthus* (cm)

Interaction effects of factors	Plant height (cm)				Length of branches (cm)			
	I cut	II cut	III cut	IV cut	I cut	II cut	III cut	IV cut
n_0b_1	170.84	174.96	177.91	176.83	169.18	172.86	176.36	174.73
n_0b_2	170.59	174.75	178.35	176.99	168.43	172.62	176.38	174.54
n_0b_3	173.42	179.41	181.72	181.12	171.40	177.35	179.48	179.08
n_1b_1	188.51	190.94	193.99	194.89	186.50	189.10	191.79	192.75
n_1b_2	188.68	190.99	193.85	195.05	186.74	188.89	192.57	193.13
n_1b_3	192.10	196.09	198.66	198.95	190.22	193.97	196.08	196.73
n_2b_1	198.50	198.13	200.49	202.85	196.08	195.78	198.06	200.24
n_2b_2	198.37	197.96	199.91	201.57	196.26	195.01	197.82	199.03
n_2b_3	202.03	201.02	203.75	204.08	199.84	198.92	200.44	201.70
$F_{4, 36}$	0.44	0.94	2.23	9.74*	2.09	2.67	1.74	6.68
K_0b_1	183.18	184.49	187.56	188.47	180.92	182.53	185.39	185.80
K_0b_2	182.69	184.53	187.46	188.53	180.98	182.42	186.38	185.96
K_0b_3	186.60	187.95	191.28	191.83	184.42	185.75	188.54	189.48
K_1b_1	186.47	187.35	191.03	191.76	184.47	185.22	188.97	189.66
K_1b_2	186.46	187.08	190.85	190.75	184.36	184.86	188.40	188.88
K_1b_3	188.85	191.40	195.44	194.68	187.04	189.55	192.26	192.57
K_2b_1	188.19	192.19	193.81	194.35	186.38	189.99	191.85	192.26
K_2b_2	188.50	192.09	193.80	194.32	186.09	190.13	191.99	191.86
K_2b_3	192.10	197.16	197.41	197.65	190.00	194.94	195.20	195.46
$F_{4, 36}$	1.25	0.94	0.67	1.10	1.30	1.86	1.74	0.77
SE	0.434	0.326	0.306	0.275	0.311	0.357	0.369	0.314
CD	-	-	-	0.789	-	-	-	-

* Significant at 5% level

** Significant at 1% level

Table 4.1.2 (a) Effects of chemical fertilizers and biofertilizers on number of branches and leaf: stem ratio of *Desmanthus*

Main effects of factors	Number of branches	Leaf: Stem Ratio			
		I cut	II cut	III cut	IV cut
n_0	6.85	0.676	0.693	0.695	0.684
n_1	8.84	0.703	0.722	0.725	0.716
n_2	9.83	0.741	0.744	0.779	0.750
$F_{2, 16}$	8206.41**	526.25**	1067.16**	945.33**	709.50**
k_0	8.20	0.706	0.717	0.725	0.707
k_1	8.46	0.705	0.718	0.734	0.717
k_2	8.85	0.709	0.723	0.740	0.726
$F_{2, 16}$	384.32**	2.42	14.76	33.22*	59.79**
SEm	0.017	0.001	0.001	0.001	0.001
CD	0.05	0.004	0.002	0.004	0.004
b_1	8.39	0.702	0.716	0.728	0.712
b_2	8.38	0.701	0.714	0.728	0.712
b_3	8.74	0.717	0.728	0.743	0.726
$F_{2, 36}$	139.82**	37.01**	50.65**	49.28**	68.20**
SE	0.017	0.001	0.001	0.001	0.001
CD	0.05	0.004	0.003	0.004	0.003

* Significant at 5% level

** Significant at 1% level

Table 4.1.2 (b) Interaction effects of nitrogen (N) with potassium (K) on number of branches and leaf: stem ratio of *Desmanthus*

Interaction effects of factors	Number of branches	Leaf: Stem Ratio			
		I cut	II cut	III cut	IV cut
n_0k_0	6.53	0.680	0.690	0.692	0.670
n_0k_1	6.68	0.671	0.692	0.693	0.687
n_0k_2	7.35	0.678	0.696	0.70	0.696
n_1k_0	8.54	0.701	0.720	0.717	0.712
n_1k_1	8.83	0.702	0.718	0.723	0.713
n_1k_2	9.15	0.707	0.727	0.734	0.721
n_2k_0	9.54	0.737	0.742	0.765	0.739
n_2k_1	9.87	0.743	0.745	0.785	0.750
n_2k_2	10.06	0.743	0.746	0.787	0.761
$F_{4,16}$	18.15*	2.74	1.75	4.82	5.06
SE	0.029	0.002	0.001	0.002	0.002
CD	0.087	-	-	-	-

* Significant at 5% level

** Significant at 1% level

Table 4.1.2 (c) Interaction effects of nitrogen (N) and potassium (K) with biofertilizers on number of branches and leaf: stem ratio of *Desmanthus*

Interaction effects of factors	Number of branches	Leaf: Stem Ratio			
		I cut	II cut	III cut	IV cut
n_0b_1	6.66	0.673	0.690	0.691	0.679
n_0b_2	6.67	0.668	0.687	0.689	0.680
n_0b_3	7.24	0.688	0.701	0.705	0.695
n_1b_1	8.77	0.700	0.719	0.721	0.712
n_1b_2	8.73	0.702	0.719	0.721	0.712
n_1b_3	9.02	0.709	0.728	0.733	0.723
n_2b_1	9.74	0.734	0.741	0.772	0.746
n_2b_2	9.76	0.735	0.736	0.773	0.746
n_2b_3	9.98	0.754	0.756	0.791	0.758
$F_{4, 36}$	13.24*	2.66	2.00	0.73	0.74
k_0b_1	8.07	0.698	0.713	0.719	0.702
k_0b_2	8.06	0.703	0.711	0.720	0.702
k_0b_3	8.48	0.716	0.727	0.735	0.718
k_1b_1	8.38	0.703	0.717	0.729	0.712
k_1b_2	8.36	0.696	0.713	0.729	0.713
k_1b_3	8.65	0.716	0.724	0.743	0.725
k_2b_1	8.72	0.706	0.718	0.737	0.723
k_2b_2	8.73	0.705	0.718	0.734	0.723
k_2b_3	9.11	0.718	0.733	0.750	0.702
$F_{4, 36}$	2.09	1.52	1.10	0.34	0.70
SE	0.030	0.002	0.002	0.002	0.002
CD	0.087	-	-	-	-

* Significant at 5% level

** Significant at 1% level

$N \times B$ interaction on the number of branches of the plant was significant. At n_0 and n_1 levels combined with either b_1 or b_2 did not produce any significant variation in the number of branches, but the combined application of biofertilizers resulted in an increase in number of branches with the rate of increase being less at the highest level of nitrogen. Maximum number of branches (9.98) obtained for treatment n_2b_3 (30 kg N ha^{-1}+ dual inoculation) was significantly superior to all other treatments. This was followed by the treatment n_2b_2 (30 kg N ha^{-1}+ AMF) which was comparable with n_2b_1 (30 kg N ha^{-1} + *Rhizobium*). The treatment n_0b_1 (0 kg N ha^{-1} + *Rhizobium)* recorded the lowest number of branches which was on par with n_0b_2 (0 kg N ha^{-1}+ AMF).

$K \times B$ interaction on the number of branches was not significant.

4.1.4. Leaf: stem ratio [Table 4.1.2 (a), (b) and (c)]

Leaf:stem ratio of the plant was significantly influenced by the application of nitrogen, potassium and biofertilizers. A significant increase in the level of nitrogen resulted in an increase in L:S ratio in all harvests while increase in level of potassium resulted in significant increase in L:S ratio in the third and fourth harvest only. Combined application of the biofertilizers resulted in an increase in leaf: stem ratio at all harvests.

None of the interactions were significant.

4.2. Yield characters

4.2.1. Green fodder yield [Table 4.2 (a), (b) and (c)]

Significant increase in green fodder yield was obtained by the application of chemical fertilizers and biofertilizers. Green fodder yield was the highest for highest nitrogen dose (30 kg ha^{-1}) in all harvests which was significantly superior to the lower doses.

A similar response was observed by increasing potassium application from 0 to 40 kg ha^{-1} in all the harvests. The highest level of potassium recorded maximum green fodder yield in all the cuts.

Biofertilizer application also significantly influenced green fodder yield in all four harvests and the highest green fodder yield was obtained for dual inoculation with biofertilizers which was significantly superior to other treatments.

Significant N×K interaction was noticed in all harvests. Application of n_2k_2 (20 kg N ha^{-1}+ 40 kg K_2O ha^{-1}) which registered maximum green fodder yield was found to be significantly superior in all harvests.

Significant N×B interaction was observed at all harvests. When nitrogen was combined with either of the biofertilizer, no yield difference was noticed. But nitrogen combined with dual inoculation resulted in significant increase in yield. A similar interaction was observed with potassium and biofertilizers. Potassium applied in combination with both biofertilizers resulted in a significant increase in green fodder yield in all harvests except third. However, in third cut, the same trend was observed though not significant.

4.2.2. Dry fodder yield [Table 4.2 (a), (b) and (c)]

The chemical fertilizers and biofertilizers significantly influenced the dry fodder yield of the plant in all four harvests. Maximum dry fodder yield was obtained with highest dose of nitrogen and was significantly superior to lower doses. Similarly highest dose of potassium registered maximum dry fodder yield which was significantly superior to other doses. Dual inoculation with biofertilizers recorded highest dry fodder yield which was significantly superior to single inoculation.

Table 4.2 (a) Effects of chemical fertilizers and biofertilizers on green fodder yield and dry fodder yield of *Desmanthus* (t ha^{-1})

Main effects of factors	Green fodder yield (t ha^{-1})				Dry fodder yield (t ha^{-1})			
	I cut	II cut	III cut	IV cut	I cut	II cut	III cut	IV cut
n_0	9.94	9.82	10.56	9.55	2.09	2.06	2.13	1.91
n_1	14.80	14.82	14.48	14.37	3.11	3.12	2.90	2.88
n_2	17.29	16.04	15.69	16.26	3.63	3.36	3.14	3.26
$F_{2,16}$	24561.62**	26406.60**	10143.85**	64462.73**	21593.31**	10525.26**	8146.92**	845.39**
k_0	13.04	12.74	12.77	12.62	2.74	2.67	2.55	2.54
k_1	13.87	13.53	13.61	13.41	2.92	2.83	2.73	2.67
k_2	15.11	14.41	14.35	14.16	3.17	3.02	2.88	2.84
$F_{2,16}$	1908.06**	1697.49**	882.67**	3191.51**	1664.31**	664.47**	792.92**	38.72*
SE_m	0.024	0.020	0.027	0.014	0.005	0.007	0.006	0.024
CD	0.072	0.061	0.08	0.041	0.016	0.02	0.017	0.072
b_1	13.73	13.27	13.30	13.15	2.88	2.78	2.67	2.64
b_2	13.79	13.32	13.33	13.08	2.90	2.79	2.66	2.64
b_3	14.51	14.09	14.10	13.95	3.05	2.97	2.83	2.77
$F_{2,36}$	642.80**	298.80**	816.66**	554.58**	492.20**	193.53**	291.54**	12.35*
SE_m	0.017	0.027	0.016	0.020	0.004	0.008	0.006	0.022
CD	0.049	0.076	0.046	0.058	0.012	0.022	0.016	0.063

* Significant at 5% level

** Significant at 1% level

Table 4.2 (b) Interaction effects of nitrogen (N) with potassium (K) on green fodder yield and dry fodder yield of *Desmanthus* (t ha^{-1})

Interaction effects of factors	Green fodder yield (t ha^{-1})				Dry fodder yield (t ha^{-1})			
	I cut	II cut	III cut	IV cut	I cut	II cut	III cut	IV cut
n_0k_0	8.37	8.71	9.60	8.29	1.76	1.83	1.92	1.71
n_0k_1	9.54	9.81	10.56	9.54	2.00	2.05	2.12	1.85
n_0k_2	11.90	10.93	11.51	10.82	2.50	2.30	2.34	2.18
n_1k_0	13.93	13.65	13.61	13.39	2.93	2.86	2.72	2.68
n_1k_1	14.69	14.87	14.58	14.42	3.09	3.15	2.92	2.88
n_1k_2	15.78	15.95	15.26	15.31	3.31	3.33	3.05	3.06
n_2k_0	16.82	15.85	15.10	16.17	3.53	3.33	3.02	3.23
n_2k_1	17.39	15.92	15.69	16.27	3.65	3.31	3.14	3.27
n_2k_2	17.66	16.34	16.27	16.33	3.70	3.43	3.25	3.27
$F_{4, 16}$	300.16**	216.61**	17.52**	676.63**	268.10**	90.44**	23.55**	8.56**
SE	0.041	0.035	0.046	0.024	0.009	0.012	0.010	0.041
CD	0.124	0.105	0.138	0.071	0.028	0.035	0.030	0.082

* Significant at 5% level

** Significant at 1% level

Table 4.2 (C) Interaction effects of nitrogen (N) and Potassium (K) with biofertilizers (B) on green fodder yield and dry fodder yield of *Desmanthus* (t ha^{-1})

Interaction effects of factors	Green fodder yield (t ha^{-1})				Dry fodder yield (t ha^{-1})			
	I cut	II cut	III cut	IV cut	I cut	II cut	III cut	IV cut
n_0b_1	9.54	9.50	10.20	9.19	2.01	1.90	2.05	1.86
n_0b_2	9.63	9.52	10.24	9.18	2.02	1.90	2.05	1.87
n_0b_3	10.64	10.43	11.23	10.29	2.23	2.18	2.28	2.00
n_1b_1	14.50	14.49	14.20	14.02	3.04	3.03	2.84	2.80
n_1b_2	14.54	14.50	14.18	14.06	3.05	3.04	2.84	2.81
n_1b_3	15.36	15.48	15.06	15.04	3.23	3.28	3.01	3.01
n_2b_1	17.14	15.81	15.50	16.24	3.60	3.31	3.10	3.25
n_2b_2	17.20	15.94	15.56	16.01	3.61	3.33	3.11	3.22
n_2b_3	17.53	16.36	16.00	16.51	3.68	3.44	3.20	3.30
$F_{4,36}$	47.24**	12.03*	34.60**	44.63**	39.23**	8.23*	16.53*	1.09
k_0b_1	12.82	12.45	12.50	12.30	2.69	2.61	2.5	2.47
k_0b_2	12.87	12.49	12.50	12.34	2.70	2.62	2.5	2.49
k_0b_3	13.42	13.28	13.30	13.21	2.82	2.79	2.66	2.66
k_1b_1	13.50	13.18	13.31	13.23	2.83	2.75	2.67	2.66
k_1b_2	13.56	13.23	13.36	13.03	2.85	2.76	2.67	2.63
k_1b_3	14.56	14.19	14.16	13.97	3.07	3.00	2.84	2.72
k_2b_1	14.86	14.17	14.10	13.93	3.12	2.96	2.83	2.79
k_2b_2	14.93	14.25	14.12	13.88	3.14	2.99	2.82	2.79
k_2b_3	15.55	14.80	14.83	14.66	3.26	3.11	2.99	2.93
$F_{4,36}$	22.16**	6.08**	1.69	4.45**	21.82**	6.83**	0.33	0.81
SE	0.03	0.046	0.028	0.035	0.007	0.013	0.010	0.038
CD	0.085	0.132	0.079	0.101	0.021	0.038	0.028	-

* Significant at 5% level

** Significant at 1% level

Similar interactions as that of green fodder yield was observed in the case of dry fodder yield also except that N×B and K × B interactions were not significant in the fourth cut. K×B interaction was not significant in third cut also. Application of nitrogen and potassium along with both biofertlizers was found to be beneficial.

4.3. Quality

4.3.1. Crude protein [Table 4.3 (a), (b) and (c)]

Application of chemical fertilizers and biofertilizers significantly influenced the crude protein content of the plant. Crude protein content increased with an increase in nitrogen levels, but the rate of increase was reduced when nitrogen was increased from 15 to 30 kg ha^{-1}. This result was observed in all cuts. Potassium application also helped to increase the crude protein, but not to the extent of the influence of nitrogen. At third cut, no significant difference in crude protein was seen with respect to various levels of potassium. Dual application of biofertilizers resulted in higher crude protein content. Among single application, *Rhizobium* was superior to AMF.

Nitrogen, potassium and biofertilizers influenced the crude protein content, but no significant difference in response was seen with their combined application. Also nitrogen and potassium in combination with biofertilizers did not produce any significant difference in crude protein content.

Table 4.3 (a) Effects of chemical fertilizers and biofertilizers on crude protein and crude fibre content in *Desmanthus* (%)

Main effects of factors	Crude protein (%)				Crude fibre (%)			
	I cut	II cut	III cut	IV cut	I cut	II cut	III cut	IV cut
n_0	15.70	16.89	16.14	15.17	17.14	17.18	17.59	17.51
n_1	17.73	19.00	18.47	16.98	17.17	17.14	17.60	17.45
n_2	18.03	19.56	18.73	17.58	17.17	17.20	17.53	17.40
$F_{2,16}$	650.82**	686.86**	877.35**	1798.06**	3.69*	8.80**	6.78*	12.15**
k_0	16.96	18.36	17.73	16.46	17.15	17.15	17.59	17.45
k_1	17.11	18.42	17.74	16.58	17.17	17.19	17.61	17.45
k_2	17.40	18.64	17.86	16.68	17.17	17.18	17.54	17.46
$F_{2,16}$	20.12*	7.17*	2.20	13.86**	0.923	4.80*	5.57*	0.12
SE_m	0.050	0.054	0.048	0.030	0.011	0.010	0.014	0.016
CD	0.149	0.161	0.145	0.089	0.033	0.030	0.042	0.048
b_1	17.25	18.58	17.82	16.63	17.23	17.26	17.67	17.50
b_2	16.81	18.15	17.54	16.28	17.13	17.13	17.54	17.43
b_3	17.40	18.73	17.98	16.81	17.13	17.13	17.53	17.43
$F_{2,36}$	50.46**	57.06**	34.89**	26.23**	46.22**	141.30**	17.89**	13.67**
SE_m	0.043	0.040	0.038	0.053	0.009	0.006	0.018	0.010
CD	0.123	0.115	0.109	0.151	0.025	0.018	0.052	0.030

* Significant at 5% level

** Significant at 1% level

Table 4.3 (b) Interaction effects of nitrogen (N) with potassium (K) on crude protein and crude fibre content in *Desmanthus* (%)

Interaction effects of factors	Crude protein (%)				Crude fibre (%)			
	I cut	II cut	III cut	IV cut	I cut	II cut	III cut	IV cut
n_0k_0	15.48	16.72	16.02	15.13	17.09	17.14	17.59	17.57
n_0k_1	15.67	16.76	16.18	15.09	17.18	17.20	17.59	17.51
n_0k_2	15.94	17.19	16.22	15.28	17.14	17.18	17.60	17.46
n_1k_0	17.50	18.82	18.36	16.88	17.17	17.14	17.61	17.45
n_1k_1	17.66	19.09	18.39	17.03	17.18	17.15	17.61	17.45
n_1k_2	18.04	19.09	18.67	17.03	17.17	17.14	17.58	17.45
n_2k_0	17.89	19.52	18.82	17.38	17.19	17.17	17.55	17.34
n_2k_1	18.01	19.52	18.67	17.62	17.15	17.22	17.61	17.39
n_2k_2	18.20	19.64	18.71	17.73	17.18	17.22	17.44	17.48
$F_{4,16}$	0.60	1.96	2.20	2.64	2.92	1.20	3.91	5.33
SE	0.086	0.093	0.083	0.051	0.019	0.016	0.025	0.027

Table 4.3(c) Interaction effects of nitrogen (N) and potassium (K) with biofertilizers on crude protein and crude fibre content in *Desmanthus* (%)

Interaction effects of factors	Crude Protein (%)				Crude Fibre (%)			
	I Cut	II Cut	III Cut	IV Cut	I Cut	II Cut	III Cut	IV Cut
n_0b_1	15.75	16.96	16.18	15.21	17.21	17.27	17.71	17.58
n_0b_2	15.40	16.53	15.83	14.97	17.10	17.13	17.55	17.48
n_0b_3	15.94	17.19	16.41	15.32	17.10	17.12	17.52	17.48
n_1b_1	17.85	19.06	18.51	17.11	17.24	17.24	17.71	17.48
n_1b_2	17.34	18.63	18.20	16.61	17.14	17.08	17.56	17.42
n_1b_3	18.01	19.33	18.71	17.23	17.14	17.11	17.54	17.45
n_2b_1	18.16	19.72	18.78	17.58	17.24	17.27	17.57	17.45
n_2b_2	17.69	19.29	15.59	17.27	17.14	17.17	17.52	17.40
n_2b_3	18.24	19.68	18.82	17.89	17.14	17.17	17.51	17.36
$F_{4,36}$	0.07	2.03	1.99	1.14	1.30	2.70	1.33	2.33
k_0b_1	17.11	18.43	17.69	16.53	17.22	17.24	17.70	17.50
k_0b_2	16.61	18.12	17.54	16.22	17.13	17.10	17.53	17.43
k_0b_3	17.15	18.51	17.97	16.64	17.11	17.11	17.53	17.43
k_1b_1	17.23	18.59	17.85	16.64	17.24	17.27	17.67	17.50
k_1b_2	16.68	18.04	17.50	16.26	17.12	17.15	17.58	17.42
k_1b_3	17.42	18.74	17.89	16.84	17.13	17.15	17.58	17.44
k_2b_1	17.42	18.71	17.93	16.72	17.23	17.28	17.63	17.50
k_2b_2	17.15	18.28	17.58	16.37	17.13	17.13	17.51	17.45
k_2b_3	17.62	18.94	18.08	16.96	17.14	17.14	17.47	17.43
$F_{4,36}$	1.53	1.72	1.16	0.26	0.32	0.42	0.66	0.67
SE	0.074	0.069	0.066	0.091	0.012	0.011	0.031	0.018

4.3.2. Crude fibre [Table 4.3 (a), (b) and (c)]

Crude fibre content of the plant was significantly influenced by the application of chemical fertlizers and biofertilizers. Crude fibre was found to reduce with nitrogen application. The response to potassium was visible only at second and third cuts. In the third harvest, lowest crude fibre content was obtained with application of 40 kg K_2O ha^{-1} (k_2) while in the second cut k_0 (0 kg K_2O ha^{-1}) registered lowest crude fibre content. Dual inoculation with biofertilizers did not influence the crude fibre content significantly in all the harvest.

None of the interactions were found to influence the crude fibre content of *Desmanthus*.

4.4. Nutrient uptake

4.4.1. Nitrogen uptake [Table 4.4.1 (a), (b) and (c)]

Application of nitrogen, potassium and biofertilizers had significant influence on nitrogen uptake by the plant in all four harvests. A marked increase in nitrogen uptake with an increase in applied nitrogen was observed. Application of potassium also helped to increase the nitrogen uptake. Higher doses of potassium resulted in higher nitrogen uptake. Individual inoculation of biofertilizers did not result in a significant difference in nitrogen uptake. But when applied dually, it resulted in higher nitrogen uptake. These results were observed in all cuts.

Table 4.4.1 (a) Effects of chemical fertilizers and biofertilizers on the uptake of nitrogen by *Desmanthus* (kg ha^{-1})

Main effects of factors	I cut	II cut	III cut	IV cut
n_0	52.67	55.69	55.02	47.31
n_1	88.33	94.83	85.68	78.27
n_2	104.45	105.08	94.02	91.62
$F_{2,16}$	7116.79**	4929.30**	6707.41**	14056.99**
k_0	75.40	79.69	73.38	67.87
k_1	81.01	84.97	78.25	72.86
k_2	89.03	90.94	83.10	76.48
$F_{2,16}$	475.50**	229.62**	375.55**	508.72**
SE_m	0.314	0.371	0.251	0.192
CD	0.942	1.113	0.752	0.575
b_1	80.72	83.60	76.86	71.14
b_2	79.07	82.11	75.71	69.54
b_3	85.66	89.89	82.15	76.52
$F_{2,36}$	167.46**	178.11**	175.74**	140.25**
SE_m	0.265	0.309	0.259	0.309
CD	0.760	0.888	0.744	0.886

* Significant at 5% level

** Significant at 1% level

Table 4.4.1 (b) Interaction effects of nitrogen (N) with potassium (K) on the uptake of nitrogen by *Desmanthus* (kg ha^{-1})

Interaction effects of factors	**I cut**	**II cut**	**III cut**	**IV cut**
n_0k_0	43.71	48.83	49.25	41.30
n_0k_1	50.49	55.04	55.01	47.62
n_0k_2	63.80	63.19	60.81	53.22
n_1k_0	81.93	86.27	79.95	72.35
n_1k_1	87.36	96.34	85.93	78.94
n_1k_2	95.69	101.88	91.17	83.50
n_2k_0	100.56	103.98	90.93	89.94
n_2k_1	105.18	103.54	93.81	92.21
n_2k_2	107.61	107.74	97.31	92.71
$F_{4,16}$	41.36**	30.08**	11.33**	59.16*
SE	0.544	0.643	0.434	0.322
CD	1.631	1.928	1.302	0.995

* Significant at 5% level

** Significant at 1% level

Table 4.4.1 (c) Interaction effects of nitrogen (N) and potassium (K) with biofertilizers on the uptake of nitrogen by *Desmanthus* (kg ha^{-1})

Interaction effects of factors	I cut	II cut	III cut	IV cut
n_0b_1	50.60	54.21	53.19	45.22
n_0b_2	50.13	52.70	51.87	44.91
n_0b_3	57.27	60.15	60.02	51.81
n_1b_1	86.96	92.31	84.25	76.82
n_1b_2	84.84	90.75	82.80	74.74
n_1b_3	93.19	101.43	90.00	83.23
n_2b_1	104.62	104.28	93.12	91.38
n_2b_2	102.23	102.88	92.48	88.96
n_2b_3	106.51	108.09	96.44	94.52
$F_{4, 36}$	9.85*	8.54*	6.82	4.20
k_0b_1	75.10	78.36	71.71	66.32
k_0b_2	73.00	77.08	71.15	65.46
k_0b_3	78.11	83.64	77.28	71.82
k_1b_1	79.19	82.95	76.90	71.77
k_1b_2	77.39	80.84	75.67	69.38
k_1b_3	84.46	91.13	82.18	77.41
k_2b_1	87.89	89.49	81.96	75.33
k_2b_2	86.80	88.42	80.33	73.78
k_2b_3	92.40	94.91	87.00	80.32
$F_{4, 36}$	7.63*	4.46	0.38	0.90
SE	0.459	0.536	0.449	0.535
CD	1.317	1.538	-	-

* Significant at 5% level

** Significant at 1% level

Significant N×K interaction was observed in all cuts. Differential response of nitrogen was observed with an increase in levels of potassium. In the absence of nitrogen, the influence of potassium in nitrogen uptake was significantly visible. But with application of nitrogen at n_1 level, though the uptake was high, the rate of increase in uptake was low with increasing levels of potassium. Again when nitrogen was increased to n_2 level, uptake of nitrogen was high but with a decrease in rate of uptake with an increase in potassium dose. This result was observed at all cuts, nitrogen uptake being on par at n_2k_1, (30 kg N+20 kg K_2O ha^{-1}) and n_2k_2 (30 kg N+ 40 kg K_2O ha^{-1}) in fourth harvest.

N×B interaction was significant in first and second cuts. The uptake of nitrogen was the highest for the treatment n_2b_3 (30 kg N ha^{-1} + dual inoculation) and was significantly superior to all other treatments.

K×B interaction could not influence the uptake of nitrogen by the plant except in the first cut. The highest dose of potassium combined with dual application of biofertilizers resulted in significantly superior uptake of nitrogen by *Desmanthus*.

4.4.2. Phosphorus uptake [Table 4.4.2 (a), (b) and (c)]

Nitrogen, potassium and biofertilizers significantly influenced the phosphorus uptake by the plant. Phosphorus uptake significantly increased with an increase in both nitrogen and potassium. Dual inoculation with biofertilizers registered significantly higher phosphorus uptake than *Rhizobium* and AMF inoculation.

Table 4.4.2 (a) Main effects of chemical fertilizers and biofertilizers on the uptake of phosphorus by *Desmanthus* (kg ha^{-1})

Main effects of factors	I cut	II cut	III cut	IV cut
n_0	6.29	5.98	5.99	5.14
n_1	9.69	9.26	8.54	7.93
n_2	11.58	10.15	9.62	9.52
$F_{2, 16}$	992.22**	2035.64**	488.58**	1020.41**
k_0	8.47	7.98	7.67	7.01
k_1	9.16	8.43	7.75	7.51
k_2	9.93	8.99	8.74	8.07
$F_{2, 16}$	73.11*	108.53**	49.69*	59.20*
SE_m	0.085	0.049	0.084	0.069
CD	0.255	0.146	0.253	0.208
b_1	7.85	7.95	7.62	6.95
b_2	9.51	8.48	8.02	7.57
b_3	10.19	8.96	8.52	8.07
$F_{2, 36}$	397.32**	104.13**	82.63**	94.81**
SE_m	0.06	0.05	0.049	0.058
CD	0.173	0.142	0.141	0.166

* Significant at 5% level

** Significant at 1% level

Table 4.4.2 (b) Interaction effects of nitrogen (N) with potassium (K) on the uptake of phosphorus by *Desmanthus* (kg ha^{-1})

Interaction effects of factors	I cut	II cut	III cut	IV cut
n_0k_0	5.23	5.26	5.31	4.55
n_0k_1	6.01	5.95	5.76	5.12
n_0k_2	7.63	6.74	6.90	5.76
n_1k_0	9.11	8.53	8.55	7.27
n_1k_1	9.78	9.36	7.95	7.89
n_1k_2	10.18	9.89	9.13	8.62
n_2k_0	11.08	10.14	9.16	9.20
n_2k_1	11.69	9.98	9.53	9.52
n_2k_2	11.98	10.34	10.19	9.84
$F_{4, 16}$	9.35**	19.39*	5.37**	2.40
SE	0.148	0.084	0.146	0.120
CD	0.446	0.253	0.440	-

* Significant at 5% level

** Significant at 1% level

Table 4.4.2 (c) Interaction effects of nitrogen (N) and potassium (K) with biofertilizers on the uptake of phosphorus by *Desmanthus* (kg ha^{-1})

Interaction effects of factors	I cut	II cut	III cut	IV cut
n_0b_1	5.11	5.65	5.58	4.61
n_0b_2	6.40	5.93	5.88	5.17
n_0b_3	7.35	6.37	6.51	5.65
n_1b_1	8.25	8.57	8.11	7.33
n_1b_2	9.98	9.30	8.52	7.79
n_1b_3	10.84	9.91	9.00	8.66
n_2b_1	10.20	9.62	9.19	8.92
n_2b_2	12.16	10.22	9.65	9.74
n_2b_3	12.39	10.61	10.03	9.90
$F_{4, 36}$	4.88**	3.69*	0.56	3.27*
k_0b_1	7.39	7.54	7.41	6.39
k_0b_2	8.80	7.97	7.63	7.08
k_0b_3	9.23	8.42	7.99	7.55
k_1b_1	7.67	7.91	7.24	7.00
k_1b_2	9.44	8.37	7.71	7.48
k_1b_3	10.37	9.01	8.30	8.04
k_2b_1	8.51	8.40	8.23	7.46
k_2b_2	10.29	9.12	8.72	8.13
k_2b_3	10.98	10.61	9.27	8.63
$F_{4, 36}$	4.66**	1.46	2.52	0.35
SE	0.104	0.086	0.085	0.100
CD	0.298	0.247	-	0.287

* Significant at 5% level

** Significant at 1% level

$N \times K$ interaction was significant at all cuts except the fourth. Though an increase in phosphorus uptake was seen with an increase in both nitrogen and potassium, the magnitude of uptake was inconsistent. At fourth cut, no significant difference was observed when nitrogen was combined with k_1 and k_2. But an increasing trend was seen when n_1 was combined with higher doses of potassium. However, when n_2 was combined with K, this type of response was not observed.

Significant interaction was observed for nitrogen and biofertilizers at first, second and fourth cuts. Highest dose of nitrogen (n_2) combined with b_3 (*Rhizobium* + AMF) was not found to be positive in phosphorus uptake in first and fourth cuts in comparison with b_2 (AMF).

$K \times B$ interaction was significant only at first cut and k_2b_3 (40 kg k_2O ha^{-1} + dual inoculation) which resulted in highest phosphorus uptake.

4.4.3. Potassium uptake [Table 4.4.3 (a), (b) and (c)]

Nitrogen, potassium and biofertilizers significantly influenced the uptake of potassium by the plant. An increase in both nitrogen or potassium resulted in an increase in potassium uptake. Dual inoculation with biofertilizers gave significantly higher potassium uptake.

Significant interaction was observed between N and K in potassium uptake. Significantly higher potassium uptake was observed at n_2k_2 followed by n_2k_1. But with an increase in nitrogen dose from n_1 to n_2 the rate of increase in potassium uptake was reduced. This pattern of response was seen in all cuts.

Table 4.4.3 (a) Effects of chemical fertilizers and biofertilizers on the uptake of potassium by *Desmanthus* (kg ha^{-1})

Main effects of factors	I cut	II cut	III cut	IV cut
n_0	25.45	24.98	25.34	23.22
n_1	39.17	39.31	35.55	36.09
n_2	46.42	43.29	39.68	41.93
$F_{2,16}$	11677.91**	8748.74**	7020.31**	6560.51**
k_0	32.28	31.56	29.95	30.33
k_1	37.03	36.26	33.68	34.11
k_2	41.72	39.76	36.93	36.79
$F_{2,16}$	2293.36**	1597.54**	1570.72**	754.05**
SE_m	0.099	0.103	0.088	0.118
CD	0.295	0.309	0.264	0.354
b_1	36.25	34.98	32.82	32.86
b_2	36.42	35.20	32.85	33.07
b_3	38.36	37.41	34.89	35.30
$F_{2,36}$	180.74**	166.04**	207.81**	176.18**
SE_m	0.087	0.104	0.082	0.102
CD	0.250	0.300	0.235	0.293

* Significant at 5% level

** Significant at 1% level

Table 4.4.3 (b) Interaction effects of nitrogen (N) with potassium (K) on the uptake of potassium by *Desmanthus* (kg ha^{-1})

Interaction effects of factors	I cut	II cut	III cut	IV cut
n_0k_0	19.65	20.57	21.63	19.03
n_0k_1	24.59	24.96	25.26	23.78
n_0k_2	32.11	29.42	29.12	26.86
n_1k_0	34.55	33.72	31.68	31.80
n_1k_1	39.40	40.23	35.81	36.37
n_1k_2	43.55	43.99	39.15	41.10
n_2k_0	42.65	40.39	36.54	40.17
n_2k_1	47.10	43.60	39.97	42.20
n_2k_2	49.51	45.88	42.52	43.41
$F_{4,16}$	84.72*	52.77*	9.45**	47.08*
SE	0.171	0.178	0.153	0.205
CD	0.512	0.535	0.461	0.614

* Significant at 5% level

** Significant at 1% level

Table 4.4.3 (c) Interaction effects of nitrogen (N) and potassium (K) with biofertilizers (B) on the uptake of potassium by *Desmanthus* (kg ha^{-1})

Interaction effects of factors	I cut	II cut	III cut	IV cut
n_0b_1	24.36	24.13	24.37	22.02
n_0b_2	24.67	24.28	24.40	22.46
n_0b_3	27.33	26.54	27.25	25.18
n_1b_1	38.32	38.14	34.91	34.85
n_1b_2	38.46	38.41	34.80	35.36
n_1b_3	40.73	41.40	36.93	38.06
n_2b_1	46.07	42.66	39.19	41.70
n_2b_2	46.15	42.91	39.36	41.40
n_2b_3	47.03	44.29	40.48	42.67
$F_{4,36}$	14.33*	6.68	11.75*	13.46*
k_0b_1	31.74	30.76	29.30	29.26
k_0b_2	31.92	31.00	29.37	29.68
k_0b_3	33.19	32.92	31.19	32.05
k_1b_1	35.86	35.10	32.88	33.21
k_1b_2	36.15	35.29	33.01	33.31
k_1b_3	39.07	38.40	35.14	35.82
k_2b_1	41.15	39.07	36.28	36.10
k_2b_2	41.20	39.30	36.17	36.23
k_2b_3	42.82	40.91	38.33	38.04
$F_{4,36}$	12.35	6.11	0.70	2.02
SE	0.151	0.181	0.142	0.177
CD	0.434	-	0.408	0.507

* Significant at 5% level

** Significant at 1% level

N × B interaction significantly influenced the uptake of potassium in first, third and fourth harvest. In all these cuts, the treatment n_2b_3 (30 kg N ha^{-1} + dual inoculation) stands significantly superior to other treatments.

K × B interaction did not significantly influence the uptake of potassium by *Desmanthus*.

4.5. Nutrient status of soil after the experiment

4.5.1. Available nitrogen [Table 4.5 (a), (b) and (c)]

The available nitrogen status of the soil was influenced by different nitrogen levels to a significant extent. An increase in nitrogen application resulted in an increase in available nitrogen status of the soil. The potassium levels failed to produce any significant effect on available nitrogen status of soil.

Rhizobium inoculation and dual application of biofertilizers was found to be significantly superior to AMF inoculation in improving the nitrogen status of the soil.

All the interactions were not significant in influencing the available nitrogen status of soil.

4.5.2. Available phosphorus [Table 4.5 (a), (b) and (c)]

Nitrogen and potassium did not influence the available phosphorus status of the soil.

Table 4.5(a) Effects of chemical fertilizers and biofertilizers on available nitrogen, phosphorus and potassium status of soil after the experiment (kg ha^{-1})

Main effects of factors	Nitrogen	Phosphorus	Potassium
n_0	205.83	30.42	51.56
n_1	215.49	30.10	53.09
n_2	219.35	29.97	52.40
$F_{2,16}$	150.144**	1.422	14.72
k_0	212.39	30.17	49.87
k_1	213.35	30.15	52.44
k_2	214.92	30.18	54.73
$F_{2,16}$	5.08	0.01	149.44**
SE_m	0.568	0.195	0.199
CD	1.704	---	0.596
b_1	215.15	28.90	52.27
b_2	209.84	30.72	52.31
b_3	215.67	30.88	52.47
$F_{2,36}$	40.43**	84.03**	0.37
SE_m	0.507	0.120	0.168
CD	1.455	0.344	--

* Significant at 5% level

** Significant at 1% level

Table 4.5(b) Interaction effects of nitrogen (N) with potassium (K) on available nitrogen, phosphorus and potassium status of soil after the experiment (kg ha^{-1})

Interaction effects of factors	Nitrogen	Phosphorus	Potassium
n_0k_0	204.41	30.39	49.03
n_0k_1	204.16	30.42	51.32
n_0k_2	208.93	30.46	54.33
n_1k_0	214.37	30.11	50.36
n_1k_1	215.77	30.07	53.61
n_1k_2	216.32	30.13	55.29
n_2k_0	218.39	29.99	50.22
n_2k_1	220.13	29.95	52.41
n_2k_2	219.53	29.97	52.43
$F_{4,16}$	2.13	0.004	1.43
SE	0.984	0.338	0.345

Table 4.5(c) Interaction effects of nitrogen (N) and potassium (K) with biofertilizers on available nitrogen, phosphorus and potassium status in soil after the experiment (kg ha^{-1})

Interaction effects of factors	**Nitrogen**	**Phosphorus**	**Potassium**
n_ob_1	207.48	29.03	51.54
n_ob_2	202.27	31.37	51.62
n_ob_3	207.74	30.87	51.52
n_1b_1	216.90	28.83	52.92
n_1b_2	211.65	30.39	52.87
n_1b_3	217.91	31.09	53.47
n_2b_1	221.08	28.85	52.36
n_2b_2	215.61	30.39	52.42
n_2b_3	221.36	30.67	52.43
$F_{4,36}$	0.10	2.47	0.48
k_ob_1	213.37	28.86	50.03
k_ob_2	208.45	30.69	49.83
k_ob_3	215.35	30.95	49.76
k_1b_1	214.47	28.58	52.12
k_1b_2	210.67	30.94	52.38
k_1b_3	214.92	30.92	52.83
k_2b_1	217.61	29.26	54.67
k_2b_2	210.42	30.53	54.70
k_2b_3	216.75	30.76	54.83
$F_{4,36}$	1.51	1.94	0.74
SE	0.88	0.21	0.29

Biofertilizers had significant influence on the available phosphorus status of the soil. Dual inoculation and AMF application were found to be on par and significantly superior to *Rhizobium* in improving the available phosphorus status of the soil.

None of the interactions were found to have a significant influence on the available phosphorus status of the soil.

4.5.3. Available potassium [Table 4.5 (a), (b) and (c)]

Various potassium levels significantly influenced the available potassium status of the soil. The highest dose of potassium (40 kg K_2O ha^{-1}) registered highest available potassium status of soil. Nitrogen and biofertilizers did not influence the available K status of the soil.

N×K, N×B and K×B interactions could not elicit any significant influence on the potassium status of the soil.

4.6. Response surface and standardization of response to applied nutrients (Table 4.6.)

The fitted quadratic response is as follows

$$Y = 37.3471 + 1.7741\ N + 0.2910\ K - 0.0287\ N^2 - 0.0009\ K^2 - 0.0060\ NK$$

F for regression= 3318.974

R^2=99.9 %

The physical and economic optimum doses of nitrogen for *Desmanthus virgatus* are 32 kg ha^{-1} and 31 kg ha^{-1} respectively. The physical and economic optimum dose of potassium was found to be 22 kg ha^{-1}.

4.7. **Economics** [Table 4.7 (a),(b) and (c)]

The net returns was positive in all the treatments. The chemical fertilizers and biofertilizers had significant influence on the net returns and benefit: cost ratio. The highest net returns and benefit: cost ratio was obtained with n_2 (30 kg N ha^{-1}) which was significantly superior to all other doses. Similarly the highest dose of potassium fetched maximum net returns and benefit: cost ratio. Among biofertilizers used, dual inoculation with *Rhizobium* and AMF was most profitable which could be evidenced from the highest net returns and benefit: cost ratio.

N × K interaction significantly influenced the net returns and benefit: cost ratio. The maximum net income of Rs 59806.69 ha $^{-1}$ and highest benefit: cost ratio of 2.49 was obtained for the treatment n_2k_2 (30 kg N ha^{-1} + 40 kg K_2O ha^{-1}), which was significantly superior to all other treatments. Rate of increase in net income was more when various doses of potassium were combined with lower levels of nitrogen.

N×B interaction significantly influenced the net income and benefit: cost ratio. The treatment n_2b_3 (30 kg N ha $^{-1}$+ dual inoculation) fetched maximum net returns and highest benefit: cost ratio.

K× B interaction also positively influenced the economics of *Desmanthus* cultivation. The highest net returns was realized for the treatment k_2b_3 (40 kg K_2O ha^{-1} + dual inoculation).

Table 4.6. Optimum doses of nitrogen and potassium for *Desmanthus virgatus*

Item	Price (Rs)	Physical optimum dose (kg ha^{-1})	Economic optimum dose (kg ha^{-1})
N	10.87 kg^{-1}	32	31
K_2O	7.5 kg^{-1}	22	22

Table 4.7 (a) Effects of chemical fertilizers and biofertilizers on the net returns and benefit: cost ratio of *Desmanthus*

Main effects of factors	Net returns (Rs ha^{-1})	Benefit: cost ratio
n_0	21368.45	1.56
n_1	48324.00	2.23
n_2	57939.19	2.45
$F_{2,16}$	51225.34**	27352.64**
k_0	37765.70	1.96
k_1	42276.71	2.07
k_2	47589.23	2.20
$F_{2,16}$	3446.18**	1810.36**
SE_m	87.763	0.003
CD	251.134	0.008
b_1	41012.48	2.04
b_2	41043.08	2.04
b_3	45576.08	2.15
$F_{2,36}$	938.35**	493.36*
SE_m	85.727	0.003
CD	246.111	0.008

* Significant at 5% level

** Significant at 1% level

Table 4.7 (b) Interaction effects of nitrogen (N) and potassium (K) on net returns and benefit: cost of *Desmanthus*

Interaction effects of factors	Net returns (Rs ha^{-1})	Benefit: cost ratio
n_0k_0	14366.44	1.38
n_0k_1	20511.11	1.53
n_0k_2	29227.78	1.76
n_1k_0	42822.00	2.10
n_1k_1	48417.00	2.23
n_1k_2	53733.00	2.36
n_2k_0	56108.67	2.41
n_2k_1	57902.00	2.45
n_2k_2	59806.89	2.49
$F_{4, 16}$	389.97**	261.14**
SE	145.082	0.005
CD	434.976	0.015

* Significant at 5% level

** Significant at 1% level

Table 4.7 (c) Interaction effects of nitrogen (N) and potassium (K) with biofertilizers on the net returns and benefit:cost ratio of *Desmanthus*

Interaction effects of factors	Net returns (Rs ha^{-1})	Benefit: cost ratio
n_0b_1	19270.22	1.50
n_0b_2	19459.67	1.51
n_0b_3	25375.45	1.66
n_1b_1	46520.11	2.19
n_1b_2	46635.78	2.19
n_1b_3	51816.11	2.31
n_2b_1	57247.11	2.43
n_2b_2	57033.78	2.43
n_2b_3	59536.67	2.49
$F_{4,36}$	55.28**	35.14**
k_0b_1	36198.78	1.92
k_0b_2	36450.78	1.93
k_0b_3	40647.56	2.03
k_1b_1	40511.00	2.02
k_1b_2	40436.78	2.02
k_1b_3	45882.33	2.16
k_2b_1	46327.67	2.18
k_2b_2	46241.67	2.16
k_2b_3	50198.33	2.26
$F_{4,36}$	9.39*	9.31*
SE	148.484	0.005
CD	426.277	0.014

* Significant at 5% level

** Significant at 1% level

DISCUSSION

5. DISCUSSION

The present investigation was undertaken with the objective of working out an integrated nutrient management technique for *Desmanthus virgatus*(L.) Willd.(Hedge lucerne) under rainfed condition. The results of the experiment, presented in the previous chapter are discussed hereunder.

5.1. Growth characters

Results indicate that all the growth parameters namely plant height, length of branches, number of branches and leaf : stem ratio were influenced by the different levels of nitrogen applied. The highest dose of nitrogen produced the tallest plants. Influence of nitrogen in promoting vegetative growth is well established. The increase in plant height consequent to the enhancement in nitrogen application is due to increased cell division and cell enlargement which is a function of nitrogen(Tisdale *et al.*,1985).Nitrogen has a direct role in influencing the rate of photosynthesis positively since it is a constituent of protein which leads to the promotion of growth of meristematic tissues. Higher doses of nitrogen upto n_2 (30 kg ha^{-1}) increased its availability to the crop which might have resulted in increased plant height, length of branches and number of branches. Similar results have been reported in *Acacia catechu* by Ragini and Nair (1996), Akter *et al.* (1998), Singh and Singh (2000) in lucerne and Sardana and Narwal (1999) in Egyptian clover.

Potassium is important for the photosynthetic process leading to greater carbon dioxide assimilation and growth (Russel,1973). The role of potassium as an essential element for the growth of meristematic tissues has been well established (Tisdale *et al.*,1985) . Decreased level of potassium markedly reduced growth of the plants right from the seedling stage. This could be attributed to the reduced carbon dioxide fixation by the leaves or photosynthetic cotyledons which inturn resulted in a lower level of export of photosynthates from the cotyledons to other parts. This is in conformity with the findings of Camper and Lutz (1977) in soybean.

Dual inoculation with *Rhizobium* and AMF increased the growth characters in comparison with that when applied alone. Similar increase in growth parameters consequent to dual inoculation was reported by Balachandar and Nagarajan (1999) in green gram. This is attributed to the synergistic effect due to interaction between the microsymbionts.

N×K interactions were significant only for plant height and number of branches. Application of the highest dose of both the nutrients had significant influence on growth which might be due to the mutually synergistic effect of the two nutrients. Nitrogen and potassium at higher concentrations resulted in growth stimulation and enhanced uptake of both the elements(Sumner and Farine,1986). This can be attributed to the fact that the highest content of these nutrients were found in the soil at n_2 (30 kg N ha^{-1}) and k_2 (40 kg K_2O ha^{-1}) which were the levels at which the absorption by the plants was also highest. Similar results were obtained in black gram and green gram by Singh *et al.*, 1993.

Interaction between biofertilizers and nitrogen had significant effect on plant height and number of branches at the final harvest stage only. Similar effect was noticed on the number of branches also. Application of the highest dose of nitrogen(30 kg N ha^{-1}) along with dual application of biofertilizers produced maximum plant height and number of branches. This might be due to the significantly higher uptake of nitrogen in the initial stages of growth of the crop [Table 4.4.1 (a), (b) and (c)]

The nutrient levels had significant influence on the leaf : stem ratio of the plant. The role of nitrogen in increasing the leafiness of crops is well established. An increase in the leaf nitrogen levels leads to the production of extra proteins in the plant which permits the plant to have more surface area for photosynthesis resulting in enhanced growth. This inturn results in increased leaf: stem ratio.

The importance of potassium in the photosynthetic process leading to greater carbon dioxide assimilation and better growth had been emphasized by Russel (1973).

Combined application of *Rhizobium* and AMF resulted in highest leaf : stem ratio. Leaf : stem ratio is a measure of the quality of fodder and hence determine its preference by animals. Similar improvement in forage leaf: stem ratio consequent to dual inoculation was reported by Bagyaraj *et al.* (1979) in soybean and Rinj *et al.* (1987) in *Leucaena leucocephala* . Nitrogen fixation by *Rhizobium* have improved nitrogen uptake [Table 4.4.1(a)] which resulted in leafiness. Similarily , the fungal hyphae of AMF increased the uptake of phosphorus [Table 4.4.2(a)] and phosphorus is known to increase the leaf area. Increased leaf : stem ratio might be the result of the synergistic effect of the microsymbionts.

None of the interactions were significant .

Plate – 2 **Treatment combination which registered the highest green fodder and dry fodder yield**

$n_2 K_2 b_3$

5.2. Yield characters

5.2.1. Green fodder yield

The highest level of 30 kg ha^{-1} of nitrogen recorded 73.9 per cent, 63.34 per cent, 48.58 per cent and 70.26 per cent increase in green fodder yield over the lowest level in first, second, third and fourth cut respectively. The increase in green fodder yield due to the application of nitrogen is a reflection of the growth attributes namely increased plant height, length of branches, number of branches, leaf : stem ratio and as a result of increased nitrogen availability. As the level of nitrogen increases, the carbohydrates synthesized in the leaves are converted to amino acids mainly in the leaves. The extra proteins help the leaves to grow larger and have more photosynthetic area, leading to higher yield (Russel,1973). Moursi *et al.* (1976) also reported that increasing the nitrogen rates resulted in an increase in top growth and subsequent enhancement in green fodder yield of lupin.

The highest dose of potassium recorded maximum green matter yield in all four harvests. Higher levels of potassium resulted in increased green fodder yield in *Trifolium alexandrinum* (Robinson and Savoy,1989). The regrowth of lucerne was higher with potassium application (Lanyon and Smith,1985).Potassium also increases the plant height, leaf size, leaf weight, number of stomata and its apertures, net photosynthesis and efficiency of carbon dioxide assimilation.

In general, the response to higher nitrogen fertilizer dose seen in this trial might have led to increased response to higher levels of potassium also. All these might have contributed to enhanced overall vegetative growth of the plant and this could be the reason for higher green matter yield.

The treatment *Rhizobium* + AMF was significantly superior to single inoculation. Dual inoculation registered 5.6 per cent and 5.2 per cent yield increase over *Rhizobium* and AMF inoculation respectively. The plant height, number of branches and length of branches were the highest in the case of dual inoculation. This could be the reason for enhanced green matter yield for this treatment. The synergistic effect of *Rhizobium* and AMF might have induced maximum uptake of nutrients (Table 4.4.1,4.4.2. and 4.4.3) by way of enhanced nitrogen fixation and extra matricial network of AMF hyphae which functions synonymous to the root hair (Barea,1991). This inturn increased the vegetative growth reflecting in increased green matter yield. Similar enhancement in herbage production by dual inoculation has been reported by Hoque and Sattar(1989) in legumes, Chellamuthu *et al.*(1998 a) in *Desmanthus* and Rajithkumar and Potty(1998) in yam bean.

N×K interaction was significant. The highest level of nitrogen and potassium recorded maximum green fodder yield. This might be due to a balanced N-K rate requirement and its cumulative effect on fodder production.

N×B and K×B interactions were also significant. For both interactions the dual inoculation of biofertilizers in combination with the highest level of nitrogen and potassium recorded significantly higher green fodder yield which was due to the increased plant height, number of branches and length of branches.

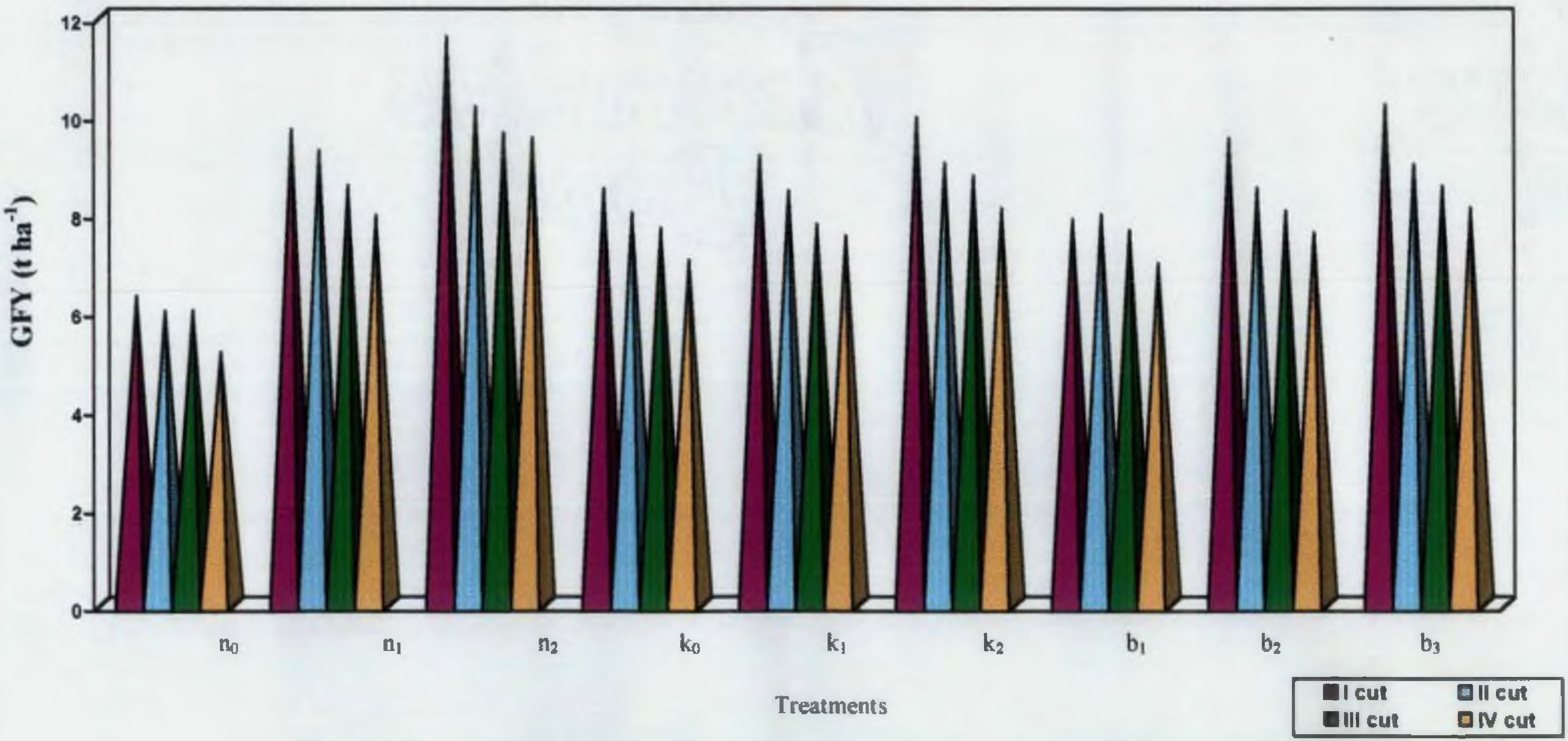


Fig. 3 Effects of chemical fertilizers and biofertilizers on the green fodder yield (t ha^{-1})

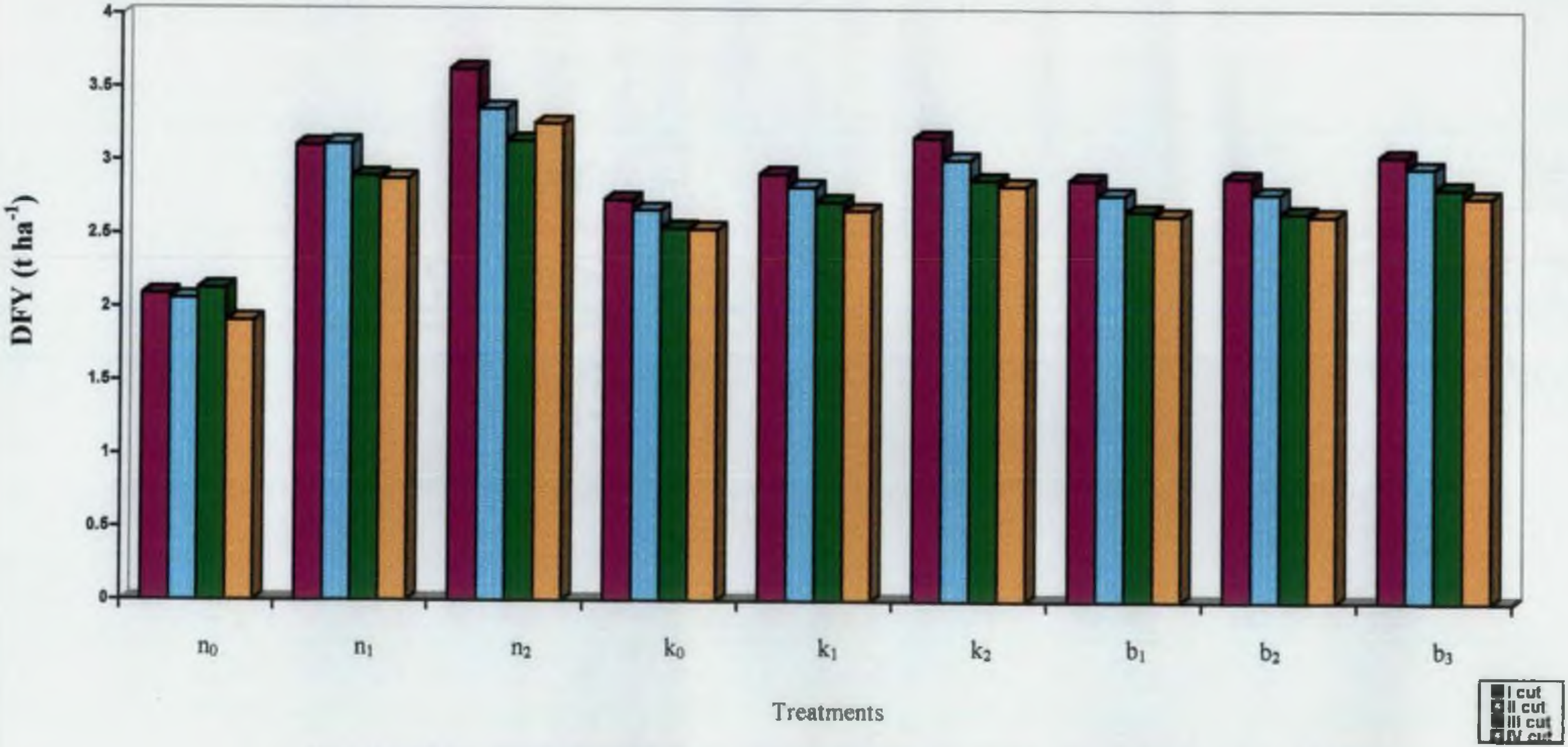


Fig. 4 Effects of chemical fertilizers and biofertilizers on the dry fodder yield (t ha^{-1})

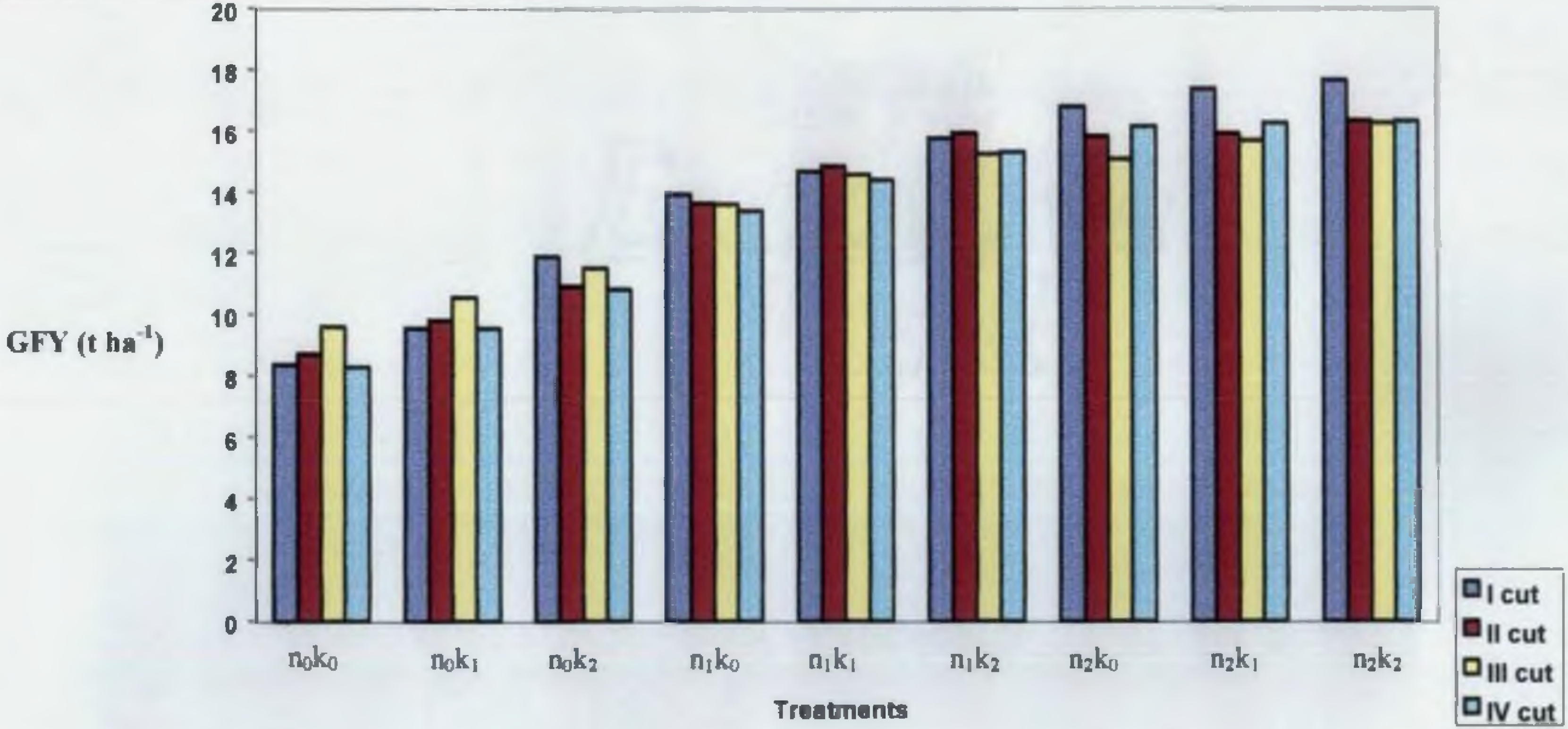


Fig. 5 Interaction effects of nitrogen (N) with potassium (K) on green fodder yield (t ha^{-1})

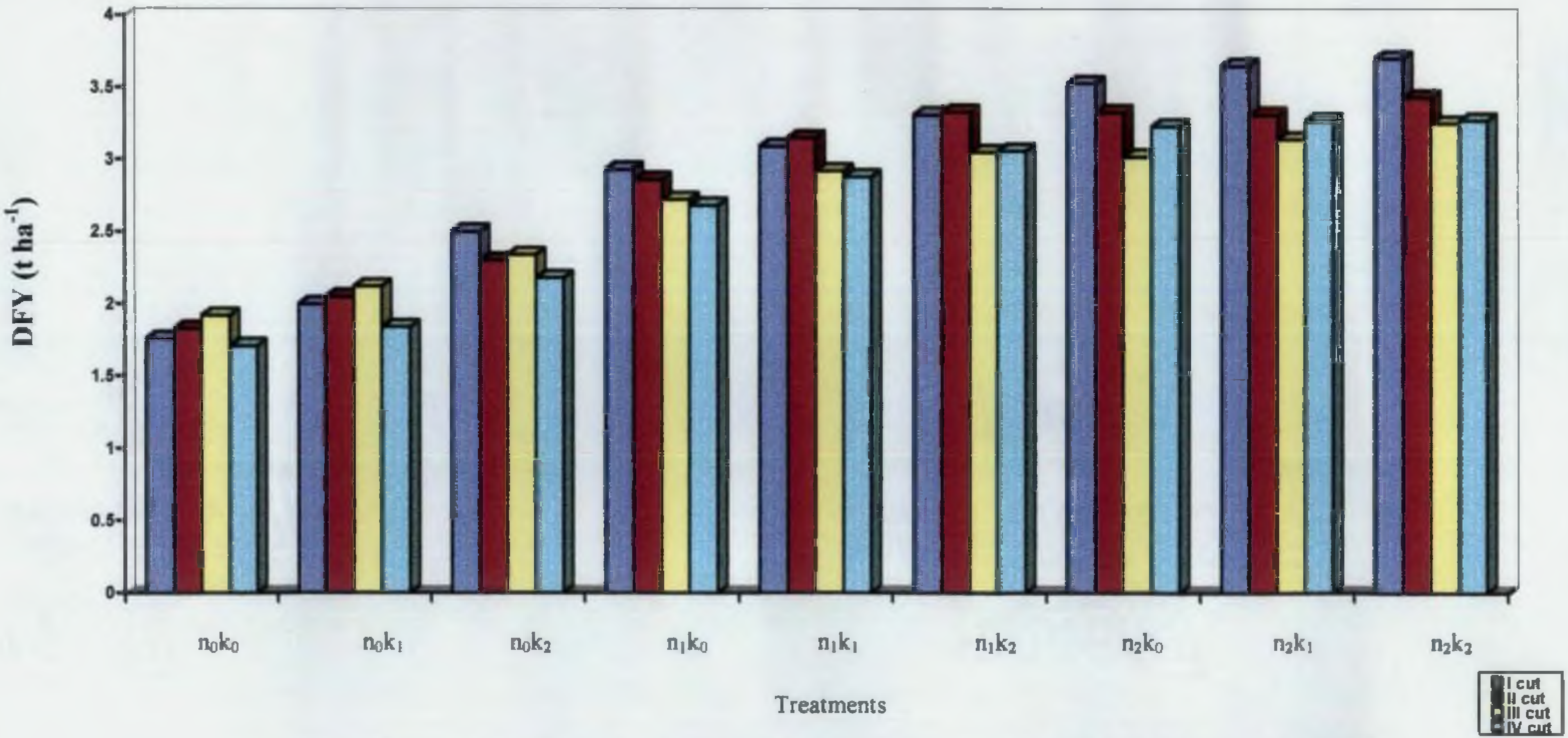


Fig. 6 Interaction effects of nitrogen (N) with potassium (K) on dry fodder yield (t ha^{-1})

5.2.2. Dry fodder yield

The highest level of nitrogen (30 kg ha^{-1}) resulted in 73.68 per cent, 63.11 per cent, 47.42 per cent and 70.68 per cent increase in dry fodder yield over no nitrogen application in first, second, third and fourth harvests respectively. Increased supply of nitrogen might have resulted in overall vegetative growth which contributed to increased dry fodder yield. The increase in dry matter production is the outcome of higher rate of growth and better accumulation of photosynthates owing to enhanced nutrient uptake. Nitrogen compounds constitute 40 to 50 per cent of the dry matter of protoplasm and because of this, at higher nitrogen levels, more dry matter production occurs. The results are in conformity with the findings of Chellamuthu *et al.*(1998 a) in *Desmanthus virgatus*, Sharma *et al.*(1992) in lucerne and Sharma *et al.* (1998) in berseem.

The highest level of potassium gave maximum dry fodder yield. This may be due to greater carbon dioxide assimilation and growth brought about by increased potassium levels (Russel,1973).Similar result was obtained in *Desmanthus* by Vasanthi *et al.*(1994).

There was significant positive response to dual inoculation with biofertilizers. Similar results were reported in lucerne by Barea *et al.*(1980), Pacovsky *et al.*(1986) in soybean and Sivaprasad and Rai (1987) in pigeon pea. Increase in plant height, number of branches and length of branches might have contributed to higher dry matter yield. The enhanced vegetative growth and high green matter yield also resulted in greater dry fodder yield.

N×K interaction significantly influenced dry fodder yield. This might be due to mutually synergistic effect of both the nutrients. Increased availability and uptake of nutrients at higher levels of nitrogen might have led to the increased uptake of potassium which led to better expression of yield attributes which ultimately resulted in higher yield.

5.3. Quality

5.3.1. Crude protein

Crude protein content of *Desmanthus* was increased at higher levels of both nitrogen and potassium. The readily available fertilizer nitrogen might have increased the protein content. Russel (1973) reported that increase in nitrogen content in a plant has a positive effect on the crude protein content. This is in conformity with the findings of Shanmugasundaram (1985) in lucerne and Desale *et al.* (1999) in fodder sorghum. Highest dose of potassium gave maximum crude protein content in *Desmanthus virgatus* (Vasanthi *et al.*,1994). Application of nitrogen and potassium fertilizers increased the crude protein content in soybean (Girenko and Levenskii, 1974).Application of nitrogen fertilizer increases the crude protein content when the other nutrient elements are not highly deficient (Ball *et al.*,1996).

Dual inoculation resulted in the highest crude protein content which may be due to the higher nitrogen content in the plant as a result of increased uptake[Table 4.4.1(a)] and assimilation of nitrogen. The major factor which enhanced protein content is plant availability of nitrogen (Capriel and Ashcroft,1972). Daft and Giahmi

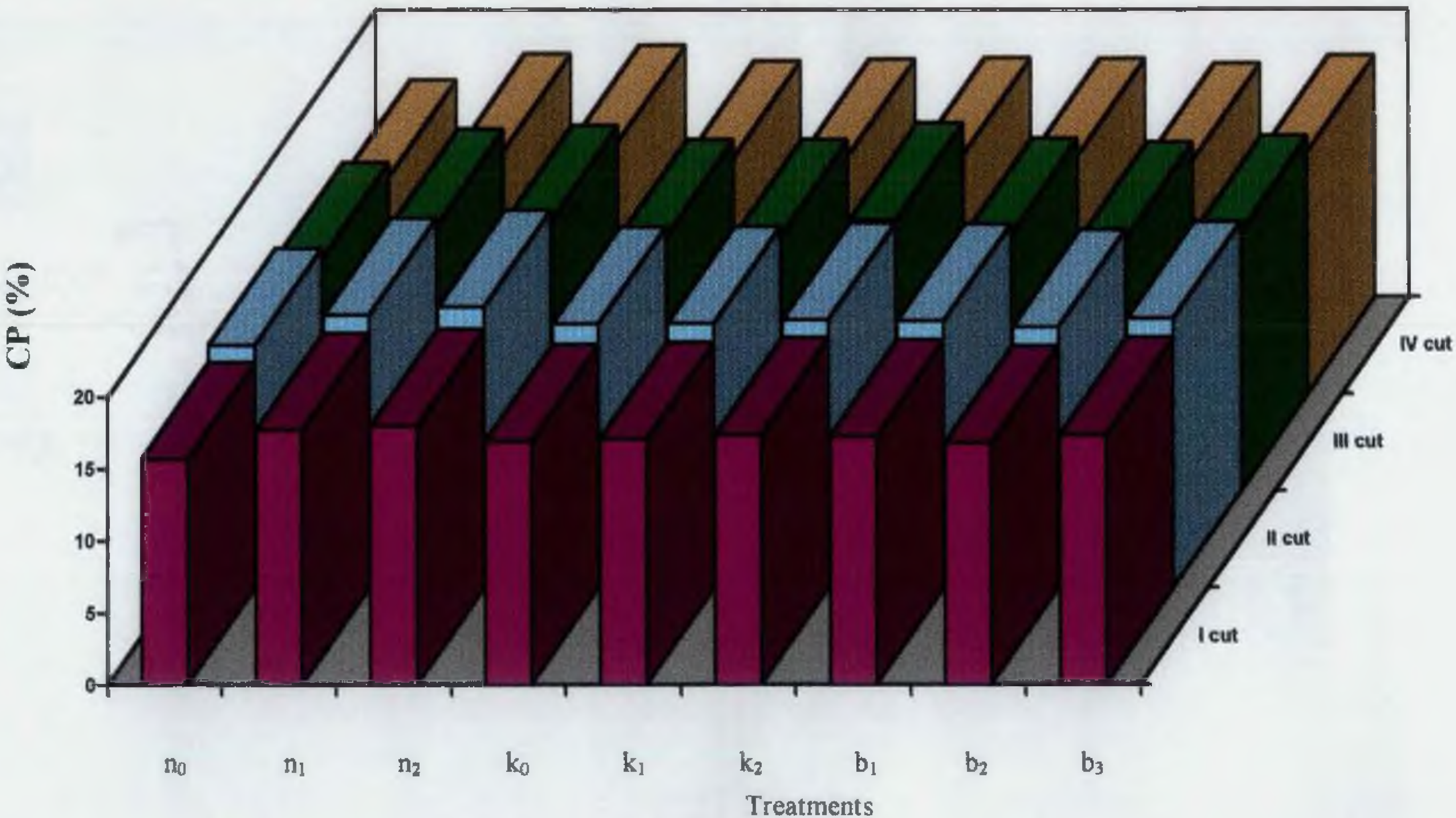


Fig. 7 Effects of chemical fertilizers and biofertilizers on the crude protein (CP) content (%)

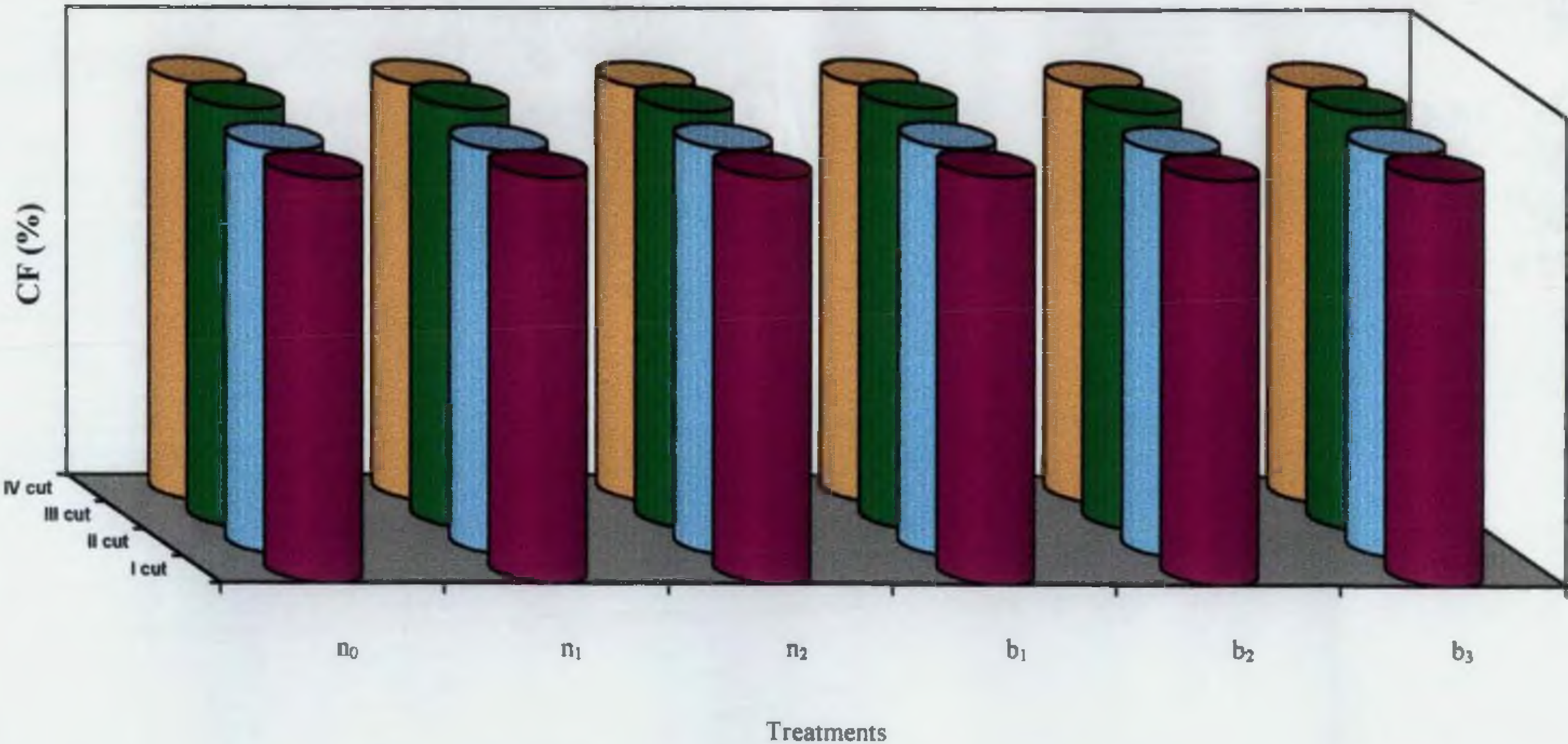


Fig. 8 Effects of nitrogen and biofertilizers on the crude fibre (CF) content (%)

(1974) had obtained similar results in cowpea. The second highest crude protein content was registered in the case of *Rhizobium* inoculated plants. This may be due to higher nitrogen content in plants. *Rhizobium,* which fixes nitrogen might have contributed to better nitrogen uptake. Increase in crude protein yield with *Rhizobium* inoculation was noticed in lucerne by Johnson(1982) and in soybean by Karyagin (1980).

The interaction effects were non-significant.

5.3.2 . Crude fibre

Crude fibre content registered a significant decrease with increase in nitrogen levels thus improving quality and palatability of fodder. This might be due to an indirect effect of nitrogen on carbohydrate metabolism. Higher levels of nitrogen might have resulted in more succulence in plants which decreased the crude fibre content (Black,1957). These results are in conformity with the findings of Tiwana *et al.* (1975) in napier-bajra hybrid, Abraham (1978) in dinanath grass and Sonia (1999) in signal grass. Crude fibre was reduced with potassium application in the third cut. Similar results were obtained by Vineetha (1995) in gamba grass and Sonia (1999) in signal grass. Dual inoculation with biofertilizers registered lowest crude fibre content and inturn better quality.

All the interactions failed to influence the crude fibre content of the plant.

5.4. Nutrient uptake

5.4.1. Nitrogen uptake

Increasing levels of nitrogen and potassium increased the uptake of nitrogen significantly. Increased doses of fertilizers resulted in better growth of plants which might have contributed to enhanced uptake. El-Bakry *et al.* (1980) reported that nitrogen application in beans increased the nitrogen content in plant parts. Elgably (1962) observed that application of nitrogen increased the root cation exchange capacity which enhanced the absorption of nutrients. The uptake of nitrogen was favourably influenced by the increasing potassium levels. The highest uptake of nitrogen was at the highest level of potassium which was due to increased dry matter production.

Dual inoculation significantly increased the uptake of nitrogen. This is in accordance with the findings of Thiagarajan *et al.* (1992). *Rhizobium*, through nitrogen fixation enhances the availability of nitrogen to plants. Smith *et al.*(1981) showed that AMF increased nitrogen inflow into the plants. AMF can absorb nitrate ions from beyond the more deficient cells around the roots. The synergistic effect of *Rhizobium* and AMF might be the reason for increased nitrogen uptake of dually inoculated plants.

N×K interaction significantly influenced the nitrogen uptake which is also due to enhanced dry matter production. Sonia (1999) obtained similar results in signal grass.

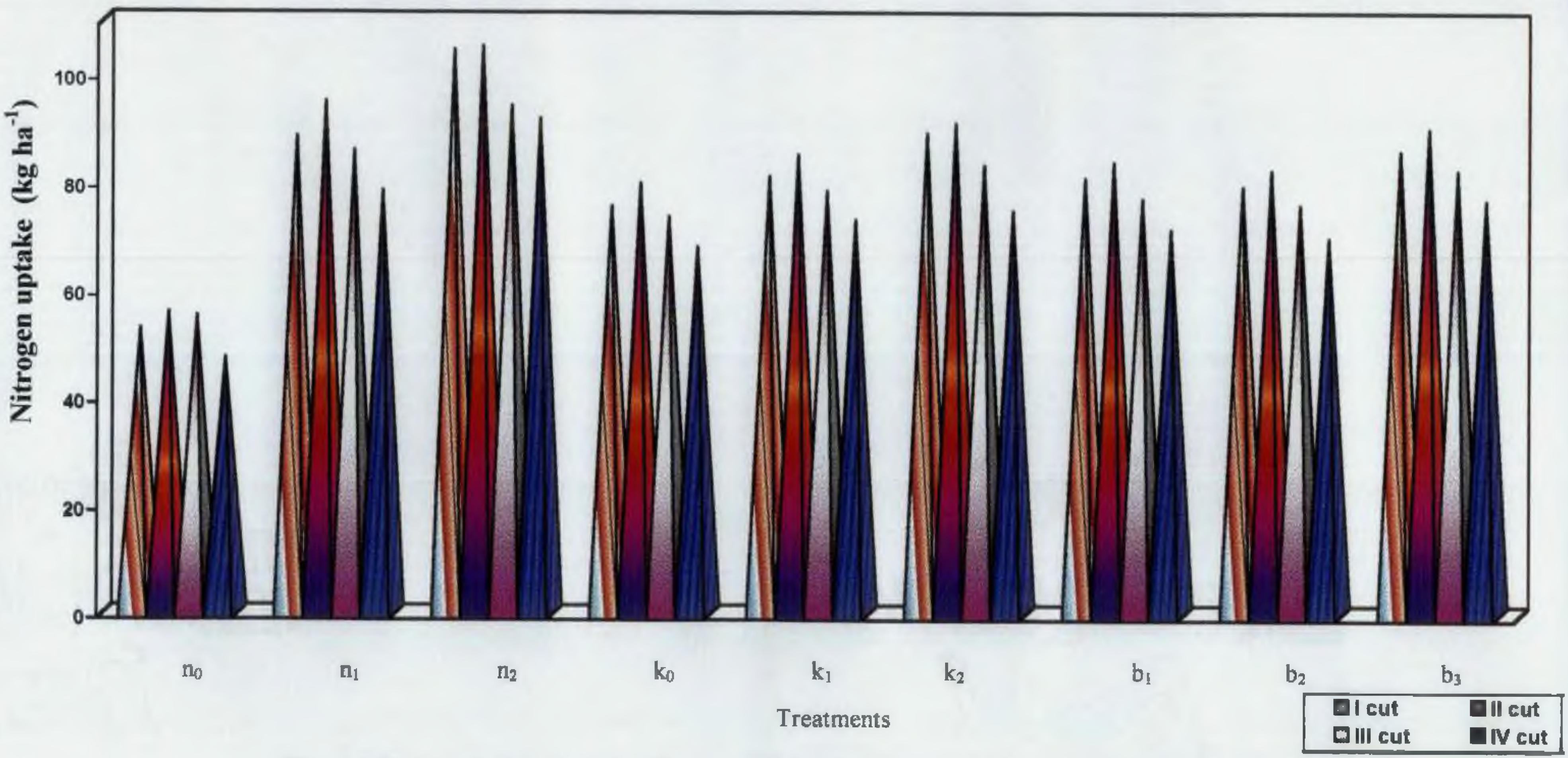


Fig. 9 Effects of chemical fertilizers and biofertilizers on the uptake of nitrogen (kg ha^{-1})

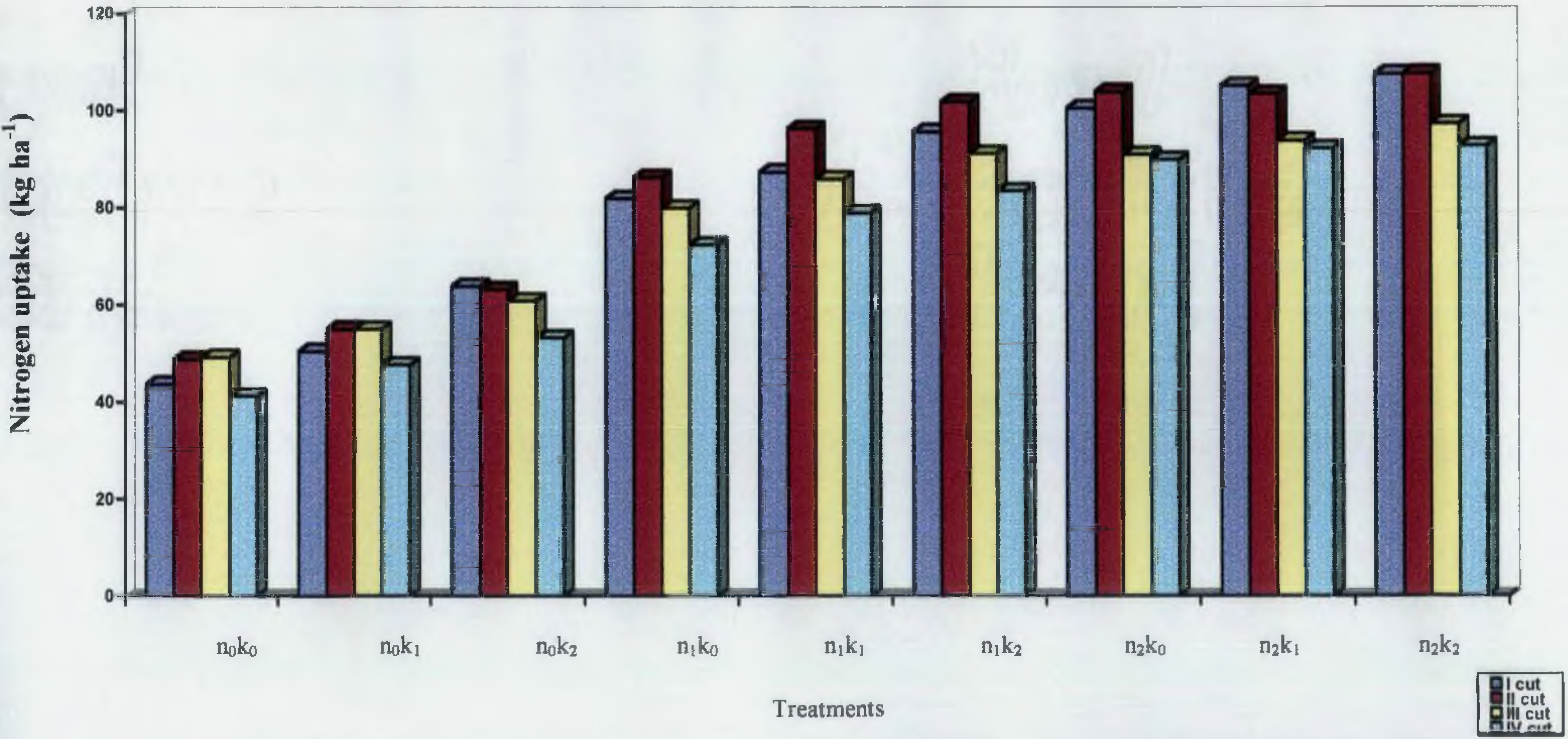


Fig. 10 Interaction effects of nitrogen (N) with potassium (K) on the uptake of nitrogen (kg ha^{-1})

N×B and K×B interactions also influenced the nitrogen uptake in first and second cuts and first cut respectively which can be attributed to the increased dry matter production at the highest levels of nitrogen and potassium in combination with the dual application of biofertilizers.

5.4.2. Phosphorus uptake

Significant increase in phosphorus uptake was obtained with increasing fertilizer levels. The enhancement in dry matter yields [Table 4.2 (a)] with increasing nutrient levels might have increased the total phosphorus recovery in the present study. Tisdale and Nelson (1975) attributed the favourable effect of nitrogen on phosphorus uptake to enhanced root growth and foraging capacity for phosphorus, better top growth thus increasing the need for phosphorus, residual acidity thus increasing phosphorus availability and salt effects of nitrogen compounds on phosphorus solubility.

Dual inoculation with biofertilizers gave significantly high phosphorus uptake. AMF can take better advantage of their geometry and better distribution than roots to acquire phosphate from transistory localized and diluted sources of the element (Harley and Smith, 1983). There are indications that AMF hyphae are able to take up phosphate from soil solutions with low phosphate concentrations more efficiently than simple roots (Barea, 1991). The better growth and yield of plants consequent to dual inoculation may have contributed to better phosphorus uptake by them. This is in conformity with the findings of Crush (1974) in herbage legumes and Daft and Giahmi (1974) in *Phaseolus*.

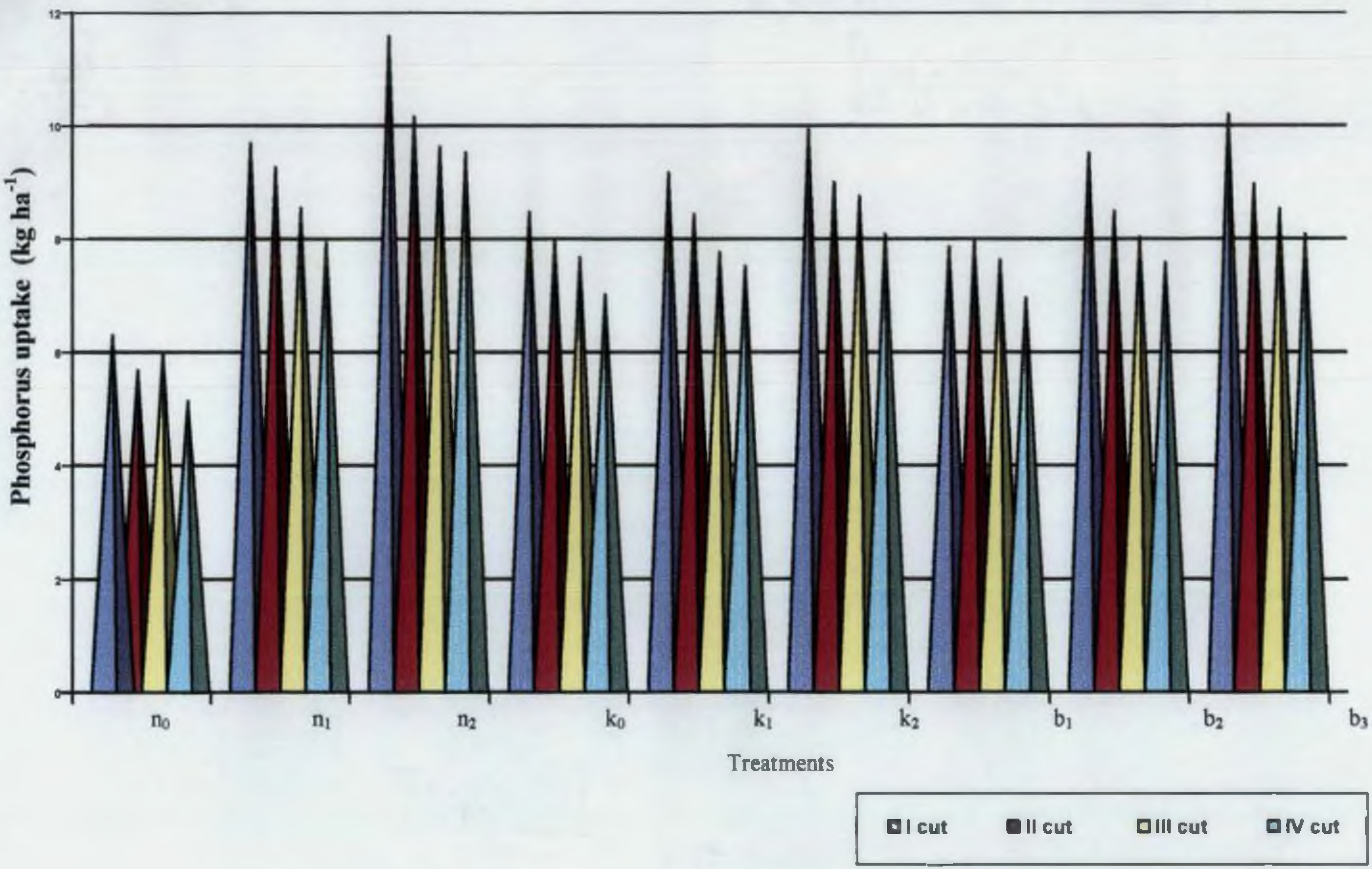


Fig. 11 Effects of chemical fertilizers and biofertilizers on the uptake of phosphorus (kg ha^{-1})

N×K interaction was significant in first, second and third cuts which is due to he above mentioned reasons. N×B interaction was significant in first, second and fourth cuts . K× B interaction was significant only in the first harvest.

5.4.3. Potassium Uptake

There was significant increase in uptake of potassium with increasing levels of nutrients. A stimulated growth under higher levels of fertilizer application might have resulted in better proliferation of root system and increased intake efficiency of plants. Similar results of increased uptake with increasing potassium concentration was reported by Robinson and Savoy (1989) in *Trifolium repens* and Balasko (1977) in tall fescue forage. The higher dry matter production with highest fertilizer dose [Table 4.2.1 (a)] might have contributed to the enhanced uptake of nutrients.

There was significant increase in potassium uptake due to inoculation. The highest potassium uptake was recorded by duel inoculation. AMF increases potassium uptake resulting in an increment in shoot growth (Nielson and Jenson, 1983). Mycorrhizal infection has been found to improve the potassium nutrition of *Trifolium subterraneum*. The increased potassium uptake might also be the result of improved phosphorus nutrition (Smith *et al*., 1981). The *Rhizobium* treatment could have contributed to better nodulation and hence better availability of nutrients to the crop. The synergistic effect might have resulted in maximum uptake of potassium by *Desmanthus* consequent to dual inoculation.

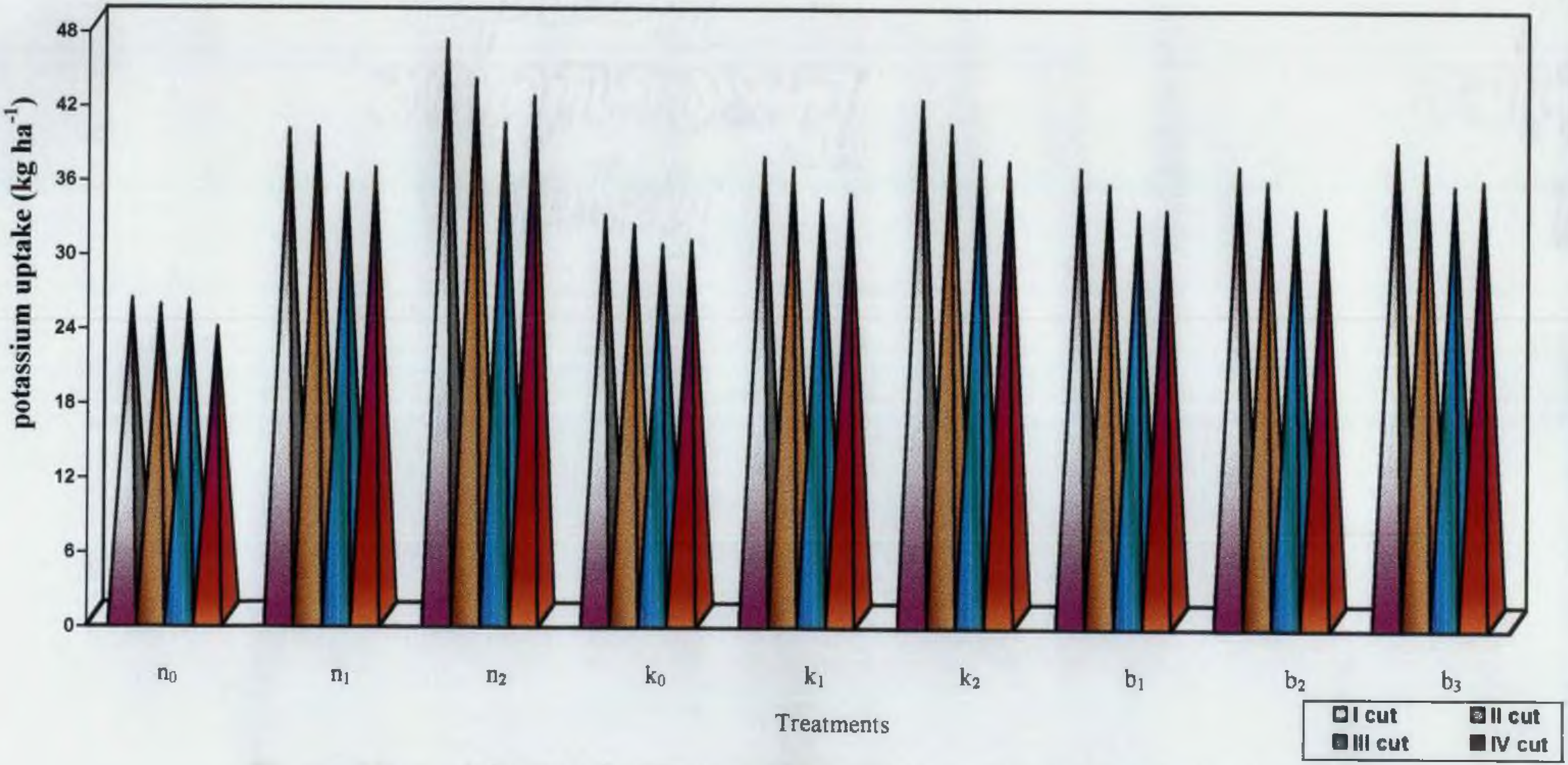


Fig. 12 Effects of chemical fertilizers and biofertilizers on the uptake of potassium (kg ha^{-1})

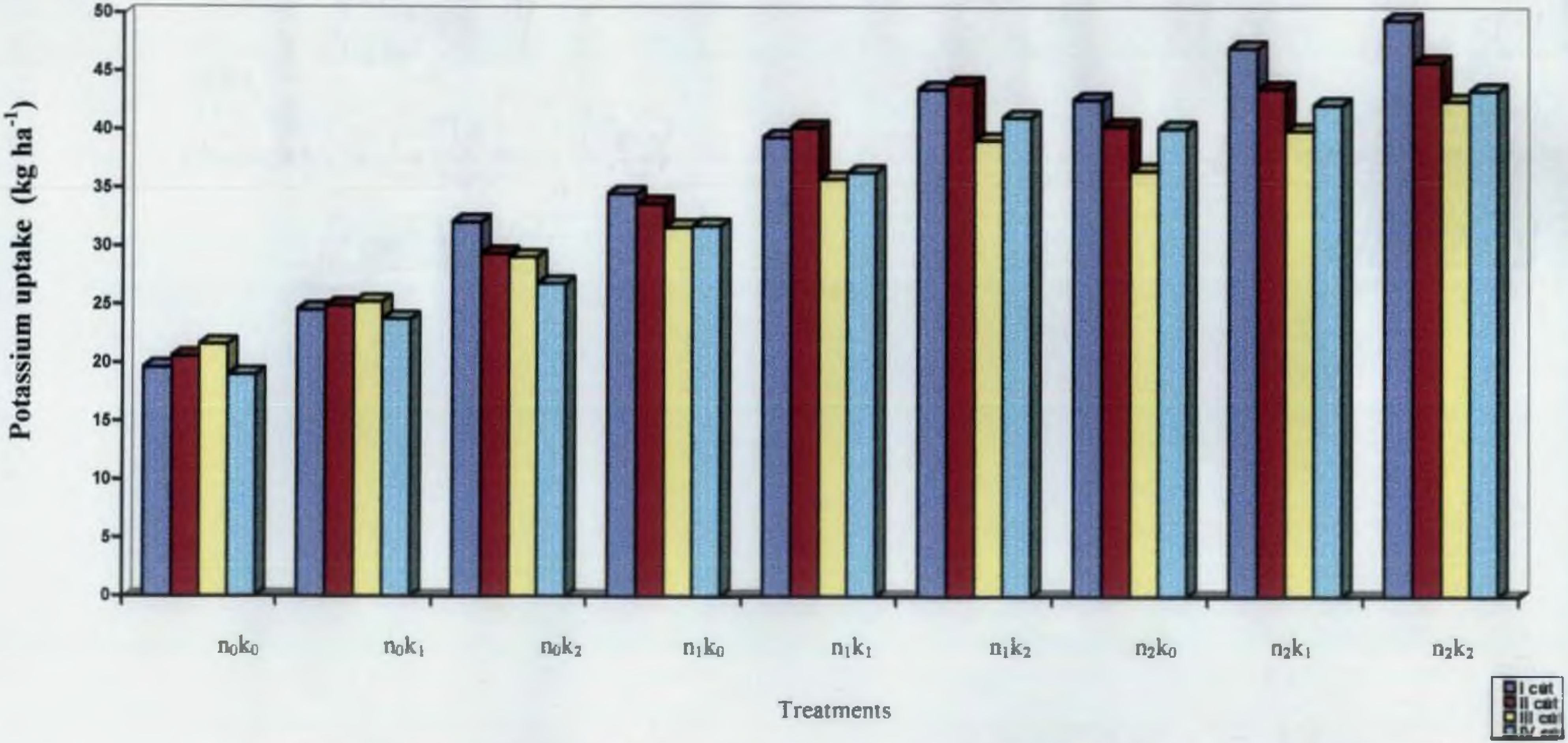


Fig. 13 Interaction effects of nitrogen (N) with potassium (K) on the uptake of potassium (kg ha^{-1})

N×K interaction was significant in all the harvests. N×B interaction significantly influenced the uptake of potassium in first, third and fourth harvests.

K×B interaction was insignificant

5.5. Nutrient status of soil after the experiment

5.5.1. Available nitrogen status

The different nitrogen levels significantly influenced the available nitrogen status of the soil. Higher levels increased the available nitrogen status of soil. Increase in soil nitrogen status with increased application of nitrogenous fertilizers had been reported by Lee *et al.*, (1990) in *Medicago sativa* and also by Bhavanse *et al.*, (1992). Dual application of biofertilizers was found to be superior to single application in improving the nitrogen status of the soil. This could be attributed to a steady enrichment of rhizosphere through biological nitrogen fixation.

The main treatment effects of potassium as well as the interaction effects were non-significant.

5.5.2. Available phosphorus status

The nitrogen and potassium levels did not influence the available phosphorus status of soil. The results confirm the findings of Kanwar (1978). Dual inoculation and application of AMF significantly improved the available phosphorus status of the soil. This is in conformity with the finding of George, 1996.

All the interaction effects were non-significant.

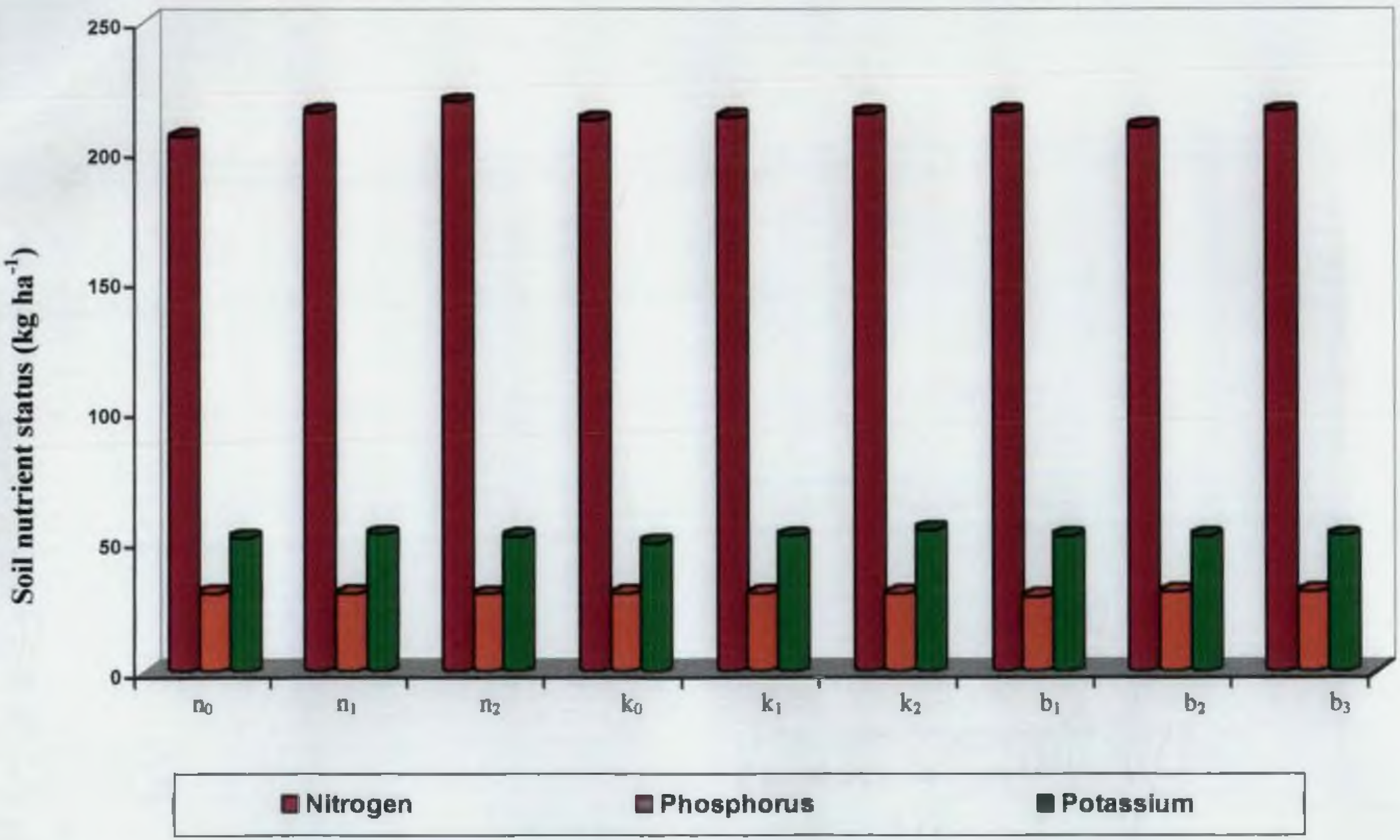


Fig. 14 Effect of chemical fertilizers and biofertilizers on available nitrogen, phosphorus and potassium status of soil after the experiment (kg ha^{-1})

5.5.3. Available potassium status

Significant increase in available potassium status of the soil was observed with increase in potassium application. This might be due to increased potassium fixation which increased slowly available fixed form there by increasing potassium status of soil (Johnkutty, 1981). The results are in conformity with the findings of Vineetha (1995) in gamba grass and Sonia (1999) in signal grass.

5.6. Response surface and standardization of response to applied nutrients

The relationship between applied nutrients and green fodder yield was estimated by fitting a quadratic response surface. From this, the physical optimum and economic optimum doses of nitrogen and potassium were estimated. The economic optimum dose was estimated by computing the price of green fodder and cost of fertilizers. The physical and economic optimum doses estimated for nitrogen were 32 kg ha^{-1} and 31 kg ha^{-1} respectively. In the case of potassium, the physical optimum and economic optimum dose was 22 kg ha^{-1}.

The response of crops to fertilizer application directly depends upon the available nutrient status of the soil and a low status of available nitrogen means the crops on such soils will respond very readily to nutrient application. In the present study, the initial soil nitrogen status was low (197.80 kg ha^{-1}) which explains the reason for better response to applied nitrogen. This is why the physical optimum dose went upto 32 kg ha^{-1}. Since the vegetative growth and green fodder yield of the crop increased with increasing nitrogen levels, the economic optimum dose of nitrogen was 31 kg ha^{-1}.

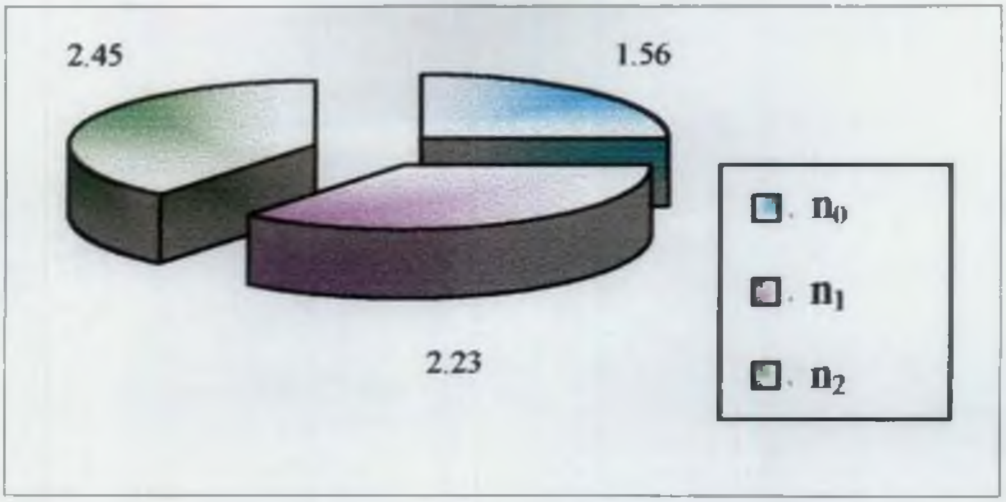
Optimum potassium dose for *Desmanthus virgatus* was found to be 22 kg ha^{-1} which indicates the scope for reducing the quantity of potassium applied. This might be due to the interaction effect of nitrogen and potassium. Even though green matter yield was maximum for the treatment combination n_2k_2 (30 kg N ha^{-1} + 40 kg K_2O ha^{-1}), the rate of increase in green fodder yield decreased when higher doses of potassium were combined with highest dose of nitrogen [Table 4.2 (b)]

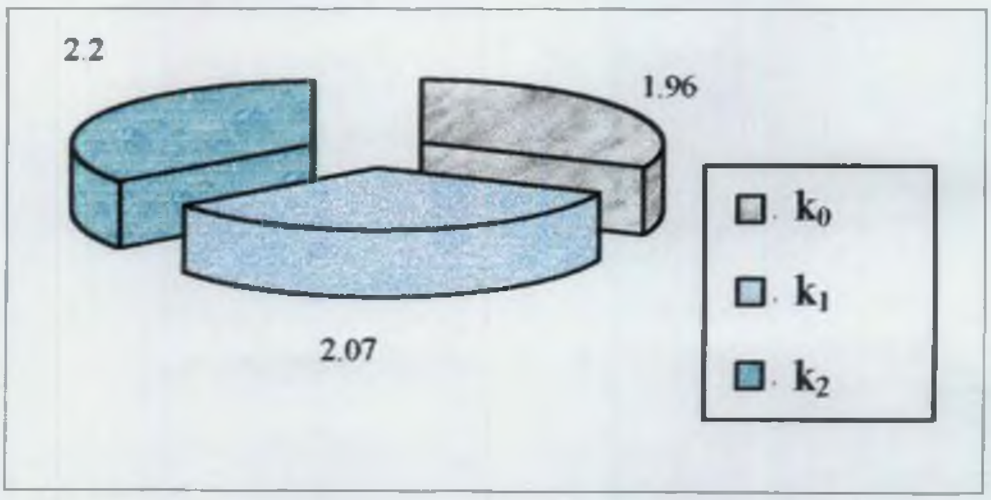
5.7. Economics

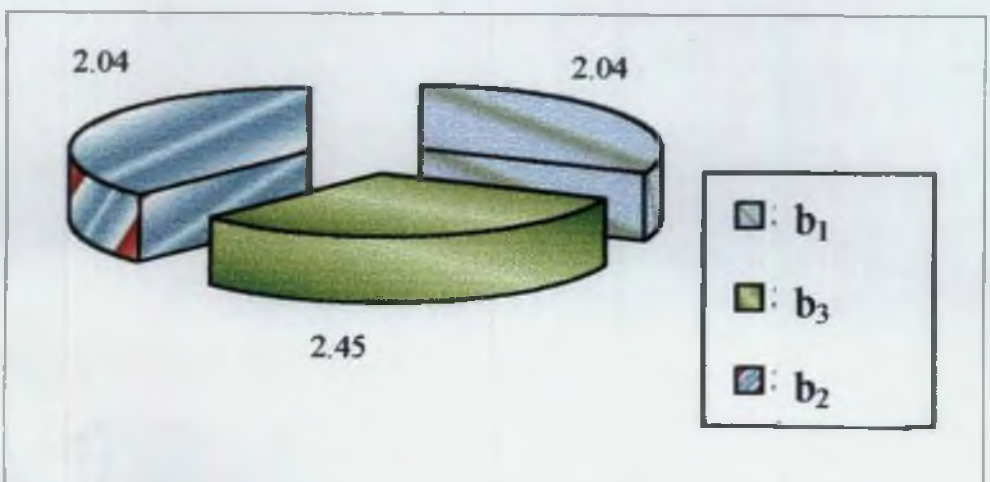
Highest net returns and benefit: cost ratio was obtained for highest dose of fertilizers and dual inoculation. The results clearly indicate that dual inoculation of *Desmanthus virgatus* with *Rhizobium* and AMF is a paying proposition. Combined inoculation gave highest benefit: cost ratio and 11 per cent increase in net returns over single inoculation. This is mainly due to the higher green fodder and dry fodder yields realized from the said treatments.

Benefit: cost ratio was highest for the combinations, n_2k_2 (30 kg N ha^{-1} + 40 kg K_2O ha^{-1}), n_2b_3 (30 kg N ha^{-1} + dual inoculation) and k_2b_3 (40 kg K_2O ha^{-1}+ dual inoculation). The increased green and dry fodder yields obtained from these treatments explains the high benefit: cost ratio and net returns registered by the said treatments.

Fig. 15 Effects of chemical fertilizers and biofertilizers on benefit: cost ratio







SUMMARY

6. SUMMARY

An investigation was undertaken in the Instructional farm, College of Agriculture, Vellayani to find out an integrated nutrient management technique for *Desmanthus virgatus* (L.) Willd. (Hedge lucerne) under rainfed condition.

The experiment was laid out in split plot design with three replications. Combinations of three levels of nitrogen (0, 15, 30 kg N ha^{-1}), three levels of potassium (0, 20 and 40 kg ha^{-1}) and biofertilizers (*Rhizobium*, AMF, *Rhizobium* + AMF) formed twenty seven treatment combinations.

The salient findings of the experiment are summarized below.

1. Growth characters namely plant height, length of branches, number of branches and leaf: stem ratio increased significantly with increasing doses of nitrogen and potassium. Dual inoculation with *Rhizobium* and AMF along with nitrogen and potassium application was superior to single inoculation in influencing the growth parameters.

2. Significant increase in green fodder yield was obtained by the application of chemical fertilizers and biofertilizers. Green fodder yield was maximum when highest dose of nitrogen (30 kg ha^{-1}) and potassium (40 kg ha^{-1}) were applied. In all the harvests, highest green fodder yield was recorded for dual inoculation with biofertilizers.

3. Chemical fertilizers and biofertilizers could significantly influence the dry fodder yield of the plant in all four harvests. Highest dose of nitrogen and potassium gave maximum dry fodder yield. Dual inoculation with biofertilizers recorded highest dry fodder yield which was significantly superior to single inoculation.

4. Quality of fodder was improved by the application of nitrogen. Crude protein content of the plant enhanced with increase in dose of nitrogen and potassium. Dual application of biofertilizers along with application of nitrogen and potassium resulted in highest crude protein content. Crude fibre content of the plant reduced significantly with nitrogen application. Combined application of *Rhizobium* and AMF decreased the crude fibre content of the plant significantly.

5. Application of nitrogen, potassium and biofertilizers significantly influenced the nitrogen uptake by *Desmanthus* in all four harvests. Highest dose of nitrogen and potassium registered maximum uptake of nitrogen. Dual application of biofertilizers also increased nitrogen uptake. The same trend was noticed in the case of phosphorus and potassium uptake also.

6. The available nitrogen status of the soil was influenced by various nitrogen levels to a significant extent. An increase in nitrogen application resulted in an increase in available nitrogen status of the soil after the experiment. *Rhizobium* inoculation and dual application of biofertilizers significantly increased the nitrogen status of the soil.

7. Dual inoculation and AMF application improved the phosphorus status of the soil after the experiment.

8. Highest dose of potassium (40 kg K_2O ha^{-1}) registered highest available potassium status of the soil, after the experiment.

9. The physical and economic optimum doses of nitrogen for *Desmanthus virgatus* were 32 kg ha^{-1} and 31 kg ha^{-1} respectively. The physical and economic optimum dose of potassium was found to be 22 kg ha^{-1}.

10. The net returns and benefit cost ratio was positive for all the treatments. Highest dose of nitrogen and potassium along with dual application of biofertilizers registered maximum net returns and benefit: cost ratio.

FUTURE LINE OF WORK

The results of the present investigation projected that the nitrogen and phosphorus status of the soil after the experiment was enhanced consequent to dual inoculation with biofertilizers. In future, a long term experiment on *Desmanthus virgatus* should be conducted and the scope of investigation should be extended to find out the extent to which the inorganic fertilizers could be substituted with biofertilizers.

REFERENCES

REFERENCES

*A.O.A.C 1975. *Official and Tentative Methods of Analysis.* Association of Official Agricultural Chemists. 12th Ed. Benjamin Franklin Station, Washington, D.C. pp. 130-137

Abraham, C.T. 1978. Performance of dinanath grass (*Pennisetum pedicellatum Trim.)* as influenced by nitrogen and lime on forage quality of dinanath grass. *Forage Res.* **6:** 95-98

Agboola, A.A. 1978. Influence of soil organic matter on cowpea's response to nitrogen fertilizers. *Agron. J.* **70**: 25-28

Akter, S., Farid, A.T.M., Shil, N.C. and Rahman, M. 1998. Effect of different fertilizers on nodulation and yield of cowpea. *Legume Res.* **21**: 74-78

Ardeshna, R.B., Modhwadia, M.M., Khampara, U.D. and Patel, J.C. 1993. Response of green gram (*Phaseolus radiatus*) to N, P and *Rhizobium* inoculation. *Indian J. Agron.* **38**: 490-492

Asimi, S., Gianinazzi-Pearson, V. and Gianinazzi, S.C. 1980. Influence of increasing soil phosphorus on interaction between vesicular arbuscular mycorrhiza and *Rhizobium* in Soyabeans. *Can. J. Bot.* **58**: 2200-2205

Bagyaraj, D.J. 1990. Ecology of VA mycorrhizae. In: *Hand book of Applied Mycology. Vol.1. Soil and plants.* Arora, D.K., Rai, B., Mukherji, K.G and Knudesen, G.R. (eds.)., Marcel Dekker, Inc. New York. pp: 3-34

Bagyaraj, D.J. and Manjunath, A. 1980. Response of crop plants to VA mycorrhizal inoculation in an unsterile Indian soil. *New Phytol.* **85:** 33-36

Bagyaraj. D.J., Manjunath, A. and Patel, R.B. 1979. Interaction between a vesicular arbuscular mycorrhiza and rhizobia and their effects on soybean in the field. *New Phytol.* **82:** 141-145

Bajpai, P.D. and Gupta, B.R. 1979. Effect of salinization, phosphorus fertilization and their interaction on the symbiosis between *Rhizobium trifolii* and berseem (*Trifolium alexandrinum L.). J. Indian Soc. Soil Sci.* **27**: 462-469

Balachandar, D. and Nagarajan, P. 1999. Dual inoculation of vesicular arbuscular mycorrhiza and *Rhizobium* in green gram. *Legume Res.* **22**: 177-180

Balaji, S. and Rangarajan, M. 1987. Growth and nodulation of *Acacia nilotica* inoculated with three Rhizobial strains. *Nitrogen Fixing Tree Res. Rep.* **7**: 38

Balasko, J.A. 1977. Effects of N, P and K fertilization on yield and quality of tall fescue forage in winter. *Agron. J.* **69**: 425-428

Ball, D.M., Hoveland, C.S. and Lacefield, G.D. 1996. *Southern Forages.* II Edn. Potash and Phosphate Institute and the Foundation for Agronomic Research, U.S.A. pp. 85-88

Barea, J.M. 1991. Vesicular – arbuscular mycorrhizae as modifiers of soil fertility. *Advances in soil science.* 15, Springer verlag, New York, Inc. pp. 1-40

Barea, J.M., Azcon-Aguilar, C. and Azcon, R. 1987. Vesicular arbuscular mycorrhiza improve both symbiotic nitrogen fixation and nitrogen uptake from soil as assessed with a ^{15}N technique under field conditions. *New Phytol.* **106**: 717-725

Barea, J.M., Escudero, J.L. and Azcon-G-De-Aguilar, C. 1980. Effects of introduced and indigenous VA mycorrhizal fungi on nodulation, growth and nutrition of *Medicago sativa* in phosphate fixing soils as affected by phosphatic fertilizers. *Pl. Soil.* **54**: 282-296

Barik, A.K. and Tiwari, D.P. 1998. Effect of cutting management and nitrogen on yield attributes and forage yield of berseem – 37. *Forage Res.* **24**: 37-40

Barnett, B.D. 1986. Nitrogen fixing trees benefit rotation crops, tropical legumes inoculated with rhizobia tolerate poor soils. *J. Forestry*.**84**: 48-49

Basu, T.K., Barui, A.K. and Bandopadhyay, S.1989. Nodulation, growth and seed yield of mung in response to *Rhizobium* inoculation and nitrogen application. *Indian J. Myco. Res.* **27**: 153-157

Bayalis, C.T.S. 1959. Effect of vesicular-arbuscular mycorrhiza on the growth of *Griselimer littoralis. New Phytol.* **58:** 274-280

Beena, S., Mathew, J. and Nair, S.K. 1990. Varietal response and host varietal specificity for nodulation by *Rhizobium* in cowpea. *Legume Res.* **13** : 136-138

Bethenfalvay, G.J. and Franson, R.L. 1989. Manganeese toxicity alleviated by mycorrhizae in soybean. *J. Plant. Nutri.* **12:** 953-970

Bhavanse, D.B., Patel, A.J. and Kulkarni. S.D. 1992. Studies on recycling of crop residues in soil and its effect on rabi sorghum under dryland condition. *Proc. Nat. Sem. Org. Fmg.* pp. 18-20

Bhuiya, Z.H., Islam, M.R., Uddin, M.J. and Hoque, H.S. 1986. Performance of some *Rhizobium* inoculants on black gam *(Vigna mungo)*. *Bangladesh J. Agric.* **11**: 55-63

Biswas, B.C., Das, S. and Kalwe, S.P. 2001. Crop response to biofertilizer. *Fert. News.* **46**: 15-24

Black, C.A. 1957. *Soil plant relationships.* John Wiley and Sons. Inc. New York. pp. 700-792

Bouyoucos, G.J. 1962. Hydrometer method improved for making particle size analysis of soil. *Agron. J.* **54**: 464-465

Camper, H.M. and Lutz, J.A. Jr. 1977. Ploughsole placement of fertilizers for soybeans and response to tillage of ploughsole. *Agron. J.* 69: 701-704

Capriel, M. and Ashcroft, G.H. 1972. Effect of irrigation, harvest interval and nitrogen on the yield and nutrient composition of napier grass. *Agron. J.* **64**: 376-378

Champawat, R.S 1990. Effect of mycorrhizal inoculation and phosphorus fertilizer on growth and mineral uptake of groundnut (*Arachis hypogaea). Indian J. agric.* Sci. **60** : 425-427

Champawat, R.S. 1989. Effect of vesicular arbuscular mycorrhizal fungi on growth and nutrition of chick pea. *Madras agric. J.* **76**: 310

Chand, K.M.L., Dixit, and Bhyankari, D.K. 1993. Effect of phosphorus on content and uptake of nitrogen and potassium in forage sorghum genotypes. *Forage Res.* **19**: 62-68

Chandrababu, R., Sadasivan, R., Natarajaratnam, N. and Sreerangasamy, S.R. 1975. Effect of potassium nutrition on growth and yield of black gram. *Madras agric. J.* **72** : 595-596

Chandrasekhara, C.P., Patil, C.V. and Sreenivasa, M.N. 1995. VAM mediated P effect on growth and yield of sunflower (*Helianthus annus* L.) at different P levels. *Pl. Soil.* **176**: 325-328

Chang, K.P., Hu, H.T. and Kao, P.C. 1986. Effect of endomycorrhizal fungi and *Rhizobium* inoculation on growth of *Acacia auriculiformis*. *Nitrogen Fixing Tree Res. Rep.* **4**: 40-41

Chellamuthu, V., Khan, F.A.K. and Malarvizhi, P. 1998 b. Studies on the effect of biofertilizers on the fodder yield of lucerne. *Forage Res.* **23**: 201-205

Chellamuthu, V., Khan, F.A.K., Malarvizhi, P., Muralidaran, C. and Peciappan, S. 1998 a. Effect of biofertilizers and inorganic fertilizers on the fodder yield of *Desmanthus virgatus* under rainfed condition. *Forage Res.* **23**: 163-168

Collins, M., Lang, D.J. and Kelling, K.A. 1986. Effects of phosphorus, potassium and sulfur on alfalfa nitrogen fixation under field conditions. *Agron. J.* **78**: 959-963

Crush, J.R. 1974. Plant growth responses to vesicular arbuscular mycorrhiza. VII. Growth and nodulation of some herbage legumes. *New Phytol.* **73**: 743-749

Dadson, R.B. and Sequaah, G. 1984. *Rhizobium japonicum*, nitrogen and phosphorus effects on nodulation, symbiotic nitrogen fixation and yield of soybean (*Glycine max* (L.) Merill.) in the southern savanna of Ghana. *Field Crps. Res.* **9**: 101-108

Daft, M.J. and Giahmi, A.A. 1974. Studies on nodulated and non-nodulated peanuts. *Ann. Appl. Biol.* **83**: 273

*Daroy, L.G., Shajahan, M.M., Faroe, R.F. and Ladha, J.K. 1987. Preliminary report on the response of *Sesbania rostrata* to inoculation under flooded and unflooded conditions. Abst. FCSSP papers. *The Philip. J. Crop. Sci.* **11**: 80-83

Desale, J.S., Babar, R.M., Pathan, S.H. and Bhilare, R.L. 1999. Effect of biofertilizers with various nitrogen levels on green forage yield of sorghum. *Forage Res.* **24**: 195-198

Desmukh, H.G. and Joshi, R.N. 1973. Effect of rhizobial inoculation on the extraction of protein from the leaves of cowpea (*Vigna sinensis*). *Indian J. agric. Sci.* **43**: 539-542

Devi, G.L., Pillai, R.G., Asan., B.R., Kumar, A.A.S. and Swadija, K.O. 1993. Fodder production potential of *Stylosanthes* as influenced by microbial inoculants in Cassava (*Manihot esculenta* C.) based intercropping system. *Forage Res.* **19**: 223-226

Dhar, S.N. 1978. Studies on the effects of different levels of phosphorus on the yield and quality of berseem (*Trifolium alexandrinum*). *Aust. J. Bot.* **22**: 23-26

Doss, D.J., Bagyaraj, D.J. and Syamsunder, J. 1983. Anatomical and histochemical changes in the roots and leaves of fingermillet colonized by VA mycorrhiza. *Indian J. Microbiol.* **28**: 276-280

Edge, O.T., Mughogho, L.K. and Ayonaudu, U.W.U 1975. Response of dry beans to varying nitrogen levels. *Agron. J.* **67**: 251-255

*El-Bakry, (AM,I)., Midan, A.A., Malash, N.M. and Omran, A.F. 1980. Effect of phosphate as localized or foliar applications and nitrogenous fertilizers along with their interactions on snap bean plants. I Growth and chemical constituents. *Monugies J. agric. Res.* **3**: 311-325

Elgably, M.M. 1962. On the mechanism of anion uptake by plant roots. 2. Effect of roots on uptake. *Biol. Sci.* **93**: 350-361

*El-leboudi, A., Maksoud, A. and Midan, A. 1974. A note on interaction between nitrogen and phosphorus in snap bean plants. *Egypt. J. Soil Sci.* **16**: 21-35

Enikov, V. and Velchov, V. 1976. Effect of nitrogen and phosphorus on yield and chemical composition of chick pea. *Pochovoznomic i Agrokhimiyia.* **11**: 19-26

Eranna, A. and Parama, V.R.R. 1994. Effect of liming, mycorrhizal inoculation and rock phosphate on phosphorus uptake and growth of soybean in an acid soil. *Mysore J. agri. Sci.* **28**: 292-296

Falade, J.A. 1973. Effect of phosphorus on the growth and mineral composition of four tropical forage legumes. *J. Sci. Food. Agric. Abstr.* **24**: 795-802

Galiana, A., Prin, Y., Mallet, B., Gnahoua, G.M., Poitel, M. and Diem, H.G. 1994. Inoculation of *Acacia mangium* with alginate bead containing selected *Bradyrhizobium* strains under field conditions. Long-term effect on plant growth and persistence of the included strains in soil. *Appl. Environ. Microbiol.* **60**: 3974-3980

Geethakumari, V.L. 1981. Phosphorus nutrition of cowpea (*Vigna unguiculata* (L.) Sairexx Hassk.). M.Sc. (Ag.) thesis, Kerala Agricultural University, Thrissur. pp. 65-78

George, S. 1996. Agronomic evaluation of biofarming techniques for forage production in coconut gardens. Ph. D. thesis, Kerala Agricultural University, Thrissur, pp. 120-144

*Girenko, A.P. and Levenskii, A. 1974. Fertilization for maize-soyabean mixture. *Kurkuruza*. **5**: 21-22

Goicoechea, N., Antolin, M.C., Sanchez-Diaz, M. 1997. Influence of arbuscular mycorrhizal fungi and *Rhizobium* on nutrient content and water relations in drought stressed alfalfa. *Pl. Soil*. **192**:216-268

*Gregr, V. 1990. Nutrient intake in winged bean and cowpea in relation to inoculation in seed. *Agric. Tropic. et Subtropic.* **23**: 39-46

Groneman, A.F. 1974. Effect of deep placement of nitrogen, phosphorus and potassium fertilizers on dry matter production, nodulation, chemical composition and yield of soybean. *Diss Abstr. Int. Bull.* **34**: 4787

Gupta, R.P., Bhandari, S.C., Pandher. M.S. and Sedha, R.K. 1988. Symbiotic efficiency in the presence of mycorrhizal and fertilizer application in mung bean. *Res. and Development Rep.* **5**: 1-5

Gupta, R.P., Chahal, V.P.S., Sahoo, S. and Beri, S.N 1980 Response of berseem new variety to *Rhizobium* inoculation and savings on inorganic fertilizer application. *Indian J. agric. Res.* **14**: 123-125

Hable, M. and Manjunath, A. 1987. Soil solution phosphorus status and mycorrhizal dependency in *Leucaena leucocephala*. *Appl. Envt. Microbiol.* **53**: 797-801

Harley, J.L. and Smith, S.E. 1983. *Mycorrhizal symbiosis*. Academic press, London. p. 496

Hayman, D.S. and Mosse, B. 1979. Improved growth of white clover in hill grasslands by mycorrhizal inoculation. *Ann. Appl. Biol.* **93**: 141-148

Hayman, D.S. 1982. Practical aspects of Vesicular arbuscular mycorrhiza (In) *Advances in Agricultural Microbiology*. (Ed). *Soil Microbiol.* Butterworths, London. pp. 114-140

Hayman, D.S. 1983. The Physiology of Vesicular arbuscular endomycorrhizal symbiosis. *Can. J. Bot.* **61**: 944-963

Hazra, C.K. 1994. Response of biofertilizers in forage and fodder crops. *Fert. News.* **39**: 43-53

Herrera. M.A., Selamanca, C.P. and Burer, J.M. 1993. Inoculation of woody legumes with selected arbuscular mycorrhizal fungi and rhizobia to recover desertified Mediterranean ecosystem. *Appl. Environ. Microbiol.* **59**: 129-133

Homachen, J., Roughley., R.J. and Date, R.A. 1989. Responses to inoculation with root nodule bacteria by *Stylosanthes humilis* and *Stylosanthes hamata* in soils of N.E. Thailand. *Trop. Grassland Res.* **23**: 98-104

Hoque, M.S. and Sattar, M.A. 1989. Status of microbiological research on pulses. *Proc. Sec. Nat. Workshop on Pulses.* Intl. Crops Research Institute for Semi Arid Tropics, Andra Pradesh. pp. 103-110

Huang, R.S., Yost, R.S. and Smith, W.K. 1983. Influence of VA mycorrhiza on growth, nutrient absorption and water relation in *Leucaena leucocephala. Leuc. Res. Rep.* **4**: 86-87

I.G.F.R.I. 1993. Response of *Medicago* sp to VAM. *Indian Grassland and Fodder Res. Inst. Annu. Rep.* pp. 111-112

I.G.F.R.I. 1998. Response of berseem to VAM fungi and levels of phosphorus *Indian Grassland and Fodder Res. Inst. Annu. Rep.* pp. 117-118

Jackson, M.L. 1973. *Soil Chemical Analysis.* Prentice Hall of India. Pvt. Ltd. New Delhi. PP. 1-498

Jain, P.C., Kushwaha, P.S., Dhakad, U.S., Khan, H. and Trivedi, S.K. 1999. Response of chick pea (*Cicer arietinum L.)* to phosphorus and biofertilizer. *Legume Res.* **22**: 241-244

Jain, R.K., Hassan, N., Pandey, P.N. and Singh, R.K. 1998. Response of some legumes to inoculation with VA-mycorrhiza at difference P levels. *Range Mgmt. and Agroforestry.* **19**: 121-125

Jalid, N. 1991. Legume cover crop establishment with maize and soybean in the acid soil of Setiung, Indonesia. *College Laguna.* p. 118

Jeffries, P. 1987. Use of Mycorrhizae in Agriculture. CRC, *Annu. Rev. Biotech.* **5**: 319-357

*Jensen, A. and Nielson, J.D. 1984. The effect of inoculating lucerne (*Medicago sativa*) with vesicular arbuscular mycorrhizal fungi and *Rhizobium melilotii. Tidskrift for Planteavl.* **88**: 147-153

Johnkutty, I. 1981. Response of ragi (*Eleusine coracana Gaertn)* to different levels of nitrogen, phosphorus and potassium under rainfed condition. M.Sc. (Ag.) thesis, Kerala Agricultural University, Thrissur. pp. 52-68

*Johnson, N. 1982. Blue lucerne – Results of agronomic trials. *Rapport.* Institution for vaxtodling sueriges lanthuruksuni – verstet. p.33

Johnson, W.A. and Evans, C.E. 1975. N, P and K fertilization of southern peas for one time harvest in a sandy soil. *J. Am. Soc. Hort. Sci.* **100**: 261-263

Kanwar, J.S. 1978. *Soil fertility- theory and practice.* ICAR. New Delhi. pp. 156-202

Karunaratne, R.S., Baker, J.H. and Baker, A.V. 1987. Benefits of mycorrhizae to soybeans grown on various regimes of nitrogen nutrition. *J. Pl. Nutr.* **10** : 871-888

Karyagin, Yu. G. 1980. Effectiveness of bacteriazation of soybean plants to active root nodule bacterial races. *Microbiologia*. **49**: 141-146

Khanna, S., Lal, B. and Adholeya, A. 1992. Biomass enhancement of tree legumes by *Rhizobium* and vesicular arbuscular mycorrhizae. In *Proc. Tissue Culture Forest Sp. Recent Research in India*. Eds. Dhavan V., Ganapathy, P.M. and Khurana, D.K. Taha Energy Research Institute, New Delhi. pp. 84-94

Koffa, S.N., Curz-Re-de-la and De-la-Cruz-re. 1995. Screenhouse performance of VAM -inoculated seedlings of *Leucaena leucocephala* in a phosphorus deficient and aluminium sulphate treated medium. *New Forests*. **9**: 273-279

*Kots, S. Ya. 1989. Intensity of photosyntheis of nitrogen fixation in lucerne under different levels of mineral nitrogen supply. *Fiziologiya i Biokhimiya Kul'kuryk Rastenii*. **21**: 436-438

Kucey, R.M.N. and Bonetti, R. 1988. Effect of vesicular arbuscular mycorrhizal fungi and captan on growth and nitrogen fixation by *Rhizobium* inoculated field beans. *Can. J. Soil. Sci.* **68**: 143-149

Kumar, P. and Agarwal, J.P. 1993. Response of lentil (*Lens esculentus*) to *Rhizobium* inoculation, nitrogen and phosphorus fertilization. *Indian J. Agron*. **38**: 318-320

Lal, B. and Khanna, S. 1996. Long term field study shows increased biomass production in tree legumes inoculated with *Rhizobium*. *Pl. Soil*. **184**: 111-116

Lal, B. and Khanna, S. 1993. Reinoculation and nitrogen fixing potential of *Acacia nilotica* inoculated with *Rhizobium* isolates. *Can. J. Microbiol.* **39**: 87-91

Lanyon, L.E. and Smith, F.W. 1985. *Potassium in Agriculture*. Mac millan publishing Co. New York. pp. 65-80

*Lee, J.K., Seo, S., Lim, Y.W. and Park, K.J.1990. Effect of nitrogen and lime application at sowing on soil properties, seed development, dry matter yield and nutritive value in alfalfa meadow. *Korean J. Ani. Sci.* **32**: 635-641

Lu, X. and Koide, R.T. 1994. The effects of mycorrhizal infection on component of plant growth and reproduction. *New Phytol.* **128**: 211-218

Manguiat, I.J., Guinto, D.P., Sebian, A.G. and Jalalon, A.T. 1987. Influence of rhizobial inoculation, phosphorus fertilization and liming on the nodulation, nitrogen fixation and biomass production of *Sesbania rostrata* grown in an acidic soil. Abstract of FCSSP papers. *Philip. J. Crop. Sci.* **12:** 525

Manjunath, A. and Bagyaraj, D.J. 1984. Response of pigeon pea and cowpea to phosphate and dual inoculation with vesicular arbuscular mycorrhiza and *Rhizobium. Trop. Agric.* **61**: 48-52

Mariyappan, H. 1978. Phosphorus nutrition in *Stylosanthes gracilis* (Swartz). M.Sc. (Ag.) thesis, Kerala Agricultural University, Thrissur. pp. 70-95

Marschner, J. and Dell, B. 1994. Nutrient uptake in Mycorrhizal symbiosis. *Pl. Soil.* **159**: 89-102

Mc lean, L.A., Sosulski, F.W. and Youngs, C.G. 1974. Effect of nitrogen and moisture on yield and protein in field pea. *Can. J. Pl. Sci.* **54**: 521-528

Medeiros, C.A.B., Clark, R.B. and Eliis, J.R. 1995. Effects of excess manganeese on mineral uptake in mycorrhizal sorghum. *J. Pl. Nut.* **18**: 201-217

Meenakumari, K.S. and Nair, S.K. 1991. Effect of phosphorus application on the production and quality of three *Stylosanthes* cultivars. *Trop. Agric.* **63**: 212-216

Mengel, K. and Kirkby, E.A. 1981: Potassium in crop production. *Adv. Agron.***33**: 59-110

Mezni, M.Y. and Sifi, B. 1998. Response of annual *Medicago* to two strains of *Rhizobium meliloti* in semi-arid conditions of Tunisia. *Proc. of the meeting of the Mediterranean Working Group on Medicago of the FAO-CIHEAM.* **18**:113-117

*Moawad, H., El-Maksoud, H.K.A. and Saad, R.N. 1988. Response of berseem clover (*Trifolium alexandrinum*) to rock phosphate fertilization and dual inoculation with *Rhizobium* and vesicular arbuscular mycorrhiza (VAM). *Egptian J. Microbiol.* **31** : 13-23

Mohammed, G. 1988. Response of *Leucaena leucocephala* K-8 to inoculation with *Rhizobium, Bacillus megatherium* and *Glomus fasciculatum*. *Leucaena Res. Rep.* **9:** 51

Morton, J.B., Yarger., J.E. and Wright, S.F. 1990. Soil solution phosphorus concentrations necessary for the nodulation and nitrogen fixation in mycorrhizal and non-mycorrhizal red clover (*Trifolium pratense*, L.). *Soil Biol. Biochem.* **22:** 127-129

Mosse, B. 1957. Growth and chemical composition of mycorrhizal and non-mycorrhizal application. *Nature* (London). **179**: 922-924

Mosse, B. 1979. Plant growth response to vesicular arbuscular mycorrhiza X Response of *Stylosanthes* and maize to inoculation in unsterile soils. *New Phytol* **78:** 277-283

Mosse, B., Powell. C. Ll and Hayman, D.S. 1976. Plant growth responses to vesicular arbuscular mycorrhiza. IX. Interactions between VA-mycorrhiza, rock phosphate and symbiotic nitrogen fixation. *New Phytol.* **76:** 331-342

*Moursi, M.A., Eldin, N.N.A and Mansour, M.A. 1976. Capacity and abscission of flowers and pods of Egyptian lupin plants. Effect of nitrogen and phosphorus. *Egypt. J. Agron.* **1**: 1-9

Munegowda, M.K., Sridhara, H. and Kumar, J.B.V. 1988. Influence of fertility levels on growth characters and herbage yield of lucerne genotype Sirsa – 8. *Curr. Res.* UAS, Bangalore. **17**: 141-143

Murali, S. 1989. Biomass productivity and nutrient accumulation in *Sesbania rostrata* inoculated with *Rhizobium*. M.Sc. (Ag) thesis, Kerala Agricultural University, Thrissur. pp. 58-75

Nair, B.G.K. 1989. Seed production in *Stylosanthes gracilis* under varying levels of population density, nutrition, moisture regimes and cuttings. Ph. D. thesis, Kerala Agricultural University, Thrissur. pp. 78-125

Nair, K.S., Perumal, R., Khan, A. and Swamy, R. 1970. Effect of seed inoculation with *Rhizobium* on yield and nitrogen content of green manure crop. *Madras agric. J.* **57**: 213-216

Ngulube, M. 1989. Nursery and field performance of inoculated and uninoculated *Glyricidia sepium* in Malawi. *Nitrogen fixing Tree Res. Rep.* **6**: 37

Nielson, J.B. and Jensen, A. 1983. Influence of VAM fungi on growth and uptake of various nutrients as well as uptake ratio of fertilizer phosphorus for lucerne. *Pl. Soil* **82**: 105-108

*Nielson, J.D. 1990. The effect of VAM on growth and phosphorus uptake in lucerne. *Agric. Ecosys. and Environ.* **29**: 99-102

Owusu-Bennoah, E. and Mosse, B. 1979. Plant growth responses to vesicular arbuscular mycorrhiza. XI. Field inoculation responses in barley, lucerne and onion. *New Phytol.* **83**: 671-679

Pacovsky, R.S., Fuller, G., Stafford, A.E. and Paul, E.A. 1986. Nutrient and growth interactions in soybeans colonized with *Glomus fasciculatum* and *Rhizobium japonicum*. *Pl. Soil* **92**: 37-45

Pahwa, M.R. 1989. Native nodulation, growth and herbage productivity of some tree legumes in soils of Bundulk. *Nitrogen Fixing Tree Res. Rep.* **6**: 14-15

*Pahwa, M.R. 1998. Effect of inoculation of *Rhizobium*, VAM fungi and phosphate solubilising bacteria on nodulation and seedling vigour of *Leucaena leucocephala. Range Mgmt. and Agro forestry.* **16** : 129-131

Pande, M. and Tarafdar, J.C. 1999. Critical levels of VAM fungal propogules in different arid crops. *Agrochimica.* **43**: 187-192

Parashar, A., Awasthi, C.P., Singh, A.B. and Gupta, M.K. 1999. Effect of *Rhizobium* inoculation and phosphorus application on yield and quality of broad bean (*Vicia faba L.*). *Legume Res.* **22**: 162-166

Patel, J.R. 1998. Effect of nitrogen and phosphorus levels on fodder and seed yield of berseem. *Forage Res.* **24**: 49-50

Patel, J.R., Patel, P.C., Sandhu, A.C and Patel , B.G. 1990. Response of luceme genotypes to phosphorus and potash. *Indian J. Agron.* **85**: 307-308

*Paulino, V.T., Piccini., D.F. and Barca, J.H. 1986. Influence of vesicular arbuscular mycorrhiza and phosphate in tropical legumes. *Revista Brasileria de Ciencia do Solo.* **10**: 103-108

Peck, N.H. and Buren, J.P. VAN. 1975. Plant response to concentrated superphosphate and potassium chloride fertilizers in snap beans (*Phaseolus vulgaris var.humilis*). *J. Search Agric.* **5**: 1-32

Phookan, D.B. and Shadeque, A. 1994. Effect of phosphorus and *Rhizobium* on yield and quality of pea (*Pisum sativum*). *Indian J. agric. Sci.* **64**: 572-573

Plinchette, C. and Morel, C. 1996. External phosphorus requirements of mycorrhizal and non-mycorrhizal barley and soybean plants. *Biol. Fertility. Soils.* **21**: 303-308

*Ponte, R.P., Acosta, M.I., Abril, A., Oliva, L. and Del, V. 1988. The *Rhizobium* legume association in lucerne field in Cordobo province. *Revista de Ciencio Agropecuarias*. **6**: 73-82

*Posjpanov, G.S. and Knyaseva, L.D. 1974. The influence of mineral nitrogen on nutrient consumption by peas. *Investiga Timivyazevasko set's Ko Khosyaistennoi*. Akadememii. **2**: 16-28

Powell, C.L. and Daniel, J. 1979. Growth of white clover in undisturbed soils after inoculation with efficient mycorrhizal fungi. *N.Z.J. agric. Res.* **21**: 675-681

Pradhan, L. and Mishra, S.N. 1994. Effect of cutting management, row spacing and levels of nitrogen on fodder yield and quality of oat (*Avena sativa*). *Indian J. Agron.* **39**: 233-236

Ragini, R. and Nair, M.A. 1996. *Rhizobium* inoculation and nutrient levels on nodulation and seedling growth in nitrogen fixing tree species. *J. Trop. Agric.* **34**: 65-67

Rai, P. and Patel, B.D. 1985. Effect of phosphorus and potassium on forage production and quality of *Stylosanthes hamata* (L.) Jacq. *Indian J. agric. Res.* **30**: 98-100

Rajithkumar, R. and Potty, V.P. 1998. Biomass production of *Pachyrhizus erosus* (L.) by individual and coinoculation with *Glomus microcarpum* and *Bradyrhizobium*. *J. Root Crps.* **24**: 143-145

Rajput, A.L. and Singh, T.P. 1998. Response to nitrogen and phosphorus with and without *Rhizobium* inoculation on fodder production of cowpea (*Vigna unguiculata*). *Indian J. Agron.* **41**: 91-94

Raju, M.S. and Verma, S.C. 1984. Response of green gram *(Vigna radiata)* to rhizobial inoculation in relation to fertilizer nitrogen. *Legume Res.* **7**: 73-74

Rana, D.S., Sheoran, R.S., Joon, R.K. and Yadav, B.D. 1992. Effect of sowing dates, seed rates and phosphorus levels on fodder and seed production of Egyptian clover (*Trifolium alexandrinum L.). Forage Res.* **18**: 34-36

Rana, N.S., Singh, G.V. and Ahlawat, I.P.S. 1998. Effect of nitrogen, *Rhizobium* inoculation and phosphorus on root nodulation, dry matter yield and nutrient uptake in pigeon pea (*Cajanus cajan*). *Indian J. Agron.* **43**: 102-105

Rao, A.V. and Sharma, R.L. 1980. Note on effect of different inoculum levels of rhizobia on symbiosis of soybean and black gram. *Legume Res.* **3**: 55-57

Rao, S.N.S. 1981. *Biofertilizers in Agriculture,* Oxford and IBH publishing Co., New Delhi. pp. 42-80

Rao, S.N.S., Tilak, K.V.B.R. and Singh, C.S. 1986. Dual inoculation with *Rhizobium* and *Glomus fasciculatum* in chick pea (*Cicer arietinum* Linn.). *Pl. Soil.* **95**: 351-359

Rao, A.V. and Tarafdar, I.C. 1993. Role of VAM fungi in nutrient uptake and growth of cluster bean in an arid soil. *Arid Soil Res. Rehabilitation.* **7**: 275-280

Raychaudhuri, M., Kailashkumar and Raychaudhuri, S. 1997. Effect of *Rhizobium japonicum* and phosphorus on nutrient uptake and yield of soybean (*Glycine max*) in an Ultisol of Manipur hills. *Indian J. agric Sci.* **67**: 459-462

Reddy, M.V. 1986. The effects of levels of nitrogen and phosphorus and rhizobial inoculation on the performance of green gram (*Vigna radiata* L. Wikzsk). *J. Res. APAU.* ***XIV***: 80-82

Rinj, V., Gupta, R.P., Bhandari, S.C., Kaul, V.K. and Pander, M.S. 1987. Dual inoculation with *Rhizobium* and *Glomus fasciculatum* enhances growth, nodulation and nitrogen fixation in *Leucaena leucocephala. Res. and Development Rep.* **4**: 1-9

*Robinson, D.L. and Savoy, H.J. Jr. 1989. Subterranean clover and white clover responses to phosphorus and potassium. *Lousiana Agric.* **32**: 6-7

Rosalus, A.M., Ilag, L.L., Mew, T.W. and Elazegui, F.A. 1987. Mycorrhizae in a rice-based cropping system. *Philippine Phytopath.* **21**: 6-7

Rosendahl, R.O. 1943. The effect of mycorrhizal and non-mycorrhizal fungi on the availability of difficultly soluble potassium and phosphorus. *Proc. Soil. Sci. Soc. Amer.* **7**: 477

Russel, E.W. 1973. *Soil conditions and plant growth.* (Ed.). 10, Longman publishing Co. London. p. 573

Sahu, S.K. and Behara, B. 1972. Effect of *Rhizobium* inoculation on cowpea, groundnut and green gram. *Indian J. Agron.* **17**: 359-360

Sairam, R.K., Tomer, P.S., Harika, A.S. and Ganguly, T.K. 1989. Effect of phosphorus levels and inoculation with *Rhizobium* on nodulation, leghaemoglobin content and nitrogen uptake in fodder cowpea. *Legume Res.* **12**:27-30

Sanni, S.O. 1976. Vesicular arbuscular mycorrhiza in some Nigerian soils and their effects on the growth of cowpea (*Vigna unguiculata*), tomato *(Lycopersicum esculentum*) and maize (*Zea mays*). *New phytol.* **77**: 667-671

Santhi, R., Kothandaraman, G.V. and Rangarajan, M. 1988. Efficiency of VAM inoculation with different sources of phosphorus on the availability and uptake of nutrients and yield of green gram. *Proc. of.the first Asian conf. Mycorrhiza.* Madras, India. pp. 166-168

Sardana, V. and Narwal, S.S. 1999. Effect of seed inoculation, nitrogen and phosphorus on the fodder yield of Egyptian clover (*Trifolium alexandrinum*). *Indian J. Agron* . **44**: 639-646

Sasidhar, V.K. and George, C.M. 1972. Study on the role of applied phosphorus and potassium on the nutrient uptake by a legume crop (Co-1 lab lab), planted at different spacings. *Agric. Res. J. Kerala.* **10**: 75-79

Saterlee, L., Melton, B., Mc castin, B and Miller, D. 1983. Mycorrhizae effects on plant growth, phosphorus uptake and nitrogen (C_2H_4) fixation in two alfalfa populations. *Agron. J.* **75**: 715-716

*Sattar, M.A. and Gaur, A.C. 1989. Effect of vesicular arbuscular mycorrhiza and phosphate dissolving micro-organisms on the yield and phosphorus uptake of lentil *(Lens Culinaris* Hoench). *Thai J. Agric. Sci.* **22**: 129-136

Shah, M.H., Singh, K.N., Kachroo, D. and Khanday, B.A. 1991. Performance of lucerne and sainfoin under different cuttings and levels of phosphorus. *Indian J. Agron.* **36**: 61-66

Shanmugasundaram, V.S. 1985. Studies on the association of perennial grass (NB-21)-legume (lucerne) mixture on the forage yield and quality. *Madras agric. J.* **73**: 61-66

Sharma, B.L., Sharma P.K., and Yadav, G.L. 1998. Effect of FYM, nitrogen and phosphorus levels on the green fodder yield of berseem. *Forage Res.* **24**: 181-182

Sharma, P.K. Sharma, B.L. and Kumar, Y. 1992. Effect of nitrogen and phosphorus on fodder yield of lucerne. In: *Nat. Symp. on Resource Mgmt. for sustained Crop production.* Madras. **2**: 76

Sharma, S., Upadhyay, R.G. and Sharma, C.R. 2000. Effect of *Rhizobium* inoculation and nitrogen on growth, dry matter accumulation and yield of black gram (*Vigna mungo* (L.) Hepper). *Legume Res.* **23**: 64-66

Sheoran, R.S. and Rana, D.S 1998. Response of lucerne genotypes to different phosphorus levels under irrigated conditions. *Forage Res.* **23**: 213-214

Simpson, J.E., Adair, C.R., Kohler, G.D., Dawson, E.N., Debald, H.A., Kester, E.B. and Klick, J.T. 1965. Quality evaluation studies of foreign and domestic rices. *Tech. Bull. No. 1331 Series*, USDA. pp.1-86

Singh, A.K. and Singh, S.S. 2000. Effect of planting dates, nitrogen and phosphorus levels on yield contributing factors in french bean. *Legume Res.* **23**: 33-36

Singh, A.K., Choudhary, R.K. and Sharma, R.R.P. 1993. Effect of inoculation and fertilizer levels on yield, yield attributes and nutrient uptake of green gram (*Phaseolus radiatus*) and black gram (*Phaseolus mungo). Indian J. Agron.* **38**: 663-665

Singh, G.V., Rana, N.S. and Ahlawat, I.P.S. 1998 a. Effect of nitrogen, *Rhizobium* inoculation and phosphorus on growth and yield of pigeon pea (*Cajanus cajan*). *Indian J. Agron.* **43**: 358-361

Singh, V., Singh, V.P., Kwatra, J. and Singh, R.K. 1998 b. Effect of phosphorus and cutting interval on yield and quality of lucerne under rainfed lower hills of U.P. *Forage Res.* **23**: 217-219

Sivaprasad, P. and Rai, P.V. 1987. Mechanism of enhanced nodulation in vesicular arbuscular mycorrhizal pigeon pea (*Cajanus cajan* (L.). Mill.). *Agric. Res. J. Kerala.* **25**: 99-102

Sivaprasad, P., Hegde, S.V. and Rai, P.V. 1983. Effect of *Rhizobium* and mycorrhizal inoculation on growth of *Leucaena. Leuc. Res. Rep.* **4**: 42

Smith, S.E. and Daft, H.J. 1977. Interaction between growth, phosphate content and nitrogen fixation in mycorrhizal and non-mycorrhizal *Medicago sativa. Aust. J. Plant Physiol.* **4**: 403-413

Smith, S.E., Smith, C.A. and Nicholas, D.I.D. 1981. Effect of endomycorrhizal infection on phosphate and cation uptake by *Trifolium subterraneum. Pl. Soil.* **63**: 57-64

Snedecor, G.W and Cochran, W.G. 1967. *Statistical Methods* (16th Ed) Oxford and IBH publishing Co. Calcutta. pp.349-351

Solomko, I. and Rudin, I. 1977. Fertilization of lucerne (*Medicago spp*). *Kornia*. Starropor skii Institute Sel' skogo Khozyaistva stavoopor, U.S.S.R. **3**: 42-43

Sonia, V.K. 1999. Forage and seed production of signal grass (*Brachiaria decumbens Stampf*) under different management practices. M.Sc. (Ag.) thesis, Kerala Agricultural University, Thrissur. pp. 45-85

Sreedurga, N. 1993. Effect of microbial inoculants on *Stylosanthes guianensis* cv Schofield for herbage production. M.Sc. (Ag) thesis, Kerala Agricultural University, Thrissur. pp. 35-60

Sreekantan, L. 1981. Seed production potential of *Stylosanthes gracilis*. M.Sc. (Ag.) thesis, Kerala Agricultural University, Thrissur. pp. 50-92

Srivastava, J.S. and Tewari, V.P. 1981. Response of green gram (*Vigna radiata)* and cowpea (*Vigna unguiculata)* to inoculation with rhizobia from wild legumes. (In) *Biol. nitrogen fixation tech. Trop. Agric.* pp. 269-273

Srivastava, S.N.L. and Sharma, S.C. 1982. Effect of bacterial and inorganic fertilization on the growth, nodulation and quality of green gram. *Indian J. agric. Res.* 16: 223-229

Stribley, D.P., Tinker, P.B. and Rayner, J.H. 1984. Relation of internal phosphorus concentrations and plant weight in plants affected with VAM. *New Phytol.* **56**: 261-266

*Subbiah, B.V. and Asija, G.L. 1956. A rapid procedure for the estimation of available nitrogen in soils. *Curr. Sci.* **29**: 259-260

Sudhakar, P., Singh, G.B. and Rao, L.M. 1989. Effect of *Rhizobium* and phosphorus on the growth parameters and yield of black gram (*Phaseolus mungo). Indian J. agric. Sci.* **59**: 402-404

Sumner, M.E. and Farine, M.P.W. 1986. Phosphorus interactions with other nutrients and time in field cropping systems. *Adv. Soil. Sci.* **5**: 201-236

Taneja, K.D., Gill, P.S. and Jatasara, D.S. 1987. Effect of dates of sowing on the fodder and seed yield of berseem under different levels of nitrogen and phosphorus. *Forage Res.* **13**: 33-37

*Tang, M., Tamayo, E.V. and Marquez, B. 1982. Study of the action of six strains of *Rhizobium* on four legumes. *Pastos Y forages*. **5**: 159-170

Thiagarajan, T.R., Amer, R.N. and Ahmad, M.H. 1992. Response of cowpea to inoculation with co-selected vesicular-arbuscular mycorrhizal fungi and *Rhizobium* strains in field trials. *Canadian J.* **38**: 573-576

Tisdale, S. and Nelson, W. 1975. *Soil Fertility and fertilizers*. Mac millan Inc., New York, 3rd Ed. pp: 122-128

Tisdale, S.L., Nelson, W.L. and Beaton, J.D. 1985. *Soil fertility and fertilizers*. 4th edn. Mac millan publishing Co. New York. P. 735

Tiwana, M.S., Bains, D.S. and Gill, S.S. 1975. Effect of various levels of nitrogen and phosphorus under different spacings on fodder yield of napier-bajra hybrid. *J. Res. Punjab Agric. Univ.* **12**: 345-350

Totey, N.G., Verma, R.K., Vergheese, M., Shadangi. D.K., Khatri, P.K. and Pathak, H.D. 2000. Effect of *(Rhizobium)* biofertilizers and varying levels of phosphorus on the growth of forest legumes (*Dalbergia sissoo* and *Albizia procera*). *Indian J. Forestry*. **23**: 205-207

Uma, M.R. and Rao, V.S. 1994. Effects of inoculation with VAM fungi, phosphate solubilising fungus and phosphate amendments on black gram and green gram. *Indian J. Microbiol.* **34**: 313-316

Umali-Garcia, M., Lubuit, S.J., Rogetio, L. and Baggayan. 1988. Effects of *Rhizobium* inoculation on growth and nodulation of *Albizia falcataria* (L.) Fosh. and *Acacia mangium.* Willd. in the nursery. *Pl. Soil.* **108:** 71-78

Upadhyay, R.G., Sharma, S. and Daramwal, N.S. 1999. Effect of *Rhizobium* inoculation and graded levels of phosphorus on the growth and yield of summer green gram (*Phaseolus radiatus L.*). *Legume Res.* **22**: 277-279

*Urzua, H., Munoz, P. and Borie, F. 1993. Effect of VA mycorrhizae on N_2 fixation in white clover growing in soils of southern region of Chile. *Giencia e Investigacion Agraria.* **20**: 47-54

Vargas, M.A.T. and Suhet, A.R. 1989. Efficiency of commercial inoculants and native *Rhizobium* strains on six forage legumes on a cerrado soil. *Agropecuarea Brasilea.* **10**: 357-362

Vasanthi, D., Venkatakrishnan, J. and Ernest, J. 1994. Effect of phosphorus and potassium on yield and quality of hedge lucerne (*Desmanthus virgatus*). *Indian J. agric. Sci.* **64**: 259-260

Verma, S.S., Singh, V. and Joshi, Y.P. 1993. Effect of nitrogen and its time of application on fodder productivity and mixed cropping of grass and legume forage. *Forage Res.* **19**: 212-215

Vineetha, L. 1995. Seed production potential of gamba grass (*Andropogon gayanus*) under varying levels of nitrogen, phosphorus and potassium. M.Sc (Ag.) thesis, Kerala Agricultural University, Thrissur. pp. 48-85

Waidyanatha, U.P., Yogaratnam, N. and Ariyaratne, W.A. 1979. Mycorrhizal infection on growth and nitrogen fixation of *Peuraria* and *Stylosanthes* and uptake of phosphorus from two rock phosphates. *New Phytol.* **82:** 147-157

Westheimer, F.H. 1987. Why nature chose phosphates. *Curr. Sci.* **235:** 1173-1178

Young, C.C., Jung, T.C. and Guo, H.Y. 1986. Effect of inoculation with VA mycorrhizal fungi on soybean yield and mineral phosphorus utilization in subtropical and tropical soils. *Pl. Soil.* **95:** 245-253

Yousef, A.N., Naowm, M.S. and Munaam, B. 1989. Interaction effects of inoculation and irrigation on growth and yield of mung ocan *(Vigna radiata)* plants. *J. Agri. Water Resour. Res.* **8**: 95-110

*Yuan, T.L., Lutricko, M.S. and Robertson, W.K. 1970. Response of soyabeans and oats to lime, phosphorus and potassium on a paleudult. *Proc. Soil Crop Sci. Soc. Florida.* **38:** 116-121

*Zeedan, E.M., Assey, A.A. and Gaweifel, H.S 1988. Effect of P fertilization and cutting schedules on dry forage yield and chemical composition of alfalfa cultivar-cut 101. (In.) *Report of the Thirty First North American Alfalfa Improvement Conference* (Eds.) Moutray, J.B and Elgin, J.A. Jr. Belstsville, Maryland, U.S.A. pp. 45-48

* Originals not seen.

APPENDIX

APPENDIX – 1

Weather data for the cropping period (June 23, 2000 to April 2, 2001) – Weekly averages

Standard week	Temperature (°C)		Relative humidity (%)	Evaporation (mm/day)	Total rainfall (mm)
	Maximum	Minimum			
26	33.10	22.37	83.00	2.80	53.30
27	28.90	21.85	84.40	3.00	29.60
28	30.40	25.77	77.64	3.60	1.40
29.	30.74	22.91	77.14	4.30	0.40
30	30.24	22.24	80.50	4.10	50.60
31	30.18	22.87	80.60	3.50	-
32	28.55	21.80	85.57	2.80	97.40
33	28.42	22.70	84.14	3.40	7.20
34	28.10	21.40	55.70	2.30	152.00
35	28.30	21.90	85.00	3.20	9.00
36	29.95	22.60	87.20	4.10	-
37	30.34	22.67	86.35	4.20	14.20
38	29.54	21.94	90.14	3.60	12.40
39	28.50	21.90	93.60	2.40	65.60
40	29.10	21.50	95.07	2.20	131.00
41	29.80	22.20	93.00	3.50	1.60
42	29.90	22.00	91.00	3.30	76.60
43	30.80	21.57	79.93	4.00	0.6
44	31.49	22.41	77.93	3.96	-
45	30.93	22.24	81.21	2.97	73.10
46	30.14	21.98	79.79	2.61	6.60
47	28.74	21.14	86.21	2.10	50.00
48	30.40	18.34	78.29	2.75	-
49	30.86	20.27	76.07	3.24	2.20
50	30.30	19.38	79.07	3.44	-
51	30.90	19.68	73.14	2.91	-
52	28.86	20.54	82.07	1.81	45.60
1	30.56	20.63	76.93	2.94	2.40
2	30.49	20.46	77.93	2.84	-
3	30.24	19.70	76.29	3.28	-
4	30.46	21.01	77.79	2.97	0.8
5	29.10	21.04	78.14	2.63	16.20
6	30.83	20.19	77.21	3.74	-
7	31.44	20.29	75.03	3.71	-
8	31.96	21.27	79.07	4.07	-
9	32.20	20.77	76.57	4.46	-
10	32.44	21.54	73.93	4.51	-
11	32.37	21.76	71.36	4.89	-
12	32.88	22.40	73.50	5.04	-
13	32.95	22.50	73.85	5.06	

INTEGRATED NUTRIENT MANAGEMENT IN HEDGE LUCERNE (*Desmanthus virgatus* (L.) WILLD.) UNDER RAINFED CONDITION

BY

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ABSTRACT OF THE THESIS

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ABSTRACT

A field experiment was conducted at the Instructional Farm, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala State to find out an integrated nutrient management technique for *Desmanthus virgatus* (L.) Willd. under rainfed condition. The influence of chemical fertilizers and biofertilizers on growth parameters, fodder yield, quality of produce, uptake of nutrients, chemical properties of soil and economics was investigated.

Three levels of nitrogen (0, 15, 30 kg N ha^{-1}), three levels of potassium (0, 20, 40 kg ha^{-1}) and biofertilizers (*Rhizobium*, AMF and *Rhizobium* + AMF) were combined to form twenty seven treatment combinations. The experiment was laid out in split plot design with three replications.

Results of the experiment revealed that the chemical fertilizers as well as bioinoculants had significant positive influence on improving the fodder production potential of *Desmanthus virgatus*. Application of inorganic fertilizers and co-inoculation of hedge lucerne with *Rhizobium* and AMF significantly increased the growth parameters namely plant height, length of branches, number of branches and leaf: stem ratio.

Highest dose of chemical fertilizers and dual inoculation with biofertilizers registered maximum green fodder yield in all four harvests. Similar results were obtained in the case of dry fodder yield also.

Quality parameters of the forage significantly improved as a result of dual inoculation with biofertilizers. Maximum crude protein content was realized with application of highest dose of nitrogen and potassium.

The nutrient uptake showed a significant increase with increase in doses of chemical fertilizers. Dual inoculation of biofertilizers significantly increased the uptake of nitrogen, phosphorus and potassium.

Combined application of biofertilizers improved the nitrogen and phosphorus status of the soil after the experiment. Highest dose of nitrogen gave the highest soil nitrogen content. Similarly highest dose of potassium recorded highest soil potassium content after the experiment.

The physical and economic optimum dose of nitrogen for *Desmanthus virgatus* was 32 kg ha^{-1} and 31 kg ha^{-1} respectively while that of potassium was 22 kg ha^{-1}. The use of chemical fertilizers and dual inoculation with biofertilizers recorded highest net returns and benefit: cost ratio, emphasizing the need for an integrated approach in nutrient management.