ECONOMISING NITROGEN IN RICE PRODUCTION WITH *Azospirillum*

By
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THESIS

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DECLARATION

I hereby declare that this thesis entitled "**Economising nitrogen in rice production with Azospirillum**" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled "**Economising nitrogen in rice production with** Azospirillum" is a record of research work done independently by Kum. Resmi, S. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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LIST OF ABBREVIATIONS

mm	millimetre
cm	centimetre
m	metre
g	gram
kg	kilogram
t	tonnes
ha	hectare
kg ha^{-1}	kilogram per hectare
g/hill	gram per hill
°C	degree celsius
Fig.	figure
et al.	and others
%	per cent
cv.	cultivar
DAT	days after transplanting
LAI	leaf area index
LAD	leaf area duration
HI	harvest index
viz.	namely
N	nitrogen
P_2O_5	Phosphorus
K_2O	Potassium
CD	Critical Difference

SEm	Standard error of mean
BCR	Benifit Cost Ratio
KAU	Kerala Agricultural University
TNAU	Tamil Nadu Agricultural University
IRRI	International Rice Research Institute

INTRODUCTION

INTRODUCTION

Rice (Oryza sativa) is one of the most important food crops in India and is the mainstay of Indian Agriculture. There is a need to increase the production of unhusked rice to 100 million tonnes by 2000 AD to meet the demands of the growing population.

Of all the inputs needed for rice production, fertilizer is the costliest one. Among the different fertilizer inputs nitrogen is the one to which rice crop responds well (IRRI, 1986). The high yield potential of modern varieties can never be realised without ensuring adequate nitrogen supply to the plant during the entire growing season. So the rice production in the tropics largely looms around efficient and economic supply of nitrogen, an element required in larger quantities in comparison with other nutrients. As the cost of nitrogen fertilizr is continuously increasing at a very fast rate, small and marginal farmers will have to think about alternative strategies which can reduce the requirement of chemical nitrogen. In this respect the bio-fertilizers play a dominant role.

There is a huge reservoir of free nitrogen around the earth to the order of 37×10^{14} tonnes (79 per cent in the air), correspondingly 80,000 tonnes in the column of air over one hectare of land. This abudant nitrogen reservoir remains untapped by plants and animals except for a few microorganisms. These microorganisms in farm use are called as biofertilizers.

In non-leguminous crops like rice, several micro-organisms like blue green algae, Azatobactor etc. have been in use since a long period. It is now confirmed that nitrogen fixation takes place in the rhizosphere of a number of tropical grasses and cereals (Dobereiner and Day, 1976). Nayak and Rao (1977) reported the presence of nitrogen fixing associative bacteria Azospirillum in the roots of several cultivars of rice and weeds associated with rice plants. The occurrence of Azospirillum in rice soils and in association with rice roots have been established by several workers (Rao et al., 1978; Watanabe et al., 1981).

Experiments conducted all over India and abroad revealed that Azospirillum can fix atmospheric nitrogen in the rhizosphere in rice. Yield increase in rice due to Azospirillum has been reported by Gopalaswamy et al. (1989b) and Subramanian and Rangarajan (1990). Considering the importance of Azospirillum as a biofertilizer, the present investigation was carried out to find out the efficiency of Azospirillum in rice culture under our conditions. The objectives of the experiment are the following:

1. To study the effectiveness of _Azospirillum_ as a biofertilizer in rice.

2. To find out the effective method of _Azospirillum_ inoculation.

3. To assess the response of rice to different levels of nitrogen in conjunction with the biofertilizer.

4. To work out the economics of the use of _Azospirillum_ in rice culture.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

A brief review on the research findings in economising nitrogen application on rice crop is presented here under.

2.1 *Azospirillum*

Azospirillum is one of the most important associative bacteria found in the rhizosphere of various grass species which is capable of fixing atmospheric nitrogen.

The first species of *Azospirillum* was isolated by Beijerinck (1925) from nitrogen deficient sandy soil in the Netherlands, and was originally named *Spirillum lipoferum*. Dobereiner and Day (1976) were the first to report that this organism was widely distributed in the rhizosphere of several tropical grasses.

Nayak and Rao (1977) reported the presence of nitrogen fixing *Azospirillum lipoferum* in the roots of several cultivars of rice and weeds associated with rice plants. The occurrence of *Azospirillum* in rice soils and its association with rice roots have also been established by Charyulu and Rao (1979), Rao *et al*. (1981) and Watanabe *et al*. (1981). Lekshmi Kumari *et al*. (1976) established the occurrence of *Azospirillum* in Indian rice soils and roots of rice. Rao *et al*. (1978) observed the ubiquitous presence of nitrogen fixing *Spirillum* in different rice soil types under both lowland and upland conditions.

2.1.1 Factors influencing the occurrence of *Azospirillum*

Azospirillum requires an optimum range of temperature lying between 32 and 40°C (Day *et al*., 1975). They also observed that nitrogenase activity of *Azospirillum* was sensitive to temperature below 18°C. Day and Dobereiner (1976) reported that nitrogen fixation rapidly declined below 24°C and above 40°C. Subba Rao *et al*. (1980) pointed out that the nitrogen fixation by the Indian isolates of *Azospirillum* was maximum at temperature ranging from 30 to 35°C.

Day and Dobereiner (1976) observed that the optimum pH for nitrogen dependent growth of *Azospirillum* lies between 6.8 to 7.8. Nitrogen fixation reduced to considerable extent at pH below 5.5 and above 8.0 . Dobereiner *et al*. (1976) found that pH around 7.0 was optimum but sporadic occurrence was observed in soils with pH 4.8. Berkeem and Bohlool (1980) reported that although the pH of the soil was shown to have strong influence on the distribution of *Azospirillum* (optimum pH is 7.0) sporadic occurrence could also be demonstrated in soils with pH values as low as 4.8. Charyulu and Rao (1980) reported the occurrence of *Azospirillum* in acid soils with a pH of 3.2. Day and Mishra (1983) observed that the optimum growth and acetylene reduction occurred in *Azospirillum* at a pH of 7.0 to 7.5. Purushothaman and

Oblisami (1985) reported the presence of Azospirillum in alkaline and saline soils with a pH of 8.0 to 8.8.

Barber *et al*. (1979) reported the ability of Azospirillum to survive, compete and grow in soils not favoured by the addition of nitrogen.

Imposition of water stress considerably affected the rhizosphere population of Azospirillum and per cent root infection by the organism (Banwari Lal and Rao,1990).

Christiansen Weniger and Van Veen (1991) observed that the nitrogen fixation by *Azospirillum brasilense* in the rhizosphere of an actively growing plant was much less sensitive to the repressing influence of free oxygen. An optimum nitrogenous activity was observed at 10 kPa O_2 with a relatively high level of activity remaining even at an oxygen concentration of 20 kPa.

2.1.2 Effect of Azospirillum inoculation on rice

2.1.2.1 Growth characters

Dewan and Subba Rao (1979) observed that the root biomass of rice seedlings increased due to inoculation with Azospirillum. The increase in root biomass could be attributed to plant growth promoting substances, thus providing maximum surface area for absorption of nutrients.

Karthikeyan (1981) reported that Azospirillum inoculation increased the plant height and dry matter accumulation in rice.

Shivaradj (1981) revealed that Azospirillum inoculation to IR-20 rice variety influenced the number of tillers per hill at tillering phase, leaf area index and dry matter production.

Bacterization of rice seedlings with Azospirillum along with an application of 90 kg nitrogen per hectare resulted in increase in plant height and number of tiller per plant (Prasad and Singh, 1984).

Somchaudhary (1984) observed significant increase in plant height, fresh weight and dry weight of rice variety Mashuri due to the application of Azospirillum.

Root dipping and soil application of Azospirillum promoted early tillering and reproductive growth of wetland rice but no increase was noticed in total dry weight (Wantanabe and Lin, 1984).

Jayaraman and Ramiah (1986) observed that the growth characters such as plant height and total number of tillers per hill were found to be maximum in the treatments which received 75 kg nitrogen per hectare and Azospirillum application. Root dipping of Azospirillum alone had significant influence on plant height and total number of tillers compared to absolute control.

Nayak et al. (1986) reported that the Azospirillum inoculation on two rice varieties significantly increased plant height , tiller number and the dry weight of root and shoot. The result indicated that in Hua rice variety total dry matter increase was 23 per cent against the total nitrogen increase of 7.2 per cent; on the other hand dry matter increase in another variety OS-4 was 15.3 per cent against total nitrogen increase of 19.7 per cent.

Balasubramanian and Kumar (1987) revealed that combined application of Azospirillum significantly increased the tiller number and plant dry weight at all fertilizer levels.

Gopalaswamy and Vidhyasekaran (1987) in a field experiment with rice (ADT 36) found that split application of Azospirillum through seed, seedling and soil increased the plant height.

A significant increase in root surface area and number of tillers of rice were reported by Murali and Purushothaman (1987), when Azospirillum was inoculated through seed and soil

Prasad and Singh (1987) in a pot culture experiment reported that root dipping of seedlings with Azospirillum with different levels of nitrogen had resulted in improved root mass.

A study carried out by Subramanian (1987) in two seasons reported that seed and soil application of Azospirillum in the nursery significantly improved the seedling height, number of leaves, shoot dry weight, root length and root dry weight over either seed or soil inoculation alone. Inoculation had no marked influence on the plant height during Kharif and while in summer it significantly increased the plant height. Number of tillers was not influenced by Azospirillum inoculation. Inoculation significantly improved the leaf area index and dry matter production at all the growth stages in both the seasons.

Gopalaswamy et al. (1989a) revealed that Azospirillum applied both by seed treatment and seedling root dip did not increase the plant height significantly over uninoculated control at any nitrogen levels.

Azospirillum applied through both seed and soil increased the root weight and plant height (Gopalaswamy et al., 1989b).

Kumar and Balasubramanian (1989) reported that both the methods of Azospirillum application (nursery plus main field and main field alone) markedly increased the number of tillers and plant dry weight.

Muthukrishnan and Purushothaman (1992) observed that Azospirillum inoculation (seed plus nursery plus main field) exerted considerable influence on leaf area index.

2.1.2.2 Yield and yield attributes

Subba Rao *et al*. (1979) found that the inoculation of rice (Pusa 2-21) with Azospirillum increased grain yield at 0, 40, and 60 kg nitrogen per hectare.

Natarajan *et al*. (1980) reported that among the three varieties of rice CO 41, TNAU 4372 and CO 40, Azospirillum performed better in TNAU 4372 and increased the yield.

Field trials conducted in Delhi, Pantnagar, Karnal and Mannuthy found that the inoculation of rice seedlings at the time of transplanting with Azospirillum increased the grain yield. In Mannuthy, variety Triveni was used and the yield was increased to about 8.6 per cent by inoculation in presence of 35 kg nitrogen per hectare (Subba Rao *et al*., 1980).

Azospirillum inoculation to rice (IR-20) influenced the thousand grain weight (Shivaradj, 1981).

Rao *et al*. (1983) reported that the response of rice to root inoculation with Azospirillum resulted in significant increase in grain and straw yields especially at low levels of nitrogen (30 and 45 kg nitrogen per hectare) than at an application rate of 60 kg nitrogen per hectare. The interaction between the nitrogen fertilizer and inoculation was not statistically significant.

Prasad and Singh (1984) reported that bacterization of seedlings with Azospirillum and application of nitrogen increased the weight of pa..icle, number of grains per panicle and also enhanced the nutrient uptake by grains. The increase in yield parameters due to Azospirillum may be due to the increase in microbial population in the rhizosphere and there by enhancement of nitrogen fixation. Combined effect of Azospirillum plus 30 kg nitrogen per hectare was more pronounced in increasing the yield contributing factors.

A significant increase in the filling rate of grains and grain yield per plant was observed when Azospirillum was applied through root dipping and soil application (Wantanabe and Lin, 1984).

Studies conducted by Jayaraman and Ramiah (1986) on the effect of root dipping of seedlings with Azospirillum along with sub-optimal levels of nitrogen indicated that application of 75 kg nitrogen per hectare along with root dipping of Azospirillum recorded significantly higher grain yield.

Nayak *et al*. (1986) reported that the grain yield at two tested varieties of rice were significantly increased by inoculation of the spontaneous mutants of *Azospirillum*.

Alice and Subramanian (1987) reported that yield difference due to *Azospirillum* treatment as well as the interaction between *Azospirillum* and nitrogen levels were not significant.

TNAU (1987a) revealed that maximum grain yield of 3010 kg per hectare was obtained at 100 per cent recommended nitrogen plus seed and soil application of *Azospirillum*. Straw yield also showed significant difference.

Application of *Azospirillum* in three equal splits through seed, root and soil resulted in higher grain yield (TNAU, 1987b).

Balasubramanian and Kumar (1987) revealed that combined application of *Azospirillum* markedly increased the grain and straw yields at all nitrogen levels. Maximum increase in grain yield due of *Azospirillum* treatment was with 50 per cent nitrogen level which equalled to that with full fertilizer nitrogen.

Gopalaswamy and Vidhyasekaran (1987) in a field experiment with rice (ADT-36) found that split application of Azospirillum inoculum through seed, seedling root dip and soil gave the highest grain and straw yields and number of productive tillers.

In another study conducted at Coimbatore, seed and soil inoculation of Azospirillum significantly increased the grain and straw yields of rice. Grain yield with 75 kg nitrogen per hectare along with Azospirillum inoculation was higher than with 100 kg nitrogen (Murali and Purushothaman, 1987).

Prasad and Singh (1987) in a pot culture experiment reported that root dipping of seedlings with Azospirillum inoculum with different levels of nitrogen has resulted in increased grain yield and nitrogen uptake. They opined that the nitrogen fixation and production of growth promoting substances by Azospirillum might have contributed to this improvement in all the parameters.

Subramanian (1987) reported that Azospirillum inoculation had marked influence on the productive tillers, panicle number, panicle length and panicle weight. Significant increase in number of filled grain per panicle and thousand grain weight was noticed due to Azospirillum inoculation while the sterility percentage was significantly reduced. Azospirillum inoculation through seed and soil both in nursery and main field recorded maximum grain yield while the straw yield and harvest index were not influenced by the treatment.

Azospirillum inoculation (seed, seedling root dip and soil application) increased the number of productive tillers, straw yield and grain yield of all the tested varieties such as TKM-9, ADT-36, IR-50 and ADT-37 (Gopalaswamy and Vidhyasekaran, 1988).

In a field experiment by Jayaraman and Purushothaman (1988) inoculation of Azospirillum biofertilizer (root dipping) along with 75 kg nitrogen per hectare gave a significant yield increase in wet and dry season which was comparable with that of 100 kg nitrogen per hectare.

Mahapathra and Sharma (1988) observed that root dipping of seedlings in 2 per cent solution of Azospirillum increased grain yield slightly over control.

Purushothaman (1988) found that combined application of Azospirillum (seed plus soil) increased grain and straw yields of rice variety TKM-9. Response was more at 75 kg and 80 kg nitrogen per hectare than at 100 Kg. He opined that the beneficial effect of Azospirillum application is due to the nitrogen fixation and enhanced root proliferation.

TNAU (1989a) observed that application of Azospirillum at 1 kg with seed, 2 kg in nursery and 2 kg in the main field resulted in 7 per cent increased grain yield over control.

On farm trials conducted in Thanjavur district revealed that Azospirillum inoculation through seed, seedling root dip and soil gave positive response in increasing grain yield of rice. The percentage of yield increase ranged from 10.7 to 13.6 (TNAU, 1989b).

Gopalaswamy et al. (1989a) reported that while Azospirillum did not have any significant influence in yield at lower nitrogen levels but at higher levels of 75 kg nitrogen, Azospirillum treatment significantly increased the grain yield. Similar result was obtained in case of straw yield also.

Azospirillum applied through both seed and soil increased the productive tillers and grain and straw yield (Gopalaswamy et al., 1989b).

Kumar and Balasubramanian (1989) observed that both the methods of Azospirillum application (nursery plus main field and main field alone) markedly increased grain and straw yields and also the total nitrogen uptake. Grain yield obtained with 50 per cent nitrogen and Azospirillum application in the nursery and main field were on par with 100 per cent nitrogen alone.

TNAU (1990) found that *Azospirillum* application coupled with extra dose of 50 kg nitrogen per hectare increased the rice yield from 12.4 per cent to 22.6 per cent over the farmers practice.

Jayaraman (1990) revealed that the application of *Azospirillum* along with suboptimal doses of either 75 kg or 50 kg nitrogen per hectare showed an increasing trend in number of productive tillers, number of filled grains, panicle length and thousand grain weight. Highest grain yield was recorded with *Azospirillum* plus 75 kg or 50 kg nitrogen as against nitrogen alone.

Combined application of *Azospirillum* (seed, seedling root dip and soil application) increased the grain yield significantly, but the straw yield showed no significant difference. (Subramanian and Rangarajan, 1990).

Govindasamy *et al*. (1992) reported that *Azospirillum* application exhibits an augmentative effect on grain and straw yields of rice.

Azospirillum inoculation (seed plus nursery plus main field) exerted considerable influence on the uptake of nutrients, panicle per metre square and yield of rice (Muthukrishnan and Purushothaman, 1992).

Ramakrishnan *et al.* (1992) found that combined application of *Azospirillum* through seed, nursery and main field increased the grain and straw yields of the tested varieties such as ASD-16 and IR-20.

2.1.3 Effect of inoculation on nitrogen enrichment

Nayak and Rao (1977)reported that the roots of rice plants exposed to low levels of combined nitrogen (20 to 40 kg per hectare) harboured *Spirillum* species possessing higher nitrogen fixing efficiency as compared to cultivars receiving 60 to 100 kg nitrogen per hectare and also reported that the nitrogen fixing efficiency of these *Spirillum* species varied with the age of plant irrespective of the dosage of combined nitrogen.

TNAU (1980) reported that application of *Azospirillum* resulted in a saving of 35 per cent nitrogen in rice.

Prasad and Singh (1984) found that *Azospirillum* alone produced better or parallel response to that of 30 kg nitrogen per hectare.

Azospirillum seed inoculation was found to add 1 to 28 kg nitrogen per hectare in rice, wheat, barley and sorghum (Tilak, 1985).

Kumar and Balasubramanian (1986) revealed that *Azospirillum* treatments in rice could save 25 to 50 kg nitrogen per hectare.

Kumar and Balasubramanian (1989) also reported that *Azospirillum* treatments on the nursery and main field could help to save 25 to 50 per cent fertilizer nitrogen without reducing the grain and straw yields in IR-20 variety of rice.

Ramakrishnan *et al*. (1992) found that by combined application of *Azospirillum* in seed plus nursery plus main field of rice saved 25 per cent fertilizer nitrogen.

2.2 Effect of nitrogen on growth and productivity of rice

2.2.1 Effect of nitrogen on growth characters

2.2.1.1 Plant height

Pillai (1971) reported an increase in plant height with graded dose of nitrogen supply upto 100 kg per hectare.

Eunus and Sadeque (1974) concluded that plant height was unaffected by different levels of nitrogen. Balachandran Nair (1976) also reported similar results with *Triveni* variety.

Nagre and Mahajan (1981) observed that the plant height increased with increase in levels of nitrogen.

Nair and Koshy (1981) and Sushamakumari (1981) also reported significant effect on plant height due to increase in levels of nitrogen.

Sreekumaran (1981) and Ajithkumar (1984) found that different levels of nitrogen had no significant effect on plant height.

Upadhya *et al*. (1985) reported that increased rates of nitrogen increased the plant height.

Premkumar (1987) also reported significant effect on plant height with enhancement of nitrogen doses.

Significant increase in plant height with increase in levels of nitrogen from 0 to 120 kg per hectare was reported by Madan Mohan Reddy *et al*. (1987).

Thakur and Singh (1987) reported that the plant height increased with increase in levels of nitrogen up to 100 kg per hectare.

Similar results were reported by Rao and Ramaiah (1988), Karuna Sagar and Ramasubha Reddy (1989) and Krishna Prasad and Madhusoodana Rao (1989).

Contrary to this Anilkumar (1989) observed that levels of nitrogen did not influence the plant height at any stage of growth.

Shalini Pillai (1992) revealed that there was no significant difference in plant height at 20 DAT and 40 DAT due to various levels of nitrogen. But a significant difference in plant height was observed at 60 DAT and at harvest.

2.2.1.2 Number of tillers per square metre

Nair (1968) did not get significant increase in number of tillers with increased rate of nitrogen application.

Enhancement of tiller production as a result of nitrogen supply has also been reported by Ramanujam and Rao (1971), Alexander et al. (1972) and Meera Sahib (1974).

Balachandran Nair (1976) did not obtain significant influence of nitrogen rates on tiller production.

De Datta and Surjith (1981), Nagre and Mahajan (1981), Nair and Koshy (1981), Sreekumaran (1981) and Sushamakumari (1981) observed an increase in the number of tillers with increased rate of nitrogen application.

Ajithkumar (1984) and Surendran (1985) also observed that nitrogen application had considerable influence on tiller Production.

Premkumar (1987) also noticed an increase in the number of tillers per metre square with increase in the level of nitrogen.

Thakur and Singh (1987) observed that the number of tillers increased with increasing levels of nitrogen upto 100 kg per hectare.

The number of tillers produced at the incremental levels of applied nitrogen was linear though the effect due to nitrogen at 90 and 70 kg per hectare was on par (Anilkumar, 1989).

Hussain *et al*. (1989) and Patra and Padhi (1989) reported that tillers per hill increased with each increment of nitrogen fertilizer.

Tillers per square metre was significantly increased with enhancement in nitrogen levels from 30 to 90 kg per hectare (Karuna Sagar and Ramasubha Reddy, 1989).

Singh *et al*. (1991) found that with increasing levels of nitrogen there was significant increase in the number of tillers per square metre.

Shalini Pillai (1992) reported that tiller production was found to increase with levels of nitrogen.

2.2.1.3 Leaf area index

Trials conducted at the IRRI, Philippines, revealed that the LAI was influenced with an increase in nitrogen levels and was highest at flowering stage (IRRI, 1965).

Singh and Pande (1974) obtained increased leaf area at increased rate of nitrogen.

Abdulgali _et al_. (1979) observed that the nitrogen fertilization increased the LAI at all growth stages.

Rai and Murthy (1979) observed no correlation of LAI with levels of nitrogen applied.

Stone and Steinmetz (1979) reported that nitrogen increased the LAI in the cultivars which was due to the influence of increased number of tillers and size of the leaves.

Murthy and Murthy (1981 observed that enhanced application resulted in an increase in LAI.

Sreekumaran (1981) showed that there was an increase in LAI along with an increase in the levels of nitrogen.

Ramaswamy (1982), Sadayappan (1982), Sobhana (1983) and Salam (1984) noticed a progressive increase in LAI by increasing the levels of nitrogen.

According to Surendran (1985) levels of nitrogen significantly increased LAI at flowering.

Vaijayanthi (1986) did not find any influence of nitrogen rates on LAI at booting stage in _Lekshmi_ variety of rice.

Premkumar (1987) observed an increase in LAI with enhanced nitrogen application.

Proportionate increase in LAI was reported by Rao (1987) and Padmaja Rao (1988) with higher levels of nitrogen application.

Anilkumar (1989) reported that the leaf area index was not influenced by different levels of nitrogen.

There was a significant decrease in LAI with increase in the levels of nitrogen from 30 to 60 or 90 kg per hectare (Dinesh Chandra, 1991).

Panda and Rao (1991) observed that LAI was increased with increasing levels of nitrogen from 30 to 120 kg per hectare.

2.2.1.4 Dry matter Production

Ramanujam and Rao (1971) reported progressive increase in dry matter production with increase in nitrogen application.

Sadayappan (1972) observed increased dry matter production with additional levels of nitrogen.

Balachandran Nair (1976) observed significant increase in dry matter production at harvest in direct sown rice variety *Triveni* when levels of nitrogen was raised from 50 to 70 kg per hectare.

Sharma and Prasad (1980) reported that dry matter production increased with increase in rate of applied nitrogen.

Sushamakumari (1981) observed a significant increase in dry matter production with increase in the level of nitrogen first from 45 to 60 kg per hectare and again from 60 to 90 kg per hectare with *Jaya* variety of rice.

Prasad (1981) Upadhyay and Pathak (1981), Rajas *et al.* (1983) and Salam (1984) also reported increased dry matter production with additional levels of nitrogen.

Results of the experiments conducted by Surendran (1985) showed that there is a progressive increase in dry matter production for *Lekshmi* variety when the levels of nitrogen was raised from 20 to 80 kg per hectare.

Application of nitrogen at 90 kg per hectare produced significantly higher dry matter over 45 kg per hectare (Ramaih *et al.*, 1986).

Premkumar (1987) reported that the dry matter production was enhanced with enhanced rates of nitrogen application.

Rao (1987) found that higher levels of nitrogen resulted in higher total dry matter production.

Total dry matter production was increased by enhancement of nitrogen levels (Padmaja Rao, 1988).

Ramasubha Reddy (1988) observed an increase in dry matter production with increase in levels of nitrogen from 40 to 120 kg per hectare.

Anilkumar (1989) found that dry matter production was significantly influenced by increments of applied nitrogen.

Karuna Sagar and Ramasubha Reddy (1989) reported a significant increase in dry matter production with increase in levels of nitrogen from 30 to 90 kg per hectare.

Mahapathra *et al*. (1991) found that nitrogen application had significant effect on total dry matter production.

2.2.2. Effect of nitrogen on yield attributes and yield

2.2.2.1 Number of productive tillers per square metre

Sood and Singh (1972) observed an increase in the number of ear bearing tillers in tall indica varieties with an increase in nitrogen levels from 0 to 90 kg per hectare.

Rathinam (1974) reported that increasing rates of nitrogen from 0 to 160 kg per hectare produced linear increase in average number of productive tillers per hill.

Balachandran Nair (1976) reported that the number of productive tillers was not influenced by levels of nitrogen.

Singh *et al*. (1979) recorded an increase in productive tillers with increase in fertilizer levels.

Number of panicles per metre square produced beneficial effect with increase in nitrogen levels (Mahajan and Nagre, 1981).

Murthy and Murthy (1981) observed an increase in productive tillers per square metre due of different levels of nitrogen.

Sushamakumari (1981) observed significant effect of nitrogen levels up to 90 kg nitrogen per hectare on the number of productive tillers per unit area.

Surendran (1985) reported progressive increase in number of productive tillers with enhanced application of nitrogen from 20 to 80 kg per hectare.

Similar findings were reported by Madan Mohan Reddy *et al*. (1987), Shrivastava *et al*. (1987), Subbiah *et al*. (1988), Anilkumar (1989), Patra and Padhi (1989), Ramasubha

Reddy and Anand Reddy (1989), Singh _et al_. (1991), Thakur (1991), Shalini Pillai (1992) and Sharma and Gupta (1992).

Contrary to these results Savithri _et al_. (1992) reported that panicles per square metre showed no significant difference with different levels of nitrogen in _Mashuri_ variety of rice.

2.2.2.2 Number of grains per panicle

Prasad and Sharma (1973)reported that the highest nitrogen level of 222 kg per hectare produced more than double the number of spikelets per panicle as against the control with no nitrogen.

Balachandran Nair (1976) observed that the number of spikelets per panicle was not influenced by levels of nitrogen in direct sown _Triveni_ variety of rice.

De Datta and Surjith (1981) found that the nitrogen application increased the number of grains per panicle.

Sushamakumari (1981) observed that levels of nitrogen significantly influenced the number of grains per panicle in _Jaya_ variety of rice.

Surendran (1985) and Vaijayanthi (1986) reported significant increase in grain number per panicle due to levels of nitrogen upto 60 kg per hectare in Lekshmi variety of rice.

Contrary to the above results Shrivastava et al. (1987) and Anilkumar (1989) did not observe any significant difference in number of grains per panicle due to different doses of nitrogen.

Grains per panicle was significantly increased with increase in nitrogen levels from 30 to 90 kg per hectare (Karuna Sagar and Ramasubha Reddy, 1989).

Lee et al. (1990) reported that number of grains per panicle was increased with different levels of nitrogen.

Dinesh Chandra (1991) observed significant increase in number of grains per panicle with increase in levels of nitrogen.

Thakur (1991) found that number of grains per panicle increased significantly with enhanced doses of nitrogen.

Sharma and Gupta (1992) noticed significant increase in number of grains per panicle due to successive increase in the doses of nitrogen.

Singh and Singh (1992) recorded an increase in the number of grains per panicle with increase in fertilizer nitrogen.

2.2.2.3 Panicle length

Iyer (1967) found that panicle length was little influenced by nitrogen application.

Chaudhary *et al*. (1969) observed a positive relationship between length of panicle and nitrogen levels in TN-I and IR-8.

Balacanadran Nair (1976) observed no significant effect due to levels of nitrogen on length of panicle.

Dixit and Singh (1978) found that length of panicle increased with enhancement of nitrogen doses.

Significant increase in panicle length due to increase in level of nitrogen was reported by Sushakumari (1981).

Sreekumaran (1981) reported that the panicle length remained unaffected due to different levels of nitrogen. Similar results were reported by Ajithkumar (1984) and Surendran (1985).

Panicle length increased significantly with enhanced application of nitrogen from 0 to 120 kg per hectare (Madan Mohan Reddy *et al*., 1987).

According to Premkumar (1987) and Singh and Sharma (1987) enhancement of nitrogen significantly increased the panicle length.

Study conducted by Patra and Padhi (1989) resulted that panicle length was not significantly influenced by levels of nitrogen.

Singh *et al.* (1991) found that enhancement of nitrogen significantly influenced the panicle length.

Sharma and Gupta (1992) also reported significant difference in panicle length with successive increase in nitrogen levels.

2.2.2.4 Panicle weight

Pillai (1971) reported increase in panicle weight up to 100 kg level of nitrogen.

Sushamakumari (1981) reported significant increase in panicle weight at 60 and 90 kg levels of nitrogen in *Jaya* variety of rice.

Ajithkumar (1984) reported that the enhancement of nitrogen levels did not influence the panicle weight significantly.

Vaijayanthi (1986) observed no significant difference in weight of panicle due to different doses of nitrogen.

Wagh and Thorat (1987) also reported that the panicle weight remained unaffected due to different doses of nitrogen.

Anilkumar (1989) observed a progressive increase in panicle weight with incremental levels of nitrogen.

Weight of the panicle increased linearly with enhancement of nitrogen levels (Thakur, 1991).

Shalini Pillai (1992) reported that panicle weight was not significantly influenced by the different doses of nitrogen.

Sharma and Gupta (1992) found that the different doses of nitrogen significant influenced the panicle weight.

2.2.2.5 Percentage of filled grains

Alexander *et al.* (1972) reported an increase in the number of filled grains per panicle with increase in the levels of nitrogen.

Sreekumaran (1981) did not observe any significant increase in the number of filled grains per panicle due to different doses of nitrogen.

Ajithkumar (1984) also observed that levels of nitrogen had no significant influence on the percentage of filled grains per panicle.

Pillai *et al.* (1984) found that the filled grain percentage was favourably influenced by nitrogen levels.

According to Surendran (1985) a significant increase in the percentage of filled grains was observed with the addition of nitrogen levels from 20 to 40 kg per hectare.

Enhancement of nitrogen levels from no nitrogen to 180 kg nitrogen per hectare increased the filled grain percentage (Srinivasalu Reddy, 1986).

Premkumar (1987) reported higher percentage of filled grains with enhanced nitrogen application.

Ramasubha Reddy and Anand Reddy (1989) also observed that the percentage of filled grains increased as the level of nitrogen was increased from 40 to 120 kg per hectare.

Shalini Pillai (1992) observed no significant effect due to levels of nitrogen on percentage of filled grains.

2.2.2.6 Percentage of unfilled grains

Balachandran Nair (1976) reported that application of nitrogen did not influence the percentage of unfilled grains in Triveni variety of rice.

Bhaumik and Ghosh (1977) observed an increase in the number of unfilled grains per panicle due to increase in levels of nitrogen.

Surendran (1985) observed a linear increase in the percentage of unfilled grains with increase in nitrogen dose from 20 to 60 kg per hectare.

Percentage of unfilled grains increased significantly by 80 and 120 kg nitrogen per hectare over 40 kg nitrogen per hectare (Madan Mohan Reddy et al., 1987).

The percentage of unfilled grains was not influenced by nitrogen levels (Anilkumar, 1989).

Shalini Pillai (1992) reported that different levels of nitrogen had no significant influence on the percentage of unfilled grains per panicle in Jyothi variety of rice.

2.2.2.7 Thousand grain weight

Alexander et al. (1972) observed that thousand grain weight was increased by nitrogen levels in Triveni variety.

Rajasekhara and Morachan (1974) reported that thousand grain weight was not affected by nitrogen levels.

Pillai et al. (1976) found that thousand grain weight remained unaffected due to levels of nitrogen.

Thousand grain weight produced beneficial effect with increase in nitrogen levels (Mahagan and Nagre, 1981).

Nair and Koshy (1981) reported that nitrogen levels showed no significant influence on thousand grain weight.

Balasubramanian (1982) noticed only a marginal increase in test weight due to application of nitrogen.

Sharma and Rajendra Prasad (1982) and Sobhana (1983) observed considerable increase in thousand grain weight due to increased fertilizer application.

Ajithkumar (1984) pointed out that the effect of nitrogen on thousand grain weight was not significant.

Surendran (1985), Srinivasalu Reddy (1986), Dalai and Dixit (1987) and Premkumar (1987) reported an increase in thousand grain weight with increasing levels of nitrogen.

Thousand grain weight remained unaffected due to levels of nitrogen (Padmaja Rao, 1988; Anilkumar, 1989).

Thousand grain weight was significantly increased with increase in nitrogen levels from 30 to 90 kg per hectare, (Karuna Sagar and Ramasubha Reddy, 1989).

Patra and Padhi (1989) pointed out that there was no significant difference in thousand grain weight with increase in levels of nitrogen.

Savithri _et al_. (1992) observed no significant effect on thousand grain weight for different level of nitrogen.

Shalini Pillai (1992) reported that thousand grain weight was not influenced significantly by doses of nitrogen.

Sharma and Gupta (1992) observed a significant increase in thousand grain weight with increase in nitrogen levels.

2.2.2.8 Grain yield

Rethinam (1974) observed steady increase in yield with enhanced doses of nitrogen and the highest yield was obtained with 160 kg nitrogen per hectare.

Four nitrogen levels from 0 to 240 kg per hectare showed increase in tillering but had very little effect on final yield (Fagundo et al., 1978). Wells and Faw (1978) found that nitrogen rate was weakly correlated with yield. Draupathi Devi et al. ,(1981) reported that nitrogen had no significant influence on yield.

The grain yield of rice was found to increase with increase in levels of nitroge.. (Mahajan and Nagre, 1981)

Sadaphal et al. (1981) also revealed that the grain yield was increased with increasing doses of nitrogen.

Sushamakumari (1981) found that fertilizer levels exerted significant influence on grain yield.

Ayyaswamy *et al*. (1983) reported that application of different levels of nitrogen significantly increased yield and 120 kg nitrogen per hectare recorded the maximum yield.

Perumal *et al*. (1985) observed that grain yield of rice variety, *Bhavani* showed considerable increase upto 150 kg nitrogen per hectare.

Surendran (1985) reported that an increase in level of nitrogen from 20 to 60 kg per hectare has brought about a progressive increase in yield.

Vaijayanthi (1986) obtained a significant increase in grain yield with increase in level of nitrogen in *Cheradi* variety of rice.

Babu Mathew (1987) observed that grain yield showed an increasing trend in grain with increase in the level of nitrogen upto 112.5 kg per hectare in *Jaya* variety of rice.

Application of 60 kg nitrogen per hectare did not significantly increase grain yield over 30 kg in upland rice (Kehinde and Fagade, 1987).

Madan Mohan Reddy *et al*. (1987) noticed significant increase in grain yield with increasing levels of nitrogen from 0 to 120 kg nitrogen per hectare.

Grain yield showed significant difference with levels of nitrogen in transplanted rice (Shrivastava *et al*., 1987).

Singh and Mishra (1987) reported that nitrogen levels significantly influenced the grain yield.

Similar results were obtained by Rao and Ramaiah (1988), Rajagopalam and Rangeswamy (1988), Ramasubha Reddy (1988), Reddy *et al*. (1988), Sharma and Raj (1988), Gulati *et al*. (1989), Karuna Sagar and Ramasubha Reddy (1989), Patra and Padhi (1989), Singandhupe and Rajput (1990), Sarawgal and Sharma (1991), Sreedevi and Sreedharan (1991), Thakur (1991), Mongia (1992) and Sharma and Gupta (1992).

Contrary to the above results Savithri *et al*. (1992) observed that nitrogen levels could not bring any significant influence on grain yield.

2.2.2.9 Straw yield

Raj *et al*. (1974) reported that straw yield was increased by the applied nitrogen from 0 to 250 kg per hectare.

Venkateswaralu (1978) pointed out that straw yields increased with increase in nitrogen levels upto 200 kg per hectare only and beyond which it declined.

Sushamakumari (1981) observed that nitrogen at higher levels progressively increased straw yield and the highest straw yield was recorded at 90 kg nitrogen per hectare.

Progressive increase in straw yield to increased application of nitrogen was observed by Sobhana (1983)

Ajithkumar (1984) reported that higher level of nitrogen progressively influenced straw yield of Mashuri rice.

Surendran (1985) reported an increase in straw yield with successive addition of nitrogen from 20 to 80 kg per hectare and was highest at 80 kg per hectare in Lekshmi variety of rice.

Babu Mathew (1987) revealed that straw yield was influenced by levels of nitrogen.

Dalai and Dixit (1987) got increased straw yield with each successive level of nitrogen.

Madan Mohan Reddy et al. (1987) reported that straw yield increased significantly with increase in levels of nitrogen from 0 to 120 kg nitrogen per hectare.

Shrivastava et al. (1987) observed a significant difference in straw yield with levels of nitrogen.

Straw yield increased significantly with increase in nitrogen levels upto 112 kg nitrogen per hectare (Rao and Ramaiah, 1988).

Enhancement of nitrogen fertilizer increased that straw yield (Hussain et al., 1989).

Karuna Sagar and Ramasubha Reddy (1989) pointed out that straw yield was significantly influenced by nitrogen levels from 30 to 90 kg per hectare.

Straw yield showed a significant increase with each increment of nitrogen application (Patra and Padhi, 1989).

In sodic soils Singandhupe and Rajput (1990) reported that each increment of nitrogen level from 40 to 120 kg per hectare showed a significant increase in straw yield.

Sarawgal and Sharma (1991) reported that straw yield was higher with the application of nitrogen.

Sreedevi and Sreedharan (1991) pointed out that the application of full dose of nitrogen (100 kg per hectare) gave highest straw yield compared to the lower doses.

Savithri et al. (1992) observed that nitrogen levels could not bring any influence on straw yield of Mashuri variety of rice.

Shalini Pillai (1992) stated that nitrogen levels did not influence the straw yield significantly.

2.2.2.10 Harvest index

Balachandran Nair (1976) obtained a significant influence of levels of nitrogen on harvest index and obtained a higher harvest index with 50 kg nitrogen per hectare in Triveni variety of rice.

Prasad (1981) reported a decrease in harvest index with increase in level of nitrogen from 0 to 100 kg per hectare.

Beneficial influence of nitrogen in increasing harvest index was reported by Sreedharan and Vamadevan (1981).

Venketeswarlu and Prasad (1982) did not notice any variation in harvest index due to nitrogen application.

Habeeburrahman (1983) reported that harvest index was influenced by graded levels of fertilizer.

Son *et al*. (1983) did not observe any significant difference in harvest index due to different levels of nitrogen.

Vaijayanthi (1986) reported that harvest index was influenced by graded levels of fertilizer.

Premkumar (1987) reported that harvest index was enhanced with nitrogen upto 9. kg per hectare.

Rao and Ramaiah (1988) observed a decrease in harvest index with increase in nitrogen levels. Ramasubha Reddy (1988) also reported similar trend.

Enhancement of nitrogen application has resulted in significant reduction in harvest index (Karuna Sagar and Ramasubha Reddy, 1989; and Krishna Prasad and Madhusoodana Rao, 1989).

A significant increase in harvest index was obtained by increasing the doses of nitrogen (Nerendra Pandey et al., 1992).

2.3 Chemical analysis

2.3.1 Nitrogen uptake

Gopalaswamy and Raj (1977) reported a linear increase in the uptake of nitrogen with an increase in the rate of applied nitrogen from 0 to 200 kg per hectare.

Agarwal (1978) observed that the nitrogen uptake was increased by the application of nitrogen upto 120 kg per hectare.

Sharma and Prasad (1980) reported that nitrogen uptake was increased with increase in rate of nitrogen applied.

Sushamakumari (1981) found that nitrogen uptake was significantly influenced by levels of nitrogen at all stages.

Perumal *et al*. (1985) pointed out that uptake of nitrogen by *Bhavani* variety showed considerable increase upto 150 kg nitrogen per hectare.

Ramasubha Reddy and Anand Reddy (1986) found that nitrogen application increased nitrogen uptake at all growth stages.

Ramaih *et al*. (1986) observed that 90 kg nitrogen per hectare recorded significantly higher uptake of nitrogen over 0 and 45 kg nitrogen per hectare.

Uptake of nitrogen increased with increased application of nitrogen on coastal saline soils (Biswas, 1987).

Premkumar (1987) found that nitrogen uptake was enhanced by nitrogen application.

Thakur and Singh (1987) observed that nitrogen uptake increased with increasing levels of nitrogen upto 100 kg per hectare.

According to Rao and Ramaiah (1988) nitrogen uptake was increased with increase in nitrogen levels upto 112 kg nitrogen per hectare.

Wankhade and Pandrangi (1988) also obtained progressive increase in nitrogen uptake with increasing levels of nitrogen.

Anilkumar (1989) reported that nitrogen levels showed significant influence on nitr gen uptake.

The nitrogen uptake by rice crop significantly increased with each increment of nitrogen dose (Karuna Sagar and Ramasubha Reddy, 1989).

Krishna Prasad and Madhusoodana Rao (1989) reported that nitrogen uptake was significantly influenced by enhancement of nitrogen doses upto 90 kg per hectare.

With each increment of nitrogen levels from 40 to 120 kg per hectare there was significant increase in nitrogen uptake (Singandhupe and Rajput, 1990).

Nitrogen application resulted in significant effect on nitrogen uptake of rice crop (Mahapathra et al., 1991).

Uptake of nitrogen was increased significantly with increase in nitrogen levels from 30 to 90 kg per hectare (Narendra Pandey et al., 1992).

Shalini Pillai (1992) reported that nitrogen uptake was not affected significantly by different doses of nitrogen.

2.3.2 Phosphorus uptake

Loganathan and Raj (1972) reported that the uptake of phosphorus was not influenced by nitrogen application.

Singh and Bhardwaj (1973) found that smaller amount of nitrogen application enhanced phosphorus absorption by rice plants.

Raju (1978) pointed out that increased application of nitrogen from 0 to 180 kg per hectare increased phosphorus uptake.

Nair and Koshy (1981) found that nitrogen had no significant influence on the content and uptake of phosphorus by grain and straw.

Increase in nitrogen levels showed significant increase in uptake of phosphorus (Ramaih et al., 1986).

Phosphorus uptake was positive and was increasing especially with higher levels of nitrogen (Biswas, 1987).

Premkumar (1987) reported that phosphorus uptake was enhanced by enhancement of nitrogen application.

Phosphorus uptake was increased with each increment of nitrogen upto to 112 kg per hectare (Rao and Ramaiah, 1988)

Salam (1988) found that nitrogen application from 0 to 120 kg per hectare has benefited the uptake of phosphorus significantly.

Wankhade and Pandrangi (1988) observed a progressive increase in the uptake of phosphorus with the increasing levels of nitrogen.

Krishna Prasad and Madhusoodana Rao (1989) observed that phosphorus uptake was increased with increase in nitrogen levels upto 90 kg nitrogen per hectare.

Different levels of nitrogen did not show any significant difference in uptake of phosphorus (Shalini Pillai, 1992).

2.3.3 Potassium uptake

Sadayappan and Kolandaiswamy (1974) noticed an increase in potassium uptake with enhancement of nitrogen level upto 100 kg per hectare.

Potassium uptake was found to be increasing with increase in levels of nitrogen (Esakkimuthu *et al.*, 1975).

Agarwal (1978) reported that potassium uptake was increased by application of nitrogen upto 120 kg per hectare.

Uptake of potassium was enhanced by the nitrogen application upto 120 kg per hectare (Singh and Modgal, 1978).

Nair and Koshy (1981) observed no significant influence of potassium uptake due to levels of nitrogen.

Uptake of potassium was increased with higher levels of nitrogen (Biswas, 1987).

Potassium uptake was enhanced by nitrogen application upto 110 kg per hectare (Premkumar, 1987).

Rao and Ramaiah (1988) reported that the potassium uptake was influenced significantly by nitrogen levels upto 112 kg nitrogen per hectare.

Nitrogen application benefited the uptake of potassium (Salam, 1988).

Wankhade and Pandrangi (1988) observed a progressive increase in the uptake of potassium with the increasing levels of nitrogen.

Potassium uptake was found to increase with enhancement of nitrogen doses upto 90 kg per hectare (Krishna Prasad and Madhusoodana Rao, 1989).

Shalini Pillai (1992) reported that the different levels of nitrogen did not show any significant influence on the uptake of potassium.

2.3.4 Protein content

Ramanujam and Rao (1970) observed an increase in protein content from 8.50 per cent to 11.50 per cent corresponding to nitrogen levels from 0 to 180 kg per hectare.

Kulkarni (1973) noticed a 40 to 50 per cent increase in grain protein content with increasing rates of nitrogen application from 0 to 150 kg per hectare.

Agarwal (1978) reported an increase in crude protein from 9.09 to 10.65 per cent due to nitrogen application.

An increase in protein content in rice grain with increase in level of nitrogen was noticed by Mahajan and Nagre (1981).

Jayakumar and Kandaswamy (1985) found that increasing nitrogen levels upto 120 kg per hectare increased the crude protein content considerably.

Surendran (1985) observed an increase in protein content of grain with increased nitrogen rates ranging from 20 to 80 kg per hectare.

Protein content was found to increase with increase in levels of nitrogen (Vaijayanthi, 1986).

Premkumar (1987) reported that the protein content was increased upto 110 kg nitrogen per hectare.

Nitrogen fertilization has improved protein content compared to no nitrogen (Reddy et al., 1988).

Increase in grain protein content was greater with higher total rates of applied nitrogen (Umestu et al., 1990).

Protein content of grain increased with increase in nitrogen levels in Ratna variety (Dinesh Chandra; 1991).

Shalini Pillai (1992) reported that the levels of nitrogen were found to influence the protein content of rice significantly.

2.4 Effect of lime on growth and productivity of rice

Deguchi and Ohata (1958) reported that increasing the calcium concentration increased the phosphorus uptake of paddy.

According to Varghese (1963) and Bhat (1964) the nitrogen content of the grain and straw in rice was appreciably increased by the application of lime.

Mudaliyar (1965) reported no significant difference in plant height due to the application of lime.

Mandal *et al*. (1966) reported that paddy did not respond to liming.

Kwack (1968) revealed that on degraded paddy soils liming the fields at the rate of 3600kg of slaked lime per hectare before transplanting increased the yield of brown rice by 19 to 37 per cent due to the increased number of spikes per clone and tillering.

Park *et al*. (1968) reported that grain yield of rice increased by 21 per cent, following the application of silicon dioxide calcium and magnesium. When lime was omitted, yield decreased but when other elements were omitted yield remained unchanged.

Kabeerathumma (1969) observed a substantial increase in yield of grain and straw due to fractional levels of liming. Notable increase in the uptake of nitrogen and phosphorus was also reported with increased dose of lime.

Kwack (1969) reported that liming increased the straw weight, number of spikelets, plant height and yield by 112 to 142 per cent in Korea, but lime did not influence the number of sterile grains, thousand grain weight and length of spikes.

Suseelan (1969) pointed out that lime application did not influence the plant height, tiller number, percentage of productive tillers, length of the panicle and straw yield, but showed significant influence on percentage of filled grains, thousand grain weight, grain yield and uptake of phosphorus.

Kwack (1970) noted that lime increased the weight of straw, number of panicles per plant, height of the plant, and yield of unpolished rice by 102 to 138 per cent, but had no effect on the panicle length, number of grains per panicle, thousand grain weight and time of maturity.

Nair (1970) reported that lime at half the lime requirement had several beneficial effect on the growth, yield and quality of rice. Length of the ear head was significantly influenced by different levels of lime, but had no effect on tiller number, number of productive tillers and height of the plant. Nitrogen content of grain and straw was appreciably increased by lime application.

Sukumaran _et al_. (1971) indicated that application of lime materials at 1/5 th of the lime requirement of soil brought about 73 per cent increase in grain yield.

According to Wang (1971) calcium carbonate at the rate of 10 tons per hectare increased the grain and straw yield by 27 and 23 per cent respectively in strongly acidic latosolic soil.

Padmaja and Varghese (1972) revealed that liming of red loam soils of Kerala at the rate of 2.5 tons per hectare raised the soil pH by 1 to 1.5 units. A rise in pH due to application of lime in acid soils was obtained by Kar (1974) and Murayamma and Inoko (1975).

Prateep and Sims (1972) revealed that lime application markedly increased the grain : straw ratio.

In a pot culture experiment, liming significantly increased the number of productive tillers and grain and straw yields (Ananthanarayana and Perur, 1973).

Gopalakrishnan (1973) revealed that an increase of 20 to 30 per cent yield was obtained when lime was applied at the rate of 500 kg per hectare in pokkali soils.

According to Goswami et al. (1973) there was an increase in the yield of rice ranging from 58 to 85 per cent by the application of lime in Kari soils.

Keranen (1974) indicated that liming only continued to increase crop yield when supply of other nutrients were adequate.

Kuruvilla (1974) reported that the application of lime alone or in combination with MnO_2 or nitrate resulted in decrease in the nitrogen and phosphorus contents of straw.

Singh and Dahiya (1975) suggested that the addition of calcium carbonate to an acid soil having pH 5.3 to 6.1 did not affect the dry matter production of rice.

Sen and Ghosh (1976) obtained an increase in yield due to liming.

Mariam and Koshy (1977) in a pot culture experiment with rice grown in acid soils revealed that application of lime showed on significant difference on the number of productive tillers, but liming increased the number of tillers per plant, panicle length, number of grains per panicle and grain and straw yield. Application of lime has increased the length, volume and dry weight of roots. The uptake of nitrogen and phosphorus were increased while the uptake of potassium decreased with levels of lime.

Padole and Deoras (1978) reported an increase in grain and straw yields with the application of lime.

Anilkumar (1980) reported that among the different growth characters studied height of the plant, number of tillers and number of productive tillers were significantly influenced by levels of liming, and beneficial effects on the grain and straw yield and on all the root parameters studied. A notable increase in the uptake of nitrogen and phosphorus was also reported.

Mahendra Singh and Singh (1980) observed that paddy plant showed lower concentration of nitrogen at tillering, heading and maturity when calcium carbonate was added at the rate of 4 to 5 per cent. Phosphorus concentration in paddy plant also decreased significant with increasing doses of calcium carbonate.

Mahendra Singh and Singh (1981) reported that liming (4 per cent calcium carbonate) significantly decreased the dry matter yield of rice at tillering and heading as against unlimed treatment. Nitrogen concentration and uptake was also decreased due to liming.

Sadashivaiah *et al.* (1981) noted that the yield was increased by the application of lime at 6.8 tons per hectare.

Application of lime to submerged soils significantly increased the dry matter production at all stages and also the grain yield of rice (Verma and Tripathi, 1981).

Datta (1984) reported no response of rice to applied lime.

Marykutty (1986) pointed out that the application of lime significantly increased the plant height, number of tillers per hill and number of productive tillers per hill. Length of earhead, number of grains per panicle and thousand grain weight were also observed to increase by lime application.

Habeeburrahman and Sreedharan (1990) reported that the application of lime at the rate of 600 kg per hectare produced highest grain yield of 2.45 tons per hectare. The yield attributes like number of panicles per square metre, thousand grain weight and number of grains per panicle also showed significant increase upto 600 kg lime per hectare.

Mongia et al. (1991) reported an increase in grain yield of rice due to the application of lime and phosphorus.

Yield of rice in plots treated with lime at 2 tons per hectare was significantly higher than those at 0, 0.5 and 1 ton per hectare (Rosmini and Sarwani, 1991).

Joy et al. (1992) reported that lime application had no measurable effect on growth and yield of rice.

MATERIALS AND METHODS

MATERIALS AND METHODS

An investigation was carried out during the period from June 1992 to September 1992 to assess the role of *Azospirillum* on growth and productivity of rice as a means of economising fertilizer nitrogen application.

The details of materials used and methodology adopted during the course of the investigation are presented below.

3.1. MATERIALS

3.1.1 Experimental site

The experiment was conducted in the wetlands of the Instructional Farm, College of Agriculture, Vellayani, located at 3.5° N latitude and 76.9° E longitude, at an altitude of 29 m above mean sea level.

3.1.2 Soil characteristics

The texture of the soil was sandy clay loam. The physico-chemical properties of the soil are given in Table 1.

3.1.3 Cropping history

The paddy field in which the experiment was laid out was lying fallow during the previous season.

3.1.4 Season

The experiment was conducted during the period from June 1992 to September 1992.

Table 1a. Mechanical analysis of the soil of experimental site

Constituent	Content in soil (%)	Method used
A.		
Mechanical Composition		International Pipette Method (Piper, 1950)
Coarse sand	51.55	
Fine sand	10.15	
Silt	6.10	
Clay	30.00	
Textural class	sandy clay loam	

Table 1b. Chemical properties of the soil of the experimental site

Constituent	Content in soil	Rating	Method used
B.			
Chemical Composition			
Available nitrogen ($kg\ ha^{-1}$)	260.52	Medium	Kjeldahl digestion (Jackson,1973)
Available Phosphorus ($kg\ ha^{-1}$)	33.34	Medium	Vanado molybdate (Jackson, 1973)
Available Potassium ($kg\ ha^{-1}$)	80.10	Low	Flame photometry (Jackson, 1973)
Organic Carbon (%)	0.93	High	Walkley and Black rapid titration method (Jackson, 1973)
pH	4.7	Acidic	1:2:5 soil solution ratio using pH meter with glass electrode

3.1.5 Weather conditions

The experimental site enjoys a humid tropical climate. The data on various weather parameters (rain fall, number of rainy days, mean maximum and minimum temperature and relative humidity) during the cropping period and for the last five years are given in the Appendix I and II and graphically represented in Fig. 1. The mean maximum and minimum temperature during the cropping period ranged from 28.22°C to 30.30°C and 22.45°C to 25.25°C respectively. The mean relative humidity ranged from 80.14 to 80.50 per cent. The total rainfall received during the crop period was 478.69 mm and the number of rainy days during the cropping period was 66. Days receiving more than 2.5 mm rainfall is considered as rainy days

3.1.6 Variety

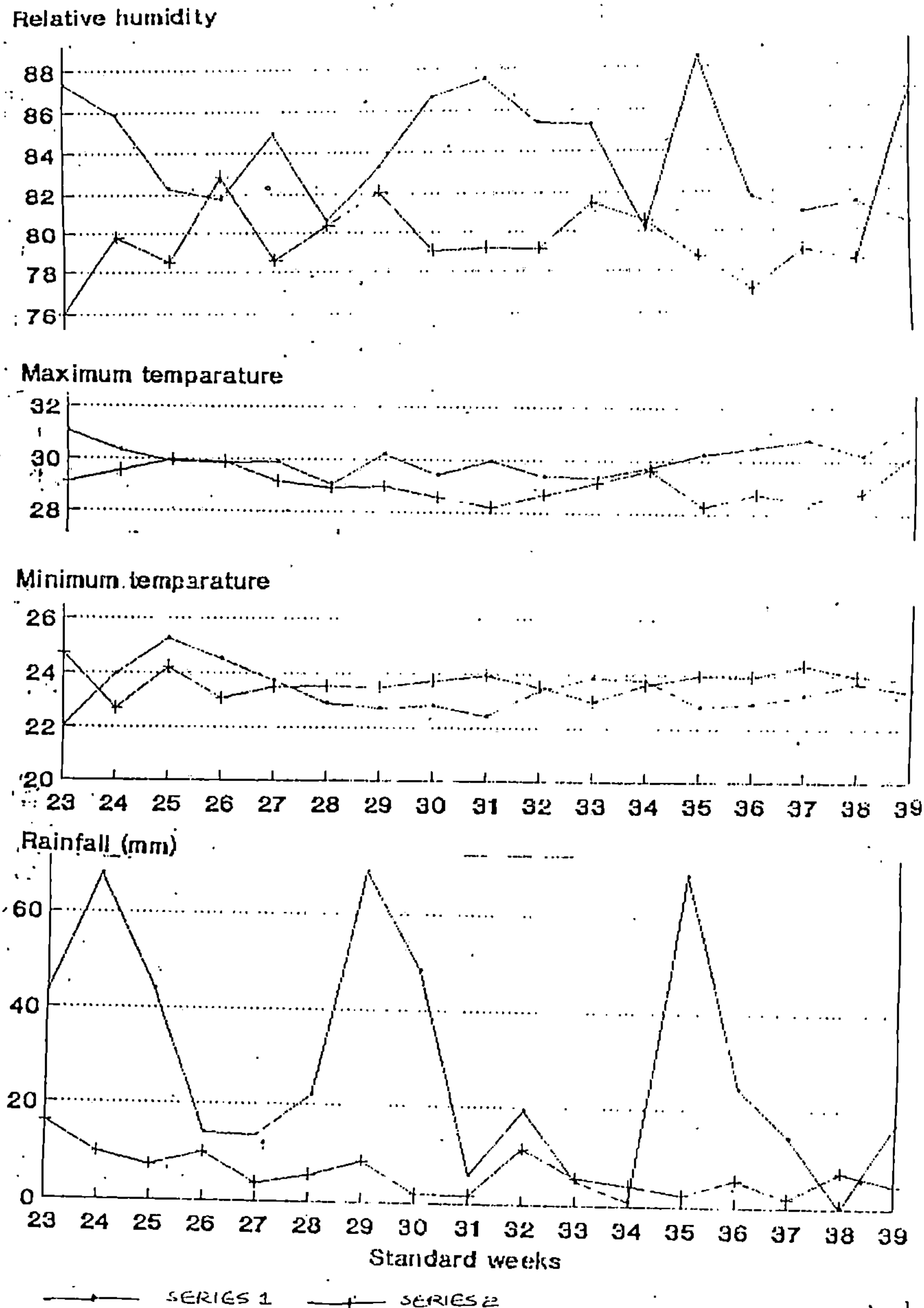
The variety used for the study was Red Triveni. It is red-riced selection made from the Triveni variety, released from Rice Research Station, Pattambi, Kerala. It is a short duration variety (100-105 days) of high yielding nature recommended for cultivation in Kerala.

3.1.7 Manures, fertilizers and soil amendments

3.1.7.1 Chemical fertilizers and manures

Chemical fertilizers used for the experiment includes urea, mussoriephos and muriate of potash. Farm yard manure was applied as a basal dressing uniformly all over the

WEATHER DATA DURING THE CROPPING PERIOD
(4TH JUNE 1992 TO 30TH SEPTEMBER 1992)



SERIES 2 : weather data during the cropping period plots. The details regarding the composition of the fertilizers and manures used are given in Table 2.

3.1.7.2 Soil amendments

As a soil amendment quick lime was applied as per the technical programme.

3.1.7.3 Biofertilizer

Biofertilizer *Azospirillum* obtained from the Department of Microbiology, Tamil Nadu Agricultural University was used for the experiment.

3.2 METHODS

3.2.1 Design and layout of the experiment

The experiment was laid out in randomized block design with two replications. The layout plan is presented in Figure 2. The details of the design and layout are given below.

Design: 4 x 3 x 2 + 1 factorial experiment in RBD

Number of treatment combinations	: 24 + 1
Number of blocks	: 2
Number of replications	: 2
Gross plot size	: 5.1 x 4.0m
Net plot size	: 4.5 x 3.6m
Total number of plots	: 50
Spacing	: 15 x 10cm

Table 2. Composition of fertilizers and manures used for the experiment.

Name	Composition (%)		
	N	P	K
Chemical Fertilizers.			
Urea	46	-	-
Mussoriephos	-	20	-
Muriate of Potash	-	-	60
Farmyard Manure	0.95	0.54	0.36

FIG.2. LAY OUT PLAN OF THE EXPERIMENT

REPLICATION I

$i_3n_1l_0$	$i_1n_2l_1$	$i_4n_3l_1$	$i_1n_3l_1$	$i_2n_1l_1$
$i_4n_2l_0$	$i_4n_1l_0$	$i_2n_3l_0$	$i_3n_2l_0$	$i_1n_1l_0$
$i_3n_3l_1$	$i_2n_1l_0$	$i_3n_2l_1$	Control	$i_4n_2l_1$
$i_1n_3l_0$	$i_1n_1l_1$	$i_1n_2l_0$	$i_4n_1l_1$	$i_2n_2l_1$
$i_2n_3l_1$	$i_3n_3l_0$	$i_4n_3l_0$	$i_2n_2l_0$	$i_3n_1l_1$

REPLICATION II

$i_4n_3l_0$	$i_2n_3l_1$	$i_3n_2l_1$	$i_2n_2l_0$	$i_4n_3l_1$
Control	$i_1n_3l_0$	$i_4n_2l_1$	$i_3n_3l_1$	$i_2n_3l_0$
$i_1n_2l_0$	$i_2n_1l_1$	$i_3n_1l_0$	$i_1n_1l_0$	$i_3n_1l_1$
$i_2n_2l_1$	$i_4n_1l_0$	$i_1n_1l_1$	$i_4n_1l_1$	$i_1n_2l_1$
$i_1n_3l_1$	$i_3n_2l_0$	$i_2n_1l_0$	$i_3n_3l_0$	$i_4n_2l_0$

Methods of *Azospirillum* inoculation

i_1 : seed inoculation

i_2 : root dip of seedling

i_3 : soil application

i_4 : combined application (seed plus seedling root dip plus soil)

Levels of nitrogen

n_1 : 50% of recommended dose

n_2 : 75% of recommended dose

n_3 : 100% of recommended dose

Levels of lime

l_0 : without lime

l_1 : with lime (600 kg ha^{-1})

Control

KAU Package of practice recommendations

Gross plot size - 5.1x4.0m

Net plot size - 4.5x3.6m

3.2.2. Treatments

Treatments include all possible combinations of methods of *Azospirillum* inoculation, levels of nitrogen, levels of lime, and one control (KAU package of practices).

Methods of *Azospirillum* inoculation

i_1 : seed inoculation

i_2 : root dip of seedlings

i_3 : soil application

i_4 : combined application (seed plus seedling root dip plus soil)

Levels of nitrogen

n_1 : 50 per cent of recommended dose

n_2 : 75 per cent of recommended dose

n_3 : 100 per cent of recommended dose

Levels of lime

l_0 : without lime

l_1 : with lime (600 kg ha^{-1})

Control plot as per KAU package of practices recommendations (1989)

3.2.3. Treatment combinations

T_1 - $i_1\ n_1\ l_0$	T_7 - $i_2\ n_1\ l_0$	T_{13} - $i_3\ n_1\ l_0$	T_{19} - $i_4\ n_1\ l_0$
T_2 - $i_1\ n_1\ l_1$	T_8 - $i_2\ n_1\ l_1$	T_{14} - $i_3\ n_1\ l_1$	T_{20} - $i_4\ n_1\ l_1$
T_3 - $i_1\ n_2\ l_0$	T_9 - $i_2\ n_2\ l_0$	T_{15} - $i_3\ n_2\ l_0$	T_{21} - $i_4\ n_2\ l_0$
T_4 - $i_1\ n_2\ l_1$	T_{10} - $i_2\ n_2\ l_1$	T_{16} - $i_3\ n_2\ l_1$	T_{22} - $i_4\ n_2\ l_1$
T_5 - $i_1\ n_3\ l_0$	T_{11} - $i_2\ n_3\ l_0$	T_{17} - $i_3\ n_3\ l_0$	T_{23} - $l_4\ n_3\ l_0$
T_6 - $i_1\ n_3\ l_1$	T_{12} - $i_2\ n_3\ l_1$	T_{18} - $i_3\ n_3\ l_1$	T_{24} - $i_4\ n_3\ l_1$

T_{25} - Control.

3.2.4 Cultivation details

3.2.4.1 Field preparation

The experimental field was initially ploughed and levelled with tractor and plots were laid out with bunds of 30 cm width all around. Main and sub irrigation channels were provided. Weeds and stubbles were removed from individual plots and then puddled and levelled. The crop was raised adopting the standard procedures and techniques as per the package of practices recommendations of the Kerala Agricultural University.

3.2.4.2 Nursery

Rice seedlings were raised in wet nursery. Seed rate used was 75kg ha^{-1}. As per the treatment Half the quantity of seeds were inoculated with *Azospirillum* (2 kg ha^{-1}). The sprouted seeds, both inoculated and uninoculated were sown separately in well prepared nursery beds.

3.2.4.3 Application of manures, fertilizers and soil amendments

3.2.4.3.1 Control plots

Lime was applied in two splits. 350 kg ha^{-1} as basal dose two weeks before sowing and 250 kg ha^{-1} one month after transplanting. Farm yard manure was applied as a basal dressing at the rate of 5 tons per hectare and incorporated into the soil during land preparation. Nitrogen, phosphorus and potash were applied as per KAU package of practices recommendation ($N : P_2O_5 : K_2O$ - 70:35:35 kg ha^{-1}). Nitrogen was given in two splits, two-third dose as basal and remaining one-third one week before panicle initiation as top dressing. Phosphorus and potash were applied entirely as basal.

3.2.4.3.2 Treatment plots

Farm yard manure was applied as per the KAU recommendation in all plots and incorporated well into the soil by ploughing.

Lime was applied @ 600 kg ha^{-1} as per the treatments and the split application schedule was similar to that for control plots.

Biofertizizer Azospirillum was applied as per the treatments. For seed inoculation a quantity of 2 kg inoculant is required for one hectare and the same quantity was used for root dip of seedlings for one hectare. For soil application to main field also 2 kg ha^{-1} was used. Seeds were inoculated with Azospirillum by soaking the seeds for 24 hrs in 60 litres of water containing 2 kg inoculum. In case of root dipping 20 days old seedlings were pulled out and roots dipped for 20 minutes in 40 litres of water containing 2 kg inoculum. For soil application 2 kg inoculum was mixed with 15 kg sand and broadcasted in to the main field before transplanting (Gopalaswamy and Vidhyasekaran, 1988). Seed treatment plus root dipping plus soil application were followed for the combined treatment.

Nitrogen was applied as per the treatments in two splits, two-third as basal and the remaining one-third as top dressing one week before panicle initiation. Phosphorus and potash were applied basally as per the rates recommended in KAU package of practices.

3.2.4.4 Transplanting

Transplanting of seedlings was taken up with a spacing of 15x10 cm. 20 days old seedlings were transplanted in the main field at two to three seedlings per hill. A subsequent gap filling was done one week after transplanting to maintain the plant population.

3.2.4.5 Irrigation

Water was maintained at 1.5 cm depth in the main field at the time of transplanting. Irrigation was given to maintain continuous submergence to a depth of 5 cm thereafter up to 13 days prior to harvest.

3.2.4.6 Weed management

Two hand weedings were given at 20 and 40 days after transplanting.

3.2.4.7 Plant protection

Rice stem borer was the major pest during the season. In the main field monocrotophos was applied @ 0.75 kg a.i ha^{-1} 20 days after transplanting to control the pest.

3.2.4.8 Harvesting and threshing

The observational plants were harvested one day prior to the harvest and observations recorded.

The crop was harvested 80 days after transplanting. The border rows were harvested first, threshed and bulked separately. Then the crop in the net area of individual plot was harvested and threshed. Grain yield at 14 per cent moisture and the weight of sun dried straw was recorded for individual plots.

3.2.5 Biometric observations

Four hills were selected at random within each net plot and tagged for recording observations at regular intervals.

3.2.5.1 Growth parameters

3.2.5.1.1 Plant height

Plant height was recorded on 20, 40 and 60 days after transplanting and at harvest. Height was measured from ground level to the tip of the top most leaf of the hill on 20 and 40 days after transplanting and upto the tip of the top most panicle on 60 days after transplanting and at harvest. Mean height was computed and expressed in centimetres.

3.2.5.1.2 Number of tillers per square metre

Total number of tillers produced per hill was counted from tagged hills on 20, 40 and 60 days after transplanting and at harvest and expressed as number of tillers per square metre.

3.2.5.1.3 Leaf area index

Leaf area index was computed on 20, 40, and 60 days after transplanting. Number of tillers present in each tagged hill was counted. The length and breadth of the leaves in the middle tiller of each tagged hill were measured and the leaf area of the middle tiller of each tagged hill was computed based on length-breadth method (Gomez, 1972).

$$\text{Leaf area of each leaf of the middle tiller} = K \times \text{length} \times \text{breadth}$$

Where K is the adjustment factor (0.75). By adding the leaf area of all the leaves of a middle tiller of a tagged hill, we get the leaf area of that particular middle tiller. Thereafter the leaf area per hill and leaf area index were calculated using the following formulae.

$$\text{Leaf area per hill} = \text{Total leaf area of middle tiller} \times \text{total number of tillers}$$

$$\text{Leaf area index} = \frac{\text{Sum of leaf area per hill of four hills}(cm^2)}{\text{Area of land covered by four hills } (cm^2)}$$

3.2.5.1.4 Leaf area duration

The leaf area duration was calculated for the periods from 20 to 40 and 40 to 60 days after transplanting as given by Power *et al*. (1967).

$$LAD = \frac{LAI_1 + LAI_2}{2} (t_2 - t_1)$$

Where LAI_1 and LAI_2 are periodical observations on leaf area index at an interval of time t_1 and t_2.

3.2.5.1.5 Root weight

One day prior to harvesting tagged hills were uprooted within each net plot and soil from the roots was carefully and thoroughly washed off. There after the roots were cut down and dried in sun and then oven dried at a temperature of 80°C ± 5°C to constant weight. The weight of oven dried roots was recorded and expressed in grams per hill.

3.2.5.1.6 Dry matter production

Dry matter production was estimated at the time of harvesting. A sample of grain and straw from each plot were weighed and oven dried at a temperature of 80°C ± 5°C to constant weight. The weight of oven dried samples were recorded and dry matter production was expressed in kg ha^{-1}.

3.2.5.2 Yield attributes

3.2.5.2.1 Productive tillers per square metre

Number of productive tillers was counted at harvest from four tagged hills and expressed as productive tillers per square metre.

3.2.5.2.2 Number of grains per panicle

The number of grains per panicle was recorded from ten samples of panicles taken from each plot and the average number of grains per panicle was computed.

3.2.5.2.3 Panicle length

The length of the panicle was measured from the point of scar to tip of the panicle. Panicle length was measured from all the panicles of four tagged hills of each plot and average worked out and expressed in centimetres.

3.2.5.2.4 Panicle weight

Weight of all the panicles in the tagged hills of each plot were taken and the weight per panicle was worked out and expressed in grams.

3.2.5.2.5 Percentage of filled grains

Ten samples of panicles were taken from each plot and the total number of filled grains were counted and expressed as a percentage of filled grains.

3.2.5.2.6 Percentage of unfilled grains

Number of unfilled grains from the sample panicles were counted and the percentage of unfilled grains was determined.

3.2.5.2.7 Thousand grain weight

One sample of thousand grains from each plot was drawn and weighed and expressed in grams.

3.2.5.2.8 Grain yield

After the harvest of each net plot grains were threshed, cleaned and dried to 14 per cent moisture and weight expressed in kg ha^{-1}.

3.2.5.2.9 Straw yield

Dry weight of straw per net plot was recorded after sun drying and expressed in kg ha^{-1}.

3.2.5.2.10 Harvest index

Harvest index was worked out by dividing the weight of grains (economic yield) with the total weight of grain and straw (biological yield). Both grain and straw were sundried.

$$HI = \frac{\text{Economic yield}}{\text{Biological yield}} = \frac{\text{Total weight of grain}}{\text{Total weight of grain} + \text{Total weight of straw}}$$

3.2.6 Chemical analysis

3.2.6.1 Plant analysis

Plant samples were taken at harvest and dried in an electric hot air oven at 70°C, ground and passed through a 0.5 mm mesh. Chemical analysis of straw and grain was done separately. The required quantity of samples were weighed and then subjected to triple acid extraction and the nutrient contents were determined and expressed as percentage on dry weight basis.

3.2.6.1.1 Total nitrogen content

Total nitrogen content was estimated by modified microkjeldahl method as given by Jackson (1973).

3.2.6.1.2 Total phosphorus content

Total phosphorus content was estimated by using Vanadao-molybdo-phosphoric yellow colour method (Jackson, 1973) and read in spectronic 20.

3.2.6.1.3 Total potassium content

Total potassium content in plant was estimated by flame photometry as suggested by Jackson (1973).

3.2.6.2 Uptake of nutrients

Total uptake of nitrogen, phosphorus and potassium of rice was calculated as the product of the content of these nutrients in the different parts of the plant samples and the respective dry weights and expressed as kg ha^{-1}.

3.2.6.3 Protein content of rice

The protein content of the grains was computed by multiplying the percentage of nitrogen content in grains by the factor 6.25 (Simpson *et al*., 1965).

3.2.6.4. Soil analysis

Composite preplanting soil sample was analyzed for available nitrogen, phosphorus and potassium. After the harvest of the crop, soil samples were drawn from each plot. The samples were shade dried, powdered and sieved to pass through 2mm sieve for the analysis of the following nutrients.

Nutrients	Methods	Suggested by
Available nitrogen	Kjeldhal digestion	Jackson (1973)
Available phosphorus	Vanadomolybdate	Jackson (1973)
Available potassium	Flame photometry	Jackson (1973)

3.2.7 Economics of cultivation

Based on the various input costs, the economics of cultivation was worked out.

Net income (Rs. ha^{-1}) : Gross income - Cost of cultivation.

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

3.2.8 Statistical analysis

Data relating to various characters under study were statistically analyzed by applying the Analysis of variance (ANOVA) technique for factorial experiment in randomized block design described by Cochran and Cox (1965).

RESULTS

RESULTS

The results of the experiment on "Economising nitrogen in rice production with *Azospirillum*" are presented here under.

4.1 Growth parameters

4.1.1 Plant height

The data pertaining to the mean height of plant taken at different growth stages are presented in Table 3.

It was seen from the data that there was significant difference in the height of the plants between different methods of inoculation at all stages of crop growth. Combined method of inoculation (seed treatment plus root dipping plus soil application) recorded maximum plant height which was significantly superior to all other methods at all growth stages.

As far as the nitrogen levels are concerned no significant difference could be observed in plant height at 20 and 40 days after transplanting, but it showed significant difference at 60 DAT and at harvest. The treatment n_3 (100 per cent nitrogen) recorded the maximum plant height during both stages.

At all the growth stages application of lime (l_1) was found to be significantly superior to no lime treatment (l_0).

Table 3. Effect of treatments on plant height and number of tillers

Treatment	Plant height (cm)				Number of tillers per square metre			
	20 DAT	40 DAT	60 DAT	At harvest	20 DAT	40 DAT	60 DAT	At haravest
i_1	38.59	58.55	73.08	74.65	612.22	715.58	677.78	622.22
i_2	39.63	60.02	75.65	77.57	645.00	762.22	708.33	644.44
i_3	37.76	58.05	73.74	75.68	582.22	695.00	640.56	574.45
i_4	43.48	61.86	77.82	79.97	702.78	827.77	756.08	713.89
$F(3,24)i$	24.01**	10.07**	56.96**	70.59**	16.73**	29.70**	13.65**	15.90**
CD	1.506	1.577	0.825	0.817	36.847	31.550	38.620	42.443
n_1	39.23	59.79	74.42	76.20	609.17	724.17	679.17	626.25
n_2	39.87	60.02	75.38	77.25	658.33	771.25	722.90	665.00
n_3	40.48	59.05	75.42	77.41	639.17	755.02	685.00	625.00
$F(2,24)n$	NS	NS	5.33*	7.31**	5.14*	6.53**	4.29*	NS
CD	-	-	0.714	0.708	31.911	27.323	33.446	-
l_0	39.19	59.00	74.35	76.21	615.56	729.72	671.65	610.83
l_1	40.54	60.25	75.79	77.69	655.56	770.57	719.72	666.68
$F(1,24)l$	6.81*	5.41*	25.86**	27.82**	10.04**	14.28**	13.20**	14.74**
CD	1.065	1.115	0.583	0.578	26.055	22.309	27.308	30.012
$SE_m \pm$	1.263	1.323	0.693	0.686	30.921	26.475	32.409	35.617
Control	41.39	60.94	75.45	77.14	613.34	763.34	773.34	733.34
Trtd. VS. Control F(1,24)	NS	NS	NS	NS	NS	NS	5.51*	6.77*

* Significant at 5% level
** Significant at 1% level
NS Nonsignificant

Interaction effect between methods of inoculation, levels of nitrogen and levels of lime did not alter the plant height significantly.

Treatments when compared to control (KAU package) showed no significant difference for this parameter.

4.1.2 Tiller number

Mean values of number of tillers per square metre recorded from the experiment are given in Table 3.

Different methods of inoculation significantly influenced the tiller number per square metre at all the stages of crop growth. Maximum number of tillers per square metre was recorded by i_4 method of inoculation, followed by i_2.

Levels of nitrogen significantly influenced the tiller production per square metre at 20, 40 and 60 DAT, while no significant difference was observed at harvest. Among the different levels, n_2 level of nitrogen recorded the maximum number of tillers per square metre at all the stages.

Among the lime treatments, l_1 treatment was statistically superior over l_0 treatment during all the stages of crop growth.

The interaction effect between factors had significant effect in this respect.

Treatments when compared with control showed no significant difference in tillers per square metre at 20 and 40 days after transplanting, but was significant at 60 days after transplanting and at harvest. The control recorded maximum values at both stages.

4.1.3 Leaf area index

Data on the mean values of leaf area index are presented in Table 4.

The leaf area index remained unaffected due to different methods of inoculation, levels of nitrogen and lime treatments.

The interaction effect of treatments also did not alter the leaf area index.

There was no significant difference when treatments were compared with control.

4.1.4 Leaf area duration

Data on the mean values of leaf area duration are presented in Table 4.

From the data it is clear that neither the method of inoculation nor the levels of nitrogen or the levels of lime did influence the leaf area duration.

Table 4. Effect of treatments on leaf area index and leaf area duration

Treatment	Leaf area index			Leaf area duration	
	20 DAT	40 DAT	60 DAT	20 to 40 DAT	40 to 60 DAT
i_1	0.78	2.75	4.00	35.29	67.51
i_2	0.82	2.85	4.10	36.72	69.48
i_3	0.73	2.86	3.96	35.94	68.25
i_4	0.82	2.94	4.12	37.49	70.56
$F(3,24)i$	NS	NS	NS	NS	NS
CD	-	-	-	-	-
n_1	0.75	2.75	4.00	35.02	67.48
n_2	0.79	2.91	4.10	36.94	70.06
n_3	0.82	2.89	4.04	37.12	69.31
$F(2,24)n$	NS	NS	NS	NS	NS
CD	-	-	-	-	-
l_0	0.78	2.82	4.00	36.05	68.22
l_1	0.79	2.88	4.10	36.67	69.68
$F(1,24)l$	NS	NS	NS	NS	NS
CD	-	-	-	-	-
$SE_m \pm$	0.066	0.166	0.162	1.820	2.445
Control	0.75	2.82	4.05	35.70	68.70
Trtd. Vs. Control $F(1,24)$	NS	NS	NS	NS	NS

NS - Nonsignificant

Interaction effect between factors showed no significant difference in this respect.

When the treatment effects were compared with control no significant difference was revealed.

4.1.5 Root weight

The mean values for root weight per hill are given in Table 5.

The data revealed that there was significant difference in root weight due to different methods of inoculation. Among the treatments i_4 recorded the maximum root weight followed by i_2, i_1 and i_3.

The effect of different levels of nitrogen on root weight was found to be statistically significant. Root weight increased with increasing levels of nitrogen and n_3 recorded the maximum root weight.

Lime treatment significantly influenced the root weight and l_1 treatment was significantly superior to l_0.

4.1.6 Dry matter production

The mean values of dry matter obtained are presented in Table 5.

Table 5. Effect of treatment on root weight and dry matter production

Treatment	Root weight (g/hill)	Dry matter (kg ha^{-1})
i_1	2.98	6138.95
i_2	3.17	6699.20
i_3	2.74	6336.34
i_4	3.24	7327.19
F(3,24)i	104.23**	38.32**
CD	0.064	246.254
n_1	2.96	6294.32
n_2	3.03	6619.15
n_3	3.10	6962.79
F(2,24)n	13.73**	20.93**
CD	0.056	213.262
l_0	2.96	6270.87
l_1	3.11	6979.97
F(1,24)l	44.64**	70.65**
CD	0.045	174.128
$SE_m \pm$	0.054	206.649
Control	2.95	7009.69
Trtd. V5. Control F(1,24)	NS	NS

** Significant at 1% level

NS - Nonsignificant

The effect of different methods of inoculation on dry matter production was significant. Combined inoculation (i_4) gave the highest value followed by root dipping (i_2). Seed treatment (i_1) and soil application (i_3) were on par.

The effect of levels of nitrogen on dry matter production was significantly superior at each successive levels, and n_3 level of nitrogen recorded the highest value followed by n_2 and n_1.

Application of lime was significantly superior to no lime treatment for dry matter production.

4.2 Yield and yield attributes

4.2.1 Productive tillers per square metre

The mean values of productive tillers produced per square metre at 60 days after transplanting and at harvest are given in Table 6.

The different methods of inoculation had a significant influence on the number of productive tillers per square metre during both stages. Combined inoculation (i_4) was significantly superior to all other treatments. Treatment i_4 recorded 13.60 per cent higher productive tillers over i_2 treatment which was next in order. Root dipping (i_2) gave a higher value compared to seed treatment (i_1) and soil application (i_3).

Table 6. Effect of treatment of productive tillers persquare metre, number of grains per panicle, length of panicle, panicle weight and thousand grain weight.

Treatment	Productive tillers per square metre		Number of grains per Panicle	Length of Panicle (cm)	Panicle weight (g)	Thousand grain weight (g)
	60 DAT	At harvest				
i_1	471.11	415.56	74.28	20.70	1.93	25.94
i_2	548.92	482.22	76.28	21.24	2.00	26.24
i_3	462.50	403.33	78.51	20.90	2.03	25.88
i_4	616.67	547.78	80.67	21.71	2.11	26.50
F(3,24)i	155.18**	88.55**	NS	NS	4.10*	NS
CD	16.997	20.704	-	-	0.112	-
n_1	506.88	437.50	74.79	21.16	1.96	26.40
n_2	525.02	462.50	77.67	20.84	2.02	26.03
n_3	542.50	486.67	79.85	21.41	2.08	26.00
F(2,24)n	12.48**	16.02**	NS	NS	NS	NS
CD	14.720	17.930	-	-	-	-
l_0	500.57	440.56	75.97	20.88	1.97	26.08
l_1	549.03	483.49	78.90	21.40	2.07	26.20
F(1,24)l	69.25**	37.32**	NS	NS	7.14	NS
CD	12.018	14.640	-	-	0.079	-
$SE_m \pm$	14.263	17.374	3.996	0.784	0.094	0.628
Control Trtd. V5. Control	586.67	500.00	77.89	21.85	2.03	26.15
F(1,24)	18.06**	4.54*	NS	NS	NS	NS

* Significant at 5% level
** Significant at 1% level
NS Nonsignificant

Nitrogen application showed a significant influence on the number of productive tillers per square metre and there was a progressive increase in the number due to increase in levels of nitrogen at both the stages. The number of productive tillers obtained in treatment n_3 was 5.23 per cent higher compared to n_2 level.

It was seen that the lime treatments significantly influenced the number of productive tillers per square metre. Application of lime (l_1) was significantly superior over no lime treatment (l_0).

Interaction effect between treatments showed no significant changes in the number of productive tillers per square metre.

The treatments showed significant difference when compared with the control. Control recorded a higher value when compared to levels of nitrogen and lime treatments during both the stages. At the same time Azospirillum treatment showed significantly higher value over the control.

4.2.2 Number of grains per panicle

Mean values for the number of grains per panicle are presented in Table 6.

Main effects of methods of inoculation, levels of nitrogen or lime treatment or their interactions did not produce any significant difference in the number of grains per panicle.

The treatment in general showed no significant superiority over the control.

4.2.3 Length of panicle

Data on the mean length of panicle are given in Table 6.

Length of the panicle was not at all influenced by methods of inoculation, levels of nitrogen or levels of lime or their interactions.

4.2.4 Panicle weight

Data on the mean values of panicle weight are presented in Table 6.

Data reveal the significant difference in panicle weight due to different methods of inoculation. Treatment i_4 recorded the maximum weight followed by i_3.

Levels of nitrogen recorded no significant difference for this attribute whereas the lime treatment showed significant influence in this respect. Treatment l_1 revealed significant superiority over l_0.

4.2.5 Percentage of filled grains

Mean values for the percentage of filled grains are presented in Table 7.

Percentage of filled grains was not significantly influenced by different methods of inoculation. However, root dipping recorded a higher percentage.

No significant difference in percentage of filled grains was observed due to different levels of nitrogen.

Although the lime treatment did not show any significant difference, a higher value was observed for l_1 treatment.

4.2.6 Percentage of unfilled grains

Mean values for the percentage of unfilled grains are presented in Table 7.

Methods of inoculation had no significant influence on the percentage of unfilled grains per panicle. However, soil application (i_3) recorded the highest percentage.

Percentage of unfilled grains per panicle was not significantly influenced by levels of nitrogen. Data reveal that the percentage of unfilled grains per panicle decreased with increasing levels of nitrogen and so n_3 recorded the lowest percentage.

Table 7. Effect of treatment on percentage of filled and unfilled grains of rice.

Treatment	Percentage of filled grains (%)	Percentage of unfilled grains(%)
i_1	81.04 (9.00)	18.96 (4.35)
i_2	81.92 (9.05)	18.08 (4.25)
i_3	80.67 (8.98)	19.33 (4.39)
i_4	81.65 (9.04)	18.35 (4.28)
$F(3,24)i$	NS	NS
CD	–	–
n_1	80.76 (8.99)	19.24 (4.38)
n_2	81.52 (9.03)	18.48 (4.29)
n_3	81.68 (9.04)	18.32 (4.28)
$F(2,24)n$	NS	NS
CD	–	–
l_0	81.21 (9.01)	18.79 (4.33)
l_1	81.43 (9.02)	18.57 (4.30)
$F(1,24)l$	NS	NS
CD	–	–
$SE_m \pm$	0.077	0.160
Control	81.92 (9.05)	18.08 (4.25)
Trtd. V5. Control $F(1,24)$	NS	NS

NS - Nonsignificant
Figures in brackets indicates transformed means.

Levels of lime did not record any significant difference in this respect.

4.2.7 Thousand grain weight

Mean values for thousand grain weight are presented in Table 6.

Thousand grain weight was not significantly influenced by methods of inoculation, levels of nitrogen and levels of lime. Among the inoculation methods treatment i_4 recorded the highest thousand grain weight followed by i_2. Among the levels of nitrogen highest thousand grain weight was observed with lowest level of nitrogen (n_1). In case of lime treatment thousand grain weight was highest for l_1 treatment.

4.2.8 Grain yield

Mean values of grain yield obtained from the experiment are presented in Table 8.

The data reveal that the grain yield was significantly influenced by the methods of inoculation. Combined method of inoculation (i_4) was significantly superior to all other methods of inoculation, recording a grain yield of 3373 kg per hectare. Treatment i_4 recorded 5.57 per cent higher grain yield over i_2 treatment which is next in order. Root dipping (i_2) was significantly superior to the other two

Table 8. Effect of treatments on grain yield, straw yield and harvest index.

Treatment	Grain yield. (kg ha^{-1})	Straw yield. (kg ha^{-1})	Harvest index.
i_1	3027.0	3238.0	0.48
i_2	3195.0	3641.0	0.47
i_3	3014.0	3452.0	0.47
i_4	3373.0	4104.0	0.45
F(3,24)i	71.33**	21.2**	5.35*
CD	58.298	233.726	0.016
n_1	3054.0	3369.0	0.48
n_2	3207.0	3548.0	0.48
n_3	3197.0	3908.0	0.45
F(2,24)n	24.57**	15.67**	10.20**
CD	50.487	202.412	0.014
l_0	3065.0	3334.0	0.48
l_1	3240.0	3883.0	0.46
F(1,24)l	76.41**	46.87**	19.84**
CD	41.220	165.269	0.011
$SE_m \pm$	48.922	196.136	0.013
Control	3115.0	4038.0	0.44
Trtd. V5. Control F(1,24)	NS	4.605**	5.54*

* Significant at 5% level
** Significant at 1% level
NS Nonsignificant

methods viz. seed treatment (i_1) and soil application (i_3) which in turn were on par.

Similarly the effect of nitrogen levels was also significant in grain yield. Treatment n_2 (75 per cent nitrogen) recorded the highest yield of 3206 kg per hectare which was on par with 100 per cent nitrogen (n_3) and both being significantly superior to n_1 (50 per cent nitrogen).

Lime application also influenced the grain yield significantly.

Interaction effect between factors had no significant influence on grain yield.

4.2.9 Straw yield

Data on the mean values of straw yield are presented in Table 8.

The data clearly reveal the significant influence of treatments on straw yield also. Among the methods of inoculation combined application of *Azospirillum* (i_4) recorded the highest straw yield of 4104 kg per hectare which was significantly superior to all other methods. Though the treatment i_2 gave a yield of 3641 kg per hectare it was on par with i_3. The straw yield obtained in treatment i_4 was 12.72 per cent higher over i_2 treatment.

Straw yield was also significantly influenced by nitrogen levels. Treatment n_3 recorded the highest straw yield of 3908 kg per hectare which was significantly superior to n_2 and n_1 and the n_3 recorded 10.15 per cent higher straw yield over n_2. The treatments n_2 and n_1 were on par in this respect.

Application of lime showed significant superiority in straw yield (3883 kg ha^{-1}) over no lime treatment.

Interaction effects showed no significant difference in straw yield.

4.2.10 Harvest index

Mean values on harvest index are presented in Table 8.

Significant difference in harvest index was observed due to methods of inoculation. Treatment (i_1) was significantly superior to (i_4) but was on par with i_2 and i_3.

Nitrogen levels significantly influenced the harvest index. A higher value was recorded for both n_1 and n_2 which were on par but superior to n_3.

Lime treatment also recorded a significant difference for this parameter. Among the levels, l_0 recorded significant superiority over l_1 treatment.

Interaction effects recorded no significant difference in this respect.

There was significant difference when treatments were compared against control. Treatments recorded a higher value compared to control.

4.3 Uptake of nutrients

4.3.1 Uptake of nitrogen

Data on the mean values of the crop uptake of nitrogen are presented in Table 9.

Methods of inoculation of Azospirillum showed significant difference in the uptake of nitrogen. Uptake of nitrogen was the highest for i_4 which was significantly superior to all other methods. Similarly treatment i_2 recorded a higher rate of uptake which was significantly superior to i_3 and i_1.

Increasing levels of nitrogen significantly increased the uptake of nitrogen. Treatment n_3 recorded the highest value in this respect which was however on par with n_2.

Application of lime also significantly increased the uptake of nitrogen by the crop.

4.3.2 Uptake of phosphorus

Mean values on the uptake of phosphorus are presented in Table 9.

Table 9. Effect of treatment on nutrient uptake of rice.

	Nitrogen uptake (kg ha^{-1})	Phosphorus uptake (kg ha^{-1})	Potossium uptake (kg ha^{-1})
i_1	60.98	23.82	65.73
i_2	70.98	25.18	71.02
i_3	64.62	23.97	73.86
i_4	79,23	27.88	83.20
F(3,24)i	24.18**	11.04**	8.26**
CD	4.749	1.641	7.434
n_1	63.95	23.56	69.04
n_2	69.50	24.97	73.45
n_3	73.40	27.14	77.87
F(2,24)n	11.35**	13.72**	4.01*
CD	4.113	1.421	6.438
l_0	65.11	24.35	69.90
l_1	72.79	26.10	77.00
F(1,24)l	22.29**	9.73**	7.78*
CD	3.358	1.161	5.256
$SE_m \pm$	3.986	1.377	6.238
Control	73.49	25.49	85.23
Trtd. V5. Control F(1,24)	NS	NS	NS

* Significant at 5% level
** Significant at 1% level
NS Nonsignificant

Phosphorus uptake was significantly influenced by different methods of inoculation. Treatment i_4 was significantly superior to all the other treatments. Treatment i_3, i_2 and i_1 were all on par.

There was significant difference in the uptake of phosphorus due to different levels of nitrogen. Among the levels of nitrogen tried n_3 recorded the highest value of phosphorus uptake which was significantly superior to other levels of nitrogen.

The uptake of phosphorus was also significantly increased by lime application.

4.3.3 Uptake of potassium

Mean values on potassium uptake are presented in Table 9.

Data reveal that there was progressive increase in the uptake of potassium by different methods of Azospirillum inoculation passing from i_1 to i_4. Treatment i_4 recorded significantly superior value of uptake whereas all the other treatments were on par in this aspect.

Though there was a progressive increase in the uptake of potassium by increasing levels of nitrogen, the highest uptake value recorded by n_3 was on par with n_2.

Uptake of potassium was significantly superior for l_1 treatment to l_0 thereby showing the influence of lime application.

4.4 Protein content

Data on the mean values of protein content are presented in Table 10.

Protein content of grain was significantly influenced by methods of inoculation. Though the treatment i_4 recorded the highest value, it was significantly superior only to treatment i_1.

Levels of nitrogen though not significant, showed a progressive increase in the protein content of rice. Treatment n_3 exhibited the highest value of protein content (8.43 per cent).

Application of lime did not show any significant influence on this quality attribute of grain.

4.5 Available soil nutrient status

4.5.1 Available nitrogen

Data on the available nitrogen in the soil after the experiment are presented in Table 11.

It was seen that there was no significant difference in the available nitrogen content of the soil due to different

Table 10. Effect of treatment on protein content of rice

Treatment	Protein Content (%)
i_1	7.80
i_2	8.20
i_3	8.20
i_4	8.79
F(3,24)i	3.79*
CD	0.612
n_1	8.14
n_2	8.17
n_3	8.43
F(2,24)n	NS
CD	–
l_0	8.14
l_1	8.35
F(1,24)l	NS
CD	–
$SE_m \pm$	0.515
Control	8.06
Trtd. V5. Control	NS

* Significant at 5% level
NS Nonsignificant

methods of inoculation, levels of nitrogen, levels of lime and their interaction effects. But in all the different treatments, a trend of increase in the available soil nitrogen with increasing levels of nitrogen and different methods of inoculation was obtained.

4.5.2 Available phosphorus

Data on the available phosphorus content of the soil after the experiment are given in Table 11.

Methods of inoculation showed no significant influence on the available phosphorus content of the soil, but i_4 recorded the highest value compared to all other methods.

Though the available phosphorus content of the soil was not significantly influenced by levels of nitrogen and levels of lime, there was a progressive increase in the available phosphorus content f the soil with higher levels of nitrogen and lime application.

4.5.3 Available potassium

Data on the available potassium content of the soil after the experiment are presented in Table 11.

Data reveal that neither the methods of inoculation nor the levels of nitrogen or the levels of lime did influence the available potassium content of the soil.

Table 11. Available soil nutrient status after the experiment as influenced by different treatments

Treatment	Available nitrogen (kg ha^{-1})	Available phosphorus (kg ha^{-1})	Available potassium (kg ha^{-1})
i_1	254.02	32.84	83.35
i_2	256.13	33.45	85.15
i_3	269.96	33.01	88.16
i_4	270.43	33.73	90.53
$F(3,24)i$	NS	NS	NS
CD	-	-	-
n_1	254.76	31.91	84.14
n_2	262.05	33.46	88.15
n_3	271.08	34.40	84.35
$F(2,24)n$	NS	NS	NS
CD	-	-	-
l_0	256.87	32.66	84.95
l_1	268.39	33.85	86.15
$F(1,24)l$	NS	NS	NS
CD	-	-	-
$SE_m \pm$	14.511	3.573	8.584
Control	280.68	32.77	90.72
Trtd. V5. Control F(1,24)	NS	NS	NS

NS - Non significant

4.6 Economics of cultivation

The data on net returns and benefit-cost ratio are presented in Table 12.

It is seen from the data that the maximum net income (Rs.9750/- per hectare) has been obtained from treatment T_{24} (combined application of *Azospirillum* plus 100 per cent nitrogen plus lime), whereas the control (KAU package) could give only a net income of Rs. 7151/- per hectare. The treatment T_{22} (combined application of *Azospirillum* plus 75 per cent nitrogen plus lime) could give almost comparable amount of net income with that of treatment T_{24}.

With regard to benefit-cost ratio, it is observed that both treatments T_{21} and T_{23} recorded the highest BCR of 1.860 each. From the data it could be seen that the treatment T_{24} recorded the highest profit of Rs. 2598/- per hectare in comparison with the net income obtained in control plot.

Table 12. Economics of cultivation of rice

Treatments	Cost of cultivation (Rs.) (y)	Gross income (Rs.) (x)	Net income (Rs.) (x-y)	Net income in comparison with control	BCR (x/y)
T_1	9915.00	15784.00	5870.00	-1282.00	1.592
T_2	11165.00	16637.00	5472.00	-1679.00	1.490
T_3	10042.00	16195.00	6153.00	-999.00	1.613
T_4	11292.00	17569.00	6277.00	-875.00	1.556
T_5	10170.00	17079.00	6910.00	-215.00	1.679
T_6	11420.00	18532.00	7113.00	-39.00	1.623
T_7	9915.00	16670.00	6755.00	-397.00	1.681
T_8	11165.00	18070.00	6905.00	-246.00	1.618
T_9	10042.00	17649.00	7606.00	+455.00	1.757
T_{10}	11292.00	19480.00	8188.00	+1037.00	1.725
T_{11}	10170.00	18090.00	7920.00	+769.00	1.779
T_{12}	11420.00	19495.00	8075.00	+924.00	1.707
T_{13}	9915.00	16147.00	6233.00	-919.00	1.629
T_{14}	11165.00	17284.00	6119.00	-1032.00	1.548
T_{15}	10042.00	16432.00	6390.00	-761.00	1.629
T_{16}	11292.00	17932.00	6639.00	-512.00	1.588
T_{17}	10170.00	16984.00	6814.00	-337.00	1.670
T_{18}	11420.00	18626.00	7206.00	+55.00	1.631
T_{19}	9926.00	18120.00	8194.00	+1043.00	1.825
T_{20}	11275.00	19432.00	8157.00	+1006.00	1.724
T_{21}	10152.00	18880.00	8728.00	+1577.00	1.860
T_{22}	11402.00	21059.00	9657.00	+2505.00	1.847
T_{23}	10280.00	19116.00	8836.00	+1685.00	1.860
T_{24}	11530.00	21279.00	9750.00	+2598.00	1.846
T_{25} (Control KAU Package)	11365.00	18516.00	7151.00		1.630

DISCUSSION

DISCUSSION

The results obtained from field experiment entitled "Economising nitrogen in rice production with Azospirillum" are discussed in this chapter.

5.1 Growth characters

5.1.1 Plant height

It is seen from the data presented in Table 3. that the methods of inoculation and levels of lime significantly influenced the plant height at all stages of growth, while the different levels of nitrogen could exert significant difference only at 60 days after transplanting and at harvest.

Among the different methods of inoculation combined inoculation (seed plus seedling root dip plus soil) recorded maximum plant height. It is a well known fact that by the presence of nitrogen fixing bacteria in the rhizosphere of plants, there will be better enrichment of nitrogen in the environment at the vicinity of the roots of plants, which will exert a favourable influence on growth of plants. The production of growth promoting substances by the bacteria will be an added effect in this respect. Similar results in plant height with Azospirillum inoculation on rice have been reported by Karthikeyan (1981), Prasad and singh (1984), Somchoudhary (1984), Jayaraman and Ramiah (1986), Nayak et al. (1986), Gopalaswamy and Vidhyasekaran (1987) and Gopalaswamy et al. (1989b).

Application of 100 per cent nitrogen recorded highest values in plant height at all stages with significant influence during the later stages viz. 60 DAT and at harvest. The role of nitrogen in increasing the vegetative growth especially plant height is a well known phenomenon (Tisdale et al., 1985). Similar results as obtained in the present study is in conformity with the findings of several earlier workers viz. Rao and Ramaiah (1988), Karuna Sagar and Ramasubha Reddy (1989) and Krishna Prasad and Madhusoodana Rao (1989).

Lime application showed significant influence in plant height. The soil of the experimental site in the present study was acidic (pH-4.7). The favourable influence of lime application observed in the present study may be due to the beneficial effect of liming in acid soils which provides favourable soil environment for better uptake of nutrients leading to better growth. Similar results have been reported by Kwack (1969), Kwack (1970), Anilkumar (1980) and Marykutty (1986).

5.1.2 Number of tillers per square metre

The results presented in Table 3. showed that methods of *Azospirillum* inoculation and lime treatments significantly influenced the tiller number per square metre at all stages of crop growth.

Combined method of application of Azospirillum enhanced the tiller production more as compared to other methods. This might be due to enhanced nitrogen uptake by rice due to the continued presence and activity of Azospirillum in the rhizosphere of rice plants. The production of growth promoting substance by Azospirillum also might have contributed for this enhanced growth. Increase in number of tillers by combined method of application of Azospirillum was reported by Balasubramanian and Kumar (1987). Enhancement of tiller production in rice as a result of Azospirillum inoculation has also been reported by Shivaradj (1981), Prasad and Singh (1984), Jayaraman and Ramiah (1986), Murali and Purushothaman (1987) and Kumar and Balasubramanian (1989).

Among the nitrogen levels 75 per cent nitrogen recorded the highest tiller number at all the stages. The nitrogen at this level might have been sufficient for better growth of rice plants. Enhancement of tiller number due to increase in levels of nitrogen has also been reported by Ajithkumar (1984), Premkumar (1987) and Anilkumar (1989).

Liming has significantly increased the tiller number. This might be probably due to the beneficial effect of liming in reducing the acidity and there by enabling the production of more tillers. Similar results have also been reported by Kwack (1968), Mariam and Koshy (1977), Anilkumar (1980) and Marykutty (1986).

5.1.3 Leaf area index

Perusal of data presented in Table 4. revealed that leaf area index was not influenced by any of the treatments. However among the inoculation methods combined method of inoculation recorded higher leaf area index. Similarly there was an increasing trend in leaf area index with increase in levels of nitrogen application. Application of lime recorded higher leaf area index over no lime.

5.1.4 Leaf area duration

The data presented in Table 4. revealed that the leaf area duration was not significantly influenced by any of the treatments.

5.1.5 Root weight

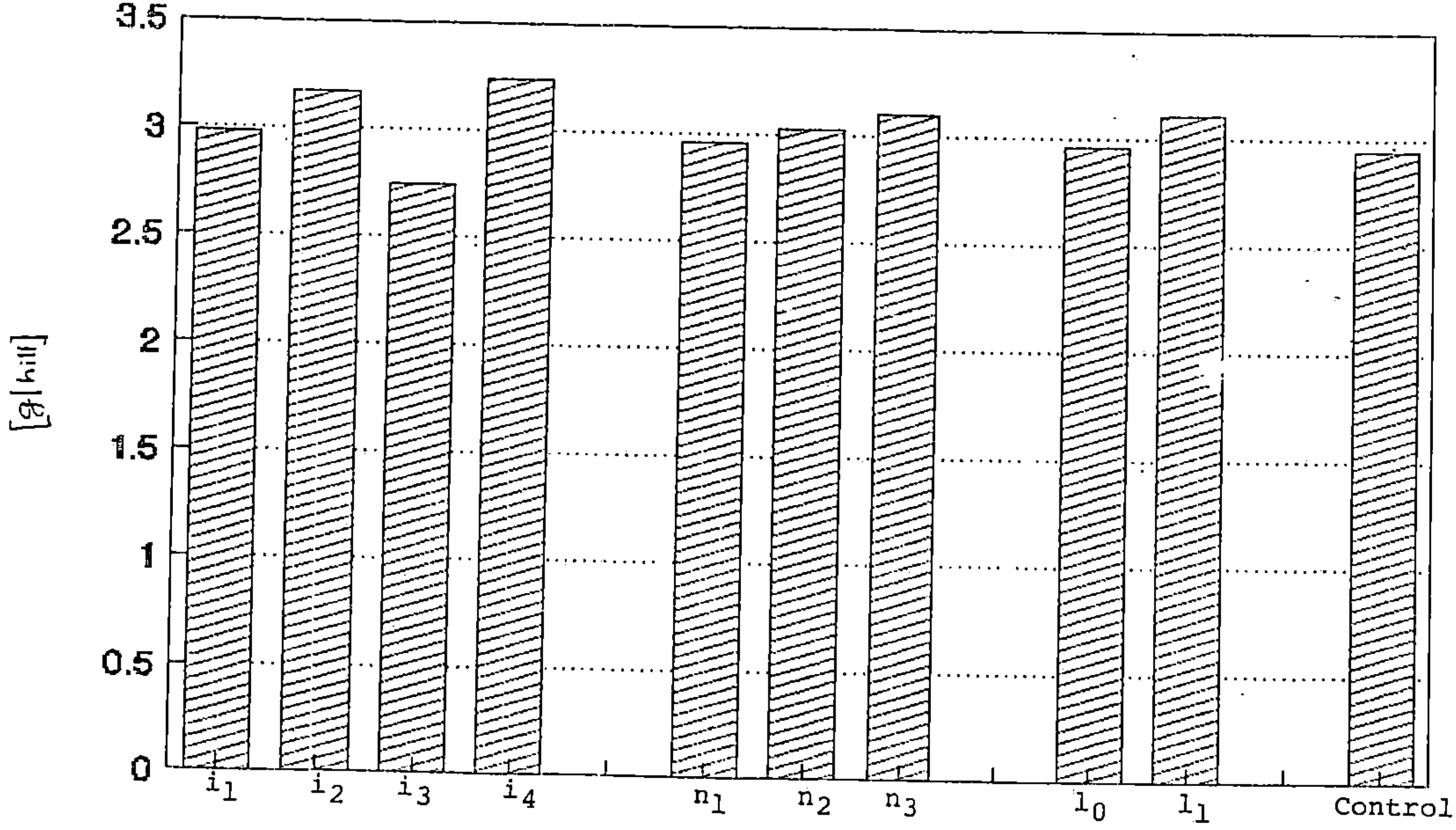
A perusal of data on root weight presented in Table 5. showed that different methods of *Azospirillum* inoculation, levels of nitrogen and levels of lime influenced the root weight significantly.

Application of *Azospirillum* in combined method (seed plus seedling root dip plus soil) was significantly superior to other methods of application. Combined method of inoculation might have increased the bacterial number in the rhizosphere which in turn might have produced more plant growth promoting substance and thus resulted in better root growth and root weight. A significant increase in root surface area of rice due to <u>Azospirillum</u> inoculation through seed and soil was reported by Murali and Purushothaman (1987). Similarly Prasad and Singh (1987) reported that root dipping of seedlings with <u>Azospirillum</u> improved the root mass. Subramanian (1987) observed that seed and soil application in the nursery significantly improved the seedling root weight.

Nitrogen at 100 per cent gave more root weight, which was superior to other levels of nitrogen. More quantity of chemical nitrogen supplied in the early growth stage in this treatment by the application of two-third of the entire dose basally might have helped the plants to get better root growth.

Root weight was more with the application of lime. Lime would have raised the pH of the soil from the acid range, which would have substantially increased the availability of nutrients which in turn might have led to the better development of root system resulting in more root weight. Mariam and Koshy (1977) also reported similar result.

FIG. 3. EFFECT OF TREATMENTS ON ROOT WEIGHT



5.1.6 Dry matter production

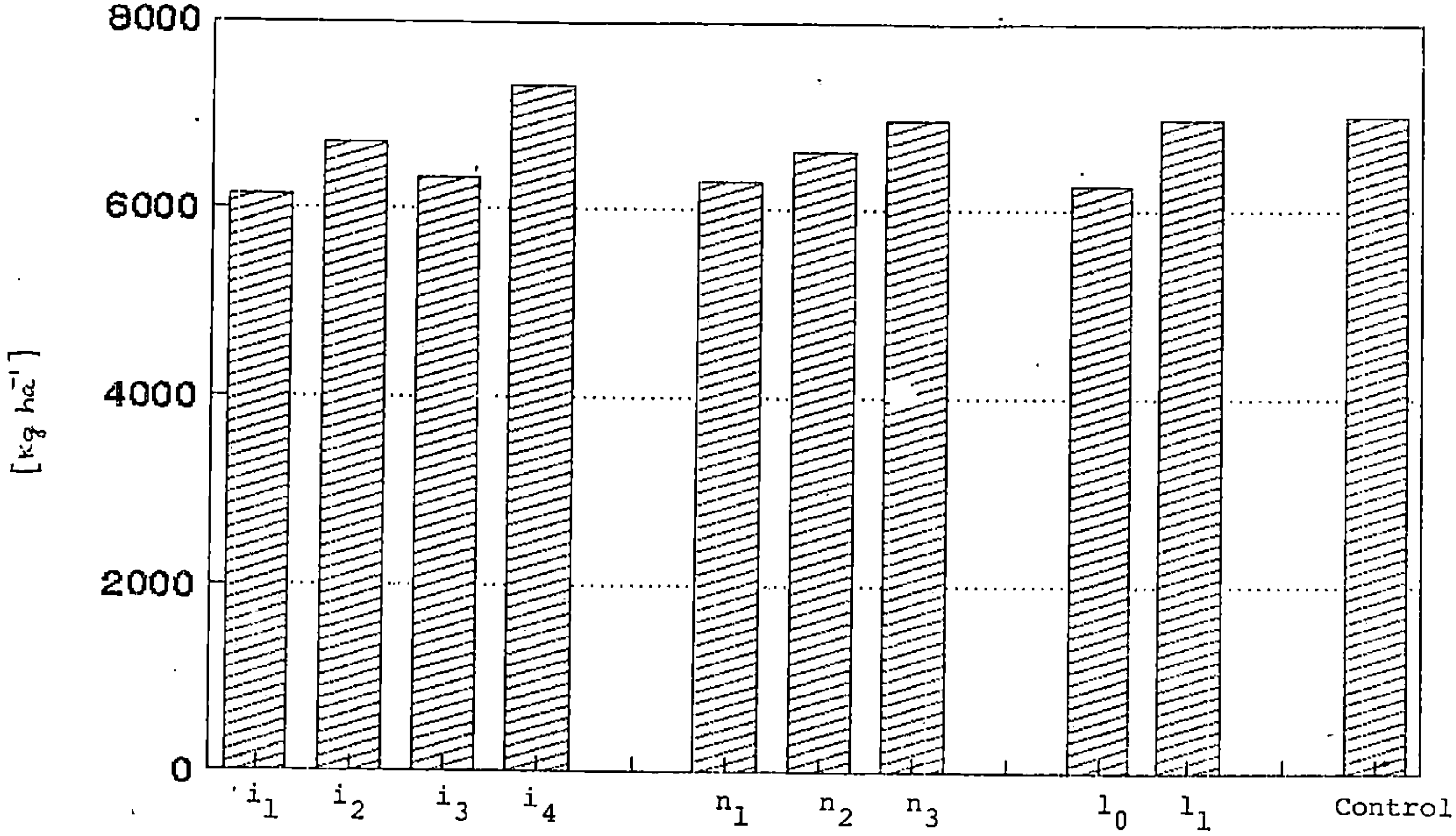
Results presented in Table 5. showed that the dry matter production was significantly influenced by all the treatments.

A greater dry matter production was recorded with combined method of inoculation of Azospirillum compared to other methods of application. This increase might be due to increase in number of tillers as revealed in data presented in Table 3. This is in conrormity with the findings of Karthikeyan (1981), Shivaradj (1981) Nayak et al. (1986) and Subramanian (1987) in rice.

Highest levels of nitrogen (100 per cent) recorded the highest dry matter production. Higher dose might have helped in vigorous growth of plant as is revealed from the data on plant height and tiller numbers mentioned earlier, which resulted in this increased dry matter production. This is in agreement with the findings of many earlier works (Ramaih et al., 1986; Rao, 1987; Padmaja Rao, 1988; Premkumar, 1989; Anilkumar, 1989; Mahapathra et al., 1991)

Application of lime showed the significant superiority over no lime application in increasing the dry matter production. Verma and Tripathi (1981) also reported significant increase in dry matter production of rice due to liming.

FIG. 4. EFFECT OF TREATMENTS ON DRY MATTER PRODUCTION OF RICE



In general the results revealed that the growth characters were significantly influenced by Azospirillum application. Among the methods of application combined inoculation was superior to all other methods of application. This increase might be not only due to increased rate of Azospirillum application but also its continuous presence in the rhizosphere due to different times of application (ie.) through seed, root dip of seedlings and soil. Among the nitrogen levels, application of 100 per cent nitrogen increased all the growth attributes. This enhanced rate of nitrogen application showed significant influence on growth characters. Liming also significantly influenced the growth attributes.

5.2 Yield and yield attributes

5.2.1 Productive tillers per square metre

The data on productive tillers presented in Table 6. revealed that different methods of Azospirillum inoculation, nitrogen levels and liming significantly influenced the productive tillers per square metre.

Among the different methods of inoculation, combined inoculation was significantly superior to all other methods followed by root dipping. Combined methods produced 13.60 per cent more productive tillers over root dipping. Combined application would have increased the rhizosphere population of Azospirillum. Moreover, the combined application is done at different stages such as seed treatment, root dip of seedlings and soil application at transplanting. This ensured continued presence of the bacteria in the rhizosphere. This might have led to higher rates of nitrogen fixation in the rhizosphere which in turn might have led to better growth of the plant. Gopalaswamy and Vidhyasekaran (1987) also reported higher number of productive tillers in rice due to split application of Azospirillum through seed, seedling root dip and soil.

Number of productive tillers increased with enhancement of nitrogen dose and 100 per cent nitrogen application recorded 5.23 per cent more productive tillers over 75 per cent nitrogen. This increasing trend due to higher levels of nitrogen application has also been reported by Mahajan and Nagre (1981), Sushamakumari (1981), Surendran (1985), Madan Mohan Reddy et al. (1987), Shalini Pillai (1992) and Sharma and Gupta (1992).

Lime application increased the number of productive tillers per square metre (9.74 per cent). Such beneficial effect of liming were reported earlier by several workers (Ananthanarayana and Perur 1973; Anilkumar, 1980; Marykutty, 1986; and Habeeburrahman and Sreedharan, 1990).

5.2.2. Number of grains per panicle

Data presented in Table 6. revealed that the methods of inoculation, levels of nitrogen and levels of lime did not exert any significant influence on number of grains per panicle.

Although the methods of inoculation showed no significant difference, combined inoculation recorded a numerical increase when compared to other methods. Similar results of increase in the number of grains per panicle has been reported by Prasad and Singh (1984) and Subramanian (1987).

Althcugh the nitrogen levels could not exert any significant influence, it showed an increasing trend in number of grains per panicle. It is quite natural that an increase in the level of nitrogen could promote better photosynthetic activity and there by increasing the number of grains per panicle, utilising the more available photosynthetes. Surendran (1985), Vaijayanthi (1986), Lee et al. (1990), Dinesh Chandra (1992), and Singh and Singh (1992) observed significant difference in number of grains per panicle with increase in doses of nitrogen.

Though the number of grains per panicle was not influenced significantly by liming, there was an increase in the number of grains by liming. Mariam and Koshy (1977), Marykutty (1986) and Habeeburrahman and Sreedharan (1990) reported influence of lime on the number of grains per panicle.

5.2.3 Length of panicle

Data pertaining to panicle length presented in Table 6. revealed that the length of panicle also was not influenced by methods of Azospirillum inoculation, levels of nitrogen and levels of lime.

Combined application of Azospirillum recorded the highest panicle length of 21.71 cm as compared to root dipping (21.24 cm), soil (20.90 cm)and seed (20.70 cm) treatment. Subramanian (1987) also reported marked influence on panicle length due to Azospirillum inoculation.

An increasing trend in the length of panicle with increase in dose of nitrogen was observed in this experiment. Dixit and Singh (1978) found that length of panicle increased with enhancement of nitrogen doses. Sushakumari (1981), Madan Mohan Reddy et al. (1987), Premkumar (1987) and Singh et al. (1991) also reported similar results in rice.

Eventhough the levels of lime showed no significant difference in panicle length, application of 600 kg lime per hectare recorded higher panicle length compared to no lime treatment. Nair (1970) reported that lime at half the lime requirement significantly influenced the length of panicle.

5.2.4. Panicle weight

Perusal of data presented in Table 6. revealed that, while the methods of *Azospirillum* inoculation and levels of lime significantly influenced the panicle weight, the levels of nitrogen did not influence the panicle weight significantly.

Combined method of application of *Azospirillum* was significantly superior to all other methods. Shivaradj (1981) also reported increased panicle weight due to *Azospirillum* inoculation.

Though not significant, there was a progressive increase in panicle weight with increasing doses of nitrogen. Similar increase has also been reported by Anilkumar (1989) and Thakur (1991).

Liming at the rate of 600 kg per hectare had great influence in increasing the panicle weight. Application of lime in two splits 350 kg basally and 250 kg as top dressing one month after transplanting might have helped to create a favourable soil pH at later stages of plant growth which in turn might have resulted in production of panicles with more weight.

5.2.5 Percentage of filled grains

The data on the percentage of filled grains presented in Table 7. revealed that there was no significant difference in percentage of filled grains due to methods of Azospirillum inoculation, levels of nitrogen and levels of lime.

5.2.6 Percentage of unfilled grains

The data shown in Table 7. revealed that there was no significant difference in percentage of unfilled grains due to different treatments viz. methods of Azospirillum inoculation levels of nitrogen and levels of lime.

5.2.7 Thousand grain weight

Table 6. shows the data on thousand grain weight. The data revealed that various treatments viz. methods of Azospirillum inoculation, levels of nitrogen and levels of lime and their interactions did not influence the thousand grain weight significantly.

Application of Azospirillum through seed, seedling root dip and soil application gave the highest thousand grain weight compared to other methods of application, though not significant. Subramanian (1987) reported that among the methods of Azospirillum inoculation, seed treatment along with application in the nursery and main field recorded the highest test weight.

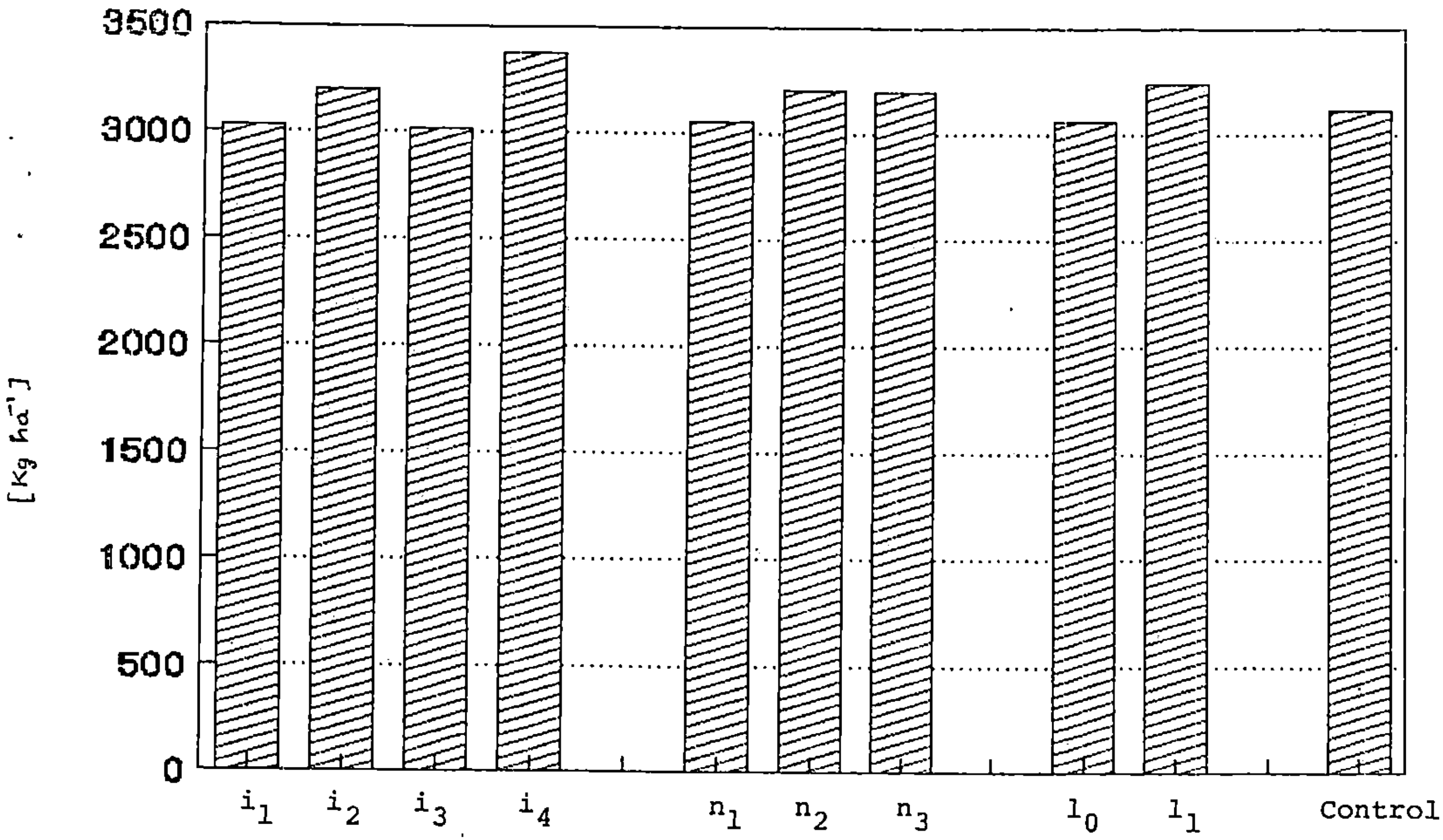
No significant effect was observed in thousand grain weight due to levels of nitrogen. Similar results of non significance was also reported by Patra and Padhi (1992), Savithri et al. (1992) and Shalini Pillai (1992).

There was a positive trend in thousand grain weight due to liming. Several workers (Suseelan, 1969; Marykutty, 1986; Habeeburrahman and Sreedharan, 1990) obtained significant increase in thousand grain weight with liming.

5.2.8 Grain yield

The data on grain yield presented in Table 8. showed that among the methods of inoculation combined inoculation recorded the highest grain yield. With combined inoculation the grain yield obtained was 3373 kg per hectare, while with other methods such as seed treatment, seedling root dip and soil it was 3027, 3195 and 3014 kg per hectare respectively. The grain yield obtained in treatment i_4 (combined method) was 5.57 per cent higher compared to i_2 (root dipping) which is next in order. The yield increase obtained by *Azospirillum* inoculation in the combined method of application might be due to the higher rates of nitrogen fixation and enhanced root proliferation (Purushothaman 1988). Many other workers have also reported increased grain yield due to *Azospirillum* inoculation (Subba Rao, 1980; Shivaradj, 1981; Rao et al., 1983; Nayak et al., 1986; Subramanian, 1987; Gopalaswamy et al., 1989b).

FIG. 5. EFFECT OF TREATMENTS ON GRAIN YIELD OF RICE



A perusal of data presented in the earlier part (Table 6.) revealed that there was significant increase in the number of productive tillers due to combined application of Azospirillum. In the rhizosphere, combined application might have provided greater opportunity for the bacteria for nitrogen fixation due to its continued presence. This increased opportunity for greater activity of bacteria in the rhizosphere would have enabled the plant to attain better growth standards such as more number of panicles. Moreover the data on nutrient uptake shown in Table 9. clearly revealed the higher rate of uptake of nitrogen, phosphorus and potassium in the treatment i_4 (combined method). Again the percentage of unfilled grains presented in Table 7. clearly showed the reduction in sterility percentage due to the treatment i_4. All these factors might have favourably influenced the higher yield obtained in this treatment.

In the present study different levels of nitrogen significantly influenced the grain yield. Application of nitrogen at 75 per cent of recommended dose gave the highest yield (3207 kg/ha) which was on par with 100 per cent nitrogen (3197 kg/ha). The increased grain yield might be due to the enhanced number of productive tillers and higher rate of uptake of nutrients (nitrogen, phosphorus and potassium) observed in these treatments. This increase in grain yield due to nitrogen application might be attributed to the role of nitrogen in photosynthesis which is directly related to the carbohydrate manufacture and grain yield (Moss and Musgrave, 1971). Similar increase in grain yield due to levels of nitrogen has also been reported by Sushamakumari (1981) and Sharma and Gupta (1992).

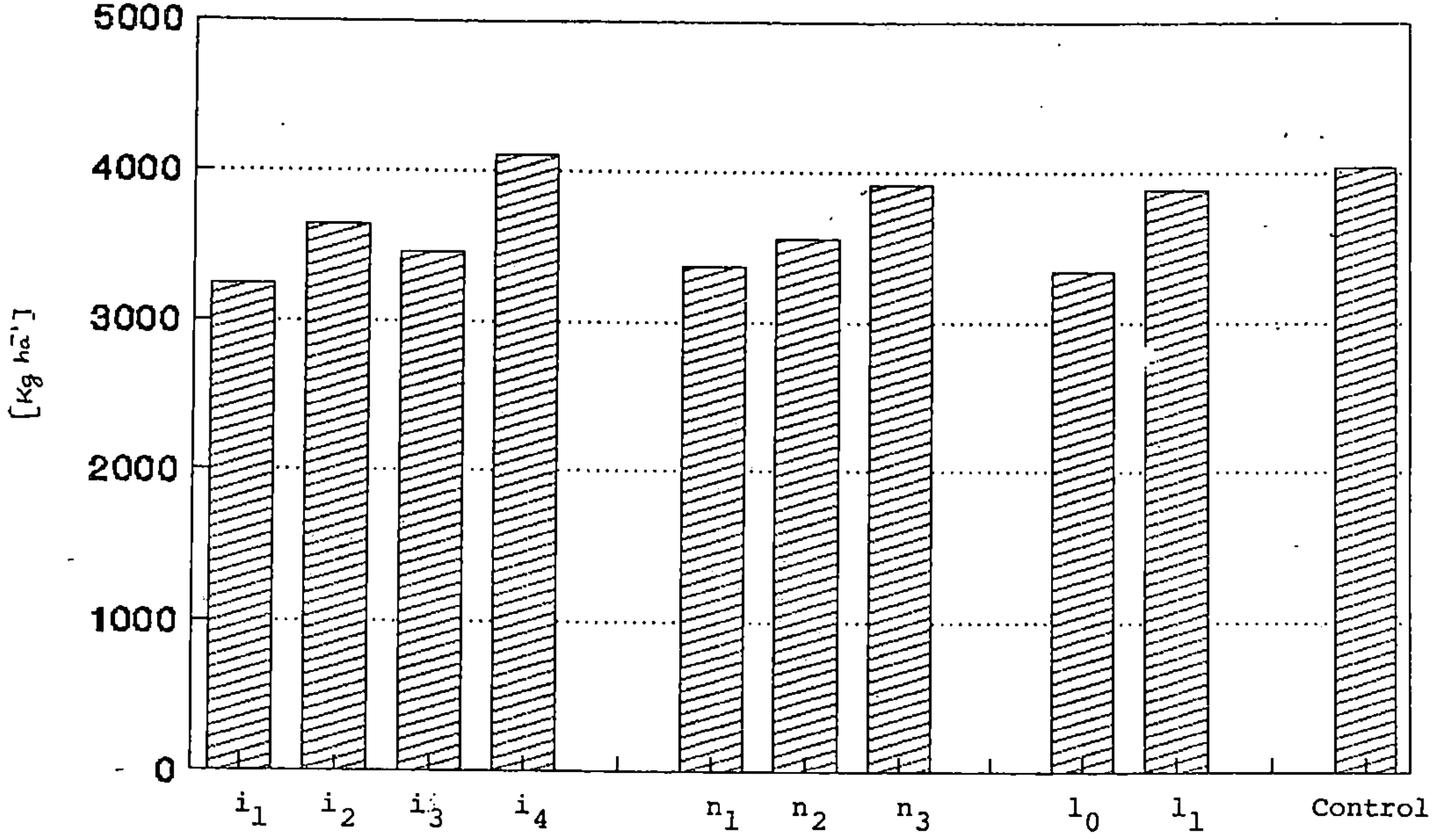
The grain yield was significantly influenced by the application of lime (3240 kg ha^{-1}). Calcium is one of the major plant nutrients and it influences plant growth characters (Tisdale *et al*., 1985). The influence of liming in increasing the soil pH as well as improving the availability of nutrients such as phosphorus, potassium, calcium and magnesium and thereby increasing the growth attributes is a well known fact which requires no further explanation. The importance of lime application in acid soil has been stressed by many workers. (Padmaja and Varghese, 1972; Kar, 1974; Murayamma and Inoko, 1975). Liming enhanced the biological activity (Ghani *et al*., 1955) which might be attributed to the increase in number of productive tillers, panicle weight and thousand grain weight. The result obtained in the present study is in conformity with the findings of Gopalkrishan (1973), Goswami *et al*. (1973), Padole and Deoras (1978), Anilkumar (1980) and Habeeburahman and Sreedhran (1990).

5.2.9 Straw yield

From the data pertaining to the straw yield presented in Table 8. it is seen that the straw yield was highly significant due to different methods of *Azospirillum* inoculation, levels of nitrogen and levels of lime.

The result indicated that the highest straw yield was obtained through combined method of inoculation of *Azospirillum*. Application of *Azospirillum* through seed plus seedling root dip plus soil gave a straw yield of 4103 kg per hectare which was significantly superior over other methods. Combined method of inoculation recorded 12.72 per cent higher straw yield over root dipping which is next in order. The data presented in Table 3. indicated that the growth characters like height of plant and number of tillers were significantly influenced by combined application of *Azospirillum*. Combined inoculation might have increased the microbial population in the rhizosphere which would have produced more quantities of nitrogen by way of fixation and thereby promoting the growth attributes, resulting in higher production of straw yield. Increased straw yield due to combined application of *Azospirillum* was reported by Balasubramanian and Kumar (1987). Gopalaswamy and Vidhyasekaran (1987) found that split application of *Azospirillum* through seed, seedling root dip and soil gave the highest straw yield in rice.

FIG. 6. EFFECT OF TREATMENTS ON STRAW YIELD OF RICE



Among the nitrogen levels it was seen that the highest levels of nitrogen tried (100 per cent) increased the straw yield significantly recording a yield of 3908 kg per hectare. The data on grain yield showed that the yield of grain was lesser at the highest level of nitrogen tried. This might probably be due to the high rate of vegetative growth obtained at the highest level of nitrogen which led to a corresponding reversion in grain yield. Beneficial effect of nitrogen in increasing straw yield has been reported by Surendran (1985), Babumathew (1987) Hussain _et al_. (1989), Patra and Padhi (1989), and Sreedevi and Sreedharan (1991).

Liming also showed significant effect on straw yield. The highest straw yield of 3883 kg per hectare was obtained by the application of 600 kg lime per hectare as compared to no lime. Since a major share of lime (350 kg ha^{-1}) was applied as basal dressing more favourable soil condition was created during early stages of plant growth which enabled the plant to absorb more nutrients and thereby getting better vegetative growth as is experienced in plant height, number of tillers etc. This is in conformity with the finding of earlier workers (Kwack, 1969; Mariam and Koshy, 1977; Anilkumar, 1980).

5.2.10 Harvest index

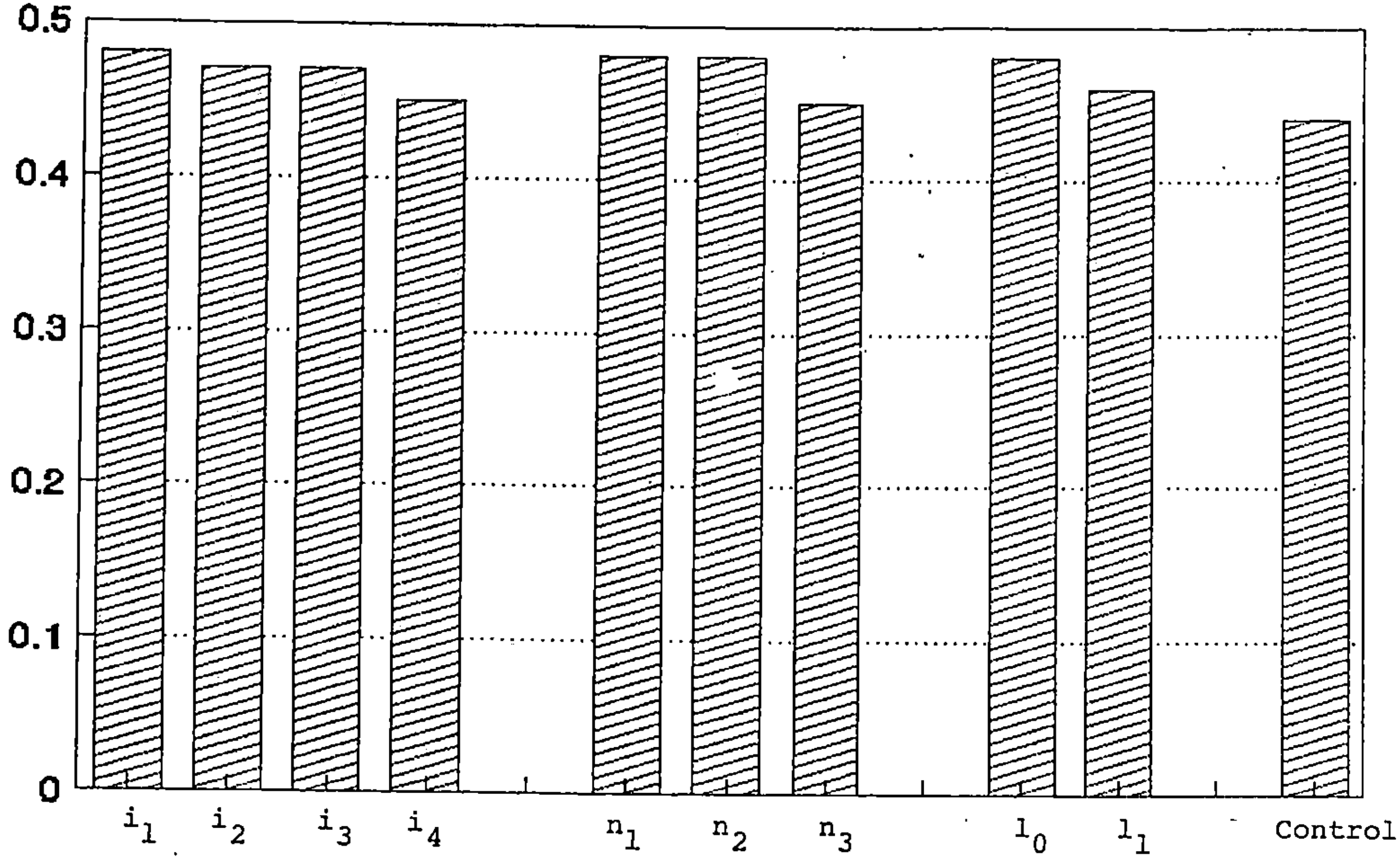
The data presented in Table 8 revealed the significant change in harvest index due to different methods of inoculation, levels of nitrogen and lime.

The combined method of application of *Azospirillum* produced the lowest value compared to other methods. The data on grain and straw yield revealed that eventhough both grain and straw yields increased in the treatment i_4 (combined method), higher straw yield noticed in this treatment led to a lower value of harvest index.

Higher levels of nitrogen showed a significant reduction in harvest index. That is, 100 per cent nitrogen recorded the lowest value when compared to 75 per cent and 50 per cent nitrogen. The data on vegetative growth characters such as plant height and number of tillers showed significant increase with increase in the level of nitrogen. This higher rate of vegetative growth might have led to a reduction in harvest index. This is in conformity with the findings of Prasad (1981), Rao and Ramaiah (1988), Ramasubha Reddy (1988), Kuruna Sagar and Ramasubha Reddy (1989) and Krishna Prasad and Madhusoodana Rao (1989).

Similarly lime application showed a decreasing trend in harvest index. Data on grain and straw yields discussed earlier showed that, by the application of lime the increase

FIG. 7. EFFECT OF TREATMENTS ON HARVEST INDEX OF RICE



in straw yield was more, which may probably be due to better vegetative growth of plants occurred by lime application.

5.3. Uptake of nutrients

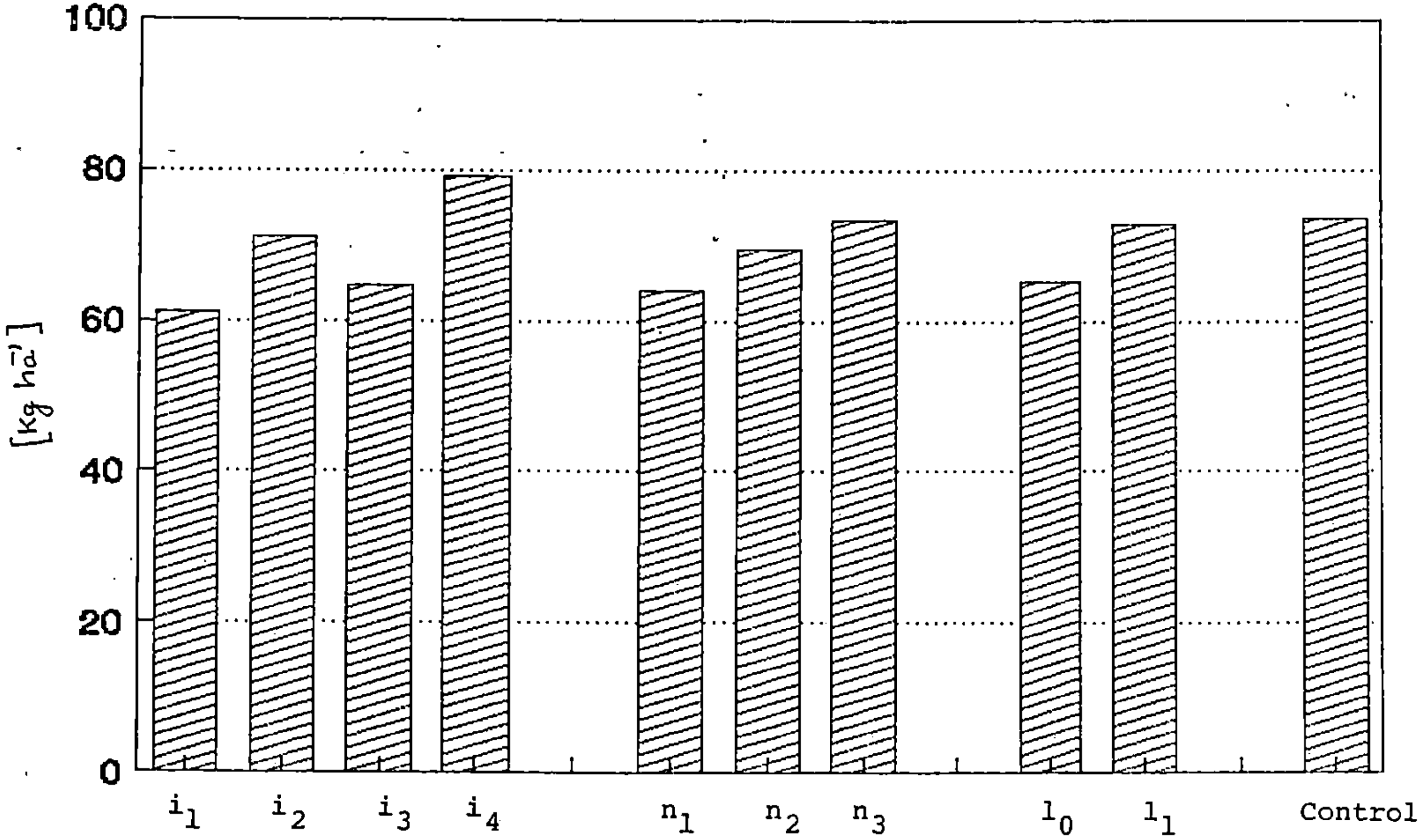
5.3.1 Uptake of nitrogen

Perusal of data presented in Table 9. revealed that methods of *Azospirillum* application significantly influenced the nitrogen uptake. Nitrogen uptake due to combined method of application was significantly superior to other methods. Combined inoculation might have increased the microbial population in the rhizosphere, which favoured nitrogen fixation resulting in more uptake of nitrogen. Kumar and Balasubramanian (1989) and Muthukrishnan and Purushothaman (1992) observed increased uptake of nitrogen due to *Azospirillum* inoculation.

A significant difference in nitrogen uptake due to nitrogen application was also observed in the present investigation. Among the doses of nitrogen 100 per cent nitrogen recorded the highest uptake. The result is in conformity with the findings of Ramaih *et al*. (1986), Biswas (1987) and Singandhupe and Rajput (1990).

The lime application also significantly influenced the uptake of nitrogen. Similar results have also been reported by Nair (1970), Mariam and Koshy (1977) and Anilkumar (1980).

FIG. 8. EFFECT OF TREATMENTS ON THE NITROGEN UPTAKE OF RICE



5.3.2 Uptake of phosphorus

The data pertaining to phosphorus uptake presented in Table 9. revealed that there was significant influence in phosphorus uptake by methods of *Azospirillum* inoculation. Among the different methods of application, combined method of application recorded the highest value. The favourable influence of *Azospirillum* inoculation at different stages (seed plus seedling root dip plus soil) might have favourably influenced the root biomass as is seen in Table 5. which might have led to a higher uptake of phosphorus.

Levels of nitrogen influenced the phosphorus uptake significantly. A successive increase in the uptake was observed due to enhancement of nitrogen levels. Premkumar (1987) reported that phosphorus uptake was enhanced by enhancement of nitrogen dose. Progressive increase in the uptake of phosphorus due to application of nitrogen has also been reported by Wankhade and Pandrangi (1988).

Lime application significantly increased the uptake of phosphorus. The application of lime would have enhanced the solubilisation and better utilization of added and native phosphorus in the soil. This might have enhanced the phosphorus uptake. Increased rates of phosphorus uptake due to liming has also been reported by Kabeerathumma (1969) and Suseelan (1969).

5.3.3 Uptake of potassium

The data pertaining to potassium uptake of rice presented in Table 9. showed that combined application of *Azospirillum* showed the superiority in uptake of potassium over other methods. *Azospirillum* inoculation would have enhanced the root proliferation and thereby more uptake of potassium.

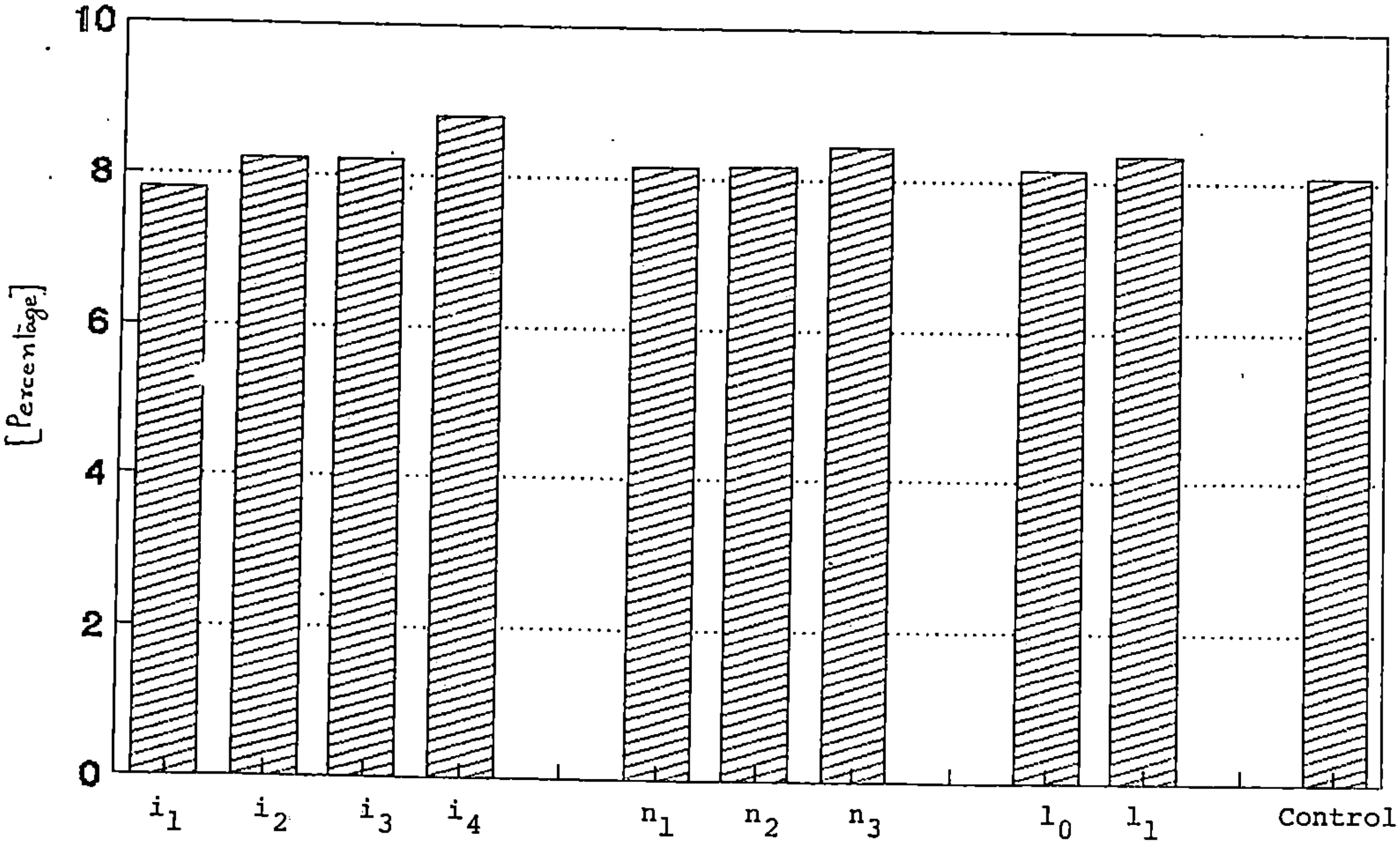
A significant difference in potassium uptake was noticed with different levels of nitrogen. Nitrogen levels increased the potassium uptake linearly. This is in conformity with the findings of Biswas (1987), Salam(1988), Wankhade and Pandrangi (1988) and Krishna Prasad and Madhusoodana Rao (1989).

Liming the soils increased the uptake of potassium significantly. The beneficial soil reaction which would have emerged by lime application might have led to a higher uptake of potassium in rice plants.

5.4 Protein content

Perusal of data presented in Table 10. revealed that *Azospirillum* inoculation significantly influenced the protein content of rice. Among the different methods of application, combined method of application recorded the highest value of protein content. The enhanced rate of

FIG. 9. EFFECT OF TREATMENTS ON PROTEIN CONTENT OF RICE



uptake of nitrogen as shown in Table 9. would have favoured the production of more protein since nitrogen is the most important constituent of protein.

Eventhough the nitrogen levels did not influence the protein in the present study, the highest protein content was obtained in the highest level of nitrogen (100 per cent). Increased protein content due to increased levels of nitrogen has been reported by Vaijayanthi (1986), Reddy et al. (1988), Umestu et al. (1990) and Dinesh Chandra (1991).

Lime treatment also did not influence the protein content significantly. However, protein content was more in treatment supplied with 600 kg lime per hectare.

5.5. Available soil nutrient status

5.5.1 Available nitrogen

The data on the available nitrogen status of the soil after the experiment presented in Table 11. revealed that the available nitrogen of soil was not altered significantly by different treatments viz. methods of Azospirillum inoculation, levels of nitrogen and lime.

Among the methods of Azospirillum inoculation, a highest value was observed for combined application. Increased microbial population in the rhizosphere and its continuous presence through combined application might have favoured the fixation resulting in more available nitrogen in the soil.

The results indicated that there was a progressive increase in the available nitrogen content in soil with enhancement of nitrogen, though not significant.

Although no significant difference was observed due to lime treatment, liming recorded a higher value over unlimed treatment.

5.5.2 Available phosphorus

Perusal of data pertaining to the available phosphorus content of the soil after the experiment presented in Table 11. revealed that the methods of Azospirillum inoculation, levels of nitrogen and levels of lime did not influence the available phosphorus in the soil significantly. Surendran (1985) also reported no significant effect of nitrogen on available phosphorus content of the soil.

5.5.3 Available potassium

The data on the available potassium of the soil after the experiment presented in Table 11. revealed that there was no significant difference in the available potassium of the soil due to various treatments.

Among the methods of Azospirillum a comparatively higher value was recorded by combined application. Among the levels of lime, application of lime recorded a higher value over no lime treatment. This may be due to the favourable soil reaction emerged by liming.

5.6 Economics of cultivation

Perusal of data on net returns and benefit cost ratio presented in Table 12. revealed that combined application of _Azospirillum_ and full dose of nitrogen and lime application (T_{24}) recorded the highest net income of Rs. 9750/- per hectare followed by a net income of Rs. 9657/- per hectare recorded by the treatment containing combined application of _Azospirillum_ and 75 per cent nitrogen and lime (T_{22}). Considering the small difference between these two values, it could be inferred that the combined application of _Azospirillum_ plus 75 per cent nitrogen plus lime application will be sufficient to get comparatively higher net income.

When BCR is compared between different treatments, it is found that the combined application of _Azospirillum_ plus 75 per cent nitrogen without lime application (T_{21}) and combined application of _Azospirillum_ plus 100 per cent nitrogen without lime (T_{23}) could give the same BCR value of 1.860. The data revealed that the package recommendation could give only a BCR value of 1.630 when full dose of nitrogen and full dose of lime was applied. The fact that a higher BCR could be obtained by two different treatments involving no lime application is an indication of lack of response for lime in the case of Viruppu rice involving the variety _Red Triveni_. The treatments T_{22} and T_{24}, which recorded comparatively higher net income could also produce a comparatively higher BCR value of 1.847 and 1.846 respectively, which again are the higher values when compared to 1.630 recorded by the control plot.

SUMMARY

SUMMARY

An investigation was carried out at the Instructional Farm, College of Agriculture, Vellayani during the period from June 1992 to September 1992 to assess the role of Azospirillum on growth and productivity of rice as a means of economising fertilizer nitrogen application. The variety used was Red Triveni. The treatment includes four methods of inoculation of Azospirillum (seed, seedling root dip, soil and combined inoculation), three levels of nitrogen (50, 75 and 100 per cent recommended dose of nitrogen) and two levels of lime (without and with lime) along with a control (KAU package of practices). The experiment was laid out as 4x3x2+1 factorial experiment in randomised block design with two replications. The result of the investigation are summerised below.

1. The combined method of inoculation (seed plus seedling root dip plus soil) and lime application significantly influenced the plant height at all growth stages. The effect of 100 per cent recommended dose of nitrogen was significant in this respect only during the later stages viz. 60 DAT and at harvest.

2. The number of tillers produced per square metre increased significantly by combined inoculation of Azospirillum, 75 per cent of recommended dose of nitrogen and lime application.

3. The leaf area index and leaf area duration were not significantly influenced by any of the treatments. However combined method of inoculation, 100 per cent recommended dose of nitrogen and lime application recorded the highest value for both these attributes.

4. Root weight was significantly influenced by all the treatments. Combined method of Azospirillum inoculation showed significant superiority over other methods. Nitrogen application at 100 per cent recommended dose and lime application gave more root weight. Treatments and control when compared recorded significant difference.

5. A greater dry matter production was recorded with combined method of inoculation of Azospirillum. Highest level of nitrogen (100 per cent recommended dose) gave the highest dry matter production. Application of lime showed significant superiority over no lime in this respect.

6. The combined method of inoculation was significantly superior over all other methods in increasing the number of productive tillers per square metre. Application of 100 per cent nitrogen recorded the highest number of productive tillers. Lime application also increased the number over no lime treatment.

7. Combined inoculation of Azospirillum recorded a higher number of grains per panicle as compared to other methods. Similarly higher level of nitrogen (100 per cent) and lime application showed an increasing trend in the number of grains per panicle.

8. The highest panicle length was recorded with combined application of Azospirillum, though not significant. An increasing trend in the length of panicle with increasing dose of nitrogen was observed. Lime application (600 kg ha^{-1}) also recorded the highest value in this respect compared to no lime treatment.

9. The methods of Azospirillum inoculation and levels of lime significantly influenced the panicle weight. Among the methods of inoculation, combined method of inoculation was significantly superior to all other methods. Though the levels of nitrogen showed no significant difference, a progressive increase in panicle weight was observed with increase in dose of nitrogen.

10. The percentage of filled grains, percentage of unfilled grains and thousand grain weight were not influenced by any of the treatments.

11. The combined application of Azospirillum recorded the highest grain yield (3373 kg ha^{-1}). Application of 75

per cent nitrogen gave the highest grain yield (3207 kg ha^{-1}) which was on par with 100 per cent nitrogen (3197 kg ha^{-1}). Grain yield was also significantly influenced by lime application.

12. The highest straw yield was obtained through combined method of *Azospirillum* inoculation(4104 kg ha^{-1}) which was significantly superior over other methods. Among the nitrogen levels, 100 per cent nitrogen increased the straw yield significantly recording a yield of 3908 kg per hectare. Liming also showed significant effect on straw yield (3883 kg ha^{-1}).

13. A significant change in harvest index was observed due to various treatments. The combined method of application of *Azospirillum* produced the lowest value. Similarly highest level of nitrogen and lime application recorded the lowest value for harvest index.

14. Uptake of nutrients (nitrogen, phosphorus and potassium) was significantly influenced by all the treatments. Among the inoculation methods, combined method of inoculation recorded the maximum uptake of nutrients. Highest level of nitrogen showed the highest uptake of nutrients. Lime application also influenced the uptake of nutrients.

15. Protein content of grain was influenced significantly by combined method of inoculation. Highest level of nitrogen, and lime application recorded the highest value of protein content.

16. The available nitrogen, phosphorus and potassium contents of the soil after the experiment were not altered significantly by different treatments.

17. Economic analysis of data revealed that a comparatively higher net income could be obtained even after forgoing 25 per cent of nitrogen dose, provided the treatment is supplemented with a combined application of Azospirillum.

FUTURE LINE OF WORK

1. The experiment will have to be continued for two more seasons to arrive definite conclusions.

2. Under the treatment, one control with out either Azospirillum inoculation or application of fertilizers should be included to apportion the definite role of Azospirillum inoculation either alone or in combination with different levels of nitrogen application.

3. As the reaction of our soil in mostly acidic in nature, acid tolerant and efficient cultures of Azospirillum should be isolated to get better results.

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APPENDICES

APPENDIX I

Weather data during the cropping period (4 June 1992 to 30 September 1992)

Standard week	Period From	Period To	Rainfall (mm)	Maximum temperature °C	Minimum temperature °C	Relative humidity (%)	No.of rainy days
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
23	June04	June10	43.A0	29.15	22.96	87.33	7
24	June11	June17	67.81	29.56	23.98	85.85	6
25	June18	June24	43.90	29.98	25.25	82.28	5
26	June25	July01	14.00	29.92	24.53	81.78	2
27	July02	July08	13.73	29.18	23.74	84.92	5
28	July09	July15	22.00	28.93	22.92	80.64	5
29	July16	July22	68.85	29.02	22.74	83.28	5
30	July23	July29	48.22	28.60	22.84	86.64	5
31	July30	Aug.05	5.84	28.22	22.45	87.50	3
32	Aug.06	Aug.12	19.42	28.70	23.40	85.40	3
33	Aug.13	Aug.19	5.20	29.19	23.88	85.28	2
34	Aug.20	Aug.26	1.06	29.65	23.80	80.14	0
35	Aug.27	Sep.02	68.82	28.29	22.84	85.50	6
36	Sep.03	Sep.09	24.50	28.77	22.95	81.71	4
37	Sep.10	Sep.16	14.60	28.48	23.27	80.92	2
38	Sep.17	Sep.23	0.00	28.80	23.70	81.42	0
39	Sep.24	Sep.30	17.34	30.30	23.38	80.35	5

Source: Meteorological observatory, College of Agriculture, Vellayani.

APPENDIX II

Weather conditions at Vellayani (Average of 5 years, 1987-1991)

Standard week	Period From	Period To	Rainfall (mm)	Maximum temperature °C	Minimum temperature °C	Relative humidity (%)	No.of rainy days
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
23	June04	June10	16.26	31.03	24.75	76.03	5.2
24	June11	June17	9.81	30.32	22.72	79.81	5.8
25	June18	June24	7.30	29.92	24.23	78.49	4.8
26	June25	July01	10.03	29.88	23.07	82.87	4.6
27	July02	July08	3.72	29.89	23.48	78.59	3.2
28	July09	July15	5.54	29.07	23.52	80.35	3.4
29	July16	July22	8.53	30.21	23.51	82.06	4.0
30	July23	July29	2.01	29.46	23.73	79.07	2.4
31	July30	Aug.05	1.80	29.98	23.96	79.18	3.2
32	Aug.06	Aug.12	11.52	29.44	23.53	79.16	3.2
33	Aug.13	Aug.19	5.69	29.40	23.01	81.47	3.4
34	Aug.20	Aug.26	4.30	29.76	23.65	80.53	3.4
35	Aug.27	Sep.02	2.58	30.25	23.98	78.72	1.8
36	Sep.03	Sep.09	5.70	30.49	23.95	77.11	1.2
37	Sep.10	Sep.16	2.07	30.75	24.36	79.01	1.6
38	Sep.17	Sep.23	7.41	30.20	23.97	78.49	4.2
39	Sep.24	Sep.30	4.87	31.43	23.84	86.87	2.8

Source: Meteorological observatory, College of Agriculture, Vellayani.

ECONOMISING NITROGEN IN RICE PRODUCTION WITH *Azospirillum*

By

RESMI. S.

ABSTRACT OF THE THESIS

Submitted in partial fulfilment of the requirement for the degree

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DEPARTMENT OF AGRONOMY
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ABSTRACT

With a view to assess the role of Azospirillum on growth and productivity of rice as a means of economising fertilizer nitrogen application , a field experiment was conducted at the Instructional Farm, College of Agriculture, Vellayani during the period from June 1992 to September 1992. The variety used as Red Triveni. The experiment was laid out as 4x3x2+1 factorial experiment in randomised block design with two replications. The treatments includes four methods of inoculation of Azospirillum (Seed, seedling root dip, soil and combined inoculation), three levels of nitrogen (50, 75 and 100 per cent recommended dose of nitrogen) and two levels of lime (without and with lime) along with a control (KAU Package of Practices). An abstract of the results is given below.

Among the different methods of Azospirillum inoculation, combined application influenced almost all the growth characters significantly. Application of 100 per cent recommended dose of nitrogen and lime application also influenced the growth characters significantly.

Among the yield attributes, productive tillers per square metre, and panicle weight were significantly influenced by various treatments.

The combined application of *Azospirillum* recorded the highest grain yield. Similarly 75 per cent recommended dose of nitrogen and liming also recorded higher grain yields. A significant change in harvest index was also observed due to various treatments.

Uptake of nutrients was significantly influenced by all the treatments. Among the inoculation methods, combined method of inoculation recorded the maximum uptake. Similarly highest level of nitrogen and lime application showed the highest uptake of nutrients. Combined method of inoculation, highest level of nitrogen and lime application recorded the highest value of protein content.

Economic analysis of data revealed that combined application of *Azospirillum* plus 75 per cent nitrogen plus lime produced a net income which is comparable with the highest net income produced by combined application of *Azospirillum* plus 100 per cent nitrogen plus lime. When compared to control the net income produced by these treatments are higher, indicating the superiority of the above treatments. Thus it is seen that we can save atleast 25 per cent of the fertilizer nitrogen by incorporating the *Azospirillum* through combined application.