UTILISATION OF AZOLLA FOR RICE IN ACIDIC SOILS

By

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THESIS

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DECLARATION

I hereby declare that this thesis entitled "Utilisation of Azolla for rice in acidic soils" 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.

Vellanikkara,
1st October 1983.

HABEEBURRAHMAN, P.V.

<u>**CERTIFICATE**</u>

Certified that this thesis, entitled "Utilisation of Azolla for rice in acidic soils", is a record of research work done independently by Shri.HABEEBURRAHMAN, P.V, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship, or associateship to him.

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Introduction

INTRODUCTION

In order to achieve the challenging task of self sufficiency in rice production the only possibility seems to be to produce more food from the same land, under Indian conditions. The enhancement of productivity per unit area requires intensive management, which mainly comprises of high level fertilizer application. All of our high yielding rice varieties exhibit their production potential only in response to increased fertilizer application, especially nitrogen.

The energy crisis, the limited quantities of raw material of mineral origin and high cost of fertilizer N have brought the aspect of fertiliser uzage to the fore front.

Reviewing the situation in Kerala, it can be seen that rice is one of the most important crops, occupying an area of about 7.9 lakh hectares out of a total cultivated area of 24.5 lakh hectares. But it produces only 50% of the total requirement of the state. Moreover, there is a tendency among the farmers, recently, to give more emphasis on other food crops due to escalating cost of chemical fertilizer and the uneconomic situation. Hence it has become highly essential to find an alternative, cheap and viable source of biofertilzer for rice.

In this context, the role of a tiny water fern Azolla inhabiting in its fronds, a nitrogen fixing strain of Blue Green Algae viz. *Anabaena azollae* can be made use of.

Azolla has already been identified as a potential source of bio-nitrogen for rice culture in countries like Vietnam, China, Philippines, Thailand, SriLanka, California and recently in India also. As a supplemental source of N, Azolla incorporation has been found to be more useful in sandy soils because of its slow releasing effect, thereby reducing the losses through percolation (Mathewkutty, 1982). Nitrogen fixed by azolla becomes available to the plant indirectly through manuring of the decaying bloom of azolla.

A number of preliminary trials have been carried out on the potentiality of azolla for partly substituting the N requirement of rice. Jaikumaran (1981) reported that basal incorporation of azolla at 5 t ha^{-1} resulted in a saving of 25% of the recommended dose of fertilizer N for rice.

To ensure the availability of azolla in right time, it should be multiplied in some other areas and transported to the field as and when required. To do away with this, dual culturing of azolla along with rice upto a certain period and then incorporating it *in situ* seems to be a suitable proposition. Mathewkutty (1982) has confirmed this as a feasible technology. However, the possibility of saving fertilizer N by dual culturing azolla and incorporating has to be investigated in detail.

Majority of the soils of Kerala are acidic in reaction. Azolla may not multiply to the required extent if dual cultured in highly acidic soils. Some preliminary investigations conducted at Pattambi, Moncompu and Karamana also showed that azolla was not coming up well when dual cultured with rice in acidic soils. However, no serious attempt has been made to make rice soils productive for azolla multiplication by liming. Therefore, it has become necessary to assess the exact quantity of lime required for dual culturing of azolla in these soils.

Taking all these factors into consideration, a project on utilisation of azolla for rice in acidic soils was carried out with the following objectives.

1. To examine the possibility of dual culturing of azolla in acidic loamy soils of Kerala for rice ecosystem.

2. to find out the requirement of lime for dual culturing azolla in acidic soils,

3. to study the effect of dual culturing of azolla in combination with lime and fertilizer N on growth and yield of rice, and

4. to assess N saving through azolla dual culture and incorporation at active tillering stage.

Review of Literature

REVIEW OF LITERATURE

The present investigation "Utilisation of azolla for rice in acidic soils" was undertaken with the objectives of assessing the possibility of utilisation of azolla in acidic loamy soils of Kerala for rice ecosystem and to study the N economy through azolla dual culture and incorporation at active tillering stage.

There are usually two methods of utilisation of azolla in rice culture. Azolla is brought from outside and incorporated basally. This involves multiplication of azolla in a separate land and transportation to the rice field. Azolla can also be grown as dual culture along with rice and subsequently incorporated whenever required. This method is cheaper and can easily be adopted by the cultivators. Several investigations on the beneficial effect of incorporation of azolla has been conducted by the previous authors. The present investigation is intended to study the performance of azolla grown as dual culture in acidic rice soils and its effects on the rice crop. Hence review pertaining to the investigation is confined to this aspect.

1. Dual culturing of azolla

It refers to the practice of growing azolla along with rice in wet lands. The beneficial effects of dual culturing in rice fields have been reported by many investigators. Sufficient stress has also been given by many workers on the rate of inoculation and time of incorporation of the dual cultured azolla.

Silvester (1977) suggested introduction of azolla in the early stage of transplanted rice so as to completely cover the water surface, and then lowering the water level for several days to kill azolla, effecting the release of nitrogen. 23 per cent increase in grain yield was obtained by dual culture in California (Talley et al., 1977). Singh (1977 a) registered stimulated rice growth by inoculation of a field with azolla at planting and its incorporation after multiplication. The possibility of inoculating azolla at the time of transplanting of rice has also been indicated by Pillai at al. (1980).

The optimum rate of inoculation and correct time of incorporation of the dual cultured azolla have been studied by many workers. When azolla was inoculated at the rate of 0.3 kg m^{-2} at transplanting, Govindarajan et al. (1979) got complete coverage of the field in two weeks' time. Singh (1979 a,b) also could register increased rice yield when dual culturing was done at a rate of 0.1 kg m^{-2}. He could get full coverage in 20-30 days.

Patel et al. (1980) have indicated the profitability of inoculation of 1 t ha^{-1} of azolla at planting and incorporating it 20 days later. Mathur et al.(1981) opined that an inoculation rate of 0.3 kg m^{-2} is better. But, Srinivasan (1981) advocated a minimum inoculation rate of one tonne of azolla per hectare, for dual culture.

Benra (1982) obtained 20 per cent yield increase by inoculation of azolla at one tonne per hectare, while Kannaiyan et al.(1982) obtained an yield equivalent to 20 kg N ha^{-1} by inoculating azolla at the rate of 0.3 kg m^{-2}. Mathewkutty (1982) has suggested that it is better to incorporate the dual cultured azolla at active tillering stage.

Scanning through the results obtained by different workers it can be concluded that dual culture of azolla is a useful practice which can be adopted in rice to a large extent. It appears that an inoculation rate ranging from 0.1 to 0.3 kg m^{-2} at the time of transplanting, is sufficient for azolla dual culturing. Higher rate can be preferred for quick multiplication.

2. Growth of azolla as influenced by soil reaction

The pH of the growing medium is an important environmental factor deciding the growth and multiplication of azolla. As azolla is grown by dual culturing with rice in the present investigation, the pH of the rice soil will predominantly influence the performance of azolla and ultimately its effect on rice. Many investigators have attempted to trace out the pH optima for azolla growth and N fixation.

Nickell (1961) reported that azolla grows well over a pH range of 4.0 to 8.0, with best growth at 4.0 to 6.5. He also pointed out that a high concentration of Calcium is required to balance the increased absorption of Iron at pH 4.0, otherwise, the fronds of azolla suffered from iron toxicity. Ashton and Walmsley (1976) observed that the growth of <u>Azolla filiculoides</u> was maximum at a pH range of 3 to 6 with low light intensity (15,000 lux), but grew better at pH 9 to 10 when the light intensity was 60,000 lux.

According to Holst and Yopp (1976), N fixation in azolla was optimal at pH 6, at 20°C, and it decreased at neutral pH. Killer and Goldman (1979) recorded maximum nitrogenase activity in azolla grown in pond water of pH 6.5. Later, Jayaprajasam (1981) observed that the N content was highest at pH 6.5 though the highest fresh weight was recorded at a pH of 5.5.

Singh (1977 a) recorded that azolla grew better in soils of pH 5.5 to 7 than in soils of pH 8. He also revealed that very acidic soils of pH 3 to 3.5 did not suppost growth and multiplication. Lumpkin and Plucknett (1980) opined that azolla could survive in a pH range of 3.5 to 10. However, Watanabe (1977) suggested that the optimum pH of water culture solution for azolla growth is 5.5. He also opined that azolla growth in flood water may be different and should be determined separately.

It can be concluded from the investigations reviewed hereabove that the optimum growth and N fixation of azolla occurs at a pH range of 5.5 to 6.5.

3. Nitrogen availability from azolla and nitrogen economy due to azolla

3.1. Dual culturing

3.1.a. Nitrogen availability

Saubert (1949) observed that only 2 per cent of the N in the azolla blanket was released into the surrounding environment. In liquid medium, Venkitaraman (1962) recorded N fixation to the tune of 3.49 mg 100 ml^{-1} after 30 days of azolla growth. A Chinese strain of azolla released 14 to 21 per cent of its fixed nitrogen into water (Shen et al., 1963).

Excretion of fixed N as ammonia was reported by Peters (1975). Release of fixed N from azolla as ammonia was also speculated by Watanabe et al.(1977). But, they could find only one ppm ammonia in an originally N free solution taken from a container where *Azolla pinnata* had been grown.

Thus, a portion of the nitrogen fixed by the *Azolla-Anabaena* symbiosis is supposed to be excreted, which may benefit the rice crop in dual culture.

3.1.b. Nitrogen economy

Inoculation of azolla at the time of planting as a self supporting source of N for rice crop, has been recommended by Watanabe et al.(1977). Dual culturing of azolla with wide double row spacing of rice plants helped to accumulate about 70 kg N ha^{-1} (Anon., 1980). Lizhuo xin (1982) reported that inoculation of azolla for dual culture during the 36 days before and after transplanting supplied a total of 119.7 kg N ha^{-1}. Singh et al.(1982) obtained a saving of 30 kg N ha^{-1} by dual culturing of azolla alone. This observation has been supported by Mathewkutty (1982).

3.2. Incorporation of dual cultured azolla

3.2.1. Nitrogen availability

Tsuzimura et al.(1957) obtained comparable rates of decomposition for azolla and soybean leaves. A study on the release of ammonia from dried azolla in a submerged soil indicated that, at 30°C, the ammonia formed from the total nitrogen of the dried azolla, measured at weekly intervals, was 13, 19, 22 and 75 per cent at Ist, 2nd, 3rd and 6th week after incubation. It appeared that nitrogen in azolla was of slow release type (Anon., 1976 a,b).

Azolla N is released slowly and its availability to the first rice crop is about 70 per cent (Watanabe, 1977). Singh (1977 f) found that azolla decomposed after 8 to 10 days of incorporation and the rice crop was benefitted noticeably after 20 to 30 days only. It is also noticed that azolla decomposed rapidly in the soil releasing 56 to 80 per cent of its N as ammonia within a period of 3 to 6 weeks (Singh, 1979 b). Higher recovery of N was obtained by incorporation of dual cultured azolla when compared to that from decomposition of azolla in water.

The availability of N from azolla was about 40 per cent less than that from ammonical fertilizer, and ammonia released was observed to be more rapid from fresh azolla than from dried azolla (Watanabe at al., 1977). He also noticed that 60 to 75 per cent of the total nitrogen in azolla was released as ammonia, after 6 weeks of decomposition. Subramanian (1981) found that when azolla was incorporated along with urea, the nitrogen was released slowly due to the formation of Azolla-Urea N Complex.

3.2.2. Nitrogen economy

In China, Liu (1979) recorded a saving of 37 to 45 kg N ha^{-1} by dual culturing followed by incorporation 15 to 20 days later. By inoculating azolla at the rate of 0.3 kg m^{-2} one week after transplanting and incorporating 22 days later, Govindarajan et al.(1979) could save 25 kg N ha^{-1}. Mathur et al., (1981) and Srinivasan (1981) have also recorded similar trends.

Patel et al.(1980), from multilocational trials, concluded that the inoculation of 1 t of azolla at planting followed by incorporation 20 days later, could economise 30 kg N ha^{-1}. Several workers (Anon., 1976 a; Anon., 1977; Singh, 1977 a,c,e; Anon., 1978 a; Singh, 1978; Watanabe, 1978; Arunachalam, 1980 and Subba Rao, 1981) concluded that one layer of azolla weighing 8 to 15 tonnes of green matter per hectare could be produced within a period of 8 to 20 days and incorporation of the same could save 30 to 50 kg N ha^{-1}.

The above reports point towards the N economy that can be obtained by dual culturing followed by incorporation of the dual cultured azolla.

4. Effect of azolla on rice

4.1. Growth

Singh (1977 b,d) observed increase in plant height and tiller number when one layer of azolla equivalent to

10 t ha^{-1} was incorporated in rice fields.

Better tillering was observed in azolla incorporated plots (Subudhi and Singh, 1980). Jaikumaran (1981) reported that application of 5 t ha^{-1} of azolla in conjunction with 75 per cent of the recommended dose of 90 kg N gave the same height as that of 90 kg N alone. He also observed, in the same study, that 75 per cent N along with azolla produced the same leaf area index as that of 100 per cent N applied either alone or with azolla or farm yard manure.

However, Natarajan et al.(1980) could obtain only a marginal increase in these growth attributes by the incorporation of azolla, either basally or 30 days after planting.

4.2. Yield attributes

Azolla applied in combination with urea increased filled grains per panicle over urea application alone. (Kulasooriya and de Silva, 1977). Singh (1977 c) reported, from a field experiment at Cuttack, that azolla incorporation at the rate of 10 t ha^{-1} could increase the number and weight of panicles per square meter in rice varieties IR 8 and Supriya.

Jaikumaran (1981) observed maximum panicle production, maximum number of filled grains per panicle, and higher percentage of filling for incorporation of azolla at 5 t ha^{-1} combined with 75 per cent of the recommended dose of N.

With regard to 1000 grain weight, the results obtained for the above treatment and 100 per cent N application were comparable.

4.3. Yield

The influence of azolla on grain yield of rice has been reported by many workers.

Moore (1969), in his excellent review, concluded that rice yield was increased to the tune of 14 to 40 per cent with azolla application. Thuyet and Tuan (1973) observed increased grain yields to the order of 10 to 25 per cent by applying 10 t ha^{-1} of azolla.

Azolla incorporation at the rate of 10 to 12 tonnes per hectare significantly increased rice yields (Singh, 1977 b,d,e). In another set of trials at Cuttack, by the above author (Singh, 1977 b,d,e), the varieties IR 8, Supriya, Vani and CR 1005 recorded increased grain yields to the extent of 12, 28, 24 and 25 per cent respectively, in kharif and, 38 and 41 per cent increase yields were recorded by IR 8 and Kalinga, respectively in rabi with azolla incorporation.

Incorporation of azolla gave 19 per cent increase in grain yield (Srinivasan, 1977). Govindarajan et al., (1979, 1980) revealed that the combined application of azolla with fertilizer recorded higher grain yields over fertilizer nitrogen alone and this increase was comparable to that of an application of 25 kg fertiliser N ha^{-1}.

The use of azolla as green manure in China gave increase in grain yield to the order of 600 to 750 kg ha^{-1} (Liu, 1979). Sawatdee and Seetanum (1979) reported that incorporation of 15 to 18 tonnes of azolla 20 days after transplanting could yield 3.5 to 3.7 tonnes of grains per hectare and was equivalent to that of 37.5 kg fertilizer N ha^{-1}.

Incorporation of azolla at the time of transplanting with 75 per cent of the recommended dose of N registered higher grain yield than application of 100 per cent N alone. (Sundaram et al., 1979). According to Arunachalam (1980) inoculation or incorporation of azolla before or after transplanting increased both grain and straw yield. Natarajan et al.(1980) could obtain increased rice yield in all the seasons by the incorporation of azolla at the rate of 10 t ha^{-1}. Srinivasan (1980) observed that azolla inoculated at the rate of 3 t ha^{-1} at the time of transplanting and incorporated 15 days after planting gave comparable yields to that of 25 kg N ha^{-1}.

Talley and Rains (1980) found that incorporation of azolla to supply 40 kg N ha^{-1} gave equivalent yields as that from a same quantity of inorganic nitrogen. According to Subudhi and Singh (1980), incorporation of azolla at the rate of 10 t ha^{-1} increased rice yields by 40 per cent over control.

AICRIP trials revealed that azolla incorporation increased rice yields particularly in North - Eastern tracts. In Kerala, Jaikumaran (1981) observed that application of 75 per cent of the recommended dose of N along with the incorporation of azolla is enough to produce as much grain yield as obtained from 100 per cent N applied either alone or in combination with farm yard manure or azolla.

Behra (1982) found that green manuring fresh azolla at the rate of 10 t ha^{-1} at puddling increased the yield of rice by 34 per cent and this corresponds with the application of N alone at 30 kg ha^{-1}. He also showed that surface application of azolla at 1 t ha^{-1} five days after transplanting recorded 20 per cent increase in yield of rice.

Kannaiyan et al.(1982) obtained grain yield on par with the application of 20 kg fertiliser N ha^{-1}, by inoculating azolla at 0.3 kg m^{-2} one week after transplanting.

Singh et al.(1982) obtained comparable yields with green manuring of one layer of azolla or dual culturing of azolla with that of 30 kg N ha^{-1}.

Based on the above reports, increased rice yields can be expected by utilisation of azolla for rice either as dual culture or incorporation separately as well as combinedly. Nevertheless, place to place variation in response was also observed.

5. **Effect of azolla on soil properties**

Improvement in some of the soil properties due to azolla has been reported by many workers. From China it is reported that soil organic matter content and soil structure were improved by the utilisation of azolla in rice fields (Anon., 1977).

Higher total and available N, organic carbon and available P were recorded from azolla treated plots by Arunachalam (1980). Singh (1980) also observed that azolla treated plots retained higher organic carbon content.

Venketaraman (1980) concluded from the results of 422 tests, that organic matter increased from 1.54 to 1.59 per cent with no change in N content and a slight decrease in P status. Total N build up in the soil was increased by the use of azolla (Subramanian, 1981). Lizhuo-Kin (1982) reported improvement in the physical, chemical and biological properties of soil by the utilisation of azolla.

Jaikumaran (1981) could not observe much difference between azolla treated plots and fertilizer N applied plots with regard to total N, organic carbon, C:N ratio, available P and exchangeable K in the soil, at Chalakudy. Application of dried azolla did not give any improvement of soil aggregates. (Roychoudhary et al., 1979).

The literature reviewed clearly indicates the possibility of azolla utilization for rice by dual culturing upto certain period and then incorporating it. But the optimum pH for dual culturing has to be worked out for different conditions.

Materials and Methods

MATERIALS AND METHODS

An experiment was conducted during the first crop season of the year 1982-'83 at Mannuthy, Kerala, to examine the possibility of utilisation of dual cultured azolla in acidic loamy soils of Kerala for rice. The materials used and methods adopted for the investigation are given below.

1. Site of experiment

The experiment was conducted at the Agricultural Research Station, Mannuthy, in Trichur District of Kerala. The Station is situated at 12°32' North latitude and 74°20' East longitude and at an altitude of 22.25 meters above mean sea level.

1.1. Soil

The trial was carried out in Block No.II of the station during the first crop season. Data on the physical and chemical properties of the soil are given in Table 1.

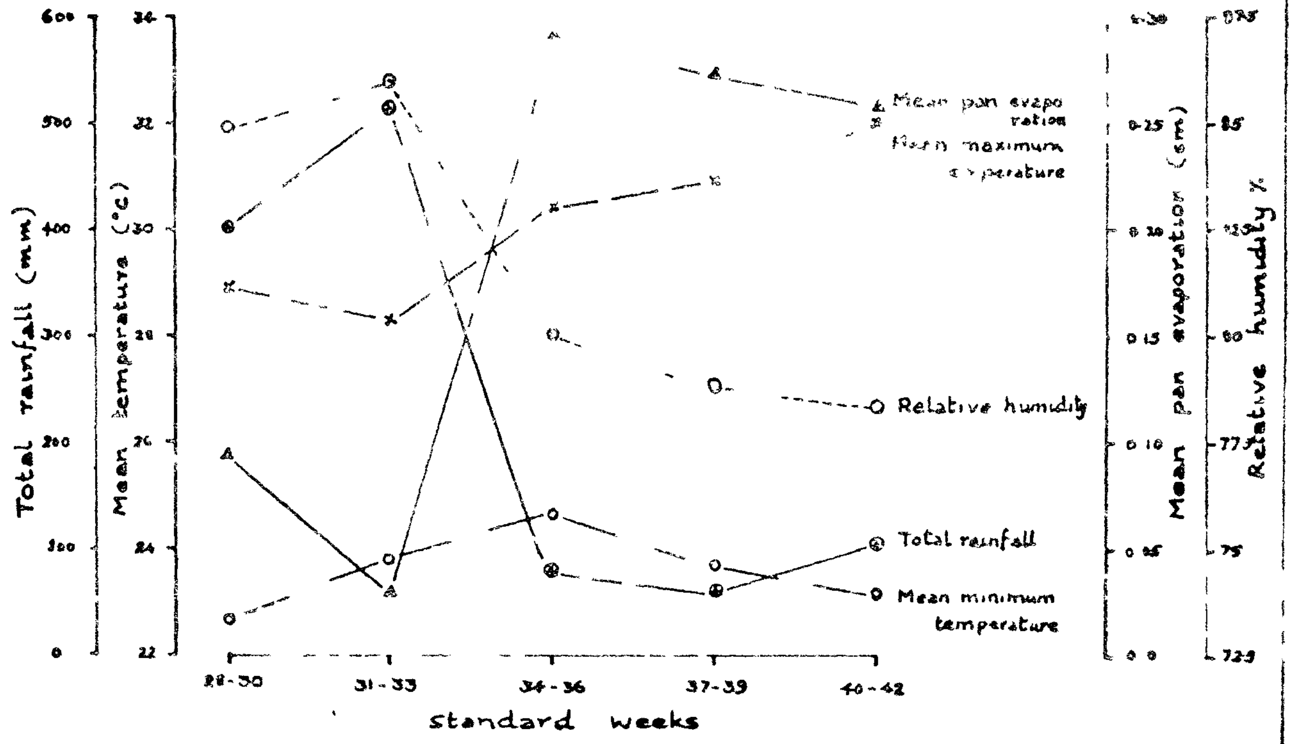
2. Climate

Data pertaining to weekly rainfall, mean maximum and minimum temperatures, relative humidity, and mean evaporation during the cropping period, collected from the meteorological observatory at Mannuthy, are given in Appendix I and shown in Figure 1.

Table 1. Physical and chemical properties of the soil of the experimental site.

I	**Mechanical composition**		
	Coarse sand	:	26.4%
	Fine sand	:	23.8%
	Silt	:	22.4%
	Clay	:	27.2%
II	pH	:	5.3
III	Organic carbon content	:	0.331%
IV	Total N content	:	0.069%
V	Available P	:	67.43 ppm
VI	Exchangeable K	:	33.92 ppm
VII	Exchangeable Ca	:	0.0107%
VIII	Exchangeable Mg	:	0.0391%

Fig 1 Weather parameters during the cropping period



The data corresponds to standard weeks starting from 9th July (starting of 28th week) to 21st October (closing date of 42nd week), the period during which the trial was conducted. The data showed that the weather conditions during the cropping period were normal and favourable for satisfactory growth of the rice crop.

3. Season

The experiment was conducted during the first crop season of the year 1982-'83.

4. Cropping history

The experimental site was double cropped wet land. In the previous season a bulk crop of rice was cultivated.

5. Materials

5.1. Variety

The variety Triveni was used for the investigation. It is a short duration, photo-insensitive variety released from the Rice Research Station, Pattambi. The duration of the variety varies between 95 to 105 days in Kerala.

5.2. Fertilizers and Lime

Urea (46 % N), Super phosphate (16% P_2O_5) and Muriate of Potash (60% K_2O) were used for the experiment. Calcium Oxide was used as the liming material.

5.3. Azolla

Azolla pinnata was used for the study. It contained 91.2% moisture, and on dry basis, it analysed to 3.46% N 0.31% P, 1.35% K, 0.10% Ca and 0.67% Mg.

6. Methods

6.1. Treatments

The treatment consisted of factorial combinations of 4 levels of nitrogen (N) and four levels of lime (L).

Levels of factor 'N'

n_1 - 25% of the recommended dose of N

n_2 - 50% of the recommended dose of N

n_3 - 75% of the recommended dose of N

n_4 - 100% of the recommended dose of N

Levels of factor 'L'

l_0 - 0 kg lime ha^{-1}

l_1 - 600 Kg lime ha^{-1}

l_2 - 900 kg lime ha^{-1}

l_3 - 1200 kg lime ha^{-1}

Treatment combinations

l_0n_1	l_1n_1	l_2n_1	l_3n_1
l_0n_2	l_1n_2	l_2n_2	l_3n_2
l_0n_3	l_1n_3	l_2n_3	l_3n_3
l_0n_4	l_1n_4	l_2n_4	l_3n_4

6.2. Design and layout

The investigation was laid out as a 4^2 factorial experiment in Randomised Block Design with 3 replications.

The layout plan and allocation of treatments for the experiment are given in Figure 2.

6.3.a. Spacing and plot size

The gross plot size was 16.8 sq.m. (4.2 m x 4 m) with a net plot size of 11.88 sq.m. (3.3 m x 3.6 m) with a spacing of 15 cm in between rows and 10 cm within rows.

6.3.b. Border rows

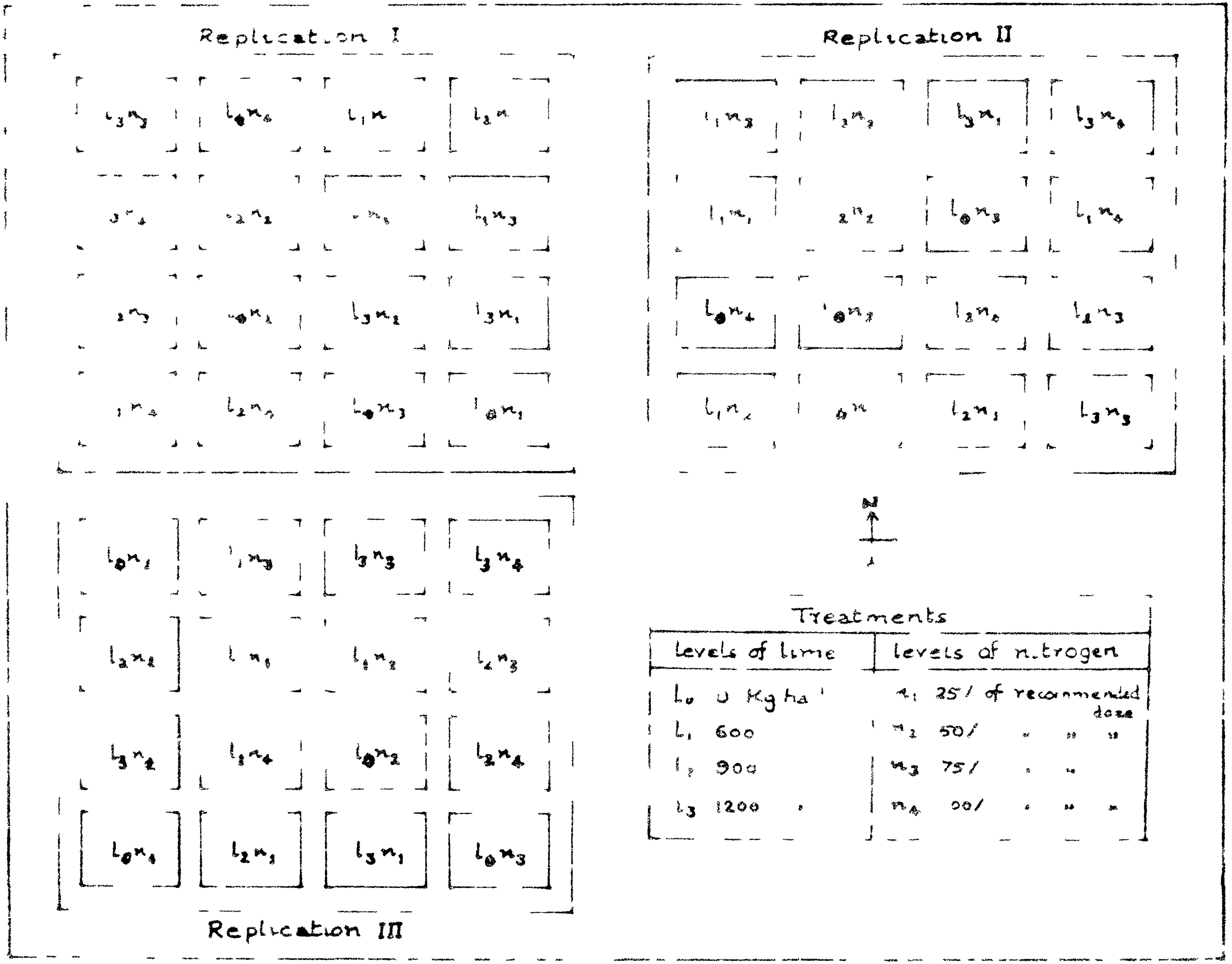
Two rows of plants were left as border rows allaround the plot. One additional row was left length wise (4.2 m side) to facilitate periodical sampling of the plant material and an additional row was also left beyond the sampling row to avoid the possible effect on the net plot.

6.4. Details of field cultivation

The Package of Practices of Kerala Agricultural University for cultivation of rice (Anon., 1982) were followed during the cropping period.

The main field was ploughed, puddled and levelled before transplanting. Twenty one day old seedlings of uniform growth were planted at the rate of two seedlings per hill on 4-8-'83. Gap filling was done on the seventh day of transplanting.

Fig. - Layout plan of the experiment in randomised block design



Treatments

Levels of lime		Levels of nitrogen	
l_0	0 Kg ha^{-1}	n_1	25% of recommended dose
l_1	600 "	n_2	50% " " "
l_2	900 "	n_3	75% " " "
l_3	1200 "	n_4	100% " " "

The crop was given two hand weedings at 20th and 40th days after transplanting. A five centimetre continuous submergence was maintained in the field from the date of planting upto ten days before harvest. Bamboo tubes of 30 cm length fitted with wire mesh at one end were used to drain the field.

6.4.1. Application of fertilizers and lime

Nitrogen was applied as per the treatment schedule. Uniform doses of 35 kg P_2O_5 ha^{-1} and 35 kg K_2O ha^{-1} were applied as basal dressing. An extra dose of 10 kg P_2O_5 ha^{-1} was applied 10 days after planting to all the treatments.

Lime was applied as per the treatment schedule one week before transplanting.

6.4.2. Application of azolla

Azolla was multiplied in plots of uniform fertility outside the experimental plots. Inoculation of azolla was done at 0.3 kg m^{-2} to all the plots two days after transplanting. The azolla was allowed to multiply upto the active tillering stage of rice and then incorporated after draining the field on the previous day.

6.4.3. Plant protection

The lot of azolla used for inoculation was treated with Furadan 3% granules and the crop was sprayed with Ekalux 25% EC against leaf rollers and Metacid 50% EC against rice bugs.

6.4.4. The crop was harvested after a period of 98 days after sowing.

7. Observations recorded

7.1. Azolla multiplication rate

Areas of 0.25 sq.m. were marked randomly at 3 spots in each plot. The fresh weights of asolla in the marked areas were noted at the time of incorporation and the multiplic tion rate was worked out.

7.2. Rice

7.2.1. Biometric observations

For periodical observations, three sample units of two hills x two hills were randomly selected in each plot as suggested by Gomez (1972), and tagged. The following observations were recorded.

7.2.1a. Height

Height was recorded from the base of the plant to the tip of the topmost leaf at tillering and panicle initiation. At flowering and harvest, the height from the base to the tip of the tallest panicle was taken, and the mean height worked out.

7.2.1b. Number of tillers per unit area

Total number of tillers of all the hills in the sampling unit at tillering and panicle initiation were recorded and expersssed as number of tillers per sq.m.

7.2.1c. Leaf area index (LAI)

LAI was calculated by adopting the method suggested by Gomez (1972). Four sample hills were uprooted from the row earmarked for the same and leaves were removed from plants for measuring the leaf area. LAI was computed using the constant 0.75 at active tillering, panicle initiation and flowering stages.

7.2.1d. Dry matter production

The samples drawn out for measuring the leaf area were also used for assessing the dry matter production at active tillering, panicle initiation and flowering stages. At harvest the grain yield and straw yield were added together to get the dry matter production.

7.2.1e. Yield attributes

e.1. Number of panicles per sq.m.

The total number of panicles from the 12 hills selected was counted and number of panicles per sq.m. was worked out.

e.2. Number of filled grains per panicle

The main culm panicles from the 12 hills were threshed and number of filled grains (f), number of unfilled grains (u) and weight of filled grains (w) were determined.

The rest of the panicles from all the the 12 hills were also threshed and number of unfilled grains (U), and weight of filled grains (W) were assessed. From this data, the number of filled grains per panicle was calculated using the formula given below (Gomez, 1972).

$$\text{Number of filled grains per panicle} = \frac{f}{W} \times \frac{W+w}{p}$$

where p is the total number of panicles from all the 12 hills.

e.3. 1000 grain weight

From the values obtained for calculating the number of filled grains per panicle, 1000 grain weight was calculated and adjusted to 14% moisture using the formula given by Gomez (1972).

$$\text{1000 grain weight} = \frac{100 - M}{86} \times \frac{W}{f} \times 1000$$

where M is the moisture content of filled grains.

e.4. Weight per panicle

All the panicles from the 12 hills were weighed and weight per panicle was calculated.

7.2.1f. Grain yield

Dry weight of grain was recorded for the net harvested plot area, weight was adjusted to 14% moisture and expressed as yield per hectare.

7.2.1g. Straw yield

Straw harvested from the net plot was uniformly dried in sun light, weighed and expressed as straw yield per hectare.

7.2.1h. Harvest Index

Harvest Index was worked out by dividing the weight of grain per hectare (Economic yield) with the sum total yield of grain and straw per hectare (Biological yield).

7.3. Chemical analyses

7.3.1. Plant analysis

7.3.1a. Nitrogen content

Nitrogen content of the plant samples at the active tillering, panicle initiation and flowering stages and that of grain and straw at harvest was determined by adopting Microkjeldahl digestion method as suggested by Jackson (1967).

7.3.1b. Phosphorus content

Phosphorus content of grain and straw at harvest and of plants pulled out at active tillering, panicle initiation and flowering stages were determined through triple acid extraction (9:2:1; HNO_3:H_2SO_4:$HClO_4$) and thereafter estimated colorimetrically by developing vanadomolybdophosphoric acid yellow colour and read as Spectrophotometer (Spectronic 20) as suggested by Jackson (1967).

7.3.1c. Potassium content

Potassium content of plants at active tillering, panicle initiation and flowering stages and of grain and straw at harvest were assessed through triple acid extraction and thereafter reading in EEL Flame Photometer.

7.3.1d. Protein content of grain

The nitrogen content of grain was estimated and the protein content was computed by multiplying the N content by a factor 6.25 (Simpson et al., 1965).

7.3.1e. Calcium and Magnesium content

The Calcium and Magnesium content of the samples were found out with the triple acid extract by titration with EDTA as suggested by Jackson (1967).

7.3.1f. Uptake of N, P, K, Ca and Mg

N, P, K, Ca and Mg contents of plant samples at active tillering, panicle initiation and flowering stages were multiplied with dry matter yield and uptake of the nutrients at these stages was computed. The nitrogen, phosphorus, potassium, calcium and magnesium contents of grain and straw were multiplied with their respective yields and values thus obtained were added together to get uptake of N, P, K, Ca and Mg at harvest.

7.3.2. Soil analysis

Soil samples were drawn from the field prior to planting, at active tillering and panicle initiation and immediately after harvest and dried in shade and processed before analysing.

7.3.2a. pH

Soil samples collected at 7, 14 and 21 days after transplanting were used for the measurement of pH using an Elico pH meter after preparing soil: water suspension in the ratio of 1:2.5 (Jackson, 1967).

7.3.2b. Total N

Total nitrogen was estimated by using Macrokjeldahl digestion method as suggested by Jackson (1967).

7.3.2c. Available P

Available P was estimated by extraction with Bray No.I solution and thereafter developing chloromolybdic acid blue colour and reading on spectronic 20 (Jackson, 1967).

7.3.2d. Exchangeable K, Ca and Mg

Exchangeable K, Ca and Mg were extracted by keeping overnight and leaching with 1N neutral ammonium acetate solution. Exchangeable K was read using EEL Flame Photometer. Ca and Mg contents were estimated by titration with EDTA as suggested by Jackson (1967).

7.3.2e. Organic Carbon

Organic carbon was determined by using the Walkley and Black (1934) method.

8. Statistical analysis

Statistical analysis was done using the analysis of variance technique for Randomised Block Design as described by Panse and Sukhatme (1978). Simple correlation among yield and yield components were also worked out.

Results

RESULTS

The observations recorded were statistically analysed. Results obtained are presented below with mean values in Tables 2 to 55 and analysis of variance in Appendices II to VI.

1. Azolla

1.1. Fresh weight of azolla at incorporation

Data on the fresh weight of azolla multiplied upto the time of its incorporation are presented in Table 2 and analysis of variance in Appendix II.

It can be observed from the data that only the levels of lime influenced the fresh weight. The levels of nitrogen and the interaction of nitrogen and lime did not have any significant effect.

There was an increase in the fresh weight of azolla multiplied from the level l_1 to l_3. However, l_2 and l_3 were on par in this regard. The zero level (l_0) recorded the minimum fresh weight of azolla, it being significantly inferior to all other levels.

The effects of nitrogen levels and the interactions were not showing a consistent trend.

2. Rice

2.1. Growth characters

Table 2. Fresh weight of azolla (kg/m²) at incorporation

Treatments	n_1	n_2	n_3	n_4	Mean
i_0	1.497	1.343	1.443	1.343	1.407
i_1	2.653	3.003	2.763	2.800	2.727
i_2	3.113	3.200	3.227	3. 90	3.156
i_3	3.550	3.293	2.990	3.307	3.286
Mean	2.763	2.627	2.511	2.535	

[illegible] C.D. for [illegible] = 0.204 [illegible]

Table 3. Height of plants (cm) at active tillering

Treatments	n_1	n_2	n_3	n_4	Mean
i_0	55.0	59.7	51.4	53.[illegible]	5[illegible].9
i_1	59.6	54.9	62.[illegible]	52.5	59.6
i_2	57.5	53.4	56.2	56.9	57.[illegible]
i_3	54.8	55.1	50.9	53.	56.5
Mean	53.6	53.5	50.[illegible]	52.0	

C.D. for [illegible] = 2.41 [illegible]

Table 4. Height of plants (cm) at panicle initiation

Treatments	n_1	n_2	n_3	n_4	Mean
i_0	51.0	73.9	62.5	55.[illegible]	53.5
i_1	37.2	32.3	33.[illegible]	34.9	35.1
i_2	53.4	30.2	34.2	3[illegible].9	32.7
i_3	30.9	30.7	34.6	33.6	33.3
Mean	33.4	31.[illegible]	34.3	35.0	

[illegible]

Table 5. Height of plants (cm) at flowering

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	79.1	61.9	79.0	67.9	62.3
l_1	63.[illegible]	61.3	67.5	65.7	64.6
l_2	64.2	66.7	65.1	64.9	62.9
l_3	61.5	62.5	62.5	64.6	62.7
Mean	62.2	62.3	63.9	65.9	

[illegible] = [illegible]   [illegible] = [illegible]   CD = [illegible]

Table 6. Height of plants (cm) at harvest

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	[illegible]	66.1	62.9	91.7	65.7
l_1	66.3	65.7	[illegible]	[illegible]	[illegible]
l_2	65.7	61.7	92.6	67.[illegible]	63.3
l_3	[illegible]	9[illegible].6	65.9	9[illegible].1	[illegible]
Mean	63.3	63.5	67.7	[illegible].5	

[illegible] = [illegible]   [illegible] = [illegible]   CD = [illegible]

Table 7. Number of tillers at active tillering stage

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	22[illegible].2	235.6	190.7	243.5	226.3
l_1	226.7	193.7	247.9	256.[illegible]	232.0
l_2	225.3	230.5	245.9	255.4	239.5
l_3	24[illegible].9	243.[illegible]	227.5	234.2	237.3
Mean	230.3	231.[illegible]	235.9	247.6	

[illegible] = [illegible]   [illegible] = [illegible]   CD = [illegible]

2.1.a. Haight of plants

Data on mean height of plants at active tillering, panicle initiation, flowering and harvesting stages are presented in Tables 3 to 6 and analysis of variance in Appendix II.

The plant height is seen increased by nitrogen levels at all stages and significantly at the active tillering stage. At this stage, the level n_4 was superior to n_1 and n_2 even though on par with n_3. The levels n_1 and n_2 were also on par at this stage.

At all other stages, the levels n_3 and n_4 gave comparatively higher values than the lower levels n_1 and n_2.

The influence of lime on plant height, however, was not significant at any of the stages. But there was a specific trend observed by lime application. The level l_1 showed a substantial increase in plant height over l_0 at all stages. Further increase in plant height over l_1 was only negligible.

At none of the stages, the interaction of nitrogen and lime was significant, with regard to plant height.

2.1.b. Number of tillers

Number of tillers per m^2 at active tillering and panicle initiation stages are presented in Tables 7 to 8 and analysis of variance in Appendix II.

Table 8. Number of tillers at panicle initiation stage

Treatments	n_1	n_2	n_3	n_4	Mean
i_0	232.9	253.3	223.4	235.[illegible]	233.3
i_1	25[illegible].1	224.4	250.[illegible]	273.2	252.2
i_2	235.3	235.7	253.9	255.6	245.[illegible]
i_3	242.3	230.0	242.3	235.7	[illegible]
Mean	243.3	247.9	250.3	250.6	

[illegible]

Table 9. Leaf area index at active tillering stage

Treatments	n_1	n_2	n_3	n_4	Mean
i_0	0.725	.794	[illegible].836	.890	[illegible].812
i_1	[illegible].8[illegible]7	0.797	.802	0.907	[illegible].816
i_2	.851	0.[illegible]13	[illegible].837	[illegible].956	[illegible].816
i_3	[illegible].8[illegible]4	[illegible].820	[illegible].861	[illegible].955	.835
Mean	.867	0.801	0.832	[illegible].825	

S. Em ± = 0.053 [illegible]

Table 10. Leaf area index at panicle initiation stage

Treatments	n_1	n_2	n_3	n_4	Mean
i_0	.932	1.[illegible]63	1.212	1.314	1.144
i_1	[illegible].941	1.[illegible]53	1.3[illegible]	1.359	1.[illegible]26
i_2	.927	1.149	1.200	1.357	1.170
i_3	[illegible].823	1.[illegible]11	1.397	1.325	1.139
Mean	[illegible].913	1.123	1.311	1.345	

C.D. for n = 0.[illegible]79 [illegible]

Table 11. Leaf area index at flowering stage

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	1.157	1.3[illegible]0	1.571	1.717	1.45[illegible]
l_1	1.209	1.364	1.531	1.630	1.513
l_2	1.020	1.43[illegible]	1.657	1.67[illegible]	1.497
l_3	1.15[illegible]	1.359	1.738	2.029	1.570
Mean	1.135	1.390	1.549	1.6[illegible]3	

C.D. for N = 0.106 L = [illegible] NxL = [illegible]

Table 12. Dry matter production (kg ha^{-1}) at active tillering

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	503.3	[illegible]	591.[illegible]	576.[illegible]	557.2
l_1	520.3	545.[illegible]	555.0	555.6	547.3
l_2	521.[illegible]	55[illegible].5	570.0	560.5	557.7
l_3	514.4	545.3	550.0	552.2	543.[illegible]
Mean	515.0	551.0	571.5	537.5	

C.D. for N = 14.35 L = [illegible] NxL = [illegible]

Table 13. Dry matter production (kg ha^{-1}) at panicle initiation

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	1511.1	1527.[illegible]	1705.5	1700.[illegible]	1311.2
l_1	1539.4	1703.3	1762.2	1629.4	1713.[illegible]
l_2	1531.2	1533.5	1620.0	1816.[illegible]	1703.0
l_3	1499.6	1732.[illegible]	1742.2	1815.5	1597.5
Mean	1520.3	154[illegible].3	1734.7	1791.[illegible]	

C.D. for N = 35.29 C.D. for L = 35.29 C.D. for NxL = 70.58

The effects of nitrogen, lime and their interactions were not significant as regards the number of tillers per square metre, at both the stages.

However, the number of tillers was found to show an increasing trend from n_1 to n_4 at all the stages. Among the levels of lime, l_0 recorded lower number of tillers at both the stages.

2.1.c. Leaf Area Index (LAI)

Mean values of LAI at active tillering, panicle initiation and flowering stages are recorded in Tables 9 to 11 and analysis of variance in Appendix II.

From the results it could be seen that there was significant difference in LAI due to nitrogen levels at all stages. However, the differences due to levels of lime as well as interactions were not significant.

Among the levels of nitrogen, n_4 recorded maximum LAI values followed by n_3, n_2 and n_1 at all stages. But at the panicle initiation stage, the LAI values recorded by n_4 and n_3 were on par.

2.1.d. Dry matter production

Data on dry matter production at active tillering, panicle initiation, flowering and harvesting stages are presented in Tables 12 to 15 and analysis of variance in Appendix III.

Table 14. Dry matter production (kg ha^{-1}) at flowering

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	2567.6	3334.4	3535.7	3623.2	3321.0
l_1	2701.2	3291.6	3792.9	3651.4	3409.3
l_2	2544.3	3113.1	3782.6	3962.9	3353.5
l_3	2571.6	3139.2	3636.4	3957.6	34[illegible]4.5
Mean	2601.3	3220.6	3734.9	3904.3	

C.D. for l = 67.1 C.D. for n = 67.1 C.D. for lxn = 174.1

Table 15. Dry matter production at harvest (kg ha^{-1})

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	3709	4714	5017	5325	4592
l_1	4166	4759	5595	5376	5055
l_2	3701	4634	5407	5392	4637
l_3	3701	4634	5407	5391	4637
Mean	3663	4710	5353	5564	

C.D. for l = 151.1 C.D. for n = 151.1 C.D. for lxn = [illegible]

Table 16. Number of panicles per m^2

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	176.6	167.9	191.4	195.3	188.3
l_1	191.1	205.5	217.4	236.4	211.1
l_2	192.2	203.0	213.6	217.1	203.4
l_3	186.6	192.6	207.5	216.1	201.3
Mean	187.2	197.1	207.5	215.3	

C.D. for l = 13.4 C.D. for n = 13.4 C.D. for lxn = [illegible]

Significant influence was exerted by the levels of nitrogen on dry matter yield at all stages. The levels of lime caused significant differences on dry matter production at all stages except at active tillering. The interactions also had significant effect on dry matter production at panicle initiation an flowering stages.

At all stages the higher levels of N have recorded proportionate increase in dry matter production and at the active tillering and panicle initiation stages the levels n_3 and n_4 were on par. However, at all the stages n_1 recorded the lowest dry matter production.

Among the levels of lime lowest dry production was given by l_0. The levels l_1, l_2 and l_3 gave dry matter production values which were on par.

The interaction effect of lime and nitrogen has shown the same trend as that of nitrogen.

2.2.a. Yield components

a.i. Number of panicles per m^2.

Data on the mean number of panicles per m^2 are presented in Table 16 and analysis of variance in Appendix III.

The number of panicles per m^2 was found to vary significantly according to the levels of nitrogen as well as lime. However, the interaction of nitrogen and lime did not have any significant influence on the number of panicles.

It is seen from the Table that the higher levels of nitrogen (n_3 and n_4) gave significantly more number of panicles than lower lower levels (n_1 and n_2). The lowest number of panicles was given by n_1.

With regard to the effect of lime on the number of panicles, the level l_1 was superior significantly, the value being on par with the levels l_2 and l_3. The level l_0 resulted in the minimum number. An increase of 12.1 per cent was obtained in the number of panicles, from l_0 to l_1.

a.ii. Number of filled grains per panicle.

Mean values on the number of filled grains per panicle are presented in Table 17 and analysis of variance in Appendix III.

The number of filled grains differed significantly due to the nitrogen levels only. No significant variation was observed due to levels of lime and interactions of nitrogen and lime.

The maximum number of filled grains was obtained with the level n_4, the value obtained being on par with n_3. The level n_1 gave the lowest number of filled grains per panicle. The percentage increase in the number of filled grains per panicle from n_1 to n_3 amounts to 35.9% whereas the corresponding increase from n_1 to n_4 was only 37.7%.

Table 17. Number of filled grains per panicle

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	40.38	34.67	53.42	51.67	45.11
l_1	37.25	39.50	43.56	52.06	43.30
l_2	40.33	39.97	52.69	52.46	43.37
l_3	37.58	43.33	55.53	58.62	48.61
Mean	38.96	39.37	52.61	53.75	

C.D. for N = 4.332 L = N.S. NxL = N.S.

Table 18. 1000 grain weight (g)

Treatments	n_1	n_2	n_2	n_4	Mean
l_0	21.45	22.33	23.40	24.17	22.91
l_1	23.83	23.43	24.93	25.83	24.52
l_2	22.37	22.37	23.40	24.07	23.23
l_3	21.5	23.73	23.27	24.13	23.16
Mean	22.32	23.12	23.67	24.55	

C.D. for N = 0.935 C.D. for L = 0.935 NxL = N.S.

Table 19. Weight per panicle (g)

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	1.17	1.21	1.55	1.52	1.33
l_1	1.52	1.99	2.03	1.55	1.77
l_2	1.31	1.55	1.82	1.90	1.64
l_3	1.12	1.50	1.49	1.93	1.51
Mean	1.28	1.56	1.72	1.72	

C.D. for N = 0.256 C.D. for L = 0.256 NxL = N.S.

a.iii. 1000 grain weight.

Data on the mean weight of 1000 grains are given in Table 18 and analysis of variance in Appendix III.

The 1000 grain weight was found to be influenced significantly by nitrogen and lime levels. But the interactions of the factors had no significant effect.

Maximum weight was recorded by the level n_4, followed by n_3, n_2 and n_1. But the values obtained with the nitrogen levels n_4 and n_3 were on par.

Among the levels of lime, the highest weight of 1000 grains was registered by l_1, followed by l_2 and l_3. The lowest weight was obtained with l_0.

2.2.b. Weight per panicle.

Data on mean weight per panicle are given in Table 19 and analysis of variance in Appendix III.

The panicle weight was influenced significantly by the levels of the factors nitrogen and lime, but not by their interactions.

The maximum weight per panicle was given by the nitrogen level n_3, which was on par with n_4. The level n_1 recorded significantly lowest weight per panicle.

Among the levels of lime, l_1 produced panicles with maximum weight, the values being on par with l_2 and l_3. The lowest weight per panicle was obtained with l_0.

2.2.c. Yield of grain.

The mean grain yield data are presented in Table 20 and analysis of variance in Appendix III.

Grain yield was influenced significantly by the levels of nitrogen and lime, whereas, the effect of interactions was not significant.

Application of N gave significant increase in grain yield only upto the level n_3. The grain yield obtained at the level n_4 was only slightly higher than n_3. The increase of grain yield from n_1 to n_3 was about 53.0%. The corresponding increase from n_1 to n_4 was 57.0%. The levels n_3 and n_4 recorded higher grain yields in the order of 2.66 t ha^{-1} and 2.72 t ha^{-1}, respectively.

The level of lime l_1 gave maximum yield of 2.45 t ha^{-1}. This was 9.2% higher than the grain yield given by l_0. The values obtained at the levels l_2 and l_3 were on par with l_1.

2.2.d. Yield of straw.

Data on the straw yield are given in Table 21 and analysis of variance in Appendix III.

It was seen that the levels of nitrogen and lime had significant influence. As seen in the case of grain yield, the interaction of the factors did not have significant effect on the straw yield.

Table 20. Grain yield (kg ha^{-1}).

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	1646	2209	2505	2615	2244
l_1	1910	2289	2605	2602	2451
l_2	1752	2212	2676	2722	2340
l_3	1605	2148	2643	2755	2294
Mean	1735	2214	2357	2724	

C.D. for N = 62.51 C.D. for L = 62.51 NxL = N.S.

Table 21. Straw yield (kg ha^{-1}).

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	2062	2504	2512	2711	2447
l_1	2[illegible]75	2470	2791	2675	2603
l_2	2193	24[illegible]2	2754	2919	25[illegible]0
l_3	2059	2516	2733	293[illegible]	2571
Mean	2150	2495	2705	2830	

C.D. for N = 77.39 C.D. for L = 77.39 NxL = N.S.

Table 22. Harvest index.

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	0.4433	0.4560	0.4683	0.4957	0.4737
l_1	0.4[illegible]23	0.4707	0.4667	0.48[illegible]	0.4723
l_2	0.4427	0.4700	0.4810	0.4683	0.4705
l_3	0.4400	0.450	0.4820	0.4695	0.4677
Mean	0.4422	0.4572	0.4640	0.4907	

C.D. for N = 0.0048 L = N.S. NxL = N.S.

The straw yield was increased from 2.15 t ha^{-1} at n_1 to 2.86 t ha^{-1} at n_4.

The data revealed that the level of lime l_1 gave maximum straw yield and the value was on par with l_2 and l_3. But all these levels were significantly superior to l_0.

2.2.e. Harvest index.

Data on the harvest indices are given in Table 22 and analysis of variance in Appendix III.

It is evident that only the levels of nitrogen exerted significant influence on harvest index.

The harvest index values showed an increasing trend from the level n_1 to n_4.

3. Chemical studies.

3.1. Quality characters.

3.1.a. Protein content of grain.

Data on protein content of grain are given in Table 23 and analysis of variance in Appendix IV.

Only the nitrogen levels showed a significant influence. Neither the levels of lime nor the interactions had any significant effect.

The protein content was found to increase in accordance with the nitrogen levels, from n_1 to n_4.

Liming also caused slight increase in protein content of grain, even though not significant.

Table 23. Protein content of grain (%).

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	4.37	5.25	5.33	7.29	5.75
l_1	4.67	5.63	7.29	7.68	6.42
l_2	4.67	6.13	6.13	7.56	6.13
l_3	4.67	5.25	7.56	7.66	6.34
Mean	4.67	5.31	6.71	7.63	

C.D. for N = 0.727 L = N.S. NxL = N.S.

Table 24. N content of straw (%).

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	0.437	0.437	0.513	0.793	0.550
l_1	0.513	0.547	0.747	0.653	0.640
l_2	0.327	0.467	0.513	0.653	0.490
l_3	0.313	0.420	0.700	0.693	0.546
Mean	0.420	0.500	0.616	0.696	

C.D. for N = 0.136 L = N.S. NxL = N.S.

Table 25. N uptake (kg ha^{-1}) at active tillering.

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	5.63	7.25	10.15	9.45	8.12
l_1	5.35	7.33	8.7[illegible]	9.15	7.71
l_2	6.33	7.57	9.14	9.75	8.16
l_3	6.03	5.65	7.15	7.99	7.11
Mean	[illegible].64	7.32	8.67	9.06	

C.D. for N = 0.697 L = N.S. NxL = N.S.

3.1.b. Nitrogen content of straw.

Mean values of N contents of straw are presented in Table 24 and analysis of variance in Appendix IV.

It was found to vary significantly due to the levels of nitrogen only. The level n_4 recorded significantly superior nitrogen content in the straw, but this was on par with n_3. The content of nitrogen in the straw was lowest at n_1, the value being on par with n_2. The levels n_3 and n_2 were also on par in this regard.

The influence of lime, ev n though was not significant, the level l_1 registered marginally higher N content in the straw.

3.2. Uptake of N.

Deta on the uptake of N at active tillering, panicle initiation, flowering and harvesting stages are presented in Tables 25 to 28 and analysis of variance in Appendix IV.

It is seen from the Tables that at the stages of active tillering and panicle initiation, the N uptake was influenced due to levels of nitrogen only. At flowering and harvest stages significant difference was brought about by both nitrogen and lime. The interaction were not significant at any of the stages.

The uptake was found to increase from the level n_1 to n_4 at all the stages. The increase was significant from n_1 to n_4 at flowering and harvesting stages. At earlier stages, the levels n_3 and n_4 were on par.

Table 26. N uptake (kg ha^{-1}) at panicle initiation

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	15.22	19.25	23.63	21.97	21.48
l_1	17.27	25.42	2[illegible].91	30.6[illegible]	25.81
l_2	13.33	22.9[illegible]	26.13	29.75	24.29
l_3	17.49	24.27	23.[illegible]	29.70	24.56
Mean	16.63	22.96	27.20	29.23	

C.D. for N = 3.098 L = N.S. NxL = N.S.

Table 27. N uptake (kg ha^{-1}) at flowering.

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	31.47	43.31	57.74	57.64	50.13
l_1	34.11	46.57	65.32	77.27	[illegible].37
l_2	29.59	37.70	56.25	65.03	47.35
l_3	25.43	34.03	57.32	56.[illegible]	43.57
Mean	30.40	39.[illegible]	59.71	69.83	

C.D. for N = 4.323 C.D. for L = 4.323 NxL = N.S.

Table 28. N uptake (kg ha^{-1}) at harvest.

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	21.93	30.17	35.47	52.[illegible]	35.14
l_1	25.93	37.33	53.57	54.[illegible]	42.70
l_2	22.33	32.27	40.33	52.01	36.75
l_3	20.33	26.57	51.30	55.7	38.68
Mean	22.71	32.08	45.42	53.29	

C.D. for N = 4.241 C.D. for L = 4.241 NxL = N.S.

Both at flowering and harvesting stages, l_1 recorded significant increase in N uptake over l_0. The higher levels l_2 and l_3 were on par with l_1.

3.3. Uptake of P.

Data on the mean values of P uptake at active tillering, panicle initiation, flowering and harvesting stages are presented in Tables 29 to 32 and analysis of variance in Appendix IV.

The uptake was differing significantly at all stages except at active tillering. The nitrogen levels influenced the uptake at panicle initiation, flowering and harvesting stages. Lime and N x L interactions did not influence the uptake at any of the stages.

The uptake increased significantly from the nitrogen level n_1 to n_3 and n_3 and n_4 were on par.

3.4. Uptake of K.

Mean values on the uptake of K at active tillering, panicle initiation, flowering and harvesting stages are presented in Tables 33 to 36 and analysis of variance in Appendix V.

At active tillering stage, the uptake was influenced by nitrogen only. At harvest, nitrogen, lime and their interactions influenced the uptake of the same.

Table 29. P uptake (kg ha^{-1}) at active tillering.

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	1.293	1.507	1.563	1.3[illegible]	1.429
l_1	1.317	1.360	1.357	1.433	1.374
l_2	1.257	1.547	1.4[illegible]	1.363	1.414
l_3	1.337	1.347	1.437	1.497	1.407
Mean	1.303	1.440	1.457	1.500	

C.D. for N = [illegible] L = [illegible] NxL = [illegible]

Table 30. P uptake (kg ha^{-1}) at panicle initiation.

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	4.147	3.353	4.213	5.[illegible]67	4.27[illegible]
l_1	3.5[illegible]	4.473	5.31[illegible]	4.583	4.[illegible]13
l_2	3.437	4.227	4.360	5.113	4.364
l_3	3.753	4.533	5.223	4.913	4.606
Mean	3.75[illegible]	4.222	4.657	4.919	

C.D. for N = 0.534 L = N.S. NxL = N.S.

Table 31. P uptake (kg ha^{-1}) at flowering.

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	[illegible].060	9.047	9.323	11.5[illegible]	9.270
l_1	7.7[illegible]7	9.317	9.30[illegible]	[illegible].733	9.1[illegible]9
l_2	7.[illegible]23	9.200	9.007	11.030	9.235
l_3	7.030	8.677	10.723	[illegible].460	[illegible].976
Mean	7.15[illegible]	9.1[illegible]5	9.913	10.448	

C.D. for N = 0.3[illegible] L = N.S. NxL = N.S.

Table 32. P uptake (kg ha^{-1}) at harvest.

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	13.09	15.53	17.90	[illegible]	15.46
l_1	[illegible]	15.37	19.57	17.94	15.97
l_2	13.31	15.51	17.65	19.47	15.56
l_3	12.73	15.57	17.51	19.45	15.31
Mean	13.58	15.74	[illegible]	[illegible]	

C.D. for N = 1.364   L = N.S.   LxN = [illegible]

Table 33. [illegible] uptake (kg ha^{-1}) at active tillering.

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
l_1	[illegible]	[illegible]	[illegible]	[illegible]	6.934
l_2	[illegible]	[illegible]	[illegible]	7.417	6.937
l_3	[illegible]	[illegible]	7.377	[illegible]	[illegible]
Mean	[illegible]	[illegible]	7.127	[illegible]	

C.D. for N = 0.351   L = N.S.   LxN = N.S.

Table 34. [illegible] uptake (kg ha^{-1}) at panicle initiation.

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	21.17	[illegible]	[illegible]	[illegible]	[illegible]
l_1	[illegible]	22.25	25.71	[illegible]	[illegible]
l_2	21.71	21.44	22.47	[illegible]	22.52
l_3	[illegible]	24.67	[illegible]	[illegible]	23.47
Mean	[illegible]	[illegible]	23.37	[illegible]	

[illegible] = [illegible]   L = N.S.   LxN = N.S.

Table 35. K uptake (kg ha^{-1}) at flowering.

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	36.96	45.79	45.33	51.45	44.[illegible]3
l_1	35.[illegible]2	45.28	53.4[illegible]	51.92	46.43
l_2	3[illegible].75	40.61	50.34	54.03	45.24
l_3	35.77	45.44	53.23	54.71	47.31
Mean	35.[illegible]	44.36	50.[illegible]7	53.03	

N = N.S. L = N.S. NxL = N.S.

Table 36. K uptake (kg ha^{-1}) at harvest.

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	35.92	44.[illegible]	45.76	51.42	44.4[illegible]
l_1	4[illegible].22	43.3[illegible]	51.5	52.93	47.[illegible]
l_2	37.1[illegible]	45.57	51.04	53.74	47.0[illegible]
l_3	33.	44.37	50.[illegible]	54.[illegible]	[illegible].57
Mean	3[illegible].74	44.49	49.61	53.05	

C.D. for N = 1.399 C.D. for L = 1.399 C.D. for NxL = 4.574

Table 37. Ca uptake (kg ha^{-1}) at active tillering.

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	0.[illegible]57	0.[illegible]7	0.3[illegible]3	0.311	0.2983
l_1	0.[illegible]93	0.307	0.32[illegible]	0.30[illegible]	0.3066
l_2	[illegible]	0.3043	0.3257	0.329[illegible]	0.3141
l_3	[illegible]	0.325	0.320[illegible]	0.[illegible]	.3068
Mean	0.2860	0.3063	0.3215	0.3112	

C.D. for N = 0.013 L = N.S. N x L = N.S.

At active tillering stage, the uptake was high at n_4 which was on par with n_3, which in turn was significantly superior to n_1.

At harvest, the uptake showed a corresponding significant increase with incremental doses of nitrogen. Among the levels of lime, l_1, l_2 and l_3 recorded significantly superior uptake values than l_0 at this stage. The interaction of nitrogen and lime was significant at this stage. It is seen from the Tables that maximum uptake of K was recorded by the different levels of lime under the treatment n_4. It is also seen that all levels of lime under n_1 recorded low values and l_0n_1 has given the lowest value.

3.5. Uptake of Ca and Mg.

Data pertaining to uptake of Ca and Mg at the various stages are given in Tables 37 to 44 and analysis of variance in Appendix V.

At active tillering and flowering stages, only the nitrogen levels exerted significant influence on uptake of Ca. At harvest, the nitrogen as well as lime influenced the Ca uptake significantly.

At all the stages mentioned, it is seen from the Tables that, the Ca uptake was more at higher levels of nitrogen (n_3 and n_4). Even though not significant, the same trend was observed at the panicle initiation stage also.

Table 38. Ca uptake (kg ha^{-1}) at panicle initiation

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	0.8497	0.8473	0.9330	0.9437	0.9009
l_1	0.8877	0.9560	1.0177	1.1937	1.1038
l_2	0.935	0.9277	1.0663	1.0359	0.9910
l_3	0.8943	0.9633	0.7233	1.0657	.9169
Mean	0.8917	0.9266	0.9426	1.0596	

[illegible] = N.S.   L = N.S.   (N×L) = N.S.

Table 39. Ca uptake (kg ha^{-1}) at flowering.

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	1.436	1.850	2.005	2.027	1.832
l_1	1.4 7	1.933	2.139	2.265	1.954
l_2	1.506	1.842	2.146	2.296	1.947
l_3	1.557	1.853	2.243	2.264	1.968
Mean	1.486	1.872	2.142	2.219	

C.D. for N = 0.113   L = N.S.   (N×L) = N.S.

Table 40. Ca uptake (kg ha^{-1}) at harvest.

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	2.191	2.775	2.88	3.196	2.763
l_1	2.412	2.791	3.304	3.441	2.987
l_2	2.379	2.823	3.227	3.459	2.964
l_3	2.303	2.892	3.147	3.541	2.952
Mean	2.324	2.820	3.154	3.410	

C.D. for N = 0.1304   C.D. for L = 0.1304   (N×L) = N.S.

Table 41. N uptake (kg ha^{-1}) at active tillering

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	0.244	0.265	0.279	0.233	0.253
l_1	0.242	0.255	0.266	0.257	0.250
l_2	0.252	0.270	0.276	0.257	0.263
l_3	0.237	0.246	0.259	0.260	0.257
Mean	0.244	0.262	0.274	0.270	

N = N.S. L = N.S. NxL = N.S.

Table 42. N uptake (kg ha^{-1}) at panicle initiation.

Treatments	n_1	n[illegible]	n_3	n_4	Mean
l_0	0.269	0.612	0.701	0.724	0.557
l_1	0.545	0.739	0.782	0.770	0.734
l_2	0.655	0.391	0.814	0.776	0.742
l_3	0.644	0.745	0.773	0.810	0.744
Mean	0.551	0.697	0.768	0.770	

C.D. for N = 0.044 C.D. for L = 0.044 NxL = N.S.

Table 43. N uptake (kg ha^{-1}) at flowering.

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	1.133	1.56[illegible]	1.674	1.769	1.544
l_1	1.263	1.572	1.804	1.884	1.633
l_2	1.287	1.591	1.815	1.994	1.672
l_3	1.254	1.375	2.079	1.959	1.744
Mean	1.246	1.601	1.843	1.904	

C.D. for N = 0.126 C.D. for L = 0.126 NxL = N.S.

Lime influence Ca uptake significantly at harvest only. It was more at l_1 then at l_0. At the other stages also, such a definite trend was noticed.

With regard to the uptake of Mg both nitrogen and lime had significant effect at all stages except active tillering. At panicle initiation stage the higher levels n_3 and n_4 recorded higher uptake values which were on par. At harvest, it was increased significantly from n_1 to n_4. Among levels of lime, l_1, l_2 and l_3 recorded uptake values significantly superior to l_0, at all stages.

3.6. Soil analyses.

3.6.a. pH of the soil.

Data on the pH measured 7 and 14 days after planting and at the active tillering stage are given in Tables 45 to 47 and analysis of variance in Appendix VI.

Only the levels of lime influenced the pH of the soil at all periods of observation.

There was an increasing trend in the soil pH from 5.68 to 6.5, 7 days after planting. Almost similar trend was followed at the time of incorporation also, but for the fact that l_3 and l_2, and l_2 and l_1 were on par.

At 14 days after planting, the level l_2 showed highest pH followed by l_3, l_1 and l_0.

Change in soil pH due to nitrogen levels as well as interactions was not significant.

Table 44. Mg uptake (kg ha^{-1}) at harvest.

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	1.944	2.374	2.539	2.795	2.420
l_1	2.225	2.495	2.750	3.413	2.771
l_2	2.141	2.533	2.664	3.157	2.674
l_3	2.225	2.507	2.671	3.172	2.394
Mean	2.134	2.477	2.614	3.135	

C.D. for N = 0.143 C.D. for L = 0.143 N x L = N.S.

Table 45. Soil pH - 7 days after planting.

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	5.300	5.533	5.567	5.[illegible]33	5.563
l_1	5.933	5.600	5.937	6.200	5.975
l_2	6.3[illegible]	6.133	6.300	6.067	6.200
l_3	6.5[illegible]	6.433	6.36[illegible]	6.467	6.500
Mean	6.063	6.000	6.133	6.142	

N = N.S. C.D. for L = 0.204 NxL = N.S.

Table 46. Soil pH - 14 days after planting.

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	5.733	5.900	5.833	5.[illegible]33	[illegible]
l_1	6.033	5.900	6.000	6.233	6.042
l_2	6.433	6.167	6.357	6.333	6.325
l_3	6.567	6.[illegible]33	6.667	6.6[illegible]7	6.600
Mean	6.192	[illegible].125	6.217	6.257	

N = N.S. C.D. for L = 0.2004 NxL = N.S.

Table 47. Soil pH - at incorporation stage.

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	5.800	6.000	5.837	5.967	5.90[illegible]
l_1	6.033	6.037	5.967	6.167	6.058
l_2	6.567	6.233	6.567	6.267	6.408
l_3	6.467	6.537	6.30[illegible]	6.567	6.550
Mean	6.217	6.217	6.250	6.242	

C.D. for N = N.S. C.D. for L = 0.1546 NxL = N.S.

Table 48. Total N (%) - active tillering stage.

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	0.0411	0.0420	0.0504	0.0564	0.0474
l_1	.0325	0.0392	0.0532	0.0597	0.0469
l_2	0.0401	0.0420	0.0522	0.0653	0.0534
l_3	.0411	0.0451	0.0576	0.0507	0.0512
Mean	0.0414	0.0423	0.0569	0.0[illegible]02	

C.D. for N = 0.0039 C.D. for L = 0.0039 NxL = N.S.

Table 49. Total N (%) - panicle initiation stage.

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	0.0345	0.0411	0.0527	0.0569	0.0451
l_1	.0452	0.0411	0.0568	0.0586	0.0510
l_2	0.0392	0.0433	0.0566	0.0700	0.0526
l_3	0.0416	0.1464	0.0586	0.0635	0.0531
Mean	0.0411	0.1432	0.0573	0.[illegible]43	

C.D. for N = 0.004 C.D. for L = 0.004 NxL = N.S.

3.6.b. Total nitrogen.

Data on the nitrogen content of the soil at active tillering and panicle initiation stages and after cropping are given in Tables 48 to 50 and analysis of variance in Appendix VI.

It is seen from the Tables that the levels of lime and nitorgen influenced the nitrogen content of the soil significantly at all stages of observation.

At all stages, the N level n_4 recorded maximum total N content of soil, followed by the levels n_3, n_2 and n_1.

As regards the effect of lime on N content, the lowest value was recorded with l_0. At all stages, l_1 has resulted in significantly higher N content than l_0 and it was on par with l_2 and l_3.

3.6.c. Organic carbon content

The percentage contents of organic carbon in the soil after cropping are given in Table 51 and analysis of varience in Appendix VI.

It is evident from the Table that the levels of N and lime as well as the interactions failed to exert significant influence.

3.6.d. Avilable P and exchangeable K.

Data pertaining to the contents of available P and

Table 50. Total N (%) - after cropping

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	0.0317	0.0345	0.0373	0.0495	0.0383
l_1	0.035[illegible]	0.0401	0.0517	0.0476	0.0437
l_2	0.035[illegible]	0.0363	0.0513	0.0504	0.0439
l_3	0.0364	0.0443	0.0471	0.0532	0.0452
Mean	0.0348	0.0393	0.0469	0.0502	

C.D. for l = 0.004 C.D. for n = 0.004 lxn = N.S.

Table 51. Organic carbon content (%) - after cropping

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	0.3475	0.3495	0.3724	0.3532	0.3557
l_1	0.3404	0.3404	0.3533	0.3475	0.3499
l_2	0.3509	0.3437	0.3671	0.3321	0.3485
l_3	0.3321	0.3590	0.3513	0.3509	0.3509
Mean	0.3475	0.3504	0.3585	0.3464	

l = N.S. n = N.S. lxn = N.S.

Table 52. Available P (ppm) - after cropping

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	33.17	3[illegible].73	33.30	31.[illegible]3	32.21
l_1	30.23	34.50	34.[illegible]0	35.[illegible]	33.[illegible]6
l_2	33.97	3[illegible].23	33.10	31.47	33.44
l_3	34.30	33.73	3[illegible].93	34.40	33.34
Mean	32.[illegible]2	33.50	33.03	33.33	

N = N.S. n = N.S. lxn = N.S.

Table 53. Exchangeable K (ppm) - after cropping.

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	1[illegible].33	16.20	16.93	17.[illegible]7	17.7[illegible]
l_1	16.80	15.63	17.7[illegible]	17.87	17.49
l_2	16.6[illegible]	15.43	16.47	1[illegible].4[illegible]	17.23
l_3	17.47	19.[illegible]	17.33	17.90	17.93
Mean	17.80	16.56	1[illegible].11	17.95	

N = n.s. L = n.s. NxL = n.s.

Table 54. Exchangeable Ca (%) - after cropping

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	[illegible].0317	[illegible].0329	[illegible].034[illegible]	0.0336	0.0322
l_1	0.0441	[illegible].0423	[illegible].046	0.0447	0.0444
l_2	0.0510	[illegible].050[illegible]	0.0496	0.0459	[illegible].0494
l_3	0.0481	[illegible].0498	[illegible].0451	0.047[illegible]	0.0477
Mean	0.043[illegible]	[illegible].0439	0.0439	0.0432	

N = n.s. L.S.D. for L = 0.0027 NxL = n.s.

Table 55. Exchangeable Mg (%) - after cropping.

Treatments	n_1	n_2	n_3	n_4	Mean
l_0	[illegible].[illegible]325	[illegible].[illegible]329	0.0354	0.0351	0.0340
l_1	[illegible].0434	[illegible].0306	0.0424	0.042[illegible]	[illegible].0417
l_2	[illegible].0422	[illegible].0444	0.0451	0.042[illegible]	0.0434
l_3	[illegible].0431	[illegible].0419	[illegible].0423	0.0426	0.0425
Mean	0.0403	0.0395	0.0413	[illegible].0406	

N = n.s. L.S.D. for L = 0.0156 NxL = n.s.

exchangeable K in the soil after cropping are presented in Tables 52 and 53 and analysis of variance in Appendix VI.

The differences in the contents of available P and exchangeable K after cropping were not significant either due to levels of nitrogen and lime or due to their interactions.

3.6.e. Exchangeable Ca and Mg.

The percentage contents of Ca and Mg in the soil after cropping are presented in Tables 54 and 55 and analysis of variance in Appendix VI.

The contents of Ca and Mg in the soil were influenced significantly by the levels of lime only. The level l_2, resulted in the highest content of Ca and Mg in the soil. The levels l_2 was on par with l_1 and l_3 which in turn were significantly superior to l_0.

The interactions did not influence the Ca and Mg contents of the soil significantly.

Discussion

DISCUSSION

The results obtained in the present study are discussed hereunder.

1. Azolla

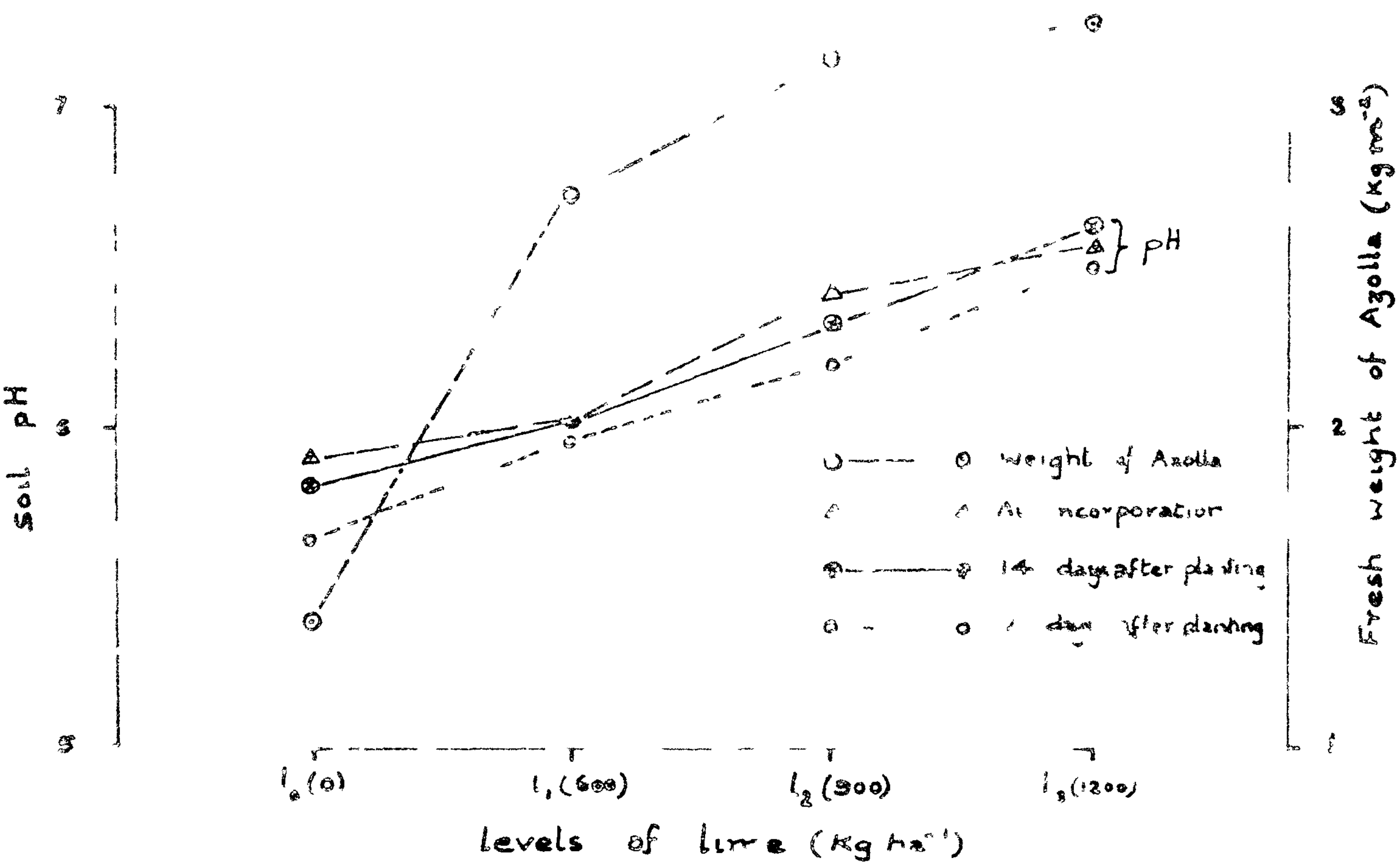
1.1. Fresh weight of azolla at incorporation

From the Table 2 and Fig.3 it is seen that the fresh weight of azolla multiplied during the period of dual culturing, is significantly influenced by liming. All levels of lime application recorded a superiority over l_0.

It is understood that a high concentration of calcium is required for azolla multiplication (Nickell,1961). The increased multiplication observed in the present study is in confirmity with the above. Moreover, it is clear from the Table 54 that the content of Ca in the soil is increased due to liming. The Table further shows that the increase in Ca content is significant upto 900 kg ha^{-1} of lime (l_2) and the multiplication is also significantly increasing upto this level (Fig.3).

A rise in pH from about 5.6 to 6.4 (Tables 45 to 47 and Fig.3) has been observed in the present study. This also might be a factor for the observed increase in fresh weight due to liming. Jayapragasam (1981) also found that a pH range of 5.0 to 6.0 is suitable for increase in fresh weight of azolla.

Fig 3 Fresh weight of Azolla and soil pH as influenced by lime



So a combined effect of increase in soil Ca and rise in pH probably resulted in the increase in fresh weight due to liming.

2. Rice

2.1. Growth characters

2.1.a. Plant height

The results presented in Tables 3 to 6 show that plant height was increased by nitrogen level at all stages and the increase was significant only at the active tillering stage.

At this stage, 100% of the recommended dose of N (n_4) resulted in maximum plant height, followed by 75 (n_3), 50 (n_2) and 25 (n_1) per cent of the doses. The trend was same at the other stages also.

The results also reveal that application of lime at 600 kg ha^{-1} (l_1) gave substantial increase in plant height over control at all stages. The increase in plant height beyond l_1 was negligible.

The role of nitrogen in increasing plant height is well known. This is observed at all stages of growth in the present study. But the differences are significant only at the active tillering stage. This can be due to the fact that, at this stage, nitrogen is available to the plant only from the fertilizer applied. At the active tillefing stage azolla is incorporated and nitrogen is slowly released into the soil.

Hence at the subsequent stages the effect of fertilizer N is probably masked by the nitrogen available from the decomposition of azolla. Slow release of nitrogen from azolla has been observed earlier by Watanabe (1977).

The increase in plant height at 600 kg ha^{-1} of lime can be probably due to the enhanced release of mineralised N from azolla resulting from an increase in fresh weight of azolla, which in turn occured due to a rise in pH by liming (Fig.3).

2.1.b. Number of tillers per m^2.

Results given in Tables 7 and 8 show that at active tillering and panicle initiation stages, an increase in N application from 25% of the recommended dose (n_1) to 100% (n_4) gave marginal increase in the number of tillers per m^2.

Being a vegetative character, it is a well established fact that the number of tillers will increase with the levels of nitrogen. This itself will explain the trend observed in the present investigation. Kumura (1956) has suggested N supply as one of the important factors affecting emergence and development of tillers.

From the results it could be seen that at both stages comparatively lower number of tillers was produced in the plots receiving no lime. In the present study azolla was dual cultured upto active tillering stage. During this period some quantity of N might have been oozed out from azolla. The increased multiplication of azolla due to liming, as seen from the Fig.3 might have resulted in an increase in the quantity of N that was released into the rhizosphere. Excretion of fixed N from azolla as ammonia was reported by Peters (1975).

At panicle initiation stage, N available from the excretion as well as due to decomposition of azolla might have resulted in more number of tillers produced due to liming. The increased P uptake due to liming (Table 30) might have also contributed to more number of tillers.

2.1.c. Leaf area index (LAI)

It is evident from the results presented in Tables 9 to 11 that nitrogen applied at 100% of the recommended dose gave maximum LAI values followed by 75 (n_3), 50 (n_2) and 25 (n_1) per cent of the doses. This trend was observed at all stages.

The increase in LAI may be due to the increased leaf length, number of tillers and number of leaves per hill. The importance of N nutrition in increasing the leaf length is well established (Ishizuka, 1971). From the Tables 3 to 6 and 7 to 8 respectively, it can be seen that there is an increase in the height of plants and number of tillers with nitrogen. A combined effect of the above factors, can be attributed as a reason for the increase in LAI.

2.1.d. Dry matter production

Data on dry matter production presented in Tables 12 to 15 and Fig.4 indicate that N levels exerted significant influence at all stages.

The results showed that application of 100 per cent and 75 per cent of the recommended dose of N gave proportionately higher dry matter yields. It is known that the increase in N application resulted in increased dry matter production (Das Gupta, 1969). The increase in plant height and tiller number with enhancing levels of N observed in the study can be attributed as a reason for an almost similar tred in dry matter production also.

At later stages, nitrogen from azolla could have become available to the crop in addition to that from the fertilizer. Hence 75% of the recommended dose of fertilizer N could give values on par with 100%. This is in agreement with the results obtained by Mohanakrishnan (1983) that the supply of N from incorporation of azolla resulted in higher dry matter production.

It is also revealed that application of lime at all levels is superior to no lime, as seen from Figure 4. The Figure 3 shows a change in pH due to liming and the resulting increase in fresh weight accumulation of azolla. This depicts the chances of increased availability of N due to liming. The data given in Tables 48 to 50 show that the N

Fig. 4. Dry matter production as influenced by nitrogen levels

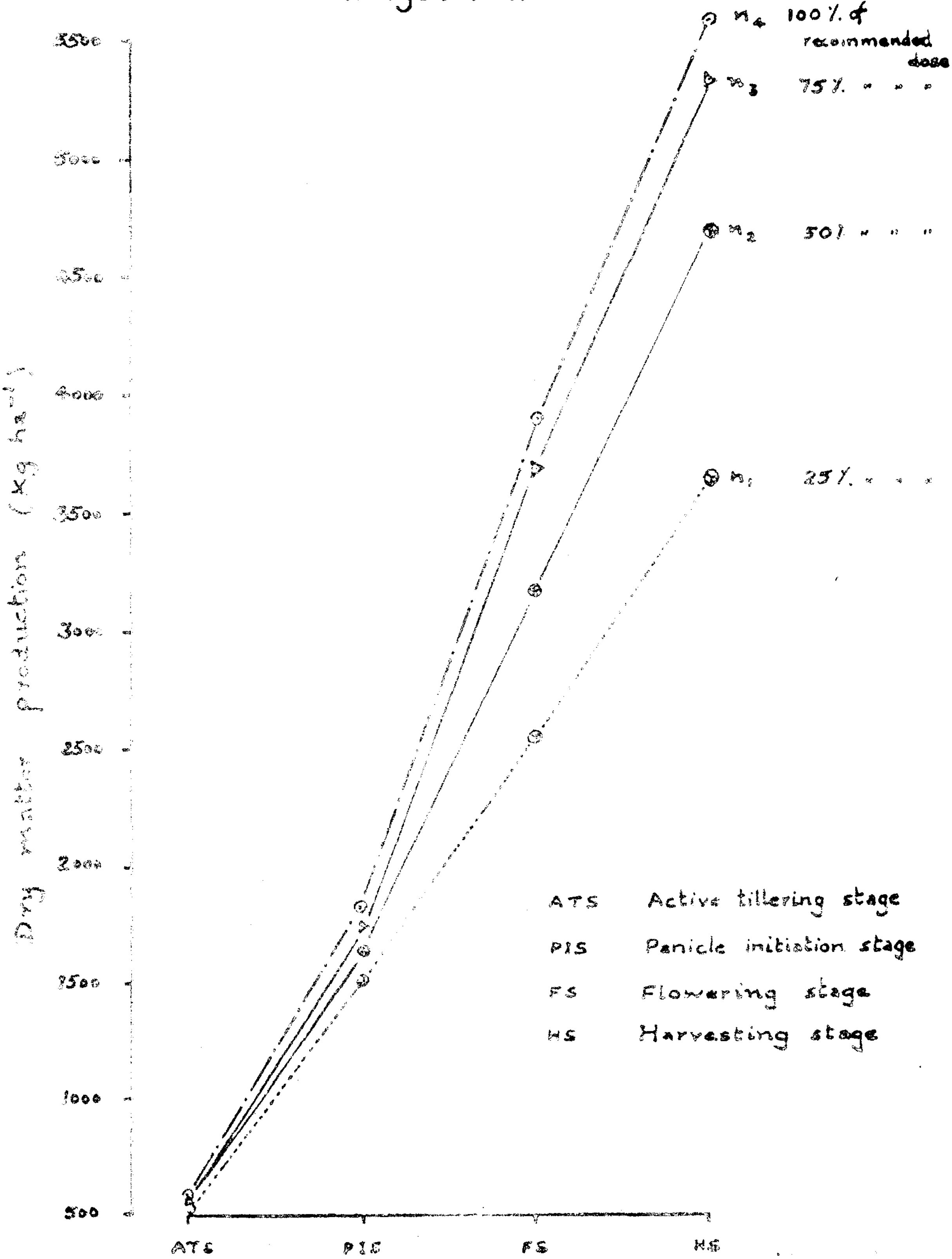
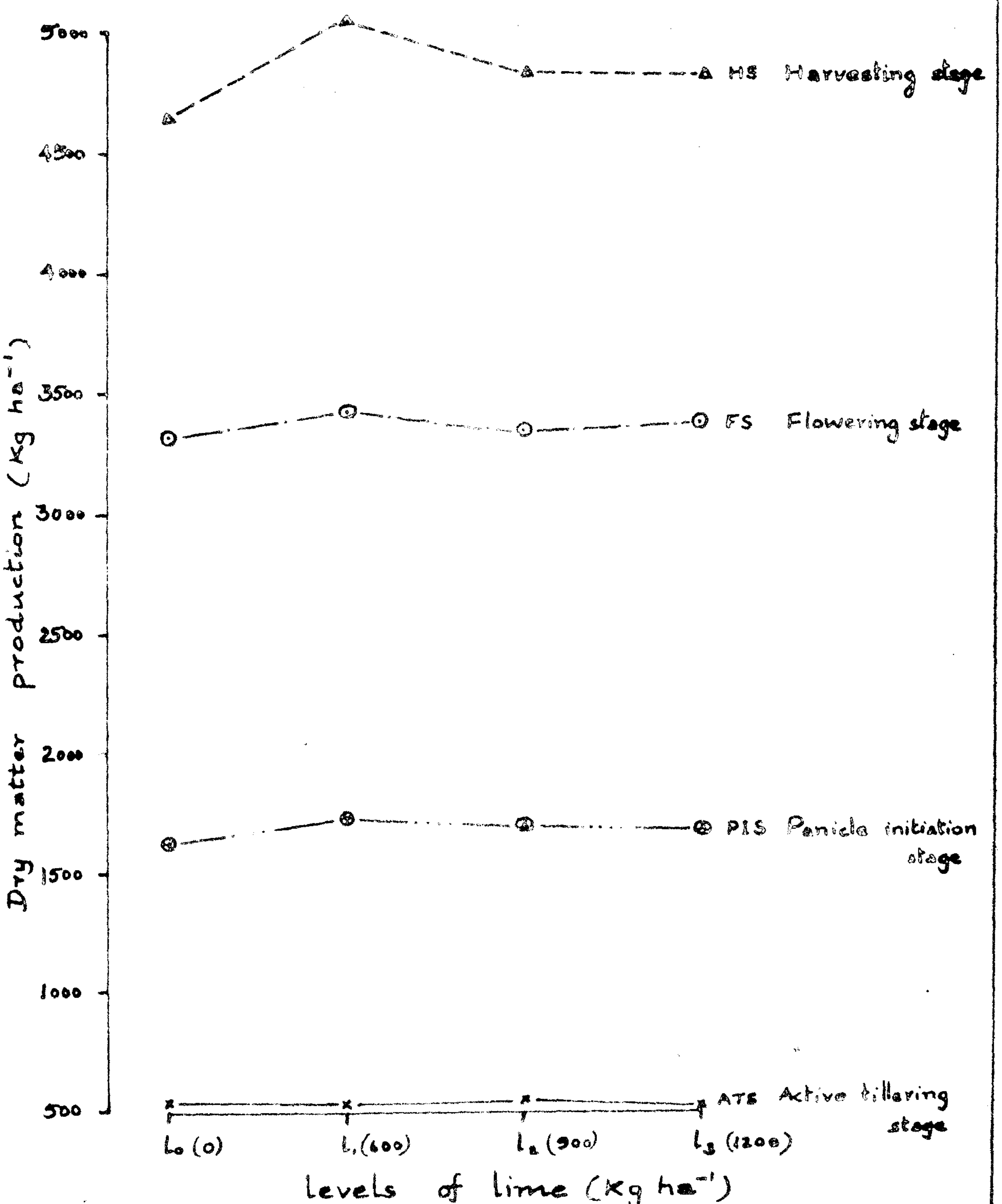


Fig. 5. Effect of lime on dry matter production



content of the soil is increased substantially by liming. This might have resulted in increased uptake of N (Fig.11) resulting in higher dry matter production. The influence of lime on the vegetative characters viz. height of plant and number of tillers is exactly similar to its effect on dry matter production.

2.2.a. Yield components

a.1. Number of panicles per m^2.

From the results (Table 16 and Fig.6) it is observed that the number of panicles produced by 75% of the recommended doze of N (n_3) was on par with that of 100% (n_4).

Increase in panicle production in accordance with N availability is well established (Subbiah et al., 1977). The reason for not showing a proportionate increase in the panicle number from 75% of the recommended dose of N to 100% may be due to the partitioning of the excess N for vegetative growth as is seen clearly in Tables 7 to 8 and 7 to 6 wherein the mean tiller count and height respectively, were increased. This trend also suggests that with the use of azolla, the requirement of fertilizer N can be reduced. This is in confirmity with the results obtained with Jaikumaran (1981).

The results also explain a superiority of liming over l_0 with regard to the number of panicles per m^2 as seen from Fig.7. This can be explained with reference to the uptake of P, K, Ca and Mg. The uptake of the above nutrients was found to increase in limed plots (Tables 32, 36, 40 and 44 respectively). The necessity of Ca and Mg to produce more number of panicles per unit area, in acid soils, was noticed earlier by Verghese and Money (1965).

a.2. Number of tilled grains per panicle.

The results given in Table 17 and Fig.6 reveal that the maximum number of filled grains per panicle could be obtained with 100% of the recommended dose of N (n_4), the value being on par with that at 75% (n_3). The number showed a significant increase from 25% to 75% of N.

It is well established that as the nitrogen uptake goes beyond a certain limit, the chances for the spikelets to become chaff increases. The lack of a proportionate increase in the number of filled grains per panicle at higher levels can be attributed due to this.

It may be further seen from the potash uptake at panicle initiation and flowering stages (Tables 34 and 35) that the uptake was more at higher levels of N and this would have contributed to more grain filling. The role of K in the filling of grains is well established (Agarwala and Sharma, 1976).

The number of filled grains per panicle seems to be not influenced by lime and treatment combinations.

Fig 6 Effect of nitrogen levels on yield attributes

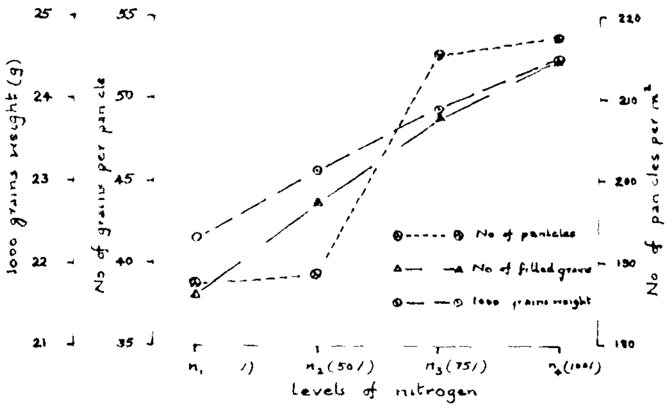
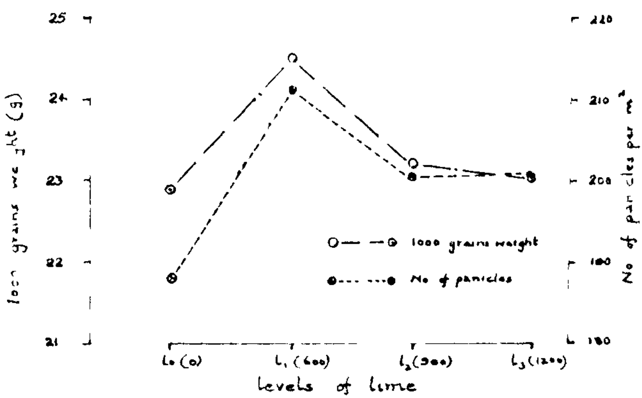


Fig 7 Effect of levels of lime on yield attributes



a.3. 1000 grain weight

Results on the 1000 grain weight given in Table 18 and Fig.6 reveal that there is an increase with the levels of N. It is also seen that n_4 (100% of the recommended dose of N) had given 1000 grain weight on par with 75% (n_3). This is in accordance with the works of Padmaja (1976) and Kalyanikutty et al. (1969).

Lime at the rate of 600 kg ha^{-1} (l_1) registered a superior weight of 1000 grains over l_0 (Fig.7). It can be due to the favourable effects of lime on the K uptake as is seen from the Tables 35 and 36.

2.2.b. weight per panicle.

From the Table 19 it is evident that the mean weight per panicle was influenced by nitrogen and lime, but not by their interactions.

Application of N resulted in an increasing trend with regard to weight per panicle, even though the values obtained with 75 and 100 per cent of the recommended doses were on par. Accumulation of photosynthates in the grains might have resulted in an increase in the weight per panicle with N. Higher levels of N application has been found to increase panicle weight (Subbiah et al., 1977 and Jaikumaran, 1981).

The weight per panicle was found to increase due to liming. The N availability at later stages from the lime treated plots, probably resulted in this favourable effect.

The K uptake due to liming as explained for 1000 grain weight, can also be attributed to the contribution in panicle weight.

2.2.c. Yield of grain.

From the Table 20 and Figures 8 and 9, it is seen that the yield variations due to levels of nitrogen as well as lime are significant.

Yield showed significant increase from 25 to 75% of the recommended doses of N. However, the yield obtained at 75 and 100 per cent of N was on par. The increase in yield noticed at 100% was only marginal.

The increase in grain yield in rice due to nitrogen is well known. Kumura and Takeda (1962) obtained remarkable increases in grain yield with increments of nitrogen, but the rate of increase in yield diminished as the N level was enhanced. In the present study also, the yield did not show any significant increase from 75 to 100 per cent of the recommended dose of N.

Main yield contributing factors are number of panicles per unit area, number of filled grains per panicle an 1000 grain weight (Matsushima, 1976). The trend shown by the above parameters to the levels of N in this investigation is in lime with that of grain yield. Correlation studies as given in Table 56 showed that there was a significant positive correlation between grain yield and number of panicles per m^2.

Table 56. Simple correlation between yield and yield components.

	Yield attributes		
	Number of panicles per m^2	Number of filled grains per panicle	1000 grain weight
Grain yield	0.8093**	0.2099	0.1313

** Significant at 1% level.

So a combined affect of the above parameters can be attributed to be the reason for the specific trend in grain yield, for the applied N.

Moreover, azolla is inoculated uniformly to all the plots at 3 t ha^{-1} and incorporated at about 26 t ha^{-1} (Table 2) at active tillering stage. Azolla contains approximately 3.46% N on dry weight basis. This N might have been taken up by the plant, thus reducing the requirement of fertiliser N. Hence a 25% saving in the recommended dose of N could be obtained due to azolla. This is in agreement with the findings of Sundaram et al. (1979); Govindarajan et al. (1979, 1980); Srinivasan (1980 a); Natarajan et al. (1980) and Jaikumaran (1981). Mathewkutty (1982) also observed that dual culturing an <u>in situ</u> incorporation can save 30 kg N.

From the Table 20 and Fig.9 it is evident that application of lime at 600 kg ha^{-1} gave the maximum yield of 2.45 t ha^{-1}, followed by 900 and 1200 kg ha^{-1}.

The superiority of liming over control can be due to an increase in multiplication of azolla due to a favourable pH (Fig.3) and subsequent increase in the quantity of N available for grain production. Moreover, the results on yield attributes in Tables 16 and 18 and Fig.9 showed that the panicles per m^2 and the 1000 grain weight were more at 600 kg ha^{-1} of lime.

Fig 9 Yield of grain and straw as influenced by lime

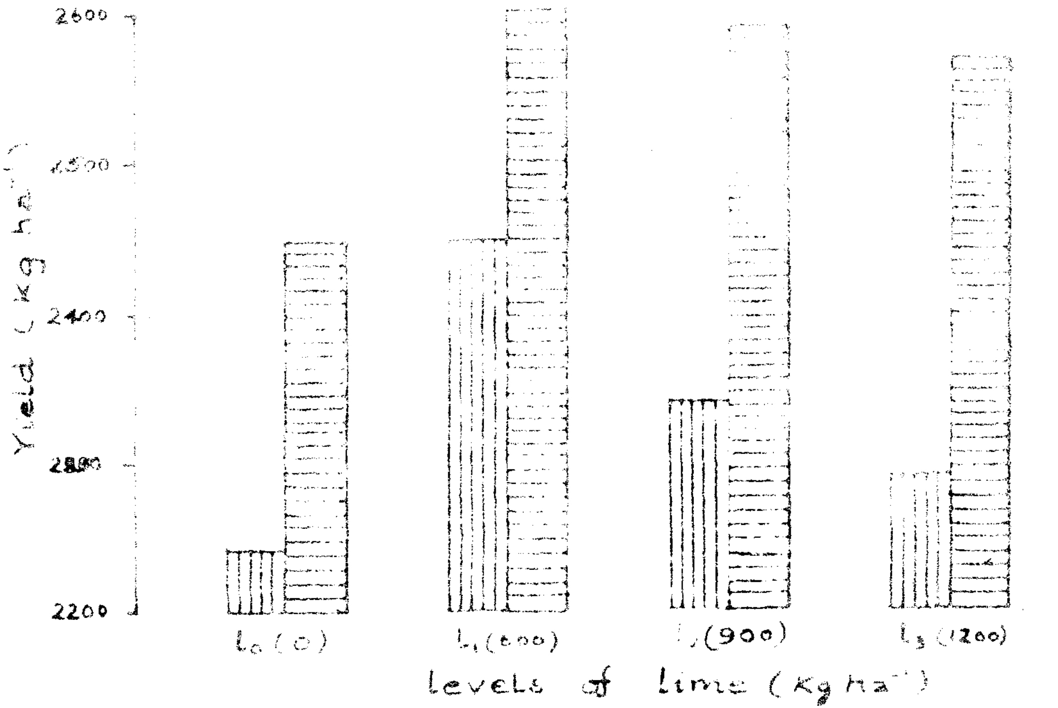
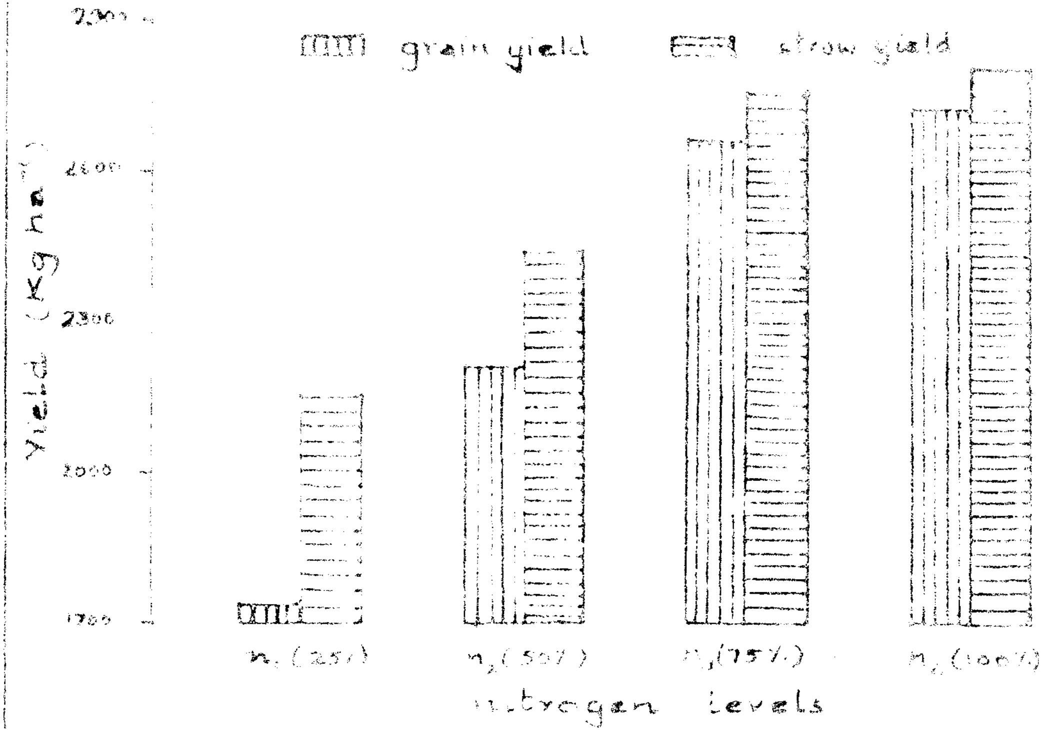


Fig 2 Yield of grain and straw as influenced by nitrogen



The lack of response at higher levels of lime can be explained due to the fact that increased quantity of N made available by enhanced multiplication of azolla could not be utilised due to the shorter duration of the variety.

2.2.d. Yield of straw.

The results presented in Table 21 and figure 8 indicate that the levels of N gave significant increase in straw yield.

It is also revealed that liming showed a superiority over control with regard to straw yield (Fig.9).

A perusal of the data on the tiller production, plant height and leaf area index (Tables 7 to 8, 3 to 6 and 9 to 11) revealed that these characters also showed an increasing trend with N levels. Probably a combined effect of these might have contributed to the increase in yield of straw observed here. Increase in straw yield in accordance with N is a common observation in rice (Kalyanikutty and Morachan, 1974).

As discussed with regard to the vegetative characters like tiller number, plant height etc. liming enhanced the multiplication rate of azolla (Fig.3) thereby increasing the N availability to rice at later stages.

The increase in the uptake of N due to liming observed at panicle initiation and flowering stages (Tables 26 and 27 and Fig.11) can also be a reason for the increase in straw yield. Moreover, the uptake of K was increased throughout the growth phase due to liming. This can be considered as an important reason for the enhanced straw yield.

2.2.e. Harvest index.

From Table 22 it is seen that there was significant difference in harvest index values. It increased from 25% of the recommended dose of N to 100%. It is also noticed that lime levels and the interactions did not have any significant effect.

The variety used in the investigation being of short duration type, the straw yield did not increase considerably over grain yield even though the variation in straw yield was significantly due to the levels of N. Hence the harvest index showed an increasing trend. The higher harvest index value can be due to the N availability from azolla which would have been utilised more for grain production than straw production. This is in accordance with the observation by Mathewkutty (1982) that higher N availability from dual culturing and in situ incorporation resulted in proper utilisation of N for grain production which ultimately led to high harvest index values.

3. Chemical studies.

3.1. Quality characters.

3.1.a. Protein content of grain.

Results presented in Table 23 reveal that there was an increase in the protein content of grain in accordance with the increments of N. This is in confirmity with the results of Kothandaraman et al. (1975) and Pisharody et al. (1976).

Mathewkutty (1982) also obtained increase in protein content, due to combination of fertiliser N with incorporation of dual cultured azolla.

Slight increase in the protein content of grain due to liming may well be due to the increase in Ca content which ultimately resulted in increased N uptake.

3.1.b. Nitrogen content of straw.

It is seen from the Table 24 that the N content of straw was influenced by levels of N. But it could not be significantly increased beyond 75% N. The variety being of shorter duration, the time available was limited and hence the content of N might not be increased at higher levels of applied N.

The marginal increase in N content due to liming can be due to the influence of Ca on N uptake.

3.2. N Uptake.

It is seen from Tables 25 to 28 and Fig.10 that there was significant increase in N uptake from 25% of the recommended dose of N to 100% at the later stages of flowering and harvesting. At the earlier stages of active tillering and panicle initiation, the increase was significant only upto 75% N.

Averages of uptake at different stages, as seen from the Tables and Fig.10 suggest that at the two earlier stages, the uptake was probably from fertiliser N. It is also seen

Fig 10 Uptake of N as influenced by Nitrogen levels

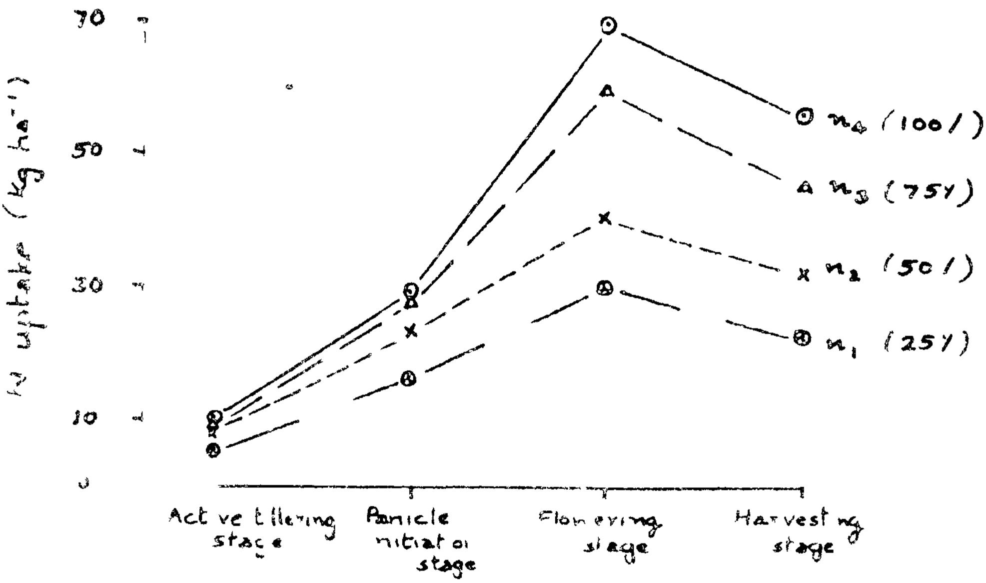
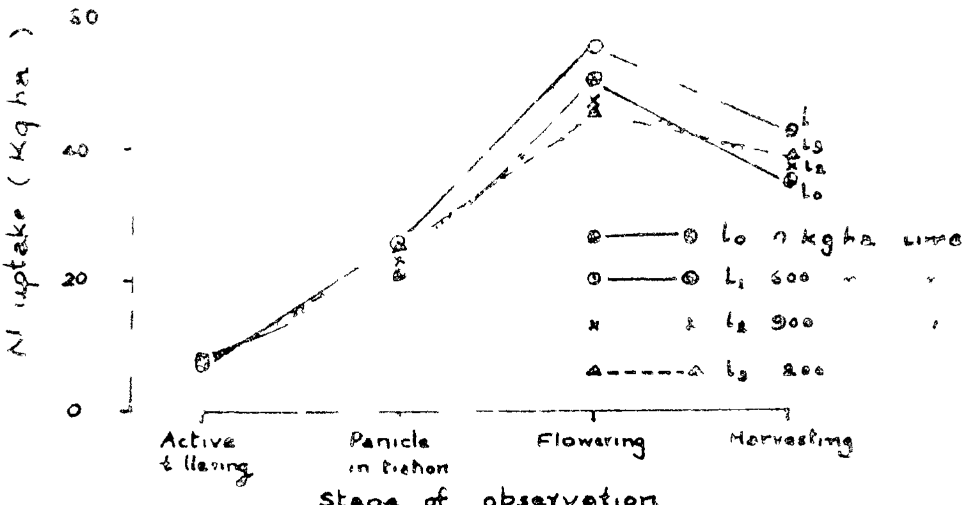


Fig ' Uptake of N as influenced by levels of lime



from the Fig. that the uptake at the later two stages is mainly contributed by asolla, due to the slow and steady availability of N. Similar results on increased availabilit of N from asolla has been reported by Mathewkutty (1982).

It is clearly seen from the Tables 12 to 14 and Fig.4 that the dry matter production values at the higher levels of N were on par. This might be a reason for an exactly similar trend in N uptake also. At harvest, the content of N in grain (Table 23) and dry matter production (Table 15 and Fig.4) showed the same trend as that of uptake of N. This can be attributed to be the reason for a specific trend in the N uptake at harvest.

The effect of lime was significant only at the later two stages wherein 600 kg ha^{-1} of lime gave significantly superior uptake values than no lime (Fig.11). From the Tables 49 and 50, it can be seen that the soil N content was increased due to Ca application at both stages.

It is seen from the Fig.11 that at all stages, lime at 600 kg ha^{-1} resulted in increased N uptake. Favourable influence of Ca in increasing the mineralisation of soil N and availability of the same was reported by Coleman (1955).

From the figures it is clearly seen that the effect of N on the uptake is more pronounced then that of lime.

3.3. Uptake of P.

From the Tables 29 to 32 it is seen that except at active tillering stage, the nitrogen levels resulted in significant increase in P uptake. Lime lev ls and interactions did not differ significantly.

The uptake was increased from 25% of the recommended dose of N to 75%. The applic tion of 75 and 100% doses gave values which were on par.

With increase in the availability of N absorption of P is also increased leading to an increase in the uptake of P at the various stages with a consequent enhancement of the dry matter production.

Uptake of P did not show a consistant trend with the levels of lime.

3.4. Uptake of K.

From the tables 33 to 36 it is seen that the uptake was maximum at the highest level of N at all stages of observation. This was on par with n_3 at active tillering stage. At panicle initiation and flowering there was no significant difference, even though there was increase corresponding to the levels of nitrogen.

The increase in absorption of K probably resulted from a rise in the content of N in the soil as revealed in Tables 48 to 50 at different stages. Similar results of increasing K absorption simultaneous with N was also reported earlier (Gopalaswamy and Raj, 1977; Raju, 1978).

With liming also the K uptake was found to increase. It can be explained on the basis of the favourable influence of Ca on K availability. The present study also revealed that the K content of soil was raised due to liming (Table 53). It is also observed by Verghese and Money (1965) that the application of Ca increased the availability of K in the soil and hence the increased uptake of K by rice.

It may be further seen from the Table 36 that the NxL interaction was significant at harvest. The difference between the levels of N under the same level of lime is more marked than the difference between the levels of lime under the same level of N. This is mainly due to the effect of N on K uptake. It may be further noted that l_1n_3 has recorded significantly higher uptake than l_0n_3 and many other combinations of n_1 and n_2 with lime. It can also be noted that l_1n_3 was on par with all other combinations which recorded higher uptake. Thus it can be inferred that one of the reasons for increase in yield obtained with this treatment combination is due to high uptake of K.

3.5. Uptake of Ca and Mg.

It is clear from the Tables 37 to 44 that the higher levels of N caused increase in Ca uptake at all stages. With regard to the uptake of Mg also the same trend was recorded.

As in the case of other nutrients, N increased uptake of Ca and Mg also mainly due to the differential absorption of these nutrients at different levels of N. It may be further seen from the Tables 12 to 15 that the dry matter production was also increased at higher levels of N.

The uptake of Ca and Mg was found to show substantial increase due to lime at 600 kg ha^{-1} over l_0. Further levels did not appreciably increase the Ca and Mg uptake at most of the stages. This observed increase in Ca and Mg uptake due to liming can be attributed to the direct effect of liming making more Ca and Mg available in the soil (Tables 54 and 55). In conformity with this, Verghose and Money(1965) observed that the application of Ca enhanced the availability of Ca and Mg in acidic soils.

3.6. Soil analyses

3.6.a. pH

From the results presented in Tables 45 to 47 and Fig.3 it can be noticed that lime had a positive influence on the soil reaction up to the highest level of 1200 kg ha^{-1}). In this connection, it may be pointed out that the original pH of the soil was only 5.3 and an increase in pH was noticed even in non-limed plots probably due to the effect of submergence. At all periods of observation, pH increase was noticed due to liming. This can be probably due to the combination of the direct effect of liming as well as submergence. The direct roll of lime in increasing the pH is a well established fact (Coleman et al., 1958). It is also opined by Ponnamperuma (1977) that the pH of acidic soils is increased on submergence.

3.6.b. Total N.

The total N content of the soil was increased significantly by nitrogen and lime.

It is clear from the Tables 48 to 50 that the increase in N content was in proportion to the levels of N. This rise in soil N can be explained to be due to the effect of fertilizer N applied.

Similarly, lime application also recorded increased N content in soil and 600 kg ha^{-1} of lime was sufficient to record the desired change in the N content. In lime treated plots more quantity of N is added due to enhanced multiplication of azolla (Fig.3). The quantity of N produced by decomposition of azolla at later stages may be left in the soil, with the crop not utilising it, thus causing an increase in the soil N content after cropping. At the other stages, the enhanced N content due to liming can be attributed to the favourable influence of Ca on N mineralisation.

3.6.c. Organic carbon content.

From the Table 51 it is clearly seen that the carbon content is not increased by nitrogen and lime. The increments of N has not resulted in an appreciable increase in the organic carbon content probably because the applied inorganic nitrogen has not resulted in increasing the carbonaceous materials of the soil. In line with this, Jaikumaran (1981) failed to obtain any significant variation in the organic carbon content due to azolla incorporation along with fertilizer nitrogen.

Lime application also has not changed the carbon content of the soil even though the azolla multiplication was enhanced. The increase in azolla multiplication need not necessarily result in a corresponding rise in C content of soil since according to Roychoudhary et al. (1979) azolla does not contribute to an increase in the carbonaceous materials of the soil since it consists of only easily decomposable matter.

3.6.d. Available P and exchangeable K.

The data presented in Tables 52 and 53 show that there was not much variation in the contents of available P and exchangeable K respectively, due to lime, nitrogen or interactions. This is in tune with the observation by Jaikumaran (1981). Similarly lime application also did not influence the contents of the above nutrients in the soil.

3.6.e. Exchangeable Ca and Mg.

From the Tables 54 and 55 it can be observed that there is significant variation in the contents of exchangeable

Ca and Mg with the lime levels, l_1, l_2 and l_3 over l_0. However, the former three were on par.

The increase in Ca and Mg contents in the soil due to lime application is already a well established fact (Coleman, 1958). Indirectly also the increased azolla multiplication due to liming (Fig.3) and consequent increase in Ca and Mg present in azolla might have contributed to high exchangeable Ca and Mg contents in the soil. The azolla used in the investigation contained 0.18% and 0.67% of Ca and Mg, respectively, on dry weight basis.

Summary

SUMMARY

An investigation to examine the possibility of azolla utilisation in acidic loamy soils of Kerala and also to study the influence of azolla on rice when it is dual cultured with rice and incorporated at active tillering stage, in combination with fertilizer N and lime, was carried out at the Agricultural Research Station, Mannuthy during the first crop season of the year 1982-83.

The findings of the investigation are summarised as follows.

1. The levels of lime increased significantly the multiplication rate of azolla upto 900 kg ha^{-1} of lime. It was not influenced by the levels of N.

2. The plant height was influenced significantly at the active tillering stage. The increase in plant height was maximum at 75% of the recommended dose of N and 600 kg ha^{-1} of lime.

3. Application of 100% of the recommended dose of N gave the maximum number of tillers at active tillering and panicle initiation stages. Lime application has also considerably increased the tiller number.

4. The leaf area index showed a significant increase with the nitrogen levels.

5. Increasing the levels of N has proportionately increased the dry matter production. However, lime beyond 600 kg ha^{-1} did not appreciably increase the same.

6. For increasing panicle production 75% of the recommended dose of N and 600 kg ha^{-1} of lime was sufficient.

7. The number of filled grains, 1000 grain weight and weight per panicle were also increased by 75% of the recommended dose of N and 600 kg ha^{-1} of lime.

8. The grain yield did not increase significantly beyond 75% of the recommended dose of fertilizer N. Lime application at the rate of 600 kg ha^{-1} resulted in increased grain yields of 2.45 t ha^{-1}, which was 9.2% more than the yield with no lime application.

9. The straw yield was found to show a significant increase (2.15 t ha^{-1} to 2.86 t ha^{-1}) from 25% of the recommended dose of N to 100%. Lime application also likewise increased the straw yield.

10. Higher levels of N resulted in increased uptake of all the nutrients viz. N, P, K, Ca and Mg.

11. Soil pH was found to increase due to lime application. The content of total N in the soil was increased by higher levels of N and 600 kg ha^{-1} of lime at all stages. The Ca and Mg contents of the soil were increased by lime application.

The following are some of the future lines of work suggested for further ingestigation.

1. Change in composition of azolla due to liming may be studied.

2. Minimum rate of inoculation of 0.1 kg m^{-2} may be tried for dual culturing, with lime application.

3. Examine the performance of heat resistant strain of azolla so that it can be grown throughout the year.

4. Possibility of multiplication of azolla through spores may be exploited so that it will have wide applicability.

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Original not seen

Appendices

APPENDIX I

Meteorological data for the croppin, period 1982-'83

Standard week	Period		Total rainfall (mm)	Mean maximum tempera-ture (°C)	Mean minimum tempera-ture (°C)	Relative humidity (%)	Mean pan evaporation (cm)
28	July	9-15	201.8	28.2	22.4	286.3	0.034
29		16-22	115.4	28.8	22.6	85.8	0.067
30		23-29	85.8	29.7	23.1	82.6	0.188
31		30- 5 Aug.	191.4	27.8	23.7	88.9	--
32		6-12	194.8	28.4	24.0	85.6	0.098
33		13-19	145.8	28.7	23.8	85.2	--
34		20-26	83.4	29.5	24.4	83.7	0.044
35		27-2 Sept.	4.2	30.7	25.2	81.0	0.341
36		2-9	0.0	31.1	24.5	76.4	0.478
37		10-16	12.6	31.4	24.4	77.0	0.343
38		17-23	54.6	30.6	24.1	80.5	0.227
39		24-30	0.2	30.7	22.6	79.6	0.257
40	October	1-7	70.0	31.6	22.9	78.1	0.230
41		8-14	37.0	32.6	23.2	76.8	0.285
42		15-21	4.4	31.7	23.7	79.4	0.265

APPENDIX II

Abstract of analysis of variance for the growth characters

Observations	Mean square					
	Black (2)	Treatment (15)	N (3)	L (3)	NxL (9)	Error (30)
I Azolla fresh weight	0.066	1.81**	0.02	8.85**	0.06	0.06
II Plant height						
a. At ATS	84.320**	29.60**	96.70**	12.50**	12.90	8.41
b. At PIS	404.250**	13.70	-	-	-	8.56
c. At FS	531.070**	28.40	-	-	-	25.20
d. At harvest	733.250**	31.60	-	-	-	23.16
III Tiller count						
a. At ATS	3539.200**	801.810	-	-	-	586.29
b. At PIS	3134.200**	497.42	-	-	-	368.02
IV Leaf area index						
a. At ATS	0.1116	0.0268**	0.1232**	0.0016	0.0016	0.0041
b. At PIS	0.0076	0.0187*	0.4767**	0.0201	0.0156	0.0089
c. At FS	0.0093	0.2570**	1.1960**	0.0267	0.0199	0.0167

Figures in parenthesis indicate degrees of freedom

* Significant at 5% level.

** Significant at 1% level.

APPENDIX III

Abstract of analysis of variance for dry matter production, yield and yield attributes

Observations	Mean square					
	Block (2)	Treatment (15)	N (3)	L (3)	N x L (9)	Error (30)
I Dry matter production						
a. At AT.	13.31	1909.49**	7998.31**	445.64	301.18	296.62
b. At PIS	315.37	45796.19**	1.83×10^{5}**	2.67×10^{4}**	6184.97	1792.72
c. At FS	1929.81	8.47×10^{5}**	4.12×10^{6}**	1.69×10^{4}	3.35×10^{4}**	1.09×10^{4}
d. At harvest	5.58×10^{4}	1.48×10^{6}**	6.93×10^{6}**	2.74×10^{5}**	5.32×10^{4}	3.3×10^{4}
II Yield components						
a. No.of panicles per sq.m	98.93	320.87*	916.02**	589.34*	32.99	133.32
b. No.of filled grains	42.60	179.98**	799.43**	42.44	19.33	27.02
c. 1000 grain weight	1.69	3.91**	11.11**	6.16**	0.76	1.26
III Weight per panicle	0.746**	0.253*	0.526**	0.371*	0.122	0.095
IV Grain yield	1.7×10^{4}	5.28×10^{5}**	2.5×10^{6}**	9.4×10^{4}**	9980.200	9799.24
V Straw yield	1.59×10^{4}	2.49×10^{5}**	1.13×10^{6}**	6.14×10^{4}**	1.9×10[illegible]	9622.41
VI Harvest index	9×10^{-5}	0.0012**	0.0056**	0.00007	0.00003	0.00003

Figures in parenthesis indicate degrees of freedom

* Significant at 5% level.

** Significant at 1% level.

APPENDIX IV

Abstract of analysis of variance for chemical analysis of plants

	Mean square					
	Block (2)	Treatment (15)	N (3)	L (3)	NL (9)	Error (30)
I Quality characters						
a. Protein content of grain	0.303	4.66**	20.27**	1.042	0.66	0.761
b. N content of straw	0.0049	0.0586*	0.1829**	0.0454	0.0214	0.0273
II Uptake of N						
a. At ATS	1.61	6.72**	27.48**	2.89	1.07	1.16
b. At PIS	18.62	82.43**	361.58**	40.2	3.44	13.82
c. At FS	74.84	819.55**	3882.0**	184.56**	17.05	26.91
d. At harvest	23.63	499.3**	2224.4**	128.42**	48.99	25.84
III Uptake of P						
a. At ATS	0.0057	0.0241				0.0167
b. At PIS	0.2476	1.076*	3.68**	0.2695	0.4768	0.4097
c. At FS	0.6929	5.998**	24.98**	0.225	1.59*	0.7006
d. At harvest	3.48	15.43**	68.76**	0.939	2.48	2.76

Figures in parenthesis indicate degrees of freedom

* Significant at 5 % level.

** Significant at 1 % level.

APPENDIX V

Abstract of Analysis of variance for chemical Analysis of the plant

		Mean square					
		Block (2)	Treatment (15)	N (3)	L (3)	NL (9)	Error (30)
I	K uptake						
	a. At ATS	0.5328	0.526^{**}	1.45^{**}	0.0387	0.381	0.188
	b. At PIS	2.029	3.75				5.079
	c. At FS	8.295	6.85				24.7
	d. At harvest	11.366	132.33^{**}	608.94^{**}	19.18^{**}	11.18^{*}	4.15
II	Ca uptake						
	a. At ATS	6.1×10^{-4}	$8.5 \times 10^{-4**}$	$2.5 \times 10^{-3**}$	5.2×10^{-4}	3.9×10^{-4}	2.2×10^{-4}
	b. At PIS	6.8×10^{-3}	0.035				0.026
	c. At FS	0.002	0.281^{**}	1.309^{**}	0.055	0.014	0.019
	d. At harvest	0.023	0.571^{**}	2.647^{**}	0.143^{**}	0.022	0.025
III	Mg uptake						
	a. At ATS	1.8×10^{-4}	3.0×10^{-4}				2.6×10^{-4}
	b. At PIS	0.006	0.013^{**}	0.041^{**}	0.016^{**}	0.002	0.003
	c. At FS	0.005	0.239	1.064	0.083	0.017	0.023
	d. At harvest	9.0×10^{-4}	0.515^{**}	2.229^{**}	0.277^{**}	0.023	0.029

Figures in parenthesis indicate degrees of freedom

* Significant at 5% level.

** Significant at 1% level.

APPENDIX VI

Abstract of analysis of variance for soil chemical Analysis

		Mean square					
		Block (2)	Treatment (15)	N (3)	L (3)	NL (9)	Error (30)
I	pH						
	a. 7 days after planting	0.020	0.322**	0.05	1.43**	0.04	0.03
	b. 14 days after planting	0.0006	0.3035**	0.0417	1.39**	0.027	0.057
	c. at incorporation	0.0231	0.245**	0.0035	1.068**	0.051	0.0345
II	Organic carbon - After cropping	0.0046	0.0009				0.0018
III	Total Nitrogen						
	a. At ATS	2.89×10^{-5}	2.69×10^{-4}**	1.13×10^{-3}**	8.5×10^{-5}*	4.1×10^{-5}	2.26×10^{-5}
	b. At PIS	6.4×10^{-5}	3.22×10^{-4}**	1.38×10^{-3}**	1.26×10^{-4}**	3.4×10^{-5}	$2.25 \times 10^{-}$[illegible]
	c. After cropping	5.1×10^{-5}	1.61×10^{-4}**	5.9×10^{-4}**	1.1×10^{-4}**	3.29×10^{-5}	$2.33 \times 10^{-}$[illegible]
IV	Available P - after cropping	0.6418	8.887				26.05
V	Exchangeable K - After cropping	6.602	3.804				3.761
VI	Exchangeable Ca- after cropping	1.04×10^{-5}	1.33×10^{-4}**	1.18×10^{-6}	6.35×10^{-4}**	9.7×10^{-6}	$1.08 \times 10^{-}$[illegible]
VII	Exchangeable Mg - After cropping	4.03×10^{-6}	5.06×10^{-5}**	6.7×10^{-6}	2.25×10^{-4}**	7.1×10^{-6}	$5.11 \times 10^{-}$[illegible]

Figures in parenthesis indicate degrees of freedom

* Significant at 5% level.

** Significant at 1% level.

UTILISATION OF AZOLLA FOR RICE IN ACIDIC SOILS

By

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ABSTRACT OF THE THESIS

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ABSTRACT

An experiment was conducted at the Agricultural Research Station, Mannuthy, during the first crop season of 1982-'83 to examine the possibility of azolla utilisation for rice in acid soils by lime application. The treatments consisted of factorial combinations of 4 levels of N (25,50,75 and 100% of the recommended dose of 70 kg ha^{-1}) with four levels of lime (0,600,900 and 1200 kg ha^{-1}) in Randomised Block Design, replicated thrice.

The investigation revealed that liming enhanced the multiplication rate of azolla.

It was also found that the vegetative characters of rice viz. height, tiller production and leaf area index showed considerable increase with N levels. Lime at 600 kg ha^{-1} also increased plant height and tiller number. Dry matter production also showed proportionate increase with N levels and lime application at 600 kg ha^{-1} have the maximum dry matter production.

Application of 75% of the recommended dose of N and 600 kg ha^{-1} of lime was sufficient to give higher number of panicles, number of filled grains per panicle and also 1000 grain weight.

The grain yield did not increase significantly beyond 75% of the recommended dose of fertiliser N. Lime application at the rate of 600 kg ha^{-1} gave maximum grain yield.

Straw yield increased significantly with nitrogen and lime.

The uptake of all the nutrients was more at higher levels of N.

The present investigation revealed the scope of dual culturing of azolla in acidic rice soils, by supplying lime at 600 kg ha^{-1}. It also suggested a saving of 25% of the recommended dose of fertiliser N.