EFFICIENCY OF *AZOLLA* FOR WEED CONTROL IN RICE ECOSYSTEM

BY

MADHAVA CHANDRAN, K.

THESIS

Submitted in partial fulfilment of the requirement
for the degree
MASTER OF SCIENCE IN AGRICULTURE
Faculty of Agriculture
Kerala Agricultural University

Department of Agronomy

College of Agriculture

Vellayani, Trivandrum

1984

DECLARATION

I hereby declare that this thesis entitled "Efficiency of Azolla for Weed Control in Rice Ecosystem" 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.

(MADHAVA CHANDRAN, K)

Vellayani,
16th January, 1984.

CERTIFICATE

Certified that this thesis, entitled "Efficiency of Azolla for Weed Control in Rice Ecosystem" is a record of research work done independently by Shri. MADHAVA CHANDRAN, K. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship, or associateship to him.

(Dr. C. SREEDHARAN)
Chairman,
Advisory Committee,
Professor and Head,
Department of Agronomy.

Vellanikkara,
16th January, 1984.

Approved by:

Chairman:

Dr. C. Sreedharan

Members:

1. Shri.K.P. Madhavan Nair

2. Dr. G. Raveendranatha Pillai

3. Smt. Alice Abraham

ACKNOWLEDGEMENT

It gives me immense pleasure to express my deep sense of gratitude and indebtedness to Dr.C. Sreedharan, Chairman of my advisory Committee and Professor and Head of the Department of Agronomy for his constant encouragement, expert advice, patient guidance and constructive criticism throughout the course of study and preparation of the manscript.

I also express my sincere thanks to Shri.K.P. Madhavan Nair, Associate Professor of Agronomy and Dr.P.Padmaja, Project Co-ordinator, Soils and Agronomy, who have given me invaluable help and suggestions during the conduct of this investigation.

I convey my heartfelt thanks to Dr.G.Raveendranath Pillai, Professor and Head of Agronomic Research Station, Chalakudy for providing the facilities for this work at Agronomic Research Station, Chalakudy and for timely advices and constant encouragement.

My grateful thanks are due to Dr.V.K. Sasidhar, Professor of Agronomy and Dr.R.S.Aiyer, Professor of Agricultural Chemistry for the help they extended during the course of this study.

I am also thankful to Dr.George, Professor of Statistics, Mr.B. Pankajakshan Nair, M.Sc.(Ag.Stat) student and Mr.Jacob, Junior Assistant Professor Statistics for the able guidance rendered in statistical analysis.

The assistance rendered by Shri.Jose Mathew, Kuruvilla Varghese, Dr.Abraham, Dr.Balachandran and Shri.Asokan, Assistant Professors of Agronomy and Shri.P.Chandrasenan, Farm Supervisor (Agri) of Agronomic Research Station, Chalakudy are gratefully acknowledged.

Above all, I am immensely grateful to all the staff members of the Department of Agronomy and Agronomic Research Station, Chalakudy for their whole hearted co-operation and assistance extended for the successful completion of this study.

I owe a great debt to the large member of friends, whose interest and help have made by work easier.

My sincere thanks are also due to Dr.N. Sadanandan, Dean, Faculty of Agriculture for providing all the facilities and the Kerala Agricultural University for awarding me a research fellowship.

(MADHAVA CHANDRAN, K)

CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

INTRODUCTION

INTRODUCTION

Azolla, the fresh water fern capable of fixing atmospheric nitrogen through associative symbiosis with the Blue green alga _Anabaena azollae_ has drawn considerable attention on a global scale as a potent source of organic nitrogen. Azolla can also be used as a substitute for costly inorganic nitrogenous fertilizers in rice culture. Besides a slow and steady availability of nitrogen is also ensured in rice-azolla ecosystem. This is particularly important in sandy soils where leaching losses are high. In addition to the organic nitrogen contribution through azolla it has also been reported to be an effective suppressor of weed growth in rice fields due to the thick mat-like covering it forms on the water surface.

Indian agriculture is plagued with the problems of diseases, insects and weed infestation. The estimated loss to Indian agriculture due to weeds alone works out to around Rs.4,200 million (Mehta and Joshi, 1965). The reduction in rice yield due to weeds is to the tune of 15-20 per cent in transplanted rice (Gopalakrishna Pillai and Rao, 1974). They further observed that the potential loss in production of rice in India due to weed infestation was 15 million tonnes amounting to 28 per cent of annual rice production.

The decrease in production is drastic when weed infestation is severe, especially during the critical stages of crop-weed competition. Several weed control methods such as manual weeding, mechanical weeding, chemical method, cropping and competition method etc.are available. However the mechanical and chemical methods do not justidy their adoption by an average rice farmer due to the high cost and pollution problems involved. Manual weeding also is not advisable due to the exorbitant wage rates, especially in Kerala, and the unavailability of labour during peak periods. This leaves the possibility of utilizing the cropping and competition method of weed control. However this method has not been widely used till now, particularly in rice.

Under these circumstances, dual culturing of azolla as a cropping and competition method of weed control offers considerable scope. It will definitely be cheaper than other traditional weed control methods since the benefits from nitrogen fixation also could be profitably utilised in rice culture.

Since no such investigation has been taken up so far in Kerala, the present study to assess the efficiency of azolla for weed control in rice ecosystem is undertaken with the following objectives:-

(1) To fix an optimum rate of inoculation of azolla that would help to check weeds in rice.

(2) To find out a suitable weeding practice, in combination with a particular rate of inoculation of azolla for rice in sandy soils.

(3) To study the combined effect of azolla and weed control on the growth and yield of rice.

(4) To assess the economy of dual culturing azolla in controlling weed growth.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Azolla, the fresh water fern, capable of associative symbiosis with Blue green Algae *Anabaena azollae* is known for its nitrogen fixing ability. Apart from soil fertility improvement the fern also helps to smother the weeds of paddy fields. Since this programme was to study the weed control efficiency of azolla in rice fields, the available information on the weed problems of rice, soil fertility contribution and weed control efficiency of azolla are reviewed below.

1. *Weed spectrum in Rice Fields*

Rice fields host a variety of weeds and it varies from location to location mainly because of ecological differences.

Chang (1969) reported that *Manochoria vaginalis*, *Marsilea quadrifolia*, *Eclipta* Species, *cyperus difformis*, *cyperus iria*, *Echinochloa crus-galli* and *Paspalam* spp. were the predominant weeds in the paddy fields of Taiwan. The common weeds found in the wet lands of Kerala were *Echinochloa colonum*, *Fimbristylis miliacea* and *cyperus rotundus* (Pillai and Rao, 1974).

Nair et al. (1975) reported that the important weeds at the Rice Research Station, Pattambi, were *Echinochloa* *crus-galli*, *Brachiaria* spp., *Cleome* spp. and *Fimbristylis miliacea*. In the Kayal lands of Vellayani, Kerala, *Echinochloa* spp., *Cyperus* spp., *Fimbristylis miliacea*, *Monochoria vaginalis* etc. were the common weeds (Raveendran, 1976; Abraham Varghese, 1978; Sukumari, 1982).

Neogi et al. (1980) concluded that dicot weeds of rice were more in number of species, but lower in density than monocots.

Generally monocot weeds of rice were found to be more frequently occuring than dicots, particularly under submerged conditions where grassy weeds and sedges formed a major component of the weed population.

2. Crop-weed competition

2.1. Critical periods of crop-weed competition

It is not economical to keep the field weed-free by frequent weeding. As an alternative controlling the weeds at the most critical periods of crop growth had been suggested.

Shetty and Gill (1974) observed that the most critical period of crop-weed competition in transplanted rice was between 4-6 weeks after transplanting. Bhan et al. (1975) reported that an initial weed-free period of 45 days should be maintained for higher rice grain yield.

Maximum weed competition in rice was observed during the first 3 weeks and competition decreased between 3 and 6 weeks (Dubey et al., 1977). Abraham Varghese (1978) reported 11 to 40 days after transplanting as the critical period of weed infestation in transplanted rice. Reports from Tamil Nadu show that a weed-free period upto 50 days during monsoon season was required for higher yield in puddled rice (Mohammed Ali and Sankaran, 1979).

According to Burga et al. (1980) the critical period of weed infestation in rice ranged from 30 to 50 days after emergence of rice. Pillai (1981) observed that weed control for the first 6-8 weeks after sowing of rice was critical.

It is evident that weed control during 3 to 6 weeks after planting is more critical in the case of rice.

2.2. Removal of nutrients by weeds

Subba Rao (1966) observed that competition between weed and crop was mainly for nutrients than for light and moisture. Swain (1967) reported that barnyard grass in rice fields removed 60-80 per cent nitrogen from the soil. Mallappa (1973) observed an inverse relationship between N uptake of rice and weed growth.

Shetty and Gill (1974) reported that competition for nutrients between weeds and crops was maximum during the early period of growth and competition for soil nitrogen was maximum during 6-8 weeks after rice transplanting. They also observed that weeds were more efficient in nitrogen uptake than the crop.

Raveendran (1976) concluded that nitrogen uptake by weeds was negatively correlated with nitrogen uptake by the crop. Abraham Varghese (1978) reported that the maximum uptake of nutrients by rice was during the critical periods of 31-40 days after planting rice.

Weeds are thus found to have severe competition for nutrients with the rice crop, particularly for nitrogen. The period of maximum nutrient uptake of rice falls during the critical period of crop-weed competition of the crop.

2.3. Competition for light and space

King (1966) reported that the growth rate of some weeds enabled them to suppress the growth of crops and finally overcrowd them altogether. Arai (1967) observed that competition for light began by 20 days after transplanting rice and depended largely on the early growth rate and size of weeds.

The highest density of barnyard grass produced 70 per cent reduction in light intensity in rice, according to Smith (1968). He also observed a clear shading of rice by barnyard grass during the growing season.

In short, competition for nutrients, light and space due to weed infestation lead to yield reduction of the concerned crop.

2.4. Effects of weed competition on yield attributes

Swain (1967) reported that reduction in tiller number of rice due to barnyard grass infestation was of the order of 45 per cent. According to Kleing and Noble (1968), there was reduction in the number of rice tillers, panicles and spikelets per panicle due to *Echinochloa* competition. Barnyard grass competition at tillering stage reduced the number of panicles and yield of rough rice and competition at later stages reduced kernel weight and number of kernels (Noda et al., 1971).

Shetty and Gill (1974) observed that weed competition did not affect plant height and number of tillers in transplanted rice, but the panicle length was reduced. Raveendran (1976) and Abraham Varghese (1978) noticed a reduction in effective tillers/m^2, percentage of productive tillers and weight per panicle due to weed competition.

There was 95 per cent yield reduction in rice when weed competition occured throughout the growth cycle

(Burga et al., 1980). They further observed that yield reduction was mainly due to lesser number of panicles/m^2 and spikelets/panicle.

Thus the important yield components found to be affected by weed competition were panicle number, weight, and number of filled grains/panicle.

2.5. Effect on yield and quality

Park and Kim (1971) reported reduction in rice yields by 48 per cent in plots with a mixed weed flora. Bhan and Maurya (1972) observed that even a low weed population reduced rice yields in unweeded control when compared to weed-free plot.

According to Pillai and Rao (1974), yield reduction in transplanted rice due to weeds was 15-20 per cent. Raveendran (1976) noticed about 25 per cent yield reduction in transplanted rice due to weeds, compared to hand weeding. Reduction in grain yield due to whole season weed competition was 26.91 per cent compared to a weed-free period of 1-60 days of transplanting (Abraham Varghese, 1978).

Gomaz and Datta (1975) observed that one of the major sources of varition in protein content of rice was weed control. Raveendran (1976) reported that controlling weeds by penoxalin (G) and hand weeding gave the highest protein content as compared to unweeded control.

Weed infestation was found to have a profound influence on rice yield, and on an average 20-25 per cent yield reduction was reported. The quality characteristics of the grain, mainly the protein content was affected due to weed competition.

3. <u>Nutrient uptake by weeds</u>

Sankaran et al. (1974) reported that the total uptake of nutrients by the crop and weeds together in unweeded plot was less than the uptake by the crop alone in weed-free treatments. Mani (1975) observed that rice weeds assimilated substantial quantity of nitrogen within 5-6 weeks of sowing. They observed that rice weeds removed 20.7, 9.5 and 17.5 kg/ha of N, P_2O_5 and K_2O respectively.

Raveendran (1976) noticed that when weed growth was unchecked, soil nitrogen was depleted to the extent of 20.86 kg/ha. Abraham Varghese (1978) noticed that nutrient removal in weedy check was 23.97, 7.92, 30.48 kg/ha of N, P_2O_5 and K_2O respectively by weeds.

Weed control is thus an important aspect as far as the crop is concerned, since the availability of nutrients to the crop is very much reduced in the presence of weeds. The main nutrient for which the crop may become deficient due to weed competition is found to be nitrogen.

4. Weed control by Azolla in Rice Fields

The ability of a thick, light-proof azolla mat to suppress weed development had been suggested by Bramer as early as 1927. He also observed that the benefits from weed suppression surpassed the benefits from N fixation.

Nguyen (1930) observed that a thick azolla mat caused the death of weeds like *Utricularia flexuosa*, *Echinochloa crus-galli* and *Sagittaria* sp. Fosberg (1942) found that a thick covering of Azolla filiculoides on the surface of water effectively prevents most other weeds from growing.

Shen et al. (1963) reported from China that a strain of *Azolla pinnata* was a valuable suppressor of weeds. Olsen (1972) opinioned that *Azolla caroliniana* successfully displaced the weed *Lemna* sp. on danish lakes, but could not survive the cold winter. Ngo (1973) observed suppressive effect of different *Azolla pinnata* mat densities on the quantity of *Echinochloa crus-galli* found in a paddy field. It was also observed that after a period of 6 weeks, the 50 per cent azolla-covered plot had 70 per cent fewer *Echinochloa crus-galli* than the control.

Watanabe (1977) in their work at IRRI reported that growth of weeds during the early stages of rice crop can be checked by the quick growth and spread of azolla on the surface. Talley et al. (1977) found that early development of a thick mat of Azolla filiculoides successfully suppressed cyperus difformis, Echinochloa crus-galli and Polygonium sp. Singh (1977 a) invariably noticed that Angiospermic weeds were less in the presence of azolla in rice fields.

5. Effect of Environmental Factors on weed growth.

Jean and John (1976) observed that light intensity underneath dense mats of water hyacinth was low enough to inhibit the growth of algae and other submerged aquatics. Eussen (1978) reported that an 80 per cent reduction in day-light intensity resulted in about 50 per cent decrease in the mean relative growth rate of weeds. Mclaren and Smith (1978) showed that both quantity and quality of light contributed to the growth and development of weeds.

Bowes et al. (1979) reported that the presence of floating mats of Hydrilla verticillata substantially altered the local aquatic weed environment. High levels of oxygen, pH and temperature in the mat surface water and low light penetration due to the formation of mats produced unfavourable conditions for weed growth.

Thus environmental factors such as light and Co_2 availability under a thick mat of azolla will have some effect on weed control in rice fields.

6. Dual culturing of Azolla

Dual culturing is the method of growing azolla along with rice under wet land conditions. Dual culturing of azolla in rice fields has been proved to be beneficial in many ways such as weed control, yield increase etc.

6.1. Rate of azolla inoculation

A field inoculation rate of 1.25 kg fresh azolla per 25 square metre was used for dual culturing immediately after transplanting at IRRI (Anon., 1976). According to Govindarajan et al. (1979) an inoculation rate of 0.3 kg/m^2 7 days after transplanting gave complete coverage of azolla within two weeks.

Singh (1979 a,b) reported an increase in rice yield when azolla was grown simultaneously with the rice crop, using an inoculation rate of 0.1 kg/m^2. He obtained full coverage in 20-30 days. Mathur et al. (1981) reported rice yields equivalent to 25 kg N/ha when azolla was inoculated at the rate of 0.3 kg/m^2 a week after transplanting.

According to Srinivasan (1981 b), a minimum of one tonne seed material/ha was necessary for dual culturing azolla. He also observed weed control effect by dual culturing of azolla in rice fields. Behra (1982) reported 20 per cent yield increase by azolla inoculation at 1 tonne/ha 5 days after planting. Kannaiyan et al. (1982) obtained yield equivalent to 20 kg fertilizer N/ha by azolla inoculation at 0.3 kg/m^2 one week after transplanting. Singh et al. (1982) reported that floating azolla controlled weeds.

6.2. Effect of dual culturing Azolla on rice yield

Kulasooriya and de Silva (1977) reported higher grain yield by culturing of azolla than applying 80 kg/ha of urea. Singh (1977 c and 1979 b) observed better growth, early flowering and increased grain yield by dual culturing of azolla. Talley et al. (1977) found increased rice yield upto 23 per cent by dual culturing *Azolla filiculoides* and upto 67 per cent by *Azolla mexicana* in U.S.A.

Liu (1979) recorded green azolla productionto the extent of 15-22 tonnes/ha by dual culturing of azolla in rice, which was equivalent to 37-45 kg N/ha. Arunachalam (1980) reported that basal incorporation of azolla produced the same effect as dual culturing on rice yield.

Watanabe et al. (1980 and 1981) observed fast growth of azolla in the early stages of rice growth and a decline in later stages due to shading. Singh et al. (1982) reported that basal dressing of azolla, followed by dual culturing during one crop season produced grain yield comparable to 60 kg N/ha as inorganic fertilizer.

6.3. Effect of Azolla on N economy

Utilisation of azolla is one of the important techniques for trapping the atmospheric N and making available for the rice crop. Saubert (1949) showed that as much as 313 kg N/ha/yr could be obtained through azolla cultivation. Moore (1969) reported that 100-160 kg N/ha could be assimilated by azolla over a period of 3 to 4 months.

At IRRI, 22 crops of azolla harvested during 335 days with a dry weight of 8 tonnes supplied 465 kg N/ha and this was more or less comparable to the N fixed by a forage legume (Anon, 1978 b; Watanabe et al., 1980). Singh (1979 a) reported that at CRRI, Cuttack, an annual production of 331 tonnes of green material containing 840 kg N/ha/yr could be made available in rice cultivation.

6.4. N economy through dual culturing

Watanabe (1977) reported that azolla was a self-supplying N fertilizer source for rice farmers and he recommended azolla dual culturing with P at the time of transplanting.

Rains and Talley (1978) observed yield response equivalent to 90 kg N/ha by simultaneous basal incorporation of *Azolla filiculoides* with dual culturing of *Azolla mexicana*. This substituted a major portion of the N requirement of paddy.

Liu (1979) reported a saving of 37-45 kg N/ha by dual culturing, followed by incorporation after 15-20 days. Govindarajan et al. (1979) could save 25 kg N/ha by azolla inoculation at the rate of 0.3 kg/m^2 seven days after transplanting and incorporating it on the 22nd day. The same results were also obtained by Mathur et al. (1981); Srinivasan (1981 a) and Mathew Kutty (1983).

Anon. (1980) concluded that dual culturing of azolla in wide double row spacing of rice led to an accumulation of about 70 kg N/ha. Patil et al. (1980) from multilocational trials reported that inoculation of 1 tonne/ha of azolla at planting followed by incorporation at 20 days later, economised 30 kg fertilizer N/ha.

Inoculation of azolla for dual culture during the 36 days before and after transplanting rice supplied 119.7 kg N/ha in total (Lizhuo-xin, 1982). Singh et al. (1982) obtained a saving of 30 kg N/ha by dual culturing azolla alone. They also observed an economy of 60 kg N/ha by basal incorporation and dual culturing. Similar results were obtained by Mathew Kutty (1983).

MATERIALS AND METHODS

MATERIALS AND METHODS

An investigation was carried out to study the 'Efficiency of azolla for weed control in Rice ecosystem' during the Kharif season (First crop) of 1982. The materials used and methods adopted are detailed below:-

1. Location of the experiment

The experiment was laid out at the Agronomic Research Station, under Kerala Agricultural University, Chalakudy in Trichur district, Kerala.

The Research Station is situated at 10°, 20′ North and 76°, 20′ East latitude and at an altitude of 3.25 metres above mean sea level.

1.1. Soil

Data on the physical and chemical properties of the soil where the trial was carried out are given in Table 1.

2. Cropping history of the field

The experiment site was under a bulk crop of rice for the previous two seasons.

3. Season

The experiment was laid out during the first crop season (Kharif) of 1982-'83. The crop was transplanted on 19-7-1982 and harvested on 5-11-1982.

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

A. <u>Physical properties</u>	
1. Mechanical composition	
Coarse sand	- 60.3 per cent
Fine sand	- 18.3 per cent
Silt	- 8.8 per cent
Clay	- 12.4 per cent
2. Bulk density	- 1.46 (g/cc)
3. Field capacity	- 16.7 per cent
4. Infiltration rate	- 0.8 mm/hr
B. <u>Chemical properties</u>	
(1) Total nitrogen	- 0.0253 per cent
(2) Available Phosphorus	- 25.576 ppm
(3) Exchangeable Potassium	- 26 ppm
(4) pH	- 5.7

4. Weather conditions during the cropping period

Data on weather parameters are presented in Appendix I.

5. Treatment details

The experiment consisted of combinations of 6 levels of azolla inoculation in the main plot and 4 levels of methods of weed control in the sub plot as detailed below.

5.1. Main plot treatments

A0 - no azolla inoculation

A1 - azolla inoculation @ 0.1 kg/m^2 at the time of transplanting paddy.

A2 - azolla inoculation @ 0.2 kg/m^2 at the time of transplanting paddy.

A3 - azolla inoculation @ 0.3 kg/m^2 at the time of transplanting paddy.

A4 - azolla inoculation @ 0.4 kg/m^2 at the time of transplanting paddy.

A5 - azolla inoculation @ 0.5 kg/m^2 at the time of transplanting paddy.

5.2. Sub plot treatments

W0 - Unweeded control.

W1 - Complete weed control.

W2 - Handweeding 15 days after planting.

W3 - Handweeding 15 and 30 days after planting.

These notations will be used in the results and discussion.

6. Design and layout

The experiment was laid out in a split plot design with 3 replications. The layout plan of the experiment is given in Fig.1.

7. Variety

The variety Jaya was used for investigation. It is a medium duration (120-125) days photo-insensitive variety released from All India Co-ordinated Rice Improvement Project, Hyderabad.

8. Plot size

The gross plot size was 20.25 m^2 (5 m x 4.05 m) with a net plot size of 11.88 m^2 (3.3 m x 3.6 m). A sampling area of 4.05 m^2 (4.05 m x 1 m) was left as a strip to facilitate weed sampling. Destructive sampling of the crop was also done from this sampling area. Two rows of plants were left as border rows all around the plot.

FIG - 1 LAY OUT PLAN OF THE EXPERIMENT IN SPLIT PLOT DESIGN

REPLICATION - I

A_0W_2	A_2W_3	A_5W_1	A_1W_0	A_3W_2	A_4W_1
A_0W_0	A_2W_2	A_5W_3	A_1W_1	A_3W_0	A_4W_3
A_0W_1	A_2W_1	A_5W_2	A_1W_3	A_3W_1	A_4W_2
A_0W_3	A_2W_0	A_5W_0	A_1W_2	A_3W_3	A_4W_0

TREATMENTS:

MAIN PLOT - RATE OF AZOLLA INOCULATION

A_0 - NO AZOLLA
A_1 - 0.1 Kg/m^2.
A_2 - 0.2 Kg/m^2
A_3 - 0.3 Kg/m^2.
A_4 - 0.4 Kg/m^2
A_5 - 0.5 Kg/m^2.

SUB PLOT - WEEDING

W_0 - UNWEEDED CONDITION
W_1 - COMPLETE WEED CONTROL
W_2 - HAND WEEDING 15 D.A.P.
W_3 - HAND WEEDING 15 AND 30 D.A.P.

A_3W_1	A_1W_0	A_2W_0	A_5W_2	A_0W_3	A_4W_3
A_3W_3	A_1W_3	A_2W_1	A_5W_0	A_0W_1	A_4W_2
A_3W_2	A_1W_2	A_2W_3	A_5W_1	A_0W_0	A_4W_0
A_3W_0	A_1W_1	A_2W_2	A_5W_3	A_0W_2	A_4W_1

REPLICATION - II

A_4W_3	A_4W_1	A_4W_0	A_4W_2
A_0W_0	A_0W_1	A_0W_2	A_0W_3
A_5W_0	A_5W_3	A_5W_1	A_5W_2
A_1W_0	A_1W_3	A_1W_1	A_1W_2
A_2W_2	A_2W_0	A_2W_1	A_2W_3
A_3W_1	A_3W_3	A_3W_2	A_3W_0

REPLICATION - III

9. <u>Spacing</u>

The spacing adopted was 20 cm in between rows and 15 cm within the rows.

10. <u>Details of field operations</u>

The package of practices of Kerala Agricultural University for cultivation of rice (Anon., 1978 a) was followed.

The main field was ploughed, puddled and levelled. 20 day old seedlings of uniform growth were planted at the rate of 2 seedlings per hill on 19-7-1982. Gap filling was done on the seventh day of transplanting.

A 5 cm continuous submergence was maintained in the field from the date of planting upto 10 days before harvest. Bamboo tubes fitted with wire mesh at one end were used to avoid the loss of dual cultured azolla and to drain the water when required.

10.1. <u>Application of fertilizers and lime</u>

A uniform per hectare dose of 90 kg N as urea, 45 kg P_2O_5 as single superphosphate and 45 kg K_2O as Muriate of Potash was applied. Half the dose of N and K and full dose of P were applied as basal dose and the remaining half of N and K as top dressing at panicle initiation stage.

Lime was applied to all the plots in two splits, viz., 350 kg/ha as basal one week before transplanting and 250 kg/ha 30 days after planting.

10.2. Application of azolla

Azolla pinnata was used for dual culturing with rice. It contained 92.3 per cent moisture, and on dry weight basis it accounted to 3.10 per cent total nitrogen, 0.48 per cent total Phosphorus and 1.63 per cent total Potassium. Azolla was multiplied in plots of uniform fertility outside the experimental area. Inoculation of fresh azolla as per treatments was done on the very next day after transplanting rice for the purpose of dual culturing.

10.3. Weeding

Hand weeding was done for the plots as per the weeding treatments.

10.4. Plant protection

Carbaryl 0.2 per cent was sprayed 20 and 40 days after planting for the control of case worm and leaf roller.

10.5. Harvest

The crop was harvested after a period of 129 days from the date of sowing.

11. Observations recorded

11.1. Observations on the crop

11.1.a. Growth characters

Periodic observations were recorded on randomly selected 3 sample units of two hills x two hills in each plot as suggested by Gomaz (1972).

11.1.a.1. Height of the plant

Height of the plant was recorded from the base of the plant to the tip of the top most fully opened leaf at maximum tillering and panicle initiation stages and from the base to the tip of tallest panicle at harvest.

11.1.a.2. Number of tillers

Total number of tillers of all the 12 hills at maximum tillering stage was recorded and expressed as tillers per m^2. Total number of panicle bearing tillers at harvest was also recorded and expressed as panicles/m^2.

11.1.a.3. Leaf area index

Leaf area index was calculated by adopting the method suggested by Gomaz (1972). Four sample hills were uprooted from the destructive row earmarked for the same and leaves were removed from plants for measuring leaf area. Leaf area index was computed using the constant 0.75 at maximum tillering and panicle initiation stages.

11.1.b. Yield attributes and yield

11.1.b.1. Number of panicles/m^2

Total number of panicles from the 12 hills selected were counted and number of panicles/m^2 was computed.

11.1.b.2. Number of filled grains/panicle

The main culm (centre) panicle from all the 12 hills were threshed and number of filled grains (f) and weight of filled grains (w) were determined.

The rest of the panicles from all the 12 hills were also threshed and weight of filled grains (W) was assessed.

From these data number of filled grains/panicle was calculated using the formula given below (Gomaz, 1972).

Number of filled grains/panicle = $\frac{f}{w} \times \frac{(W + w)}{p}$ where p is the total number of panicles from all the 12 hills.

11.1.b.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 per cent moisture using the formula given by Gomaz (1972).

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

where M is the moisture content of filled grains.

11.1.b.4. <u>Grain yield</u>

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

11.1.b.5. <u>Straw yield</u>

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

11.1.c. <u>Harvest index</u>

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

11.2. <u>Observations on weeds</u>

The weed species growing before and during the experiment in the field were collected and identified.

11.2.a. <u>Dry matter production of weeds</u>

Three weed samplings were done in all plots from an area of 0.5 m^2 in the sampling area at an interval of 15 days from the date of transplanting and the final weed sampling was done at harvest in the same manner. The weeds from 0.5 m^2 area were dried in an hot air oven and weight noted.

11.2.b. <u>Weed index</u>

Weed index denotes the reduction in yield due to the presence of weeds, in comparison with the plot with no weeds (complete weed control).

Weed index was calculated using the formula suggested by Gill and Vijayakumar (1969).

$$W1 = \frac{(x-y)}{y} \times 100$$

W1 = Weed index

x = Grain yield from weed free plot.

y = Grain yield from the plot (treatment) for which index is calculated.

12. <u>Chemical studies</u>

12.1. <u>Uptake of N, P and K by crop and weeds at harvest</u>

The grain samples, straw samples and weed samples at harvest were oven dried, ground in a wiley Mill and was analysed for N, P and K and their uptake worked out by multiplying with the respective dry weights. Crop uptake of N, P and K at harvest was expressed as the sum total of grain and straw uptake. The plant analysis for N, P and K was done as detailed below.

12.1.a. <u>Total nitrogen</u>

Total nitrogen was analysed by adopting the Microkjeldahl digestion method as suggested by Jackson (1967).

12.1.b. Total phosphorus

Phosphorus concentration of the plant sample was estimated in triple acid (9:2:1 of HNO_3, H_2SO_4 and $HClO_4$ respectively) extract of the sample by developing Vanadomolybdophosphoric acid yellow colour (Jackson, 1967). The intensity of colour developed was measured using Klett-Summerson photoelectric colorimeter.

12.1.c. Total potassium

Total potassium concentration was assessed in triple acid extraction using EEL Flame Photometer.

12.2. Crude protein content of grain

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

13. Soil analysis

Soil samples were drawn from the field prior to planting and immediately after harvest and dried in the shade and processed before analysing.

13.1. Total N

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

13.2. Available P

Available Phosphorus was estimated by extracting with Bray No.1 solution and thereafter developing chloro-molybdic acid blue colour and reading on Klett-Summerson Photoelectric colorimeter (Jackson, 1967).

13.3. Available K

Available Potassium was leached with one normal neutral ammonium acetate solution and estimated using EEL Flame Photometer.

14. Statistical analysis

Statistical analysis was done using the analysis of variance technique for Split Plot Design as described by Panse and Sukhatme (1978).

RESULTS

RESULTS

The observations recorded were statistically analysed. Results obtained are presented below with mean values in Tables 2 to 28 and the analysis of variance in Appendices II to VI.

I. Observations on Crop

1.1. Growth and Growth characters

1.1.a. Height of plants

Data on mean height of plants at maximum tillering panicle initiation and harvest stages are presented in Tables 2, 3 and 4 and analysis of variance in Appendix II.

Results revealed that at any of these stages plant hieght was not significantly influenced by the various treatments or their interaction. However it was observed that among the azolla applied treatments A5 recorded the maximum height at all stages and A0 the lowest. It was also seen that unweeded control recorded the lowest height and the differences between othe weed control treatments were negligible.

1.1.b. Number of tillers

Data on mean tiller count at maximum tillering stage is given in Table 5 and analysis of variance in Appendix II.

Table 2. Height of plants (cm) at maximum tillering stage.

	W0	W1	W2	W3	Mean
A0	43.55	45.22	44.65	44.21	44.41
A1	47.22	47.44	48.87	49.21	48.19
A2	44.77	46.11	44.87	45.77	45.38
A3	48.87	47.67	47.75	48.20	48.13
A4	46.11	45.21	46.77	46.99	46.27
A5	49.10	49.82	46.87	49.97	48.94
Mean	46.60	46.92	46.63	47.39	

A - N.S.   AxW - N.S.
W - N.S.

Table 3. Height of plants (cm) at Panicle initiation stage.

	W0	W1	W2	W3	Mean
A0	52.99	56.77	53.66	51.11	53.63
A1	55.87	58.99	58.22	58.77	57.96
A2	53.65	54.54	55.78	54.55	54.63
A3	53.75	53.20	58.55	58.55	56.01
A4	53.11	56.89	57.33	53.55	55.22
A5	56.99	58.78	58.99	59.91	58.67
Mean	54.39	56.53	57.09	56.08	

A - N.S.   AxW - N.S.
W - N.S.

Table 4. Height of plants (cm) at harvest.

	W0	W1	W2	W3	Mean
A0	59.67	67.37	64.17	59.87	62.77
A1	60.20	65.40	64.70	66.67	64.24
A2	65.43	63.87	60.47	65.17	63.74
A3	63.07	61.83	67.43	62.63	63.74
A4	63.40	64.73	64.37	64.40	64.23
A5	61.57	68.73	61.47	69.90	65.42
Mean	62.22	65.32	63.77	64.77	

A - N.S. AxW - N.S.
W - N.S.

Table 5. Tiller count (No./m^2) at maximum tillering stage.

	W0	W1	W2	W3	Mean
A0	191.78	236.89	195.55	229.11	213.33
A1	244.44	266.44	240.22	217.78	242.22
A2	233.33	217.77	262.22	236.66	237.44
A3	250.66	243.33	277.33	247.77	254.77
A4	236.88	263.44	221.99	252.44	243.44
A5	288.44	240.66	259.77	296.22	271.27
Mean	240.92	244.59	242.84	246.67	

A - N.S. AxW - N.S.
W - N.S.

Tiller count at maximum tillering stage was not significantly influenced by the treatments or interactions. However, among the weed control treatments W0 recorded the lowest tiller count. It may be further seen that the magnitude of differences between weed control treatments were not much when compared to that between azolla treatments with respect to tiller count.

1.1.c. Leaf area index (LAI)

Mean values of leaf area index at maximum tillering and panicle initiation stages are presented in Tables 6 and 7 and analysis of variance in Appendix II.

It can be seen that at both stages, Leaf area index, eventhough not significant, showed a definite trend with respect to azolla application. Treatment A5 gave a higher LAI at both the stages. The increase in LAI due to an increase in the rate of azolla inoculation was more marked at panicle initiation stage than at maximum tillering stage. Among the weed control treatments W1 recorded the maximum LAI at both stages.

1.2. Post harvest observations

1.2.a. Yield components

Data on yield components such as number of panicles/m^2 number of filled grains/panicle and 1000 grain weight are presented in Tables 8, 9 and 10 and analysis of variance in Appendix III.

Table 6. Leaf area index at maximum tillering stage.

	W0	W1	W2	W3	Mean
A0	0.4315	0.3866	0.3833	0.3016	0.3758
A1	0.4188	0.3626	0.3150	0.4483	0.3862
A2	0.4088	0.4318	0.4407	0.5152	0.4435
A3	0.4710	0.4589	0.4900	0.4320	0.4630
A4	0.3663	0.5999	0.5015	0.4062	0.4685
A5	0.4610	0.4995	0.4297	0.5591	0.4873
Mean	0.4262	0.4566	0.4272	0.4437	

A - N.S. AxW - N.S.
W - N.S.

Table 7. Leaf area index at panicle initiation stage.

	W0	W1	W2	W3	Mean
A0	0.5212	0.7217	0.7359	0.5665	0.6363
A1	0.6179	0.6310	0.6863	0.6324	0.6419
A2	0.6673	0.6248	0.7294	0.7575	0.6947
A3	0.6024	0.7995	0.7465	0.7636	0.7155
A4	0.7168	0.7712	0.7001	0.7413	0.7323
A5	0.7194	0.9102	0.6004	0.8387	0.7672
Mean	0.6408	0.7347	0.6998	0.7166	

A - N.S. AxW - N.S.
W - N.S.

Table 8. Number of panicles/m^2.

	W0	W1	W2	W3	Mean
A0	196.67	247.78	198.55	202.22	211.31
A1	211.11	241.11	208.88	253.33	228.61
A2	213.33	214.44	253.33	222.22	229.83
A3	232.22	239.99	272.22	224.44	242.22
A4	254.44	284.44	211.11	245.55	248.89
A5	264.44	289.99	231.11	246.66	258.05
Mean	228.70	252.96	229.20	232.40	

A - N.S. C.D. (0.05) AxW - (71.53)

W - N.S.

Table 9. Number of filled grains/panicle.

	W0	W1	W2	W3	Mean
A0	32.00	32.60	43.60	37.30	36.38
A1	35.30	38.60	35.80	37.30	36.75
A2	32.90	40.80	33.90	40.40	37.00
A3	37.70	36.10	42.90	37.00	38.43
A4	34.80	47.90	46.20	41.20	42.53
A5	36.80	52.40	44.80	41.90	43.98
Mean	34.92	41.40	41.20	39.18	

A - N.S. AxW - N.S.

W - N.S.

1.2.a.1. Number of panicles/m^2

Data showed that only the interaction between azolla and different weed control treatments were significant with regard to the number of panicles/m^2. However a clear trend was seen in the case of azolla levels, though not statistically significant. Azolla treatments gave a progressive increase in panicle number from A0 to A5 with regard to the weed control treatments W1 recorded the maximum number of panicles/m^2. All other treatments gave more or less the same panicle number. The interaction effects followed almost the same pattern of main effects. Interaction effects A5W1 and A4W1 gave significantly higher panicle number than many other combinations. A0W0 recorded the lowest number of panicles/m^2.

1.2.a.2. Number of filled grains/panicle

Number of filled grains/panicle was seen to be influenced by azolla as well as weed control treatments, though not statistically significant. There was a steady increase in the number of filled grains/panicle from azolla treatments A0 to A5. With regard to weed control treatments, W1 recorded the maximum value and W0 the minimum value. W1 and W2 showed nearly equal values, followed by W3. The interaction effect also was not significant.

1.2.a.3. 1000 grain weight

Results showed that there was significant variation among the weed control treatments with respect to 1000 grain weight. The maximum weight was recorded by W1. Azolla application also gave a definite trend, though not statistically significant. Maximum 1000 grain weight was recorded by A5.

1.2.b. Yield

1.2.b.1. Yield of grain

Mean grain yield data are presented in Table 11 and analysis of variance in Appendix III.

Results showed that there was significant difference between azolla treatments as well as weed control treatments with respect to grain yield. However the interaction was not significant. Among the azolla treatments, the highest yield was obtained at A5 and the lowest at A0 level. Treatments A3 and A5 were on par and gave significantly higher yield than A0. It was also seen that the treatment A5 was significantly superior to A1.

As far as weed control treatments are concerned W1 recorded the highest grain yield and was significantly superior to all other treatments. Treatments W2 and W3 recorded significantly higher yield than W0 which recorded

Table 10. 1000 grain weight (g).

	W0	W1	W2	W3	Mean
A0	20.10	22.18	23.43	20.13	21.46
A1	20.93	26.66	23.12	22.55	23.32
A2	23.72	24.26	25.69	21.85	23.88
A3	26.55	24.25	21.91	23.30	24.00
A4	25.36	26.46	24.35	23.25	24.86
A5	20.84	29.19	23.85	25.77	24.92
Mean	22.92	25.50	23.73	23.81	

A - N.S. AxW - N.S.

C.D. (0.05) W - (1.08)

Table 11. Grain yield (kg/ha).

	W0	W1	W2	W3	Mean
A0	2026.44	3251.55	2693.61	2130.33	2525.47
A1	2214.50	3688.22	2788.22	2422.73	2778.42
A2	2476.20	3394.86	2255.64	2568.93	2673.91
A3	2286.97	3701.20	2818.30	2950.88	2939.34
A4	2255.64	3668.93	2652.47	2768.01	2836.26
A5	2787.60	3606.27	2694.24	3147.56	3058.92
Mean	2341.22	3551.83	2650.41	2664.74	

C.D. (0.05) A - (208.20)

C.D. (0.05) W - (197.62)

AxW - N.S.

the lowest grain yield. Among the treatments W2 and W3, the latter one gave numerically higher yield, though not significant.

1.2.6.2. Yield of straw

Mean straw yield data are presented in Table 12 and analysis of variance in Appendix III.

Results showed that the difference between azolla treatments was not significant with respect to straw yield. However an increase in straw yield was noticed along with the increase in the levels of azolla inoculation. A5 recorded the maximum straw yield. Among the weed control treatments, the highest straw yield was recorded by A1, which was significantly superior to W0 and W2. It was also observed that W3 was significantly higher than W2. Treatment W0 gave the lowest straw yield. The interaction effect was however not significant.

1.2.c. Harvest index

Mean harvest indices are given in Table 13 and analysis of variance in Appendix III.

The data revealed that there was no significant difference between the treatments and the interaction effects with respect to harvest index. However maximum harvest index was obtained by the azolla treatment A0 and

Table 12. Straw yield (kg/ha).

	W0	W1	W2	W3	Mean
A0	1566.42	3240.43	1879.70	2819.55	2376.54
A1	3550.54	3587.26	3383.45	3132.83	3413.52
A2	3362.57	3482.83	3801.17	3929.55	3644.03
A3	2715.12	4492.73	3654.97	3550.54	3603.34
A4	1775.26	3359.23	2819.55	2965.75	2729.95
A5	4177.11	4812.53	3947.37	5430.24	4591.80
Mean	2857.84	3829.17	2969.23	3639.08	

A - N.S.

C.D. (0.05) W - (464.81)

AxW - N.S.

Table 13. Harvest index.

	W0	W1	W2	W3	Mean
A0	0.564	0.501	0.589	0.430	0.521
A1	0.384	0.507	0.452	0.436	0.445
A2	0.424	0.494	0.372	0.395	0.421
A3	0.457	0.452	0.435	0.454	0.450
A4	0.560	0.522	0.485	0.483	0.513
A5	0.400	0.428	0.406	0.367	0.400
Mean	0.465	0.484	0.457	0.428	

A - N.S. AxW - N.S.

W - N.S.

the minimum harvest index by treatment A5. With respect to the weeding treatments W1 recorded the maximum harvest index. This was closely followed by the treatment W0.

2. Chemical studies (CROP)

2.1. N, P and K uptake at harvest

Data on uptake of N, P and K by the crop at harvest are given in Tables 14, 15 and 16 and analysis of variance in Appendix IV.

2.1.a. N uptake by crop at harvest

Results presented showed that the effect of azolla was non significant with respect to N uptake by the crop at harvest. However a trend was observed where the maximum N uptake was recorded by the treatment A5 and the minimum by A0. The weed control treatment W1 recorded the maximum N uptake and was significantly superior to W0, W2 and W3. W0 recorded the lowest uptake. Among treatments W2 and W3 latter recorded a numerically higher N uptake though both of them were on par.

The interaction effect was significant. The interaction A5W1 recorded the highest N uptake while A0W0 gave the lowest uptake with regard to the combinations involving W1 with different levels of azolla, A5W1 showed a significant effect over A0W1. For different weed control treatments at

Table 14. N uptake by crop (kg/ha) at harvest.

	W0	W1	W2	W3	Mean
A0	51.77	87.54	97.54	73.91	77.69
A1	92.50	87.07	68.05	76.51	81.03
A2	52.79	102.22	84.32	89.38	82.18
A3	69.60	110.89	96.36	80.67	89.38
A4	90.99	108.16	86.08	75.83	90.26
A5	98.35	145.16	74.67	125.60	110.94
Mean	76.67	109.58	84.50	90.24	

A - N.S.
C.D. (0.05) W - (10.99)
C.D. (0.05) AxW - (31.39).

Table 15. P uptake by crop (kg/ha) at harvest.

	W0	W1	W2	W3	Mean
A0	9.64	10.75	9.73	9.77	9.97
A1	7.38	11.69	8.67	13.86	10.40
A2	13.59	14.63	10.97	10.32	12.38
A3	9.72	17.08	16.80	11.87	13.86
A4	11.10	23.41	13.20	10.63	14.58
A5	15.83	17.71	13.67	12.87	15.02
Mean	11.21	15.88	12.17	11.55	

C.D. (0.05) A - (3.18)
C.D. (0.05) W - (1.39)
AxW - N.S.

the same level of azolla inoculation, a trend was observed where W1 gave maximum uptake, followed by W3 and W2 in most of the cases.

2.1.b. P uptake by crop at harvest

It could be observed from the data that there was significant variation among the treatments with respect to the uptake of P by the crop at harvest. A specific trend was observed for the azolla treatments with A5 recording the maximum uptake. A5 was significantly superior to A0 which recorded the minimum uptake. Treatment A5 was on par with A2, A3 and A4.

The weed control treatment W1 recorded the highest P uptake at harvest and was significantly superior to all other treatments. W0 recorded the lowest uptake. Treatments W2 and W3 were on par. The interaction effect was non-significant.

2.1.c. K uptake by crop at harvest

As regards K uptake, the effect of azolla inoculation was not significant. But a trend was observed where A5 recorded maximum uptake and A0 minimum uptake. The weed control treatment W1 recorded the highest K uptake and was significantly superior to W0, W2 and W3. W0 recorded the lowest uptake. W2 and W3 treatments were on par. However W3 recorded a numerically higher K uptake than W2.

The interaction effect was also significant. A5W1 recorded the maximum and AoWO the minimum K uptake values. A5W1 was significantly superior to most of the other interaction effects.

2.2. Crude protein content of grain

Mean data on crude protein content of grain are presented in Table 17 and analysis of variance in Appendix VI.

The results showed that only the azolla treatments and interaction effects were significant with respect to protein content of grain. The treatment A5 recorded the highest protein content and was significantly superior to A0, A1 and A2. But A5 was on par with A3 and A4. A0 recorded the lowest protein content of grain. The weed control treatments, though non-significant, showed a definite trend with respect to protein content of grain. W1 recorded the highest protein content, followed by W3 and W2. W0 recorded the lowest content.

The combination A5W1 recorded the maximum protein content and was significantly superior to all other interactions involving W1 with the azolla treatments, except A3W1 with which it was on par.

Table 16. K uptake by crop (kg/ha) at harvest.

	W0	W1	W2	W3	Mean
A0	46.07	107.86	49.51	88.09	72.88
A1	554.63	115.16	84.29	58.50	80.89
A2	104.42	105.69	56.15	72.64	84.72
A3	68.88	107.29	106.17	72.25	88.65
A4	94.14	100.44	83.77	87.34	91.42
A5	114.66	164.96	110.62	126.16	101.56
Mean	80.68	116.90	81.75	84.17	

A - N.S.
C.D. (0.05) W - (12.04)
C.D. (0.05) AxW - (45.01).

Table 17. Crude protein content of grain (%).

	W0	W1	W2	W3	Mean
A0	4.004	4.431	4.004	3.575	4.000
A1	3.148	4.004	4.863	4.431	4.110
A2	4.431	4.863	4.860	4.004	4.540
A3	4.719	6.575	4.431	4.431	5.040
A4	6.148	4.004	4.860	6.150	5.290
A5	3.575	7.436	5.290	6.148	5.610
Mean	4.340	5.220	4.720	4.790	

C.D. (β.05) A - (0.796)
W - N.S.
C.D. (0.05) AxW - (1.691).

3. Observations on Weeds

3.1. Weed species

The common weeds found in the experimental field were: Echinochloa spp., cyperus spp., Fimbristylis miliacea, Monochoria vaginalis.

3.2. Dry matter production of weeds

Mean data on dry matter production of weeds at different stages are presented in Tables 18, 19, 20 and 21 and analysis of variance in Appendix V.

Results presented showed that at all the stages the treatments and interaction effects were significant with respect to dry matter production of weeds. With regard to azolla treatments A5 recorded a lower dry matter production than other azolla treatments at all the stages, while A0 recorded the highest dry matter production of weeds. It was observed that at 15 days after planting, treatments A1, A2 and A3 were on par and gave significantly higher weed dry matter production than A5. Treatments A4 and A5 were also on par. At 30 days after planting only the treatment A5 gave a significantly lower dry matter production than the other azolla treatments. At this stage, treatments, A1, A2, A3 and A4 were on par. At 45 days after planting, treatments A4 and A5 were on par and gave lower dry matter production

Table 18. Dry matter production of weeds (gm/m^2) (15 D.A.P).

	W0	W1	W2	W3	Mean
A0	79.27 (1.90)	0 (0)	64.50 (1.81)	69.53 (1.84)	53.33 (1.73)
A1	12.07 (1.08)	0 (0)	9.60 (0.98)	5.03 (0.70)	6.68 (0.82)
A2	8.80 (0.94)	0 (0)	6.53 (0.81)	4.77 (0.68)	5.03 (0.70)
A3	10.07 (1.01)	0 (0)	6.80 (0.83)	2.33 (0.37)	4.80 (0.68)
A4	5.37 (0.73)	0 (0)	4.17 (0.62)	2.53 (0.40)	3.02 (0.48)
A5	3.77 (0.58)	0 (0)	2.23 (0.35)	2.22 (0.33)	2.06 (0.31)
Mean	19.89 (1.34)	0 (0)	15.64 (1.19)	14.41 (1.14)	

C.D.(0.05) A - (0.28) C.D.(0.05) W - (0.14)
C.D.(0.05) AxW - (0.42)

Table 19. Dry matter production of weeds (gm/m^2) (30 D.A.P)

	W0	W1	W2	W3	Mean
A0	112.00 (2.05)	0 (0)	63.33 (1.80)	52.00 (1.72)	56.83 (1.75)
A1	9.64 (0.98)	0 (0)	1.13 (0.05)	3.73 (0.57)	3.63 (0.57)
A2	8.50 (0.93)	0 (0)	1.01 (0.01)	3.93 (0.59)	3.36 (0.54)
A3	9.00 (0.95)	0 (0)	0 (0)	7.20 (0.86)	4.05 (0.61)
A4	6.77 (0.83)	0 (0)	0 (0)	4.87 (0.69)	2.91 (0.46)
A5	3.10 (0.49)	0 (0)	0 (0)	1.50 (0.18)	1.15 (0.06)
Mean	24.84 (1.39)	0 (0)	10.91 (1.04)	12.12 (1.08)	

C.D.(0.05) A - (0.36) C.D.(0.05) W - (0.20)
C.D.(0.05) AxW - (0.54)
(Log. transformed figures given in parenthesis)

Table 20. Dry matter production of weeds (gm/m^2) (45 D.A.P)

	W0	W1	W2	W3	Mean
A0	208.47 (2.32)	0 (0)	136.07 (2.13)	74.13 (1.87)	104.67 (2.02)
A1	58.55 (1.77)	0 (0)	45.93 (1.66)	28.87 (1.46)	33.34 (1.52)
A2	20.70 (1.32)	0 (0)	7.93 (0.90)	13.60 (1.13)	10.56 (1.02)
A3	20.17 (1.30)	0 (0)	8.90 (0.95)	7.60 (0.88)	9.17 (0.96)
A4	4.73 (0.67)	0 (0)	0 (0)	2.77 (0.44)	1.87 (0.27)
A5	2.80 (0.45)	0 (0)	0 (0)	1.30 (0.11)	1.02 (0.01)
Mean	52.57 (1.73)	0 (0)	33.14 (1.51)	21.36 (1.33)	

C.D. (0.05) A - (0.27) (C.D. (0.05) W - (0.20)
C.D. (0.05) AxW - (0.48)

Table 21. Dry matter production of weeds (gm/m^2) (Harvest)

	W0	W1	W2	W3	Mean
A0	271.67 (2.43)	0 (0)	208.33 (2.32)	130.00 (2.11)	152.50 (2.18)
A1	157.20 (2.20)	0 (0)	77.67 (1.88)	78.00 (1.89)	117.52 (2.07)
A2	143.27 (2.16)	0 (0)	84.67 (1.93)	55.27 (1.74)	70.80 (1.85)
A3	115.57 (2.06)	0 (0)	49.00 (1.69)	81.53 (1.91)	61.53 (1.79)
A4	111.07 (2.04)	0 (0)	92.87 (1.97)	36.33 (1.56)	60.07 (1.78)
A5	55.79 (1.72)	0 (0)	9.00 (0.94)	44.33 (1.65)	27.28 (1.43)
Mean	142.43 (2.16)	0 (0)	86.92 (1.93)	70.91 (1.85)	

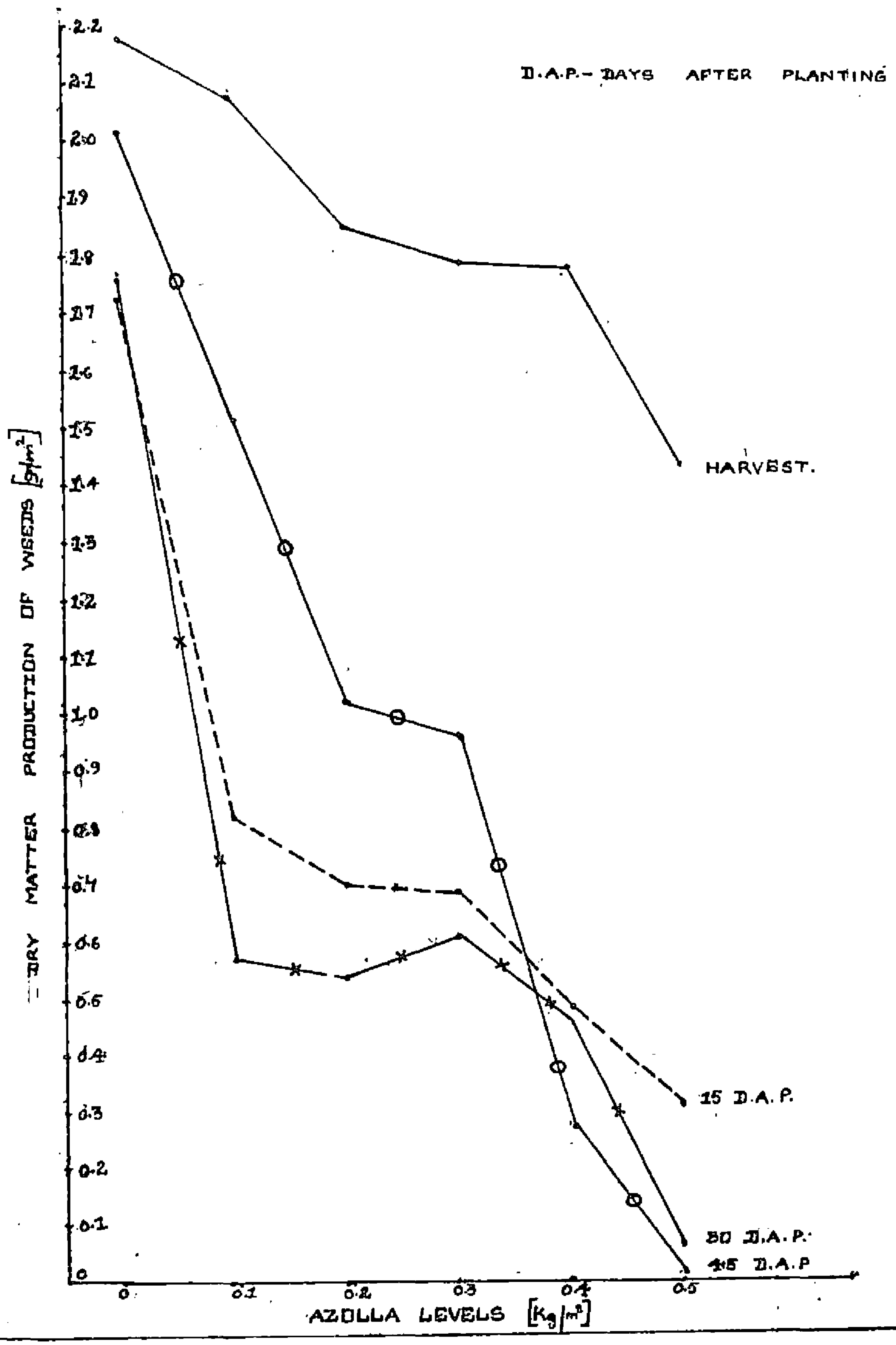
C.D. (0.05) A - (0.31) C.D. (0.05) W - (0.20)
C.D. (0.05) AxW - (0.35)
(Log. transformed figures given in parenthesis)

than the other treatments. At harvest stage A1, A2, A3 and A4 were on par. Only the treatment A5 gave a significantly lower weed dry matter production than the other treatments.

It could be observed from Fig.2 that at 30 and 45 days after planting azolla treatments A4 and A5 gave lower weed dry matter production than at 15 days after planting. The treatment A0 recorded a marked increase in weed dry matter production at 45 days after planting and harvest. At 30 days after planting A1 recorded a lower weed dry matter than at 15 days after planting, whereas at 45 days after planting and harvest weed dry matter production was higher than at 15 and 30 days after planting in the case of A1. The same trend was observed in the case of A2 and A3. Azolla treatments A4 and A5 generally recorded lower weed dry matter production than the other azolla treatments at 15, 30 and 45 days after planting. Dry matter production of weeds at harvest was always at a higher level than the other stages for all the azolla treatments.

With regard to weed control treatments W0 recorded maximum dry matter production of weeds and gave significantly higher values than W2 and W3 at all the stages. Treatments W2 and W3 were on par among themselves, though W3 gave a

FIG - 2 DRY MATTER PRODUCTION OF WEEDS AT DIFFERENT STAGES



numerically lower weed dry matter production at most of the stages. W1 recorded lowest dry matter production at all the stages.

The interaction effect A0W0 recorded maximum weed dry matter production at all the stages and gave significantly higher values than A3W0, A4W0 and A5W0. Treatments A4W2 and A5W2 recorded the lowest weed dry matter production at 30 and 45 days after planting.

3.3. Weed index

Mean data on weed index are presented in Table 22 and analysis of variance in Appendix V.

Results presented showed that azolla treatments were significant with regard to weed index. A progressive decrease in weed index was noticed as the level of azolla inoculation increased from A1 to A5. Treatment A0 recorded the maximum weed index. Treatment A3 recorded significantly lower weed index than A0 and it was on par with A4 and A5. However A0, A1 and A2 were on par among themselves.

With regard to weed control treatments W0 recorded the highest weed index and gave a significantly higher value than W1 and W3. W1 recorded the lowest weed index. W2 and W3 were on par among themselves, eventhough W3 gave a numerically lower weed index than W2. The interaction effect was non-significant.

4. Chemical studies (WEEDS)

4.1. N, P and K uptake by weeds at harvest

Mean data on N, P and K uptake by weeds at harvest are presented in Tables 23, 24 and 25 and analysis of variance in Appendix VI.

4.1.a. N uptake by weeds at harvest

Data revealed that the treatments and interaction effects were significant with respect to N uptake by weeds at harvest. Azolla treatment A0 recorded significantly higher N uptake than the other azolla treatments. A5 recorded the lowest uptake. Treatments A1, A2, A3 and A4 were on par. With regard to weed control treatments W0 recorded significantly higher N uptake than the other treatments. W1 recorded the lowest N uptake by weeds. W2 and W3 were on par among themselves.

Regarding the interaction effects, A3W0, A4W0 and A5W0 recorded significantly inferior N uptake values when compared to A0W0. A5W0 recorded the lowest N uptake among them. The same effect was also observed in the interaction effects involving weeding treatments W2 and W3 also. There was no significant difference observed between the various combinations involving azolla treatment A4 with the weeding treatments. The same effect was seen in the case of

Table 22. Weed index

	W0	W1	W2	W3	Mean
A0	70.20 (56.91)	0 (2.87)	46.88 (43.19)	23.26 (28.81)	35.09 (36.29)
A1	62.65 (52.31)	0 (2.87)	28.04 (31.95)	25.75 (30.48)	29.11 (32.65)
A2	50.00 (45.13)	0 (2.87)	20.17 (26.67)	32.54 (34.76)	25.68 (30.42)
A3	12.93 (21.05)	0 (2.87)	50.36 (45.18)	20.35 (26.82)	20.91 (27.32)
A4	22.92 (28.59)	0 (2.87)	32.82 (34.94)	4.52 (12.25)	15.07 (22.81)
A5	9.23 (17.64)	0 (2.87)	15.97 (23.51)	19.14 (25.92)	11.09 (19.41)
Mean	37.99 (38.03)	0 (2.87)	32.37 (34.65)	20.93 (27.20)	

C.D. (0.05) A - (8.34) C.D. (0.05) W - (9.12)
AxW - N.S.
(Angular transformed figures given in parenthesis).

Table 23. N uptake by weeds (kg/ha) (Harvest)

	W0	W1	W2	W3	Mean
A0	38.401	0	36.331	30.180	26.230
A1	25.281	0	13.193	10.076	12.140
A2	23.582	0	13.345	8.121	11.260
A3	19.228	0	7.780	13.683	10.170
A4	16.902	0	14.498	6.947	9.590
A5	8.901	0	1.337	6.786	4.250
Mean	22.050	0	14.420	13.630	

C.D. (0.05) A - (11.57) C.D. (0.05) W - (7.20)
C.D. (0.05) AxW (15.86).

Table 24. P uptake by weeds (kg/ha) (Harvest).

	W0	W1	W2	W3	Mean
A0	8.890	0	7.509	4.308	5.180
A1	6.685	0	3.036	3.261	3.250
A2	5.431	0	2.753	2.747	2.730
A3	4.407	0	3.917	0.997	2.330
A4	4.565	0	1.678	2.846	2.270
A5	1.547	0	0.277	1.735	0.890
Mean	5.250	0	3.190	2.650	

C.D. (0.05) A - (2.04)
C.D. (0.05) W - (1.07)
C.D. (0.05) AxW - (2.99).

Table 25. K uptake by weeds (kg/ha) (Harvest)

	W0	W1	W2	W3	Mean
A0	47.570	0	35.400	18.353	25.330
A1	26.664	0	13.502	14.740	13.730
A2	25.417	0	10.043	16.243	12.930
A3	31.577	0	10.375	8.915	12.720
A4	19.350	0	20.115	5.710	11.290
A5	11.220	0	1.552	10.510	5.820
Mean	26.970	0	15.160	12.410	

C.D. (0.05) A - (7.87)
C.D. (0.05) W - (4.28)
C.D. (0.05) AxW - (11.74).

combinations involving A5 also. It was further observed that most of the combinations involving weeding treatment W3 recorded lower N uptake by weeds.

4.1.b. P uptake by weeds at harvest

Results showed that the treatments and interaction effects were significant with respect to P uptake by weeds at harvest. The azolla treatment A0 recorded maximum uptake and A5 minimum uptake of P. The rest of the azolla treatments were on par among themselves. The weed control treatment W0 recorded a significantly higher uptake than the other weed control treatments. W1 recorded the lowest uptake of P. W2 and W3 were found to be on par among themselves.

With respect to the interaction effects, A2W0, A3W0, A4W0 and A5W0 recorded significantly lower P uptake by weeds when compared to A0 W0. A5W0 recorded the lowest P uptake among them. The combinations involving azolla treatment A4 with the weed control treatment were all on par among themselves with respect to P uptake by weeds. The same effect was observed in the case of combinations involving A5 also. It was further observed that the interaction A3W3 recorded significantly lower P uptake by weeds than A3W0.

4.1.c. K uptake by weeds at harvest

There was significant variation among the treatments as well as the interaction effects with respect to K uptake by weeds at harvest. Regarding the azolla and weed control treatments the same effect as in the case of P uptake by weeds was observed. The interaction effects A5W0, A5W1, A5W2 and A5W3 were all on par. The interaction effect A4W3 recorded a significantly lower K uptake when compared to A4W0 and A4W2. It was further observed that at lower levels of azolla inoculation, the combinations involving W2 and W3 gave lesser K uptake by weeds.

5. Soil analysis

Mean values of total N, available P and exchangeable K are given in Tables 26, 27 and 28 and analysis of variance in Appendix VI.

5.1. Total N

The data revealed that the treatments and interaction effects were not significant with respect to total N content of soil. However in the case of azolla treatments there was a progressive increase in total N content with the level of azolla inoculation. A5 recorded the maximum content and A0 the minimum content. The weed control treatments also showed a definite trend with treatment W1 recording the highest

Table 26. Soil analysis data after cropping
Total N (%).

	W0	W1	W2	W3	Mean
A0	0.0271	0.0233	0.0271	0.0233	0.0252
A1	0.0271	0.0224	0.0277	0.0247	0.0255
A2	0.0259	0.0330	0.0200	0.0330	0.0280
A3	0.0225	0.0295	0.0319	0.0295	0.0284
A4	0.0331	0.0402	0.0229	0.0331	0.0323
A5	0.0249	0.0485	0.0319	0.0497	0.0388
Mean	0.0267	0.0328	0.0269	0.0322	

A - N.S.　　AxW - N.S.
W - N.S.

Table 27. Soil analysis data after cropping
Available P (ppm).

	W0	W1	W2	W3	Mean
A0	25.68	36.29	35.00	42.90	34.97
A1	39.75	40.18	37.28	28.39	36.40
A2	44.94	39.99	35.31	41.73	40.27
A3	41.23	46.31	40.64	34.70	40.72
A4	48.64	42.22	43.70	47.40	45.49
A5	39.99	43.66	49.38	50.37	45.85
Mean	40.04	41.44	40.22	40.91	

A - N.S.　　AxW - N.S.
W - N.S.

Table 28. Soil analysis data after cropping
Exchangeable K (ppm).

	W0	W1	W2	W3	Mean
A0	8.67	14.00	11.33	12.00	11.50
A1	11.33	14.00	14.00	11.33	12.67
A2	14.67	19.33	12.00	11.33	14.33
A3	8.71	20.00	12.67	22.00	15.85
A4	13.33	10.00	17.33	24.00	16.17
A5	16.67	22.67	16.67	11.33	16.84
Mean	12.23	16.67	14.00	15.33	

A - N.S.
W - N.S.
C.D. (0.05) AxW - (7.02).

total N content of soil, followed by W3, W2 and Wo. Wo recorded the lowest content of total N in the soil.

5.2. Available P.

The available P content of soil was not found to vary significantly with the various treatments or interaction effects. However in the case of azolla treatments, there was a progressive increase in available P content with the level of azolla inoculation. A5 recorded the maximum and A0 the minimum content. The weeding treatments also showed a definite trend with W1 recording the highest available P content of soil, followed by W3, W2 and W0. W0 recorded the lowest content.

5.3. Exchangeable K

Data revealed that only the interaction effects had significant influence on the exchangeable K content of soil. The interactions A5W1, A3W1 and A3W3 were on par. A0W0 recorded the lowest exchangeable K content of soil. With regard to azolla and weed control treatments, the same trend was observed as in the case of available P content of soil.

DISCUSSION

DISCUSSION

The main objectives of the present investigation are to assess the efficiency of azolla for weed control in rice ecosystem, to fix an optimum rate of inoculation of azolla for weed control and to find out a suitable weeding practice in combination with a particular rate of inoculation for rice in sandy soils. The results obtained are discussed below.

1. Observations on Crop

1.1. Growth and Growth characters

1.1.a. Height of plants

The results presented in Tables 2,3 and 4 showed that plant height was not significantly influenced by the treatments. However a clear trend was observed for the azolla treatments with the no azolla treatment recording the minimum and azolla inoculation @ 0.5 kg/m^2 recording the maximum height. The unweeded control had recorded the lowest height and the differences in height between the other weed control treatments are not much.

The increase in plant height occured due to azolla inoculation is attributed to the better nitrogen availability through azolla. It could also be seen from the soil N content (Table 26) that azolla applied plots had recorded a higher N content. The data presented in Table 23 also revealed that the uptake of N by weeds was minimum in plots receiving higher levels of azolla. These conditions might have enabled the plant to take up more N, with a consequent increase in the plant height. The role of N in increasing the plant height is already well known. Similar results of increase in plant height due to growth of azolla in rice fields have been reported by Singh (1977 a,b).

In the unweeded control the uptake of nutrients by the crop, especially that of nitrogen was the lowest when compared to the other weed control treatments as observed in Table 14. This is attributed to the higher dry matter production of weeds (Table 21), with a consequent enhanced uptake of N by weeds (Table 23), resulting in a lower N content of the soil (Table 26). All these make it clear that competition for nutrients, especially nitrogen was much in the unweeded control, with the result that the crop suffered a reduction in plant height in this treatment. Similar reports of competition for nutrients between crop and weed, especially for nitrogen are available in literature (Shetty and Gill, 1974; Raveendran, 1976).

1.1.b. Number of Tillers

Data on tiller counts presented in Table 5 revealed that at maximum tillering stage either the treatments or interaction effects failed to bring about any significant differences in the tiller count. However it could be seen that unweeded control has recorded the lowest tiller count.

In the unweeded control there was maximum competition for nitrogen between weeds and crop as could be seen from Table 14 which showed that the N uptake by crop was the least in this treatment, resulting in a decrease in tiller count. The reasons for the low uptake of N by the crop have already been stated. Similar reduction in tiller number due to weed infestation has already been reported by Swain, 1967; K_1eing and Noble, 1968.

It may be further seen from Table 5 that the differences in tiller counts between weed control treatments were not much when compared to azolla treatments. This is likely to be due to the better control of weeds by azolla. This is made clear from Tables 18, 19, 20 and 21 wherein, at most of the stages, dry matter production of weeds was seen more influenced by azolla rather than weed control treatments.

1.1.c. Leaf area index (LAI)

The LAI in experimental plots was low when compared to the generally observed LAI in rice. This may be due to the fact that the crop was grown in sandy soil of poor fertility where the general growth rate was low. The wider recommended spacing of 20 x 15 cm adopted in the study might be another probable reason for recording low LAI values.

Azolla application has shown a definite trend in increasing the LAI at higher levels, eventhough the effect was not statistically significant. Azolla application @ 0.5 kg/m^2 has given the maximum LAI. The contributing characters for LAI are number of tillers, number of leaves/tiller and the size of leaves (Matsushima, 1970). It has already been observed that number of tillers have been increased due to azolla application. Leaf number/tiller is almost a constant character. Hence the only other reason for increase in LAI is a probable increase in the size of leaves. The higher uptake of N by the crop in azolla treatments (Table 14) would have played a definite role in increasing the leaf size of the plants. Ishizuka (1971) also has come out with such a finding. Tanaka et al. (1964) has stressed the combined effect of increased leaf number, leaf size and number of tillers manifested in increasing the LAI in relation to N application.

It was also observed that increase in LAI due to a higher rate of azolla inoculation was more marked at panicle initiation than at maximum tillering stage. In the case of higher levels of azolla inoculation, at later stages there will be more decomposition of azolla resulting in higher N availability to the crop. Singh (1979 b) reported that azolla releases 56-80 per cent of its N as ammonia in 3-6 weeks by decomposition. Thus by the time the crop reached the panicle initiation stage more N would have been made available. It can be further seen from Tables 19, and 20 that the decrease in dry matter production of weeds due to an increase in the rate of azolla inoculation was more at 45 D.A.P. than at 30 D.A.P. This is another probable reason for a marked increase in LAI at panicle initiation stage, which in this crop has occured around 50 days after transplanting.

The results further show that complete weed control has recorded the highest LAI. This treatment has recorded the maximum N uptake by the crop (Table 14) and the least weed dry matter production (Table 21) also. These would have benefited the crop and resulted in producing more LAI.

1.2. Post harvest observations

1.2.a. Yield components

1.2.a.1. Number of panicles/m^2

The results presented in Table 8 showed a clear trend of increase in panicle number by azolla inoculation eventhough not statistically significant. It was seen from Table 14 that N uptake by crop and total N content of soil (Table 26) were more in plots receiving higher levels of azolla inoculation. This might be attributed to a decreased weed growth in thickly inoculated plots (Table 21). Another probable reason is the increase in soil N consequent to decomposition as well as excretion (Peters, 1975) resulting from a higher rate of azolla application. The P and K content of soil (Tables 27 and 28 respectively) and uptake by crpp (Tables 15 and 16) also have shown a positive influence. All these have definitely contributed to an increase in the panicle number. The increase in panicle production in accordance with increased N availability is well established (Subbiah et al., 1977, Raju, 1978).

The weeding treatments also have exhibited a definite trend. The unweeded control has recorded the lowest panicle number. It may be seen from Tables 18, 19 and 20 on dry matter production of weeds at 15, 30 and 45 D.A.P. respectively that during the early stages of crop growth weed dry matter production was significantly more in unweeded control. There would have been maximum competition for nutrients in this plot. This is also evidenced by the lowest uptake of N (Table 14), P (Table 15) and K (Table 16) by the crop. Instantly it may also be stated that the ultimate soil N, P and K content was also the least in this treatment (Tables 26, 27 and 28). Such decrease in panicle number due to weed competition has already been reported (Burga et al., 1980).

The interaction effect showed that higher levels of azolla in combination with complete weed control had given significantly more number of panicles than many other combinations. This is only a combined manifestation of the main effects.

1.2.a.2.<u>Number of filled grains/panicle</u>

It could be seen from Table 9 that both azolla application as well as weed control have beneficially influenced the number of filled grains/panicle. Because of reasons already explained this increase would have been resulted. This experiment was conducted in a sandy soil and the slow and steady availability of N from azolla, coupled with the factor responsible for competition such as weeds would have definitely ensured an optimum environment for increase in the number of filled grains/panicle.

1.2.a.3.<u>1000 grain weight</u>

The plot receiving maximum azolla inoculation had recorded the highest 1000 grain weight as in seen from the result (Table 10). This might be due to a steady and higher N availability to the crop (Table 14) which would have led to a higher rate of carbohydrate synthesis in the plant system. This carbohydrate would have been favourably utilised in grain filling and so the 1000 grain weight has increased.

Another factor is that in the no azolla plots the N availability to the crop was only through the usual fertilizer dose supplied, and since the soil under study was of sandy nature heavy losses of the applied N would have occured due to leaching. This is probably another reason for the no azolla plot recording the lowest 1000 grain weight. But in the case of treatments receiving azolla inoculation, the characteristic nature of azolla under dual culturing system to ooze out N into the surrounding water (Shen et al., 1963) would have facilitated the crop to acquire the N requirement from the immediate surroundings of the plant. This shows the benefit of azolla as a slow and steady supplier of N, especially useful in sandy soils, as reported by Jaikumaran (1981).

There was significant variation among the weed control treatments with respect to 1000 grain weight with complete weed control recording the maximum 1000 grain weight. Table 14 on N uptake by crop showed that this treatment had recorded significantly higher uptake when compated to others. The beneficial effect of increased availability of N is reflected here in increasing the 1000 grain weight. Tables 18, 19, 20 and 21 on dry matter production of weeds showed that it was the lowest in this treatment at all the stages. This again proves that weed competition is the least and this benefited the crop very much. Reduction in weight of grains due to weed competition have already been reported by Noda et al., 1971.

1.2.b. Yield

1.2.b.1. Yield of grain

Results on grain yield are presented in Table 11. Data showed that azolla inoculation had benefited the grain yield of rice crop. Eventhough maximum yield was obtained by azolla inoculation @ 0.5 kg/m^2 it was on par with the inoculation rate of 0.3 kg/m^2 and this treatment was also significantly superior to no azolla inoculation. It was further seen that complete weed control had given the maximum grain yield. Minimum grain yield was obtained in unweeded plot. Weeding twice had given more yield than weeding once.

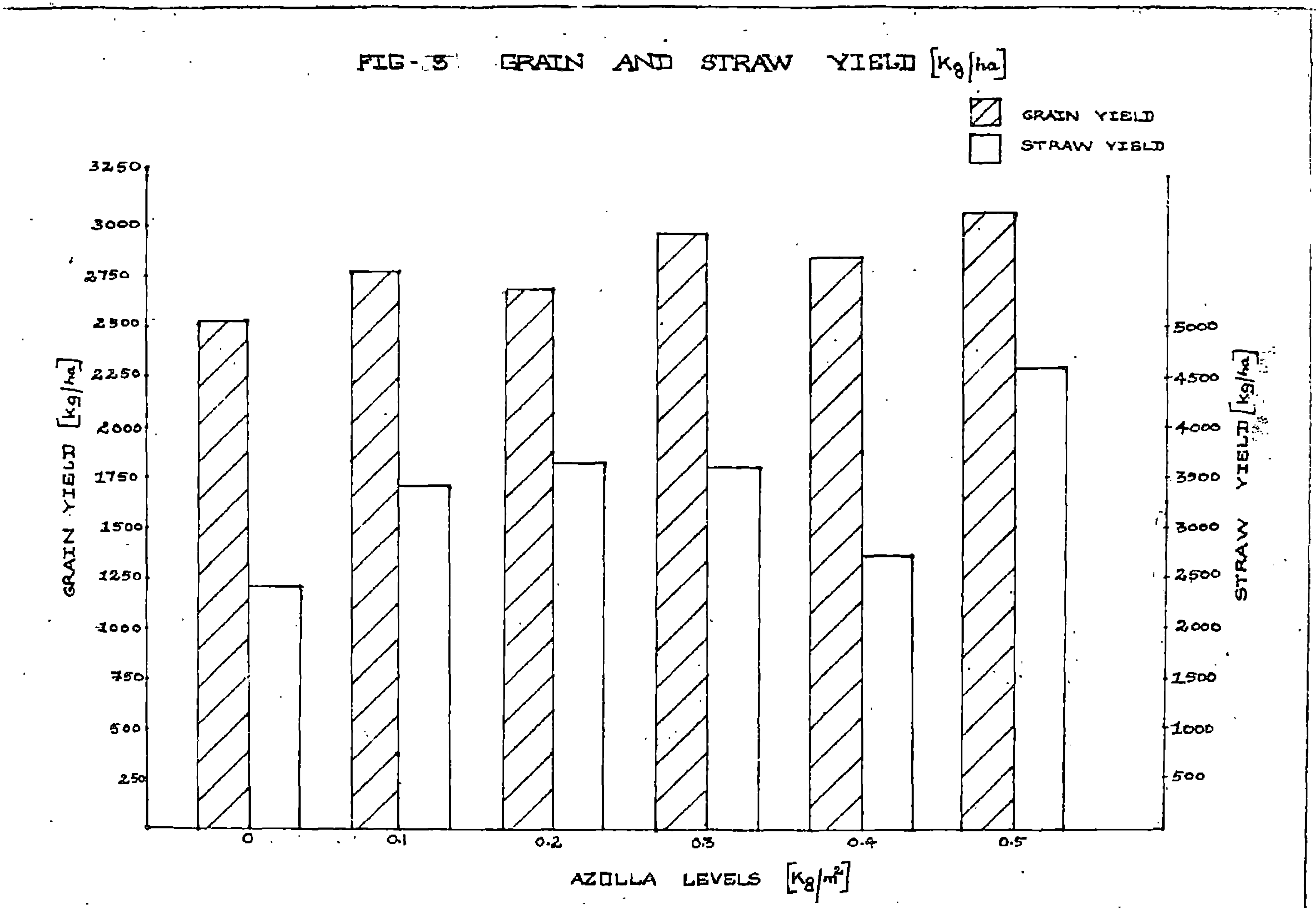


FIG-5 GRAIN AND STRAW YIELD [Kg/ha]
GRAIN YIELD
STRAW YIELD
GRAIN YIELD [Kg/ha]
3250
3000
2750
2500
2250
2000
1750
1500
1250
1000
750
500
250
STRAW YIELD [Kg/ha]
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0.1
0.2
0.3
0.4
0.5
AZOLLA LEVELS [Kg/m²]

The increase in yield obtained in plots receiving azolla to the extent of 3 tonnes/ha and above is likely to be due to N released by oozing out as well as decomposition of dual cultured azolla. Shen et al., 1963 has reported that azolla releases N by oozing. The 3 tonnes of inoculated azolla had multiplied and covered the yield within 15 days in the present investigation. Similar results of multiplication of azolla within 15 days of inoculation has been reported by Govindarajan et al., 1979. In treatments receiving azolla inoculation @ 0.1 kg and 0.2 kg/m^2 complete coverage was not obtained within this time. Thus the availability of N by decomposition of azolla at the early stage of rice crop has ensured better yields than treatments without azolla inoculation.

Results on yield components presented in Tables 8, 9 and 10 also showed that application of azolla had influenced these characters favourably.

The beneficial effect of complete weed control had been manifested in grain yield. This resulted mainly from the benefits accrued to yield attributes (Tables 8, 9 and 10) due to the effect of complete weed removal. It was also seen that weeding 15 and 30 D.A.P. had given more yield than weeding 15 D.A.P. This might also be due to the same effect.

Data on weed index (Table 22) and weed dry matter production (Tables 18, 19, 20 and 21) showed that weeded plots had given lower values. The availability of nutrients also was better ensured in weeded treatments as revealed by N, P and K uptake by crop (Tables 14, 15 and 16 respectively). Results on uptake of nutrients by weeds (Tables 23, 24 and 25) also showed that in weeded plots more nutrients were conserved which would have been made available to the crop.

The yield increase obtained in treatment receiving weeding twice over that receiving only one weeding and unweeded control is probably because in this treatment, a weed free period is ensured in the field upto 45 days after planting by which time the critical period of crop weed competition will almost be over. Similar reports of yield increase due to weeding during critical stages is already available in literature (Bhan et al., 1975). Beyond this stage weeding may not influence yield (Lakshmi, 1983). However in this investigation maximum yield was obtained in the complete weed control plot. Two more weedings are given here than the plot receiving weeding only twice. Thus in a sandy soil tract, weeding seems to be essential even beyond the critical stage of crop weed competition due to the fact that the soils are very poor. The presence of weeds even at later stages is likely to compete with the crop and decrease yield. Some more investigations have to be conducted in this line to identify the critical stages of crop weed competition in sandy soils.

ı.2.b.2. Yield of straw

Results on straw yield presented in Table 12 revealed an increase in straw yield with the levels of azolla inoculation. It was also seen that complete weed control gave maximum yield and that weeding twice had given better straw yield than weeding once. Unweeded plot had recorded the lowest straw yield.

The increase in yield due to a higher level of azolla inoculation is due to the effect of azolla on growth characters like height of plants (Table 4) and number of tillers (Table 5) which had generally shown an increase with the levels of azolla inoculation. Similar reports of increase in height and number of tillers due to azolla application are available (Singh, 1977 a,b). Another probable reason is the increase in N uptake by the crop (Table 14) observed at higher levels of azolla application.

Similarly the beneficial effect of complete weed control had been reflected on straw yield and the increase in straw yield observed was due to the favourable influence of weeding on growth characters presented in Table 2 to 7. Kleing and Noble (1968) have also come out with similar results. A higher N uptake by crop due to weeding was also observed from Table 14. This might be another probable reason for the weeding treatments giving more straw yield.

1.2.c. Harvest index

From the results presented in Table 13 it could be made out that the treatments or interaction effects were not significant with respect to harvest index. However the treatment receiving no azolla inoculation and the one receiving azolla inoculation @ 0.5 kg/m^2 had recorded the maximum and minimum harvest indices respectively. Complete weed control had registered the highest harvest index, closely followed by the unweeded control.

Data on N uptake by crop (Table 14) and soil N content (Table 26) revealed that N availability was increasing from no azolla inoculation to azolla inoculation @ 0.5 kg/m^2. This has led to a higher straw yield in the latter treatment. However grain yield did not increase proportionately in this treatment (Table 11), resulting in a low harvest index. In the case of no azolla treatment, the grain yield recorded also was very low. Therefore this treatment had given the highest harvest index.

Complete weed control had recorded the highest grain yield, with the result harvest index was maximum. Data on N uptake by the crop (Table 14) showed a significantly higher value in this treatment than the other weed control treatments. This nitrogen would have been properly utilised for grain production which had ultimately led to a high harvest index. In the case of unweeded control a lower grain as well as straw yield were noticed, resulting in a higher harvest index.

2. Chemical studies (CROP)

2.1. N, P and K uptake at harvest

Results presented in Tables 14, 15 and 16 showed that P uptake by crop was significantly influenced by azolla application. However in the case of N, P and K uptake, a trend was observed where the highest rate of azolla inoculation has recorded the maximum and no azolla treatment the minimum uptake. The data on dry matter production of weeds at harvest (Table 21) shows that weed population is minimum in plots receiving higher rate of azolla inoculation. This is coroborated by the finding that nutrient uptake of weeds is also the lowest in these plots (Tables 23, 24 and 25). This has naturally resulted in a higher content of N, P and K in the soil which has been favourably utilised by the crop, leading to an increased uptake at harvest.

The N, P and K uptake by crop was significantly influenced by weeding treatments (Tables 14, 15 and 16). Complete weed control has recorded significantly higher uptake values than others. Weeding 15 D.A.P. and weeding 15 and 30 D.A.P. were found to be on par. In completely weeded plots weeds are not at all allowed, with the result that weed dry matter production (Tables 18, 19, 20 and 21) as well as nutrient removal by weeds (Tables 23, 24 and 25) are nil. This has obviously given the highest soil nutrient content in this treatment (Tables 26, 27 and 28). These nutrients have been advantageously utilised by the crop resulting in appreciable uptake of N, P and K as revealed in the respective tables.

With regard to interaction effects, results showed that N and K uptake were increased in treatment combinations receiving higher rate of azolla inoculation along with complete weed control. While discussing the individual effects of these treatments it was pointed out that both azolla application as well as complete weeding individually were giving higher uptake values. This has naturally reflected in the interaction effect also.

2.2. Crude protein content of grain

It could be made out from the results presented in Table 17 that only the azolla treatments and interaction effects were significant with respect to crude protein content of grain. The treatment receiving azolla inoculation @ 0.5 kg/m^2 has recorded the maximum protein content, while no azolla inoculation has recorded the minimum content. The former was on par with azolla inoculation @ 0.3 kg/m^2.

Thus a higher rate of azolla inoculation has led to a higher availability of N in the concerned plot (Table 14) which has naturally resulted in a higher protein content. Another probable reason is that at later stages, higher amount of N is made available in plots receiving larger quantity of azolla. This also would have enhanced the protein content.

With respect to the effect of weeding, there was a trend observed with complete weed control recording the highest protein content, followed by weeding 15 and 30 D.A.P, weeding 15 D.A.P.and then unweeded control, which has recorded the lowest content, eventhough not significant. This shows the effect of weeding in rice on increasing the protein content of grain. Similar reports on weed control in rice as an important aspect for increasing the protein content of grain are seen in literature (Raveendran, 1976).

The combination of azolla inoculation @ 0.5 kg/m^2 with complete weed control, which recorded the highest protein content was found to be on par with the combination involving azolla inoculation @ 0.3 kg/m^2 with complete weed control. This again shows that the azolla level of 0.3 kg/m^2 gives the same effect as 0.5 kg/m^2 inoculation, if combined with complete weed control with regard to protein content of grain.

3. Observations on weeds

3.1. Dry matter production of weeds

Results presented in Tables 18, 19, 20 and 21 showed that at all the stages the treatments as well as their interaction effects were significant with respect to dry matter production of weeds. Azolla level of 0.5 kg/m^2 has recorded the lowest and no azolla inoculation the highest weed dry matter production. It has been observed in general that only the azolla inoculation rate of 0.5 kg/m^2 was able to give a significantly lower weed dry matter production than the other azolla treatments at most of the stages. This treatment had a higher rate of inoculation and hence the multiplication rate and coverage was rapid. This had resulted in reducing the weed population to a certain extent. But in the case of lower rates of azolla inoculation sufficient multiplication and coverage could not be obtained so as to have effective weed control. This suggests that a higher azolla inoculation rate is needed to achieve better weed control in rice fields. This is contrary to the usual recommended inoculation rate of 0.1 to 0.3 kg/m^2 for dual culturing (Govindarajan et al, 1979; Mathur et al., 1981). These workers have only considered the N economy by utilization of azolla in rice fields. Reports on weed control by azolla in rice fields (Singh, 1977a) do not specify the rate of inoculation for the specific purpose. Hence this finding has got some practical importance.

Fig.2 showed that azolla inoculation @ 0.4 kg and 0.5 kg/m^2 gave lower weed dry matter production at 30 and 45 D.A.P. than at 15 D.A.P. This shows that by 30 D.A.P. azolla multiplication and coverage has reached the maximum.

The figure further showed that at 30 D.A.P. the weed dry matter production in treatments receiving azolla inoculation @ 0.1, 0.2 and 0.3 kg/m^2 decreased when compared to 15 D.A.P, while at 45 D.A.P. and harvest the dry matter production of weeds increased when compared to 15 and 30 D.A.P. However the treatments receiving 0.4 and 0.5 kg/m^2 of azolla inoculation generally recorded a lower weed dry matter production than the other azolla levels at 15, 30 and 45 D.A.P, while at harvest all the azolla treatments recorded a higher dry matter production of weeds than the other stages. In plots receiving azolla inoculation @ 0.1, 0.2 and 0.3 kg/m^2, by 30 D.A.P, azolla might have multiplied and given sufficient coverage in the field, resulting in reduced weed growth. But by 45 D.A.P. azolla would have decomposed in the plots, leaving some patches on the surface of water that would have enabled weeds to come up. Similar reports on decomposition of asolla are available (Singh, 1977 b).

However in treatments receiving azolla inoculation @ 0.4 and 0.5 kg/m^2, eventhough decomposition of azolla was there, sufficient quantity was left in these plots to give adequate coverage upto 45 D.A.P. due to a higher rate of inoculation. At harvest stage, decomposition of azolla might have completed earlier that even in plots receiving a higher rate, not much azolla was left so as to provide adequate weed control. This shows that a higher azolla inoculation rate is necessary if weed control has to be achieved, especially during the critical periods of crop-weed competition.

With regard to weed control treatments results presented in Tables 18, 19, 20 and 21 showed that unweeded control which recorded maximum weed dry matter production at all the stages, gave significantly higher values than weeding 15 D.A.P. and weeding 15 and 30 D.A.P. This shows the effect of weeding, as compared to no weeding at all. It was also observed that weeding twice (15 and 30 D.A.P.) gave a numerically lower weed dry matter production than weeding once (15 D.A.P.), though they were on par. This shows that weeding twice is better than weeding once as far as weed control is concerned.

The combination of no azolla inoculation with unweeded control recorded significantly higher weed dry matter production than the combinations involving azolla inoculation @ 0.3, 0.4 and 0.5 kg/m^2 with the unweeded control at all the stages. This indicates that even in unweeded plot, azolla inoculation is helpful in reducing weed infestation. It was further observed that the combinations of azolla inoculation of 0.4 and 0.5 kg/m^2 with weeding 15 D.A.P. recorded the lowest weed dry matter production at 30 and 45 D.A.P. This again demonstrates the usefulness of a higher rate of azolla inoculation on weed control at the critical period of crop weed competition.

3.2. <u>Weed index</u>

Data presented in Table 22 revealed that the azolla treatments significantly influenced weed index. As the level of azolla inoculation was increased from 0.1 to 0.5 kg/m^2, the weed index decreased progressively. The no azolla treatment recorded the highest weed index. Since weed index denotes reduction in yield due to a particular treatment in comparision with the completely weed-free treatment, the results revealed that when the level of azolla inoculation increased, the yield decrease became lesser and lesser. The data on yield components (Tables 8, 9 and 10) and on yield (Table 11) substantiates this result. The decrease in yield would have been caused mainly due to weed competition. Results on dry matter production of weeds (Tables 18, 19, 20 and 21) also showed that it decreased

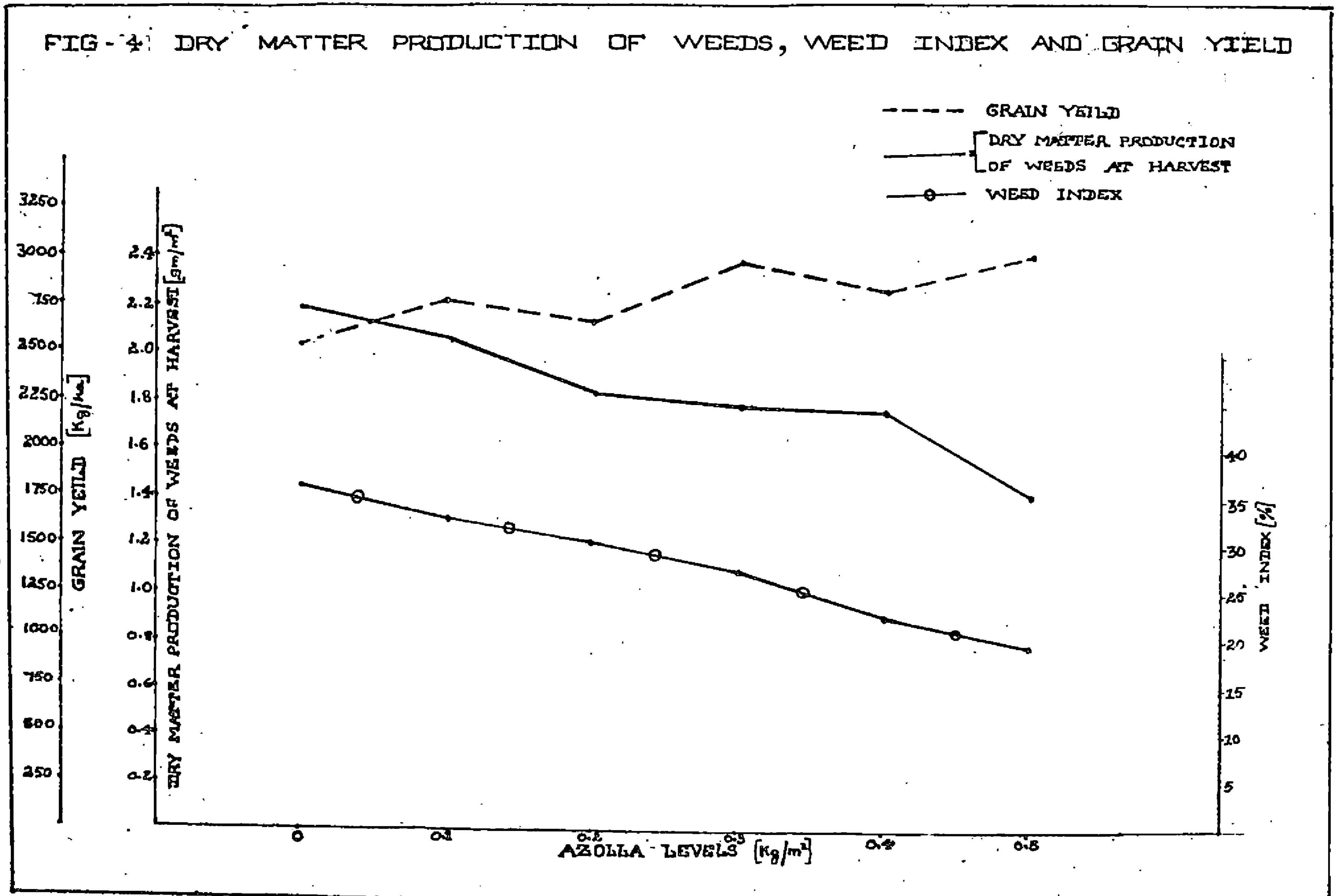


FIG-4: DRY MATTER PRODUCTION OF WEEDS, WEED INDEX AND GRAIN YIELD
GRAIN YEILD
DRY MATTER PRODUCTION OF WEEDS AT HARVEST
WEED INDEX
GRAIN YEILD [Kg/ha]
DRY MATTER PRODUCTION OF WEEDS AT HARVEST [gm/m²]
WEED INDEX [%]
AZOLLA LEVELS [Kg/m²]
3250
3000
2750
2500
2250
2000
1750
1500
1250
1000
750
500
250
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
40
35
30
25
20
15
10
5
0
0.1
0.2
0.3
0.4
0.5

with an increase in azolla levels and so competition between weeds and crop might have also decreased. In the case of no azolla plots, the yield components and yield were the lowest and weed dry matter production was the highest. Thus it recorded the maximum weed index.

Results on weed index further showed that azolla inoculation @ 0.3 kg/m^2 was on par with inoculation rate of 0.5 kg/m^2. The yield data (Table 11) also showed that these treatments were on par. This means there was no significant difference in yield reduction between these two treatments, and so 0.3 kg/m^2 inoculation rate is equally effective as 0.5 kg/m^2 inoculation as far as yield is concerned, eventhough from a better weed control point of view the latter treatment seems to be necessary.

As far as weed control treatments are concerned, results revealed that unweeded control gave a significantly higher weed index than complete weed control and weeding 15 and 30 D.A.P. This is only the effect of weeding as could be made out from Tables 18, 19, 20 and 21 on dry matter production of weeds which showed that at all the stages weed dry matter production in unweeded control was significantly higher than the completely weed-free treatment and weeding 15 and 30 D.A.P. Thus an intense competition from weeds might have resulted in a significantly higher decrease in yield in unweeded control. The data on yield (Table 11) also showed that this treatment recorded the lowest yield. Bhan and Maurya (1972) observed that even a low weed population was sufficient to reduce rice yield in unweeded control when compared to weed-free plot. Yield reduction due to weed competition have been reported by other workers also (Raveendran, 1976; Abraham Varghese, 1978).

It was further observed from Table 22 that weeding 15 and 30 D.A.P. recorded a lower weed index than weeding 15 D.A.P. The weed dry matter production in the former treatment was lower than the latter at most of the stages (Tables 18, 20 and 21). This infers that a lower weed competition was resulted in the plot receiving two weedings, when compared to that receiving only one weeding and hence it recorded a lower weed index.

4. Chemical studies (WEEDS)

4.1. N, P and K uptake at harvest

It could be observed from results presented in Tables 23, 24 and 25 that the treatments and their interactions were significant. No azolla treatment recorded the maximum N, P and K uptake and azolla inoculation @ 0.5 kg/m^2 the lowest uptake. The rest of the azolla treatments were on par. It could be seen from Tables 18, 19, 20 and 21 that dry matter production of weeds was progressively decreasing with an increase in rate of azolla inoculation. This is one of the probable reasons for recording the maximum nutrient uptake of weeds in the no azolla plots. An examination of uptake figures of the crop given in Tables 14, 15 and 16 showed that the uptake was minimum in no azolla plots and maximum in plots receiving 0.5 kg/m^2 azolla inoculation. As the rate of inoculation is increased, the weed population is proportionately decreased and the available nutrients are being taken up by the crop, leaving lesser quantity of nutrients for the weeds. This is another probable reason for the reduced uptake of N, P and K in plots receiving higher rates of azolla inoculation.

Among the weed control treatments the unweeded control recorded a significantly higher N, P and K uptake of weeds at harvest. This was followed by weeding 15 D.A.P., weeding 15 and 30 D.A.P and complete weed control. This is the direct effect of weeding on population of weeds as could be observed from the data on weed dry matter production at harvest (Table 21). The crop uptake (Table 14, 15 and 16) was more or less inversely related to weed uptake in these treatments. As the weed control is made effective, more nutrients are made available to the crop, resulting in a proportionate decrease in uptake of weeds.

The combinations involving azolla inoculation @ 0.3, 0.4 and 0.5 kg/m^2 with unweeded control recorded significantly lower N, P and K uptake than the combination of no azolla inoculation with unweeded control. The combination of 0.5 kg/m^2 azolla inoculation with unweeded control recorded the lowest N and K uptake by weeds among them. This seems to be the effect of azolla inoculation, since even in an unweeded plot azolla has been able to control weed growth as is evident from the data on weed dry matter production at harvest (Table 21), where the very same combinations gave significantly lower dry matter production of weeds.

It was also observed that there was no significant variation between the various combinations involving azolla inoculation rates 0.4 and 0.5 kg/m^2 with weeding treatments. This is because as the level of azolla inoculation was increased, even in unweeded plot weed dry matter production was found to decrease (Table 21).

The results further showed that most of the combinations involving weeding 15 and 30 D.A.P. recorded lower N, P and K uptake by weeds than combinations involving weeding 15 D.A.P. This is only the effect of weeding twice on controlling weed growth when compared to weeding only once. Table 25 also showed that at a lower level of azolla inoculation the combination involving weeding 15 and 30 D.A.P. recorded significantly lower nutrient uptake by weeds. This shows that a lower level of azolla inoculation is not that effective in weed control, and only weeding can bring about a significant effect in this regard. But as the level of inoculation increase, even in an unweeded plot there is sufficient degree of weed control due to the effect of azolla, as already explained.

5. Soil analysis

5.1. Total N, available P and Exchangeable K content of soil

Data presented in Tables 26, 27 and 28 revealed that azolla inoculation gave a progressive increase in soil nutrient status, with 0.5 kg/m^2 recording maximum content of soil nutrients. This is in conformity with the findings of Arunachalam (1980) and Mathew Kutty (1982) who observed that azolla treated plots yielded a higher total residual N and available P content. The higher N content might be due to the reduced losses of N taking place from an organic source of N like azolla, when compared to heavy losses of inorganic source in sandy soils. As far as available P content is concerned, the dual cultured azolla might have utilised phosphorus from native as well as applied fertilizer. In addition to this azolla itself contains about 0.3 per cent P_2O_5. Similar findings were also reported by Arunachalam loc.cit and Mathew Kutty loc.cit.

Complete weed control recorded the highest and unweeded control the lowest content of total N, available P and exchangeable K (Tables 26, 27 and 28 respectively). Complete weed control was followed by weeding 15 and 30 D.A.P. weeding 15 D.A.P. and then unweeded plot. This could be explained on the basis of N, P and K uptake by weeds at harvest (Table 23, 24 and 25 respectively) which showed just the reverse trend of soil nutrient status with respect to the weeding treatments.

6. Economics of Azolla dual culturing and weeding practices.

The economy of dual culturing azolla for weed control as well as weeding practices in sandy soils of Kerala in terms of grain and straw production worked out on the basis of cost and income is given in Table 29.

From the table it can be seen that the treatment receiving azolla inoculation @ 0.5 kg/m^2 has recorded maximum net income (Rs.4,468/ha). Among the weeding treatments, complete weed control has recorded the highest net income of Rs.3,717/ha.

Thus it is evident that azolla dual culturing with an inoculation rate of 0.5 kg/m^2 or 5 tonnes/ha is definitely economic and this practice can be advocated in areas where manual weeding is costly and when labour availability is meagre during peak periods of requirement

Table 29. Economics of azolla dual culturing and weeding practices in rice culture.

		W0	W1	W2	W3		
A0	(C)	0	800	720	1170	922	(A.C)
	(I)	4135	7145	5357	5169	5452	(A.I)
						1530	(N.I)
A1	(C)	13	1633	643	1057	837	(A.C)
	(I)	5806	8043	6550	5826	6556	(A.I)
						2719	(N.I)
A2	(C)	26	1466	566	926	746	(A.C)
	(I)	6067	7530	6045	6605	6562	(A.I)
						2816	(N.I)
A3	(C)	39	1299	489	849	669	(A.C)
	(I)	5330	8696	6786	6912	6931	(A.I)
						3262	(N.I)
A4	(C)	52	942	312	672	495	(A.C)
	(I)	4627	7855	5952	6228	6165	(A.I)
						2670	(N.I)
A5	(C)	65	605	155	515	335	(A.C)
	(I)	7106	8777	6804	8523	7803	(A.I)
						4468	(N.I)
	(A.C)	33	1291	481	865		
	(A.I)	5512	8008	6249	6544		
	(N.I)	2479	3717	2768	2679		

(C) - Cost (Rs/ha). (I) - Income (Rs/ha) from grain and straw

(A.C) - Average cost (Rs/ha). (A.I) - Average income (Rs/ha)

(N.I) - Net income after deducing cost (Rs/ha).

Cost of cultivation other than weeding - Rs.3,000/ha.

The cost involved for treatments includes labour cost for weeding (Rs.18/woman/day) and the cost of azolla multiplication and inoculation (Rs.13/ton/ha).

Price of Paddy - Rs.1.50/kg. Price of straw - Rs.0.70/kg.

as in Kerala. Keeping the field completely weed-free, eventhough involves excess labour has proved to be economic in this investigation. This practice may be necessary in sandy soils where the critical period may extend even after 45 days of planting rice. The high net income obtained in this treatment is due to the higher price of paddy (Rs.1.50/kg) which was prevalent during that season.

From the above discussion it can be concluded that eventhough from the yield and quality point of view of rice, an azolla inoculation rate of 0.3 kg/m^2 seems to be sufficient, a higher inoculation rate is necessary if proper weed control has to be achieved in rice fields, particularly during the critical periods of crop-weeed competition.

SUMMARY

SUMMARY

An investigation to assess the efficiency of azolla for weed control in Rice ecosystem during the first crop (*Kharif*) season was carried out in sandy soils of the Agronomic Research Station, Chalakudy during 1982.

The findings of the investigation are summarised as follows:-

Azolla inoculation @ 0.5 kg/m^2 and complete weed control treatment recorded the maximum plant height at all the stages.

Application of azolla @ 0.5 kg/m^2 and complete weeding registered higher LAI.

Dual culturing of azolla with an inoculation rate of 0.5 kg/m^2 produced the highest number of panicles, filled grains and 1000 grain weight, while no azolla treatment recorded the minimum value. The completely weeded plot gave a significantly higher 1000 grain weight. The combination of azolla inoculation with complete weed control recorded highest panicle production.

Basal inoculation of azolla @ 0.3 kg/m^2 recorded a grain yield of 2939 kg/ha. However the maximum yield (3059 kg/ha) was recorded by azolla inoculation @ 0.5 kg/m^2,

though both these treatments were on par. Among the weeding treatments complete weed control gave the maximum grain yield (3552 kg/ha) and unweeded control the minimum yield (2341 kg/ha).

An increase in straw yield was noticed with the levels of azolla inoculation. Complete weed control treatment recorded the highest straw yield.

N, P and K uptake by the crop at harvest was seen increased with the rates of azolla inoculation. Complete weeding also registered maximum uptake values.

Inoculation of azolla @ 0.5 kg/m^2 recorded a significantly higher protein content of grain. Among the weeding treatments, complete weeding registered the maximum protein content.

Azolla inoculation @ 0.5 kg/m^2 recorded a significantly lower weed dry matter production than the other azolla levels at most of the stages. Among the weed control treatments, unweeded control recorded a significantly higher weed dry matter production. The combinations involving higher rates of azolla inoculation with unweeded control recorded significantly lower weed dry matter production when compared to the combination of no azolla with unweeded control.

A significant decrease was noticed in weed index as the level of azolla inoculation increased. Unweeded control recorded the highest weed index.

The lowest N, P and K uptake by weeds was recorded by azolla inoculation @ 0.5 kg/m^2. Unweeded control recorded significantly higher nutrient uptake than other weeding treatments.

Increasing azolla levels led to a progressive increase in total N, available P and exchangeable K content of soil. Complete weed control recorded the highest and unweeded control the lowest content of these nutrients.

Future lines of work

The following are some of the future lines of work suggested:-

(1) From this study it is seen that weeding beyond 45 days after planting is giving beneficial results in sandy soils. Hence the critical stages of crop-weed competition will have to be worked out in sandy soils in a detailed manner.

(2) In the present investigation weed dry matter production is comparatively less even in unweeded control.

Hence similar trials will have to be conducted in severely weed infested areas also to have wider acceptability.

(3) Azolla was seen to control weeds such as <u>Echinochloa</u> spp., <u>cyperus</u> spp., <u>Fimbristylis</u> <u>miliacea</u>, <u>Monochoria</u> <u>vaginalis</u> etc. in this study. However the efficiency of azolla in controlling other serious weeds of rice may also be investigated.

REFERENCES

REFERENCES

Abraham Varughese. 1978. Studies on the critical periods of weed infestation and effect of weed growth on yield and quality of a short duration rice. M.Sc.(Ag) thesis, Kerala Agricultural University.

Anonymous. 1976. Nitrogen fixation by Azolla-Anabaena Association. Annual Report 1976. International Rice Research Institute, Los Banos, Philippines. p. 232-233.

__________ 1978 a. Package of Practices Recommendations. Kerala Agricultural University: 1-26.

__________ 1978 b. Soil and Crop management. Annual Report 1978. International Rice Research Institute, Los Banos, Philippines. p. 245-258.

__________ 1980. Biological Nitrogen Fixation. Annual Report 1980. International Rice Research Institute, Los Banos, Philippines.

Arai, M. 1967. Competition between rice plants and weeds. Weed control basic to agricultural development. Proc. Ist Asian Pacific weed Control Interchange. Hawai. 37-41.

Arunachalam, G. 1980. Application of Azolla for rice production. Azolla A Biofertilizer. Tamil Nadu Agricultural University. 33-39.

Behra, B. 1982. Nitrogen fixation by Azolla in lowland rice culture. National Symposium on Biofertilizer Nitrogen fixation. New Delhi, 1982.

Bhan, V.M. and Maurya, R.A. 1972. Ann. Rept Res. Govind Ballah Pant University of Agriculture and Technology: 68.

_____, Naidu, N.G. and Dheer Singh. 1975. Ann. Conference of Indian Soc. Weed Sci. 1980. Abstr. Papers.

Bowes, G., Holaday, A.S. and Haller, W.T. 1979. Seasonal variation in the Biomass, tuber density and Photosynthetic metabolism of Hydrilla in three Florida lakes. Journal of Aquatic Plant Management., 17:61-65.

Bramer, P. 1927. La culture des Azolla an Tonkin. Rev. Int. Bot. Appl. Agric. Trop., 7 : 815-819.

Burga, C.A. and Togani, R. 1980. Weed competition in upland rice. Resumos XIII Congresso Brasileiro de Herbicidas e Ervas Daninhas. Bahia. 22-23.

-Chang, W.L. 1969. The effect of weeds on rice in paddy field. 1 Weed Species and population density. J. Taiwan Agrl. Res. 19(4) : 18-25. (Weed Abstr. 21(1) : 46 (297).

*Dubey, A.N., Manna, G.B. and Rao, M.V. 1977. Studies on weed competition, weed control and varietal interaction with propanil and parathion in direct seeded rice. Rep. Weed Science Conference and Workshop. Andra Pradesh Agricultural University, Rajendranagar, Hyderabad. Abstr. 14.

Eussen, J.H. 1978. The effect of light intensity on some growth characteristics of alang - alang (*Imperata cylindrica* (L.) *Beauv*). *BIOTROP*. p.9.

Fosberg, F.R. 1942. Uses of Hawaiian ferns. *Amer. Fern J.* 32 : 15-23.

Gill, G.S. and Vijayakumar. 1969. "Weed index", A new method for reporting weed control trials. *Indian J. Agron.* XIV(1) : 96-98.

Gomaz, K.A. 1972. *Techniques for field experiments with rice.* (1972). IRRI, Los Banos. Philippines.

Gomaz, K.A. and Datta, S.K. 1975. Influence of environment on protein content of rice. *Agron. J.* 67(4) : 565-568.

Gopalakrishna Pillai, K. and Rao, M.V. 1974. Current status of herbicides research on rice in India. *Pepaerpresented at the Annual International Rice Research Conference held at IRRI. Manila, Philippines from 22nd to 25th April, 1974*.

Govindarajan, K., Kannaiyan, S. and Ramachandran, M. 1979. Azolla manuring to rice. *Aduthurai Reptr.* 3(7) : 89-90.

Ishizuka, Y. 1971. Physiology of rice plant. *Adv. Agron.*, 23 : 241-315.

Jackson, M.L. 1967. Soil chemical analysis. Prentice Hall of India Pvt. Ltd.

Jaikumaran, U. 1981. Nitrogen economy through incorporation of Azolla in rice. M.Sc.(Ag.) thesis (Agronomy). Kerala Agricultural University.

Jean, W.W. and John, D.D. 1976. Growth of Water hyacinths in treated Sewage effluent. Econ. Bot. 30 (1): 29-36.

Kannaiyan, S., Thangaraju, M. and Oblisami, G. 1982. Studies on the multiplication and utilization of Azolla biofertilizer for rice crop. National symposium on biofertilizer Nitrogen fixation - New Delhi, 1982.

King, L.J. 1966. Weeds of the world, biology and control. Inter Science publishing Inc. New York, Ist Edn. p. 526.

*Kleing, C.R. and Noble, J.C. 1968. Competition between rice and barnyard grass (Echinochloa). Influence of weed density and nutrient supply in the field. Austr. J. Exp. Agric. Anim. Husb. 8(32) : 358-363 (Weed Abstr. 18(1) : 49(332))

Kulasooriya, S.A. and de Silva, R.S.Y. 1977. Nitrogen fixing blue-green algae in rice soils of Sri Lanka and their potential as a fertilizer in rice cultivation. In limitations and potentials for Biological Nitrogen fixation in the Tropics. Basic Life Science Vol. 10. p. 345-346.

Lakshmi, S. 1983. Weed control method for semi-dry dibbled crop of rice. M.Sc.(Ag.) thesis. Kerala Agricultural University.

Liu, Chung-Chu. 1979. Use of Azolla in rice production in China. Nitrogen and Rice. IRRI. p. 375-394.

Lizhuo-xin. 1982. Nitrogen fixation of Azolla in rice fields and its utilization in China. Non-symbiotic Nitrogen fixation and organic matter in the tropics. Symposia papers-1. 12th International Congress of Soil Science, New Delhi. p. 83-95.

Mallappa, M. 1973. Studies on chemical weed control in drill sown paddy. M.Sc.(Ag.) Dissertation. University of Agricultural Sciences, Bangalore.

Mani, V.S. 1975. Nutrient drain by weed growth in crop field. Fert. News. 20(2): 21-27.

Mathewkutty, T.I. 1982. Utilization of Azolla in rice ecosystem - Effect of dual culture and incorporation in first crop rice. M.Sc.(Ag.) thesis. Kerala Agricultural University.

Matsushima, S. 1970. Crop Science in Rice. Fuji Publ. Co., Tokyo. p.38.

Mathur, S.A., Krishnamoorthy, S. and Anavaradham, A. 1981. Azolla influence on rice yields. IRRN., 6(5) : 20.

*Mclaren, J.S. and Smith, H. 1978. Phytochrome control of of the growth and development of *Rumex obtusifolius* under simulated canopy light environments. *Plant, Cell and Environment*. 1(1) : 61-67.

Mehta, P.R. and Joshi, N.C. 1965. Chemical weed killers in tackling weed problems of India. *Sci. Cult.* *31* : 281-286.

Mohammed Ali, A. and Sankaran, S. 1979. Studies on crop-weed competition in direct-sown rice under puddled and non-puddled conditions. *Annual Conference of Indian Soc.Weed Sci. Abstr. papers*.

*Moore, A.W. 1969. Azolla: Biology and agronomic significance. *Bot. Rev.*, *35* : 17-34.

Nair, R.R., Pillai, G.R., Pisharody, P.N. and Gopalakrishnan R. 1975. Investigations on the competing ability of rice with weeds in the rainfed uplands. *Agri. Res. J.Kerala*. *13*(2) : 146-151.

Neogi, B. and Rao, R.R. 1980. Floristic composition of the weed flora, seasonal variation and phenology of some weeds of Agriculture lands in Khasi hills, Meghalaya. *Proc. Indian National Science Academy, B.* *46*(4) : 579-586.

Ngo Gia Dinh. 1973. The effect of *Azolla pinnata R. Br.* on rice growth. *Biotrop Report - Second Indonesian Weed Science Conference, Jogjakarta. April 2-5*.

*Nguyen Cong Tieu. 1930. L' Azolle cultivee comme engrais vert. Bull. Econ. Indochine. 33 : 335-350.

*Noda, K., Ozawa, K. and Shibayana, S. 1971. Studies on weed competition and effect of rice - competitive effects of barnyard grass at successive stages of rice. Weed Res. Japan 12 : 28-29. (Weed Abstr. 21(1)).

Olsen, C. 1972. On biological nitrogen fixation in nature, particularly in blue-green algae. Compt. Rend Trav. Carlsberg Lab. 37 : 269-283.

Panse, V.G. and Sukhatme, P.V. 1978. Statistical method for agricultural workers. 3rd Edn. Indian Council of Agricultural Research, New Delhi.

*Park, J.K. and Kim, D.S. 1971. Distribution of weeds and their competition with rice in Korea. 3rd Conference of the Asian Pacific Weed Science Society, Kaulalampur 2 App : 12 (Weed Abstr. 21(4) : 319 (1983)).

Patil, C.S., Jai Singh, Mittra, B.N., Patro, G.K. and Md. Zia Suhravordy. 1980. Use of Azolla fern as a good source of organic N in rice. Fert. News, 25(6) : 15-17.

Peters, G.A. 1975. The Azolla - Anabaena azollae Symbiosis. Pl. Physiol., 56(2) : 34.

Pillai, K.G. 1981. Land preparation, methods of crop establishment and weed management practices in upland rice. International Rice Commission Newsletter. 30(1) : 43-45.

*Rains, D.W. and Talley, S.N. 1978. Uses of Azolla in North America. In Proc. N. and Rice Symp. Sept. 1978. IRRI., Philippines.

Raju, R.A. 1978. Effects of levels and sources of nitrogen on Jaya. IRRN., 3(2) : 14.

Raveendran, C.S. 1976. Chemical control of weeds in transplanted rice during third crop season. M.Sc. (Ag.) thesis, Kerala Agricultural University.

Sankaran, S., Sethinam, P., Rajan, A.V. and Raju, K. 1974. Studies on nutrient uptake of certain field crops and associated weeds and its effect on seed production. Madras Agric. J. 61(9) : 624-628.

*Saubert, G.G.P. 1949. Provisional communication on the fixation of elementary nitrogen by floating fern. Ann. Roy. Bot. Gard. Buitenzorg, 51 : 177-197.

*Shen, C., Lu, S., Chen, K. and Ge, S. 1963. The initial experiment of Azolla's nitrogen fixing ability. Turang Tongbao (Pedology Bull.), Peeking. 4:46-48.

Shetty, S.V.R. and Gill, H.S. 1974. Critical period for crop weed competition in rice. Indian J. Weed Sci. 6(2) : 101-107.

Shetty, S.V.R., Gill, H.S. and Bhas, L.S. 1975. Weed flora of rice (oryza sativa) in Punjab. J. Res. 7(1) : 43-51.

Simpson, J.E., Adair, C.R., Kohler, G.O., Dawson, E.H., Dabald, H.A., Kester, E.B. and Klick, J.J. 1965. Quality evaluation studies of foreign and domestic rices. Tech. Bull. No.1331. Service U.S.D.A. 1-186.

Singh, P.K. 1977 a. Azolla plants as fertilizer and feed. Indian Frmg., 27(1) : 19-22.

__________ 1977 b. Multiplication and utilization of fern Azolla containing N fixing algal symbiont as a green manure in rice cultivation. 11 Riso., 26 : 125-136.

__________ 1977 c. The use of Azolla pinnata as a green manure for rice. IRRN., 2(2) : 7.

__________ 1979 a. Effect of dual culture of Azolla pinnata on yield of rice. Proc. 66th Indian Sci. Cong. Part IV. Sect. X. Agric. Sci., p. 114.

__________ 1979 b. Use of Azolla in rice production in India. Nitrogen and Rice - IRRI, p. 407-418.

Singh, P.K., Satapathy, K.B., Mishra, S.P., Nayak, S.K. and Patra, R.N. 1982. Application of Azolla in Rice cultivation. National Symposium on Biological Nitrogen fixation - New Delhi, 1982.

Smith, R.J. 1968. Weed competition in rice. Weed Sci. 16 : 252-255.

Srinivasan, S. 1981 a. Effect of Azolla manuring without incorporation. IRRN., 6(4) : 16.

__________ 1981 b. Population of the Weed *Marsilia quartrifoliata* in plots with Azolla. IRRN., 6(3) : 22.

Subba Rao, M.S. 1966. Stam F-34 can kill the weeds of gyora paddy. Indian Frmg. 16(4) : 6 and 37.

Subbiah, K.K., Morachan, Y.B. and Michaelraj, S. 1977. Influence of levels of N on yield and yield components. Madras Agricl J., 61(9) : 657-658.

Sukumari, P. 1982. Studies on the critical periods of weed infestation and effect of weed growth on yield and quality of a short duration direct-sown rice under semidry condition. M.Sc.(Ag.) thesis. Kerala Agricultural University.

Swain, D.J. 1967. Controlling barnyardgrass in rice. Agric. Gaz. 78(8) : 473-475.

Talley, S.N., Talley, B.J. and Rains, D.W. 1977. Nitrogen fixation by Azolla in rice fields. In Genetic Engineering for nitrogen fixation. Hollaender et al. (ed.) Plenum Publishing Corporation, New York, p. 259-289.

Tanaka, A., Navasero, S.A., Garcia, C.V., Patras, F.T. and Ramirez. 1964. Growth habit of the rice plant in the tropics and its effects on nitrogen response. IRRI Tech. Bull., 3 : 1-80.

Watanabe, I. 1977. Azolla utilization in rice culture. IRRN., 2(3) : 10.

Watanabe, I., Berja, N.S. and Rosario, D.C.D. 1980. Growth of Azolla in paddy field as affected by phosphorus fertilizer. Soil Sci. Plant Nutr., 26(2) : 301-307.

Watanabe, I., Osamulto and Coragon, R.Espinas. 1981. Growth of Azolla with rice and its effect on rice yield. IRRN., 6(1) : 21.

* Originals not seen.

APPENDICES

APPENDIX - I

Meteorological data for the cropping period (1982) and the average values for the last five years (1977-1981).

Period		Total rainfall (mm)		Mean minimum temperature (°C)		Mean maximum temperature (°C)		Mean pan evaporation (cm)		Mean relative humidity at 8 A.M. (%)	
		A	B	A	B	A	B	A	B	A	B
July	15-22	106.3	208.7	23.9	23.7	27.6	27.0	0.412	0.307	85.6	92.3
	23-29	79.9	191.1	24.4	23.3	28.1	28.9	0.460	0.240	81.4	90.0
	30-5th	27.2	142.7	24.5	23.6	30.6	29.6	0.540	0.296	79.8	89.9
Aug.	6-12	193.6	216.4	23.9	23.3	26.9	28.1	0.364	0.280	89.9	91.1
	13-19	49.5	110.5	23.9	23.7	27.6	29.2	0.315	0.309	85.9	89.1
	20-26	143.2	99.9	24.1	24.1	28.3	30.0	0.253	0.303	90.1	88.3
	27-2nd	162.5	86.7	23.7	23.8	29.4	29.9	0.282	0.280	90.1	87.9
Sept.	3-9	62.0	97.7	23.3	23.8	29.0	29.4	0.279	0.274	83.1	89.6
	10-16	78.6	87.8	24.1	23.6	29.1	29.5	0.233	0.292	87.3	89.3
	17-23	143.9	39.6	24.0	24.1	30.1	30.4	0.364	0.314	88.6	87.0
	24-30	211.1	29.2	23.4	23.8	27.7	30.8	0.370	0.376	86.9	87.1
Oct.	1-7	285.6	31.3	23.4	23.7	27.4	30.8	0.212	0.338	92.0	84.1
	8-14	47.8	67.1	23.8	23.9	29.9	30.4	0.330	0.303	87.4	86.8
	15-21	1.5	66.1	23.4	24.1	31.4	31.3	0.317	0.336	76.6	85.3
	22-28	87.2	115.4	23.6	24.1	31.0	31.7	0.249	0.378	83.6	86.4
	29-4th	47.0	122.0	24.1	23.9	31.3	31.1	0.285	0.315	72.6	88.3
Total		1737.8	1726.0	-	-	-	-	-	-	-	-
Mean		-	-	24.2	25.3	28.7	31.1	0.327	0.308	84.3	88.2

A - During the cropping period B - Average for the last five years

APPENDIX - II

Abstract of analysis of variance table for growth characters

Character	Mean square				
	A (5)	Error A (10)	W (3)	AxW (15)	Error W (36)
I. <u>Growth characters</u>					
a. Height of plants (MTS)	45.72	61.54	2.13	3.60	7.55
b. Height (PIS)	91.36	61.68	23.23	25.89	28.10
c. Height (Harvest)	6.94	105.22	22.35	25.95	23.12
d. Tiller number/m^2 (MTS)	5639.16	7342.22	988.61	1306.56	1112.39
e. Leaf area index (MTS)	2.42	4.43	5.07	6.97	1.10
f. Leaf area index (PIS)	4.44	4.85	4.07	1.56	2.87

MTS - Maximum tiller stage
PIS - Panicle initiation stage
A - Azolla levels
W - Weeding treatments
Figures in parenthesis indicate degrees of freedom.

APPENDIX - III

Abstract of analysis of variance table for yield components, yield and harvest index

Character	Mean square				
	A (5)	Error A (10)	W (3)	AxW (15)	Error W (36)
Yield components					
a. Number of panicles/m^2	2980.26	4203.23	821.02	1793.68*	853.66
b. Number of filled grains/panicle	41.76	124.30	133.23	73.59	48.78
c. 1000 grain weight	7.52	7.85	30.98*	13.60	10.41
Yield					
a. Grain yield	143911.41*	352284.95	2322942.07*	115285.44	85380.29
b. Straw yield	7371987.09	2353095.17	3637905.23*	754986.13	472319.94
Harvest index	0.042	0.015	0.010	0.004	0.004

* Significant at 5 per cent level
A - Azolla levels
W - Weeding treatments
Figures in parenthesis indicate degrees of freedom.

APPENDIX - IV

Abstract of analysis of variance table for chemical analysis (CROP)

Character	Mean square				
	A (5)	Error A (10)	W (3)	AxW (15)	Error W (36)
Nutrient uptake by crop					
a. N uptake at harvest	1678.29	582.20	2317.06*	945.54*	264.04
b. P uptake at harvest	55.58*	12.22	83.52*	23.59	4.22
c. K uptake at harvest	2347.10	1719.16	3635.82*	1502.74*	316.73
Quality character					
a. Crude protein content of grain	3.10*	0.47	1.65	1.90*	0.97

* Significant at 5 per cent level
A - Azolla levels
W - Weeding treatments
Figures in parenthesis indicate degrees of freedom.

APPENDIX - V

Abstract of analysis of variance table for Dry matter production of weeds and weed index

Character	Mean square				
	A (5)	Error A (10)	W (3)	AxW (15)	Error W (36)
Dry matter production of weeds					
a. 15 days after planting	1.45*	0.10	3.58*	0.18*	0.05
b. 30 days after planting	1.84*	0.15	3.48*	0.23*	0.09
c. 45 days after planting	3.23*	0.09	5.63*	0.42*	0.08
d. Harvest	0.65*	0.11	15.69*	0.20*	0.09
Weed index	463.90*	84.04	4297.78*	347.21	181.83

* Significant at 5 per cent level
A - Azolla levels
W - Weeding treatments
Figures in parenthesis indicate degrees of freedom.

APPENDIX - VI

Abstract of analysis of variance table for chemical analysis (WEED) and soil analysis.

Character	Mean square				
	A (5)	Error A (10)	W (3)	AxW (15)	Error W (36)
<u>Nutrient uptake of Weeds</u>					
a. N uptake at harvest	771.67*	161.78	1517.97*	125.72*	61.18
b. P uptake at harvest	23.99*	5.05	84.24*	5.43*	2.49
c. K uptake at harvest	491.26*	74.78	1967.03*	192.14*	39.98
<u>Soil analysis</u>					
a. Total N	0.0002	0.0002	0.00005	0.00003	0.00005
b. Available P	182.12	150.92	5.57	60.89	45.46
c. Exchangeable K	45.81	52.51	18.01	64.79*	19.86

* Significant at 5 per cent level

A - Azolla levels

W - Weeding treatments

Figures in parenthesis indicate degrees of freedom.

EFFICIENCY OF AZOLLA FOR WEED CONTROL IN RICE ECOSYSTEM

BY

MADHAVA CHANDRAN, K.

ABSTRACT OF A THESIS
Submitted in partial fulfilment of the requirement
for the degree
MASTER OF SCIENCE IN AGRICULTURE
Faculty of Agriculture
Kerala Agricultural University

Department of Agronomy
College of Agriculture
Vellayani, Trivandrum

1984

ABSTRACT

An experiment was conducted in sandy soils of the Agronomic Research Station, Chalakudy during the first crop season (Kharif) of 1982. The efficiency of azolla for weed control in rice ecosystem was investigated in order to find out a suitable alternative to the traditional weed control methods used in rice culture.

The treatments consisted of a combination of 6 levels of azolla inoculation (0, 0.1, 0.2, 0.3, 0.4, 0.5 kg/m^2) in the main plot and 4 weeding treatments (unweeded control, complete weed control, handweeding 15 D.A.P, handweeding 15 and 30 D.A.P.) in the sub plot. The 24 treatment combinations were replicated thrice and laid out in splot plot design.

The study revealed that the growth characters like plant height, tiller production and leaf area index were higher in the treatment receiving azolla inoculation @ 0.5 kg/m^2. The completely weeded plots also recorded higher values for these parameters.

Dual culturing of azolla with an inoculation rate of 0.5 kg/m^2 recorded maximum values with regard to the yield components viz., number of panicles/m^2, number of

filled grains/panicle and 1000 grain weight, ultimately resulting in higher grain production by this treatment. However an inoculation rate of 0.3 kg/m^2 was seen to be sufficient for producing optimum grain yield. Treatment receiving no azolla inoculation recorded the lowest grain yield.

The azolla levels as well as weeding treatments recorded a progressive increase in straw yield of the crop.

The highest rate of azolla inoculation as well as complete weeding registered a higher N, P and K uptake by the crop at harvest.

Azolla inoculation @ 0.5 kg/m^2 recorded a significantly higher protein content.

A significantly lower dry matter production of weeds was noticed at the azolla inoculation level of 0.5 kg/m^2 at most of the stages. Even in an unweeded plot, azolla inoculation at higher rates gave sufficient degree of weed control. The N, P and K uptake by weeds also followed the same trend.

Increase in azolla levels produced a significant decrease in the weed index.

Soil nutrient status was not significantly influenced by the treatments.

The present investigation revealed the scope of dual culturing azolla in rice culture for control of weeds. A higher rate of azolla inoculation of 0.5 kg/m^2 (5 tonnes/ha) could bring about satisfactory weed control and produced a grain yield of 3059 kg/ha. Similarly complete weed control was found to be the most effective and recorded a grain yield of 3552 kg/ha, followed by weeding 15 and 30 D.A.P. (2665 kg/ha), weeding 15 D.A.P. (2650 kg/ha) and unweeded control (2341 kg/ha).