ECOPHYSIOLOGY OF AZOLLA AND ITS MANAGEMENT FOR RICE PRODUCTION

By

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THESIS

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DECLARATION

I hereby declare that this thesis entitled 'Ecophysiology of azolla and its management for rice production' 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 titles, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled 'Ecophysiology of azolla and its management for rice production' is a record of research work done independently by Mr. D. Alexander under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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Introduction

I. INTRODUCTION

Rice, the staple food of India, occupies an area of about 40.09 million hectares and contributes about 41 per cent of the total food grain production. Nitrogen is the 'Kingpin' in rice production and with the introduction of high yielding rice varieties, there has been an increasing tendency to rely more on the inorganic nitrogenous fertilizers for enhancing rice production. But the energy crisis and consequent escalation in the cost of chemical fertilizers have imposed serious limitation in crop production. In this context biological nitrogen fixation is considered as the best alternate strategy. It is reported that biological nitrogen fixation by different types of organisms contributed to the earth about 175 million metric tonnes of nitrogen per annum (Swaminathan, 1980).

It has long been recognized that a biological nitrogen fixing mechanism prevails in the ecosystem of submerged soil. In the tropical rice soils, this rolo is fulfilled by the activity of blue green algae either alone or in association with azolla and certain non-symbiotic nitrogen fixing bacteria.

Azolla has been widely used in rice production for long time (Venkataraman, 1980). The merits of azolla lie in its ability to harness solar energy and fix atmospheric nitrogen simultaneously. *Azolla pinnata* is an aquatic fern which harbours the microsymbiont *Anabaena azollae* in a symbiotic association. The nitrogen fixing ability of azolla has been claimed from the lowest of 80 kg to a highest of 670 kg nitrogen $ha^{-1}yr^{-1}$ depending upon the intensity of cultivation and management (Singh, 1977a). The easy availability of nitrogen from azolla to the standing rice crop and synchronized growth make it suitable as the best biotic component in the integrated nitrogen management system. Further, its high phytomass which can be a substitute for bulky organic manures, which are becoming costly and scarce, is a boon to the present day agriculture. Thus the Azolla-Anabaena symbiosis has gained global significance as an agronomically viable nitrogen source for flooded rice. The relevance of this technology to Kerala is obvious from the fact that rice which occupies an area of 7.07 lakh hectares is the major consumer of available fertilizers in the State.

With the identification of azolla as a potential nitrogen source for rice, research on azolla has been intensified all over India to exploit its full potential. However, results vary with species, soil and climatic conditions. As far as Kerala is concerned growth of azolla has been varying widely and even in the same place the growth is erratic in different years. Detailed investigations about weather parameters, water quality and soil factors affecting its growth are very few in India, so also studies on the nutritional requirement of azolla for rapid multiplication in the field. The possibility of growing azolla elsewhere and collecting, transporting and applying in far away places as an organic manure is not practically feasible because of high cost of labour involved. As most of the areas in Kerala are dry sown in the first crop season (May-August) and time gap between the harvest of the first crop and planting of the second crop (September-January) is short, growing azolla as a monocrop before planting is not practicable. Thus in Kerala, there is scope for simultaneous cultivation of azolla as an intercrop with rice. Though a few trials have been conducted in India on this line, information on quantity of azolla inoculum required and time of its application in rice field is quite inadequate.

In tropical region, solar radiation and temperature play dominant roles in the multiplication of azolla in the rice field. Methods of planting rice, adoption of row spacing and alteration of direction of planting (so as to protect azolla from high temperature and solar radiation) are worth trying as information on these lines is practically nil. Similarly concomittant problems like rate of mineralization of azolla, both as fresh and dry materials, and use of azolla as an organic manure and the possibility of partial substitution of mineral fertilizers for rice by azolla also demand investigation.

In view of the above facts, the present investigation on 'Ecophysiology of Azolla and its Management for Rice Production' was undertaken with the following objectives.

1. To study the influence of environmental conditions on the growth and establishment of azolla.

2. To assess the nutritional requirement of azolla.

3. To find out the optimum quantity of azolla inoculum required and time of application for growing it as an intercrop with rice.

4. To identify the method of planting rice favouring multiplication of azolla in the field.

5. To study the rate of mineralization of azolla compared to other organic manures.

6. To evaluate azolla as an organic manure and to explore the possibility of reducing the fertilizer requirement of rice by the use of azolla.

The findings which have emerged from this study have been presented here.

Review of Literature

II. REVIEW OF LITERATURE

The water fern azolla with its nitrogen fixing endosymbiont, Anabaena is being traditionally used as a biological source of nitrogen in rice cultivation in Vietnam and some parts of China (Singh, 1983) and interest on azolla research got a fillip when FAO brought it to the scientific attention (FAO, 1977). Of late, considerable attention is being given to such a system in India (Singh, 1977a), in Philippines (Watanabe, 1977) and in U.S.A. (Rains and Talley, 1979).

The available literature on azolla pertaining to the scope and use of azolla in rice culture, features of Azolla-Anabaena complex, ecological requirement of azolla, nutritional requirement of azolla, time and quantity of azolla inoculum to be applied in the field, method of planting of rice favouring azolla growth, mineralization of azolla after incorporation into the soil, evaluation of azolla vis-a-vis other organic manures and its effects in reducing the fertilizer requirement of rice are reviewed.

2.1. Scope and use of azolla in rice culture

Azolla is a genus of water fern that assimilates atmospheric nitrogen in association with nitrogen fixing blue green algae Anabaena azollae, that lives in the cavities of dorsal lobes of azolla as a microsymbiont (Moore, 1969; Ashton and Walmsley, 1976 and Becking, 1978). Azolla is widely distributed in the rice growing tracts of tropical and temperate zones and it grows in the irrigated rice fields.

Azolla has been used as a green manure for rice in Indonesia (Saubert, 1949), Vietnam (Bui, 1967), Thailand (Moore, 1969) and in China (Lin, 1976). Venkataraman (1980) stated that in China azolla is often described as "fertilizer from the soil to the soil", "field fertilizer factory", "miniature N fertilizer factories" and "indestructable N factories".

Azolla is a potential substitute for fertilizer nitrogen due to its rapid growth, doubling in 3-5 days, and its high nitrogen fixing capacity. Singh (1977c) estimated that a layer of azolla covering one hectare of field produces 10 t of green matter containing about 30 kg N. According to Stewart (1977) azolla can produce a green matter yield of 200-300 t compared to 30-50 t ha^{-1} yr^{-1} produced by other green manure crops. The Azolla-Anabaena association has been reported to fix 80-600 kg N ha^{-1} yr^{-1} as compared to 60-70 kg fixed by blue green algae (Sreerangasami, 1980).

Moore (1969) suggested that the azolla-blue green algae combination appears to be capable of fixing amounts of nitrogen in the field of the same order of magnitude in a leguminous crop. The nitrogen fixing capacity of azolla exceeded that of the legume rhizobium symbiosis (Lumpkin and Plucknett, 1982).

Examining the scope of growing azolla, Joy (1984) found that monocropping of azolla during the twenty days before transplanting yielded 19.8 t fresh azolla ha^{-1} thus contributing 30 kg N ha^{-1} whereas intercropping of azolla with rice during the thirty days after transplanting yielded 15.6 t fresh azolla ha^{-1} thus supplying 22.4 kg N ha^{-1} and dual cropping of azolla during the period of fifty days yielded 35.4 t of fresh azolla ha^{-1} supplying 51.5 kg N ha^{-1} to the rice crop.

Mathewkutty and Sreedharan (1983) found that azolla is an efficiont substitute for nitrogen fertilizer where there is a possibility of vertical and lateral leaching.

The effect of azolla was relatively more consistent than that of blue green algae, however interlocation differences were similar. When azolla is grown in a dual cropping system with rice, cost of inoculating with 500 kg azolla may be Rs.40 ha^{-1} which is similar to the blue green algae (Pillai, 1984). Sreerangasami (1980) reported that the blue green algae system admittedly cannot compete very effectively with the smothering algal blooms. In contrast, the azolla system is bestowed with such advantage that normally an emergent floating waterplant has. In addition, the size, growth, development and multiplication of azolla is visually perceived well and appreciated. It can be used along with N fertilizer and the requirement of N can be reduced (Singh, 1977c). It was invariably noticed that angiospermic weeds were less in the presence of azolla in rice fields (Singh, 1977b). Azolla improves soil productivity and rectifies zinc deficiency in rice (Srinivasan, 1981).

Importance of azolla lies in the fact that as an aquatic green manure, azolla does not occupy land needed for upland crops and can grow where terrestrial green manures cannot. Its symbiotic relationship with nitrogen fixing cyanobacterium produces nitrogen under suitable condition. Azolla grows fast, doubling in 3-5 days and a thick mat helps to control weeds (Lumpkin and Plucknett, 1982).

Pillai et al. (1985) reviewing the experiments on azolla reported that partial substitution of nitrogen requirement of rice could be achieved through the use of azolla with some promise, only in the rainfed lowland areas covering the river delta system especially in North Eastern India, where there is perennial water resources and silt laden soils, which help easy multiplication of azolla.

Pillai et al. (1980) further stated that in many locations in South India, failure of multiplication of azolla and blue green algae is due to the extremely high and low atmospheric and water temperatures and low availability of P and Ca.

It can be concluded that there is considerable scope for growing azolla as an intercrop with rice compared to blue green algae. It is more adaptable to soil conditions, and has the capacity for high biomass production. This is particularly important at the present time when the bulky organic manures are becoming costly and scarce.

2.2. Features of the *Azolla-Anabaena* complex

Azolla belongs to the phylum Felicophyta, order Salviniales and family Azollaceae. The genus *Azolla* comprises seven species.

Azolla caroliniana, A. filiculoides, A. mexicana, A. microphylla, A. rubra, A. nilotica and A. pinnata (Konar and Kapoor, 1974; Lumpkin and Plucknett, 1982).

The azolla plant has a branched floating system that bears alternatively arranged, overlapping leaves and true roots. Each leaf is deeply bilobed and the dorsal lobe contains the algal symbiont in the internal cavities at the proximal end (Peters et al., 1978). The fern provides nutrients and protective leaf cavity for the Anabaena which in turn supplies fixed N for the fern (Hill, 1975; Peters, 1976; Singh, 1977c).

Nitrogen fixation occurs only in the Anabaena cells and most of the energy requirement is fulfilled through the photosynthesis of the host azolla.(Ladha and Watanabe, 1982).

Azolla reproduces often vegetatively by fragmentation and rarely by producing spores (Gopal, 1967; Ashton, 1977). Sexual reproduction of azolla through the sporocarp was studied by Gurunathan and Sreerangasami (1983) who reported that in the field azolla micro and mega spores do not germinate until they are liberated from sporangia, and fertilization occurs only in water. The zygote formed after fertilization is deposited on the soil surface where it remains in dormancy for 2-3 months. After this dormancy period normally zygotes sprout into small seedlings 10-15 days after incubation.

The fern grows well in nitrogen free nutrient solution and exhibits a rapid doubling time varying from 63 to 108 hours.

A. pinnata had an average moisture content of 94.5 per cent of the fresh weight and total N content of 3.01 per cent of the dry weight (Brotonegaro and Abdulkadir, 1976). Ashton and Walmsley (1976) found that the *Anabaena azollae* could supply all the N required by the host through nitrogenase activity.

Peters *et al.* (1978) found that in comparison with blue green alga and legume rhizobium symbiosis, nitrogenase activity by *Anabaena* did not cease when grown for long periods with adequate or excessive amounts of combined nitrogen in the medium.

Becking (1979) reported that the nitrogen fixation of azolla is generally in the order of 1.0-2.5 µmol g^{-1} fresh weight hr^{-1} and with 3-4 per cent N, it fixed over 300 kg N ha^{-1} yr^{-1}. Singh (1979) found that about 333 t ha^{-1} of fresh azolla containing about 840 kg N could be harvested annually. Talley and Rains (1980) reported that the rate of nitrogen accumulation was 2.7 kg N ha^{-1} day^{-1} under field conditions whereas Watanabe *et al.* (1981) could get only 1.4 kg N $ha^{-1}day^{-1}$ from a year round pot experiment.

Peters and Mayne (1974) reported that a major portion of nitrogen fixed by the symbiont is released into leaf cavities and removed by ammonia assimilating enzymes specifically glutamine synthetase of the host plant, possibly localized in the hairy cells which line the cavities.

The azolla was estimated to account for 90 per cent of the glutamine synthetase activity and 80 per cent of the glutamate dehydrogenase activity of the system (Ray et al., 1978). According to Peters et al. (1981) the isolated symbiont exuded upto 50 per cent of its fixed nitrogen into the incubation medium as ammonia.

Lumpkin and Plucknett (1982) indicated that dry matter content of azolla varied from 4.8 to 7.7 per cent and the dry matter contained 41.5-45.3 per cent carbon, 39.2 per cent crude fibre, 13-30 per cent crude protein, 1.96-6.0 per cent N, 0.16-1.59 per cent P, 0.31-5.97 per cent K. The C:N ratio of azolla was 7-18:1.

To sum up, azolla is a water fern usually found floating in stagnant water. The nitrogen fixing blue green algae (*Anabaena azollae*) lives in the internal cavity formed at the proximal portion of upper lobe of leaves. The fern provides nutrients and protective leaf cavity for the *Anabaena* which in turn provides fixed nitrogen for the fern. Among the seven species of azolla, *Azolla pinnata* is the species found in India. Value of azolla as an organic manure is high as it contains 1.96-6.0 per cent N, 0.16-1.59 per cent P and 0.31 to 5.97 per cent K and the C:N ratio varies from 7-18:1.

2.3. Ecological requirement of azolla

Ahmad (1941) reported that in lower intensities of light, root system of azolla showed poor development and the older roots were observed to fall off from the plant. He also found that light and temperature both act as limiting factors simultaneously.

Lu *et al.* (1963) found that the growth of azolla began to decline approximately thirty days after transplanting rice as the light below the canopy was reduced to less than 50 per cent of full sunlight.

Ashton (1974) observed that both the growth rate and the nitrogenase activity of *A. filiculoides* changed with the increasing light intensity. At optimal light intensity which was 50 per cent of full sunlight i.e., about 49 klx and with a day length of 12 hr, he observed a growth rate of 0.150-0.175 g day^{-1} in South Africa.

Since full sunlight is of the order of 80 to 150 klx, the fern prefers an environment where a certain degree of shading is available and it is able to tolerate a wide range of pH and temperature (Ashton and Walmsley, 1976). They have also found that light plays a major role in governing the growth of the fern largely through its effects on the process of photosynthesis. The action of light is further complicated by the fact that light intensity and pH of the medium have interacting effects on the growth rate of fern. When plant experiences light intensity above 60 klx there is inhibition of growth at all pH values.

Holst and Yopp (1976) recognised that nitrogen fixation was reduced (30 per cent) less than nitrate reduction (50 per cent) in response to decreasing quantity from 2400 to 1200 ft.c.

Both were reduced drastically at still lower light levels (100 ft.c).

Becking (1979) opined that azolla prefers an environment with a certain degree of shading in rice fields depending on plant density. He also found that at day lengths longer than 8 hr, specific nitrogenase activity does not increase while growth rate does. Optimum solar energy for growth of azolla is from 20 to 50 Klx (FAO, 1979).

Holst (1977) was of the opinion that the presence of azolla symbiosis under natural condition appeared to be affected by air and water temperature and light quantity. Plant material exposed to the direct sun was red pigmented and senesced when air and water temperatures exceeded 25°C, shaded green pigmented plants appeared to be more tolerant to high temperature.

Van Hove et al. (1983) observed that azolla growth increased with light intensity upto a certain level. At optimum temperature, saturation was reached at 50 per cent of full sunlight but growth remained good even at maximum light intensities.

Ahmad (1941) noticed that the maximum growth of azolla species took place at 22°C ± 1°C. The light compensation point for *Azolla filiculoides* is not constant but varies directly with the temperature. High water temperatures are inimical to the growth of *Azolla pinnata* (Moore, 1969).

Lumpkin (1977) stated that in winter and spring when temperature was mild and the fern was free of pests, azolla reached a density of 24 t ha^{-1}. Densities were also high during summer if pesticides were used and water temperature was kept below 30°C. Brotonegoro and Abdulkadir (1976) concluded that temperature rather than light intensity affected the nitrogenase activity.

According to Becking (1979) the most favourable period for vegetative growth of azolla was August-February during which the mean daily temperature was 16-17°C. Towards the end of March when the temperature rose to 22-24°C, much of the azolla died. Therefore one of the main problems of growing azolla in Vietnam was observed to be the deleterious effect of hot season.

Watanabe <u>et al</u>. (1977) found that azolla growth at a temperature of 35/27°C was reduced by about 50 per cent and in their view 27°C is favourable for growth of <u>Azolla pinnata</u>. Tuan and Thuyet (1979) mentioned that negative response of azolla to high pH was more due to high temperature and high light intensity. He also found that when the temperature at 14 hr rose to 30°C, azolla turned reddish and at 35°C it began to die.

Talley and Rains (1980) in their laboratory studies in controlled environment noticed exponential growth rate of <u>Azolla filiculoides</u> and the growth rate increased linearly with temperature between 10/1 and 25/15°C and remained high upto 35/25°C. Watanabe <u>et al</u>. (1981) tested 15 strains of azolla and observed that the biomass production was higher at 22°C than at 33°C in all the strains. At 20°C, maximum biomass was obtained in 20-35 days in *A. caroliniana*. Nitrogen fixation (6.3 g m^{-2}) and dry matter production (15 g m^{-2}) were also maximum at this temperature.

It is reported that water temperature was probably the most important environmental factor limiting the spread of azolla cultivation in the tropics and the most favourable mean air temperature ranged between 20 and 30°C (Lumpkin and Plucknett, 1982; Van Hove *et al.*, 1983).

Pal *et al.* (1982) reported that azolla biomass production was sharply deteriorating with the extremes of temperature prevailing either in winter or in summer coupled with other environmental factors. They also found that heterocyst frequency of the symbiont was also higher during the months of peak biomass production.

Singh (1979) suggested that azolla grew at a water temperature of 14-40°C but it grew better at 20-30°C. At higher temperatures growth was slow and the plants turned brown. In China when day temperature is higher water is drained from the field daily and cool water is let in to the field during night time (Venkataraman, 1980).

Goss (1973) reported that temperature above optimum caused metabolic disturbances and desiccation due to higher rate of water loss. He further observed that at higher temperatures protoplasmic streaming decreased as protoplasm became more viscous. Photosynthesis was greatly reduced but the respiration rate continued to increase. High light intensity caused increase in temperature which increased the rate of respiration.

The optimum relative humidity for growth of azolla is 85-90 per cent and at humidity below 60 per cent azolla does not grow (FAO, 1979). Roger and Kulasooriya (1980) observed that in paddy field in Italy where the dry period was relatively short, nitrogen fixing blue green algae comprised only about 30 per cent of the algal flora, but in Senegal, where the dry season lasts about eight months, spores of heterocystous blue green algae constituted more than 95 per cent of potential flora at the end of the dry period and homocystous blue green algal forms were present primarily because of their introduction through irrigation water. There is evidence that variations in sporulation rate and number of sporocarps of A. filiculoides are closely related to temperature. Observations on the dynamics of sporulation in a nursery field during the summer showed that sporocarp formation commenced at an average temperature over 13°C (ranging from 6.5°C to 26.5°C). Sporocarps developed rapidly after the temperature rose, but declined sharply when the field temperature exceeded 25°C. At that time the azolla sporocarp matured and sporulation ceased.

In addition to temperature, sporulation was related to the morphological stage of the azolla lobe and to fertility management (Shi-ye li, 1984).

Studying the effect of wind, Ashton and Walmsley (1976) reported that azolla plants are very fragile and susceptible to fragmentation if physically disturbed. Therefore an exposed water surface, where wind and wave action are very high and a large degree of turbulence exists, Azolla filiculoides would show poor growth and development of azolla mats would be highly unlikely. Lumpkin and Plucknett (1982) studying the effect of wind, stressed that wave action and turbulence were deleterious to azolla. They further explained that wind caused the amassing of plants on the leward side of water surface and wave action and turbulence caused premature fragmentation and eventual death. Wind produced a state of overpopulation which inhibited growth of azolla (Van Hove et al., 1983).

Discussing the effect of frost, Becking (1979) remarked that A. filiculoides dies if the water surface freezes and azolla cannot survive as sporophytes in temperate region after prolonged period of frost in winter.

Studying the effect of atmospheric gases, Ashton and Walmsley (1976) noted that growth of azolla is not complete unless a constant circulation of atmospheric gases is maintained over the plant. They also observed that O_2, N_2 and CO_2 exert their effects through metabolic process of photosynthesis, nitrogen fixation and respiration. Becking (1978) is of the opinion that for optimal metabolic activity and growth a constant supply of N_2, O_2 and CO_2 is necessary and obstruction of free gas diffusion reduces growth rate.

Janiya and Moodi (1981) reported that all herbicides used were deleterious and caused significant reduction in fresh weight, 30 days after transplanting. 2,4-D caused the least reduction on growth. Propanil was more detrimental than 2,4-D at four days after transplanting. It appears unlikely that herbicides can be used for weed control when rice is inoculated with azolla. Venkataraman and Kannaiyan (1984) were of the opinion that increasing the concentration of Butachlor had gradually decreased the growth of azolla.

Among the factors influencing the growth of azolla, soil also plays a significant role. Venkataraman (1980) reported that even in South China large scale use of azolla has been taken up only in coastal belt of Yangtese river basin. In fertile soils, the growth of azolla is very fast and in sandy soils growth of azolla is poor.

The widely publicized success of azolla production and utilization in South Cotobato in Philippines were because of two reasons (1) the soil of that area contained relatively high level of P and (2) the wet season extends from April to December with only three dry months. During dry season, the average monthly rainfall remain above 50 mm (IRRI, 1984).

Ashton and Walmsley (1976) reported that acidic soils, having pH 3-3.5, did not support growth of azolla and the inoculum dried out. Singh (1977a) also found that azolla grew better in soils of pH 5.5-7 than in soils of pH 8 although plants grew at pH 10.

While studying the effect of liming on soil pH and azolla growth, Habeeburrahman (1983) observed a rise in pH from 5.6 to 6.4 due to liming. He concluded that a combined effect of increase in soil calcium and rise in pH due to liming had resulted in the increase of fresh weight of azolla. Brady (1970) observed that when the soil reaction is held within a soil pH range of 6.0 and 7.0, toxicity of elements can satisfactorily be suppressed, at the same time their availability will be assured unless these elements are inherently lacking in the soil.

According to Becking (1979) water is a fundamental requirement for the occurrence of azolla. Although azolla can grow on a wet mud surface, it prefers to grow in a free floating state on the water surface. In shallow water, the azolla plant may touch the soil surface with its roots but it can also grew in much deeper water where the nutrient uptake is completely from the water environment. He also found azolla getting wilted in paddy fields in Northern Vietnam if the concentration of salts during the warmest summer period reached 1480-1872 mg liter^{-1} because of intensive evaporation.

Van Hove et al. (1983), studying the ecophysiology of azolla, reported that growth of azolla is promoted by a fairly shallow depth of water (5 cm) which favours mineral nutrition since roots are near to the soil and reduces the negative effect on growth by water turbulence, on the other hand it should not allow rooting in the soil which sustains growth because it creates a premature state of over population. They were also of the opinion that azolla is tolerant to pH. It survives in a pH ranging from 3.5 to 10 and grows well from 4.5-9.0.

On the water quality and azolla growth, Lumpkin and Plucknett (1982) reported that among pH, salinity and turbulence, pH has been the most widely studied and is probably the most limiting in rice paddies. The most serious _in situ_ pH effects on azolla occur indirectly because of pH related toxicities or deficiencies of elements in the soil solution. The pH for optimum growth of azolla in solution culture is within the range of 4.5 to 7.0. They further observed that there was no significant growth difference between plots having a standing water of 5 cm and 15 cm depths.

Salinity has rarely been mentioned as a problem on the cultivation of azolla. Halten _et al_. (1974) reported that the growth of _A. caroliniana_ ceases in a solution containing 1.3 per cent salt. Lumpkin and Plucknett (1982) found healthy looking azolla in thirty different locations where water conductivity ranged from 70-368 µmhos.

It can be summarised that among the conditions congenial for growth of azolla, temperature and light play dominant roles. Light intensity of 20-50 klx and a water temperature of 20-30°C are optimum for the growth of azolla. Wind and wave action and other physical disturbances also affect its growth. A fertile soil with a pH of 5.5-7.0 favour its rapid growth. A fairly shallow depth of water (5 cm) having a neutral pH favours the growth of azolla.

2.4. Nutritional requirement of azolla

Ashton and Walmsley (1976) reported that for optimal growth, the fern requires all the macro and micronutrients which are essential for normal plant growth. Macro nutrients such as P, N, K, Ca and Mg are especially important and produce marked effect on the growth of the fern. Since nitrogen fixation by the symbiont also plays a dominant role in regulating growth of the fern, micronutrients such as Fe, Co, Mo which have been shown to be essential for nitrogen fixing process are also important.

Becking (1979) found that introduction of combined nitrogen reduced fresh weight of azolla to 34 per cent and total N content to 40 per cent compared to the control. He further observed that for nitrogen, the association can rely on the supply of N_2 in the air. Combined nitrogen is however also assimilated and may support the system even when N_2 fixation goes on. Both nitrogen sources can be assimilated simultaneously because the combined nitrogen is assimilated by the roots while the N_2 is assimilated by the endosymbiont. According to him, azolla can be cultivated in a simple nitrogen free medium containing only a few salts such as magnesium sulphate, calcium chloride, potassium chloride, sulphates and an iron source.

Foliar spray of nitrogenous fertilizer increased output of the green matter by 14-17 per cent (Venkataraman, 1980).

Watanabe *et al.* (1977) reported that azolla in nitrogen amended medium had lower fresh weight and reduced N assimilation than that of the control, but retained a similar acetylene reduction activity.

Many workers have emphasized the role of phosphorus on the growth of azolla. Addition of 30 kg P ha^{-1} as superphosphate stimulated azolla growth. In phosphorus treated plots, the surface coverage of azolla, 22 and 40 days after inoculation was 85 and 96 per cent respectively. The deficiency of Fe, P and Ca, affected azolla causing low fresh weight, low number of algal cells in the frond cavities and low rate of N fixation. Potassium deficiency had less effect and Mg deficiency had the least effect (IRRI, 1976).

Watanabe (1977) found that P, Ca, N and Fe are essential nutrients in the water culture for azolla growth. Singh (1979) was of the opinion that application of superphosphate is an essential requirement for azolla multiplication. Rains and Talley (1979) observed that *A. filiculoides* and *A. mexicana* required 0.8 μg P ml^{-1} to maintain sufficient P for maximum growth. Liu (1979) in one of his experiments noticed that the ratio of P to N should be 3:1 in spring, 1:1 in summer and 1:0 in winter. The ratios vary according to the changes in weather. He further noted that azolla propagates most rapidly in soils containing 21-87 ppm available P and grows poor in soils containing 2.1-8.7 ppm.

Watanabe (1977) found that P deficiency reduced the fresh weight to 22 per cent, the total N content to 16 per cent and acetylene reduction rate to 3.5 per cent of the control. Becking (1979) found that P deficient plants produced a red brown discolouration and a smaller frond size. In most paddy systems P is the most common element limiting the growth of azolla. If the dry weight P content of azolla drops below 0.23 per cent both growth and N content will be affected (Lumpkin and Plucknett, 1982). Subudhi and Watanabe (1981) were of the opinion that P represents a major limiting factor in the field for the growth of Azolla-Anabaena symbiotic nitrogen fixing system. The threshold concentration of P in azolla appeared to be 0.2-0.3 per cent, below that growth was proportional to the P content. Mandal and Bharati (1983) showed that P deficient azolla had reddish brown fronds and shoot and roots were long, fragile and easily detachable. Watanabe and Ramirez (1984) found that *Azolla pinnata* can grow satisfactorily without P application in the soils with Olsen P values higher than 30 mg kg^{-1} and P sorption capacity lower than 1500 mg P_2O_5 100 g^{-1}. The soil that supported azolla growth well (higher than 1 kg azolla m^{-2}) appears to have available P (Olsen's P) higher than 25 ppm.

Studying the influence of potassium on the growth of azolla, Watanabe (1977) observed that fresh weight and N content of the azolla in the K deficient solution were less than those in the control. Potassium deficient azolla did not have any discolouration but its frond size was relatively smaller than that of azolla in the control. Its deficiency decreased the fresh weight and total N content of the plants to 32 and 24 per cent of the control respectively.

Singh (1979) opined that the addition of potassium fertilizer at 4-10 kg K_2O ha^{-1} and domestic ash at 50 kg ha^{-1} encouraged growth of azolla to some extent. Lumpkin and Pluckmett (1982) observed that the application of potassium is essential for the cultivation of azolla in the light soils of Vietnam and China. Threshold concentration for this element is about 0-4 mmole l^{-1}.

Agarwala and Sharma (1976) reported that calcium is involved in the maintenance of cellular organization by regulating the permeability of cellular membrane and by hydration of protoplasm. They further noted that Ca favours the assimilation of N into organic constituents especially proteins. Watanabe <u>et al.</u> (1977) observed that Ca deficient azolla showed more browning than the P deficient azolla and had the smallest frond size among treatments. Becking (1979) stated that the Ca deficient plants had a fresh weight of only 9 per cent and total N content of 5 per cent respectively of the control receiving the complete solution. Microscopic examination revealed that the fronds had lost the algal symbiont. A deficiency of Ca, and P had more pronounced effect on growth and N_2 fixation than a deficiency of K and Mg. Regarding the Mg deficiency, Becking (1979) also observed that fresh weight was reduced to 82 per cent and total N content to 77 per cent of the control. But acetylene reduction rate was 1.3 times more than that of normal plants. Watanabe et al. (1977) also recorded that fresh weight and N content of azolla in the Mg deficient solution were slightly lower than those in the control. The Mg deficient azolla did not usually differ in colour and frond size from the control azolla.

Agarwala and Sharma (1976) noted that magnesium is involved in carbon assimilation and organic acid metabolism. The decreased rate of photosynthesis found in Mg deficient plants could be perhaps largely accounted for in terms of the known role of Mg as a constituent of chlorophyll.

Aziz and Watanabe (1983) found that dry matter in the control and P, Ca and Mg deficient azolla were 5.0, 8.1, 14.5 and 13.2 per cent respectively and they further noted that omission of Mg, P, Ca from the culture solution increased the doubling time of azolla growth.

Olsen (1970) reported that when the water pH was in the range of 7.0-8.1, azolla could not grow due to the poor availability of Fe and Mn. In the case of A. caroliniana he found that an omission of Fe from a complete nutrient solution gave a dry matter production of only 11 per cent of the control. The omission of Mn decreased yield to 23 per cent of the control.

Ashton and Walmsley (1976) concluded that the fern thrived where waters were anaerobic and Fe was present as Fe^{2+}; whereas in lakes where waters were not anaerobic and Fe was present as

Fe^{3+}, plants became chlorotic and stunted on account of Fe deficiency. Becking (1979) noticed luxuriant growth of azolla in an irrigation water having pH value of 5.5-6.6 and soluble Fe, content of 0.28-0.50 mg Fe l^{-1}. He concluded that Fe seems to be important for azolla growth and it should be present in soluble form to give a concentration of 2.5 ppm Fe.

Watanabe et al. (1977) while testing the growth of A. pinnata in a pH range of 4.5-7.5 at 2 and 4 ppm Fe as iron citrate observed less healthy chlorotic plants due to Fe deficiency at pH 7.5. Rains and Talley (1979) reported that water used for irrigating experimental plots was frequently Fe deficient and then the azolla become chlorotic and stunted.

Becking (1979) stated that micronutrients are required for the growth of azolla in the usual concentrations required for other green plants. However, molybdenum and cobalt are required in somewhat higher concentration than normal because they are needed for nitrogenase activity of the symbiont. The nutrients, Mo, Mn and B have conspicuous effect on the growth and N_2 fixation of azolla. Addition of small amounts of Mo has been reported to stimulate azolla growth in China and Korea.

Lumpkin and Plucknett (1982) were of the opinion that in addition to the nutrients required by other plants, it requires Mo, Co and Na for the use of its nitrogen fixing symbiont. They further stated that zinc is required by azolla in very small amounts and has not been reported to be deficient at any of the sites where azolla is presently cultivated. But they have collected a sample of _A. caroliniana_ suffering from Zn toxicity in which the Zn concentration in the plant exceeded 0.2 per cent on dry weight basis.

According to Johnson _et al._ (1966) cobalt is essential for the symbiotic growth of _A. filiculoides_ and _Anabaena_. Its requirement is associated with the growth of _Anabaena azollae_. Tungston appeared to be beneficial to some extent for the growth of azolla. According to Becking (1979) Vanadium had inhibitory effect on azolla.

It can be concluded that azolla requires all the macro and micronutrients which are essential for normal plant growth. Macronutrients such as P, N, K, Ca and Mg are especially important and produce marked effect on the growth of azolla. Since the endosymbiont also plays a significant role in the nitrogen fixation and ultimately on the growth of azolla, micronutrients such as Fe, B, Co and Mo have been shown to be essential for nitrogen fixing process.

2.5. Time and quantity of azolla inoculum to be applied in the field

Singh (1977b) found that an inoculum density of 0.1-0.3 kg m^{-2} was found to be most favourable for rapid multiplication of azolla. He further observed that inoculum of 0.1-0.4 kg m^{-2} increased to 0.8-1.5 kg m^{-2} of green matter in 8-20 days amounting to 30-50 kg N ha^{-1}. Pande (1979) reported that the density of azolla inoculum at 0.1-0.4 kg m^{-2} was found to be most favourable for rapid multiplication. Thin population will take more time to cover the field.

Srinivasan (1980b) laid out a trial in Thaladi with inoculum levels of 1, 2 and 3 t ha^{-1}. Azolla was applied one week after planting. Water level was maintained at 5 cm. The inoculum levels at 1, 2 and 3 t ha^{-1} covered the field 55, 33 and 15 days respectively after application. In the trial where azolla was inoculated at 3 t ha^{-1}, yield increase to that of 25 kg N ha^{-1} was observed. In trials with inoculum levels of 1 and 2 t ha^{-1}, there was no appreciable yield increase because of delayed incorporation of azolla 62 and 42 days after planting respectively. Mathur et al. (1981) got a favourable effect when azolla was applied at 300 g m^{-2}, one week after planting and incorporated 15 days later. Similar results were obtained by Kannaiyan and Govindarajan (1982).

Barthakur and Talukdar (1983) inoculated with 1 t fresh azolla ha^{-1} after planting and incorporated it 20 days later which resulted in an increased yield of 38 per cent in 1979 and 36.5 per cent in 1980. Mahendran and Ramiah (1983) inoculated azolla at 500 kg ha^{-1} 10 days after planting and incorporated it after 35 days. Azolla multiplication ranged from 3-4 t ha^{-1} and addition of nitrogen to the field through its incorporation ranged from 5.7-6.6 kg N ha^{-1}.

In the final analysis it can be seen that inoculation, one week after planting seems to be the best time of application of inoculum in the field. A sowing density of 100-400 g m^{-2} was found to be most favourable for rapid multiplication of azolla in the field. Thin population will take more time to cover the field.

2.6. Method of planting rice favouring growth of azolla

Liu (1979) stated that double-narrow-row method of planting rice facilitated better growth of azolla. The space of the wide row is 53-66 cm and that of the narrow row is 13 cm and that between 2 clusters 6.5 cm. Thus azolla and rice can grow in the same field for a comparatively long time to bring about high yields of both rice and azolla. Watanabe et al. (1981) in a similar experiment observed that in rice fields azolla growth is fast at the rice crop's early stage but declines later because of shading by the rice plants. In another study, Gunning et al. (1984) noted that this practice has been found to prolong the growth of azolla, increasing the fresh weight yield to 77 to 186 t ha^{-1} (compared with the usual 40-55 t ha^{-1}) without reducing rice grain yield. It was tried in IRRI and found that 4 to 6 crops of azolla would be obtained during a crop season equivalent to 70-100 kg N ha^{-1}.

Ramasami et al. (1984) while studying the effect of dual cropping of azolla in low land rice got a maximum biomass of 7.9 t ha^{-1} at a multiplication rate of 195 g m^{-2}. Dual cropping of fresh azolla with 60 kg N ha^{-1} gave a yield equal to that with 90 kg N ha^{-1}.

While evaluating the effect of systems of cropping of azolla, Joy (1984) found that monocropping of azolla 20 days before transplanting yielded 19.8 t ha^{-1} of fresh azolla containing 30 kg N ha^{-1} whereas intercropping of azolla with rice during the 30 days after transplanting yielded 15.6 t ha^{-1} supplying 22.4 kg N and dual cropping of azolla during the period of 50 days yielded 35.4 t ha^{-1} of fresh azolla which supplied 51.5 kg N ha^{-1} to the rice crop.

Thus it can be summarized that in rice field, growth of azolla is fast in the early stage but declines later because of shading of rice plants. Double-narrow-row method is a suitable method of planting rice which will facilitate good growth of azolla for a longer period, without being detrimental to the yield of rice.

2.7. Mineralization of azolla

While studying the decomposition pattern of azolla, Pande (1979) inferred that about half the quantity of N is mineralized within three weeks of water logging and 2/3rd after 6-8 weeks of flooding. Talley and Rains (1980) observed that when the amount of N incorporated into the soil as azolla green manure was increased, the proportion of N available to rice crop decreased. The mineralisation of azolla after its incorporation was faster at room temperature than when incubated at 24 $\pm$ 2°C. About 56 per cent of N as ammonia was released in three weeks of incubation at 24°C whereas 80 per cent was released at room temperature (Singh, 1979).

Mineralization may differ with C:N ratio or simply with N content of azolla. Mineralization at 30°C took place rapidly during the first week. After third week,mineralization slowed down. Lower the N in azolla, lesser the mineralizable N. Chemical components other than nitrogen may affect the availability of azolla N. When azolla was placed on the soil surface highest loss amounting to as much as 60 per cent for six weeks was observed compared to 56 per cent when remained in floating condition on water and 33 per cent when incorporated into the soil (IRRI, 1981).

Behra (1982) observed that the release of N after azolla incorporation continued progressively and by eight weeks 79.5 per cent was released. As azolla is succulent, it is quickly decomposed by soil microbes and is available to paddy. Comparing the release of N from blue green algae and azolla, Singh (1982) reported that the soil became reduced when blue green algae and azolla had been incorporated in comparison to control and urea incorporation. The release of azolla N to soil was more rapid than from blue green algae, the former released about 41-67 per cent N within 7-35 days whereas only 12-35 per cent N was released in case of blue green algae during the same period. In another study, soil amended with azolla had a pH value of 7.2 after 50 days of flooding whereas compost and farm yard manure amended plot recorded comparatively low pH value of 7.0.

Lumpkin and Plucknett (1982) stressed that C:N ratio affected the decomposition rate of soil incorporated azolla and ratios of 7:1 to 18:1 had been reported for azolla and the dry weight carbon content ranged from 41.5 to 45.3 per cent. Results of studies with $^{14}CO_2$ by Wang (1982) indicated that mineralization of azolla biomass peaked at two to three weeks after incorporation into the soil and declined markedly by the ninth week. At the peak phase, in the third week, the amount of mineralization of A. imbricata was 12.3 per cent of the total carbon added, but that of A. filiculoides was only 11.1 per cent. Six weeks later, mineralization of A. imbricata was 59.6 per cent of the total and that of A. filiculoides was 57.6 per cent. A. imbricata which had a low C:N ratio, consistently had a lesser amount of mineralization than A. filiculoides which had a higher C:N ratio.

From a study on the release of N from dried azolla (4.9% N) in a submerged soil at 30°C, it was observed that the ammonia formed from total N of dried azolla, measured weekly, was 13 per cent upto one week, 19 per cent at two weeks, 22 per cent at three weeks, 46 per cent at four weeks and 75 per cent at six weeks. It appeared that N in azolla is of the slow release type. In another pot culture study it was observed that N in azolla was slightly less available than that of N in ammonium sulphate (IRRI, 1976). Ito and Watanabe (1985) remarked that as A. pinnata had a high N content, mineralization of N was faster than in other fern species. Fresh azolla released at maximum 2.5 times more NH_4-N from its body than dry azolla did. Mineralization of fresh azolla was intensive till 16 days after start of incubation and then it reached a plateau. Rapid mineralization during the first four days in the case of dry azolla was followed by a slow release of NH_4-N. The initial rapid mineralization of N in dry azolla may have been due to the small amount of easily decomposable substances that remained after drying. About 50 per cent N incorporated through azolla into soil was recovered in the plants at 42 days after planting. This indicated that N in azolla is rapidly available to plant.

Leaf portion of green manure which is rich in N when incorporated with the soil with an abundance of water decomposes in about 4-5 days and behaves like quick acting inorganic fertilizer in supplying available N (ICAR, 1964). It was also reported that the lopping of Glyricedia maculata showed the lowest C:N ratio (5.0:6.7). The response of rice to compost made from green leaves is inferior to the fresh green matter.

Bandyopadhyay and Bandyopadhyay (1983) reported that when rice straw was added at 20 t ha^{-1} about 50 per cent of mineral N in soil was immobilized at the end of the first week and at 40 t ha^{-1} about 92 per cent was immobilized during the same period.

Studying the immobilization pattern, Yoshida and Padre (1977) concluded that a large portion of fertilizer N was immobilized into the soil and the availability of immobilized N in the soil appeared low. The amount of immobilized N increased as the rate of applied N increased. When this amount was calculated as per cent, higher values were obtained with lower rates of applied N. Saha and Mukhopadhyay (1983) noticed that the increased pressure of mineralized ammonium in the exchangeable and solution form in the soil caused immobilization of a part of this fraction through entrapment in the lattice of clay minerals because an increase in magnitude of ammonium fixation was observed with the increase in period of incubation in the absence of any source of added N. During the initial period of incubation the magnitude of ammonium fixation was maximum under waterlogged condition with least scope for nitrification.

In a study to detect the N transformation in the soil, Mahmoud et al. (1984) found that NH_4-N generally increased upto sixth week after flooding and decreased thereafter in organic manured and unmanured treatments. High NO_3-N figures were recorded throughout the experiment, in organic manured treatments while NO_2-N figure were insignificant throughout the experiment. Mian and Stewart (1985) observed that in the absence of rice plants 30, 43 and 45 per cent of applied ^{15}N of azolla, Anabaena and Nostoc was released respectively in 60 days of which 93-96 per cent was lost as N_2 through denitrification. They further observed that the applied biomass of azolla and blue green algae started decomposition within a few days of incorporation into the soil as evidenced by $^{15}NH_4$-N accumulation in the soils. However, after 15 days $^{15}NH_4$-N in soil gradually declined to a negligible amount at 60 days although N uptake by the rice plants progressively increased with time. The NO_3-N did not accumulate partly due to loss through denitrification. In addition it may be expected that the soil microbes also assimilated some of the generated $^{15}NH_4$-N and NO_3-N.

Lian *et al.* (1981) opined that in excessive application of azolla, its higher lignin content (18-24 per cent) slowed the decomposition and N liberation, resulting in lower efficiency. They further cautioned that it is important to incorporate it into the soil at the proper time to prevent delayed maturing in the rice plants.

Studying the inhibitive action of quinones Bundy and Bremner (1973) reported that the usual lignin degradation products such as 2-methoxy and 2,6-dimethoxybenzoquinone which are formed by oxidative decarboxylation of vanillic or syringic acid, inhibit urease activity. Nitrification is also inhibited by quinones. The effectivity of quinones is comparable with that of substances produced industrially. Quinones inactivate urease which is the enzyme responsible for decomposition.

To sum up, mineralization of azolla is affected by C:N ratio. Rate of decomposition and availability of N and immobilization are affected by the form and quantity of azolla applied.

2.8. Evaluation of azolla as an organic manure

Estimates of the total N input of azolla in paddy soils are rather variable because they are influenced by factors such as farming system used, fertilization of the rice field, the presence of soluble iron and whether azolla had been previously grown as fallow crop or as dual crop with rice (Becking, 1979). Studies conducted at I.R.R.I. revealed that grain and straw yields were higher in plots with azolla inoculation, added P and mid-season puddling to incorporate azolla than in the treatment without those inputs. Azolla inoculation significantly affected straw yield (IRRI, 1976). While studying the effect of azolla inoculation on yield of rice, Singh (1977c) obtained 41 and 58 per cent increased yield of grain and straw respectively due to the incorporation of azolla at 10 t ha^{-1}. It was 53 and 55 per cent respectively due to the combined effect of fertilizer nitrogen and azolla, for a short duration rice variety. He further inferred that a layer of azolla covering one hectare of rice field will produce 10 t of green matter which will ensure about 30 kg N.

In a study on the nitrogen recovery of azolla incorporated and unincorporated treatments, it was found that highest recovery was noted in azolla incorporated treatments. When azolla was applied at later stages, the availability of N decreased. Response of azolla incorporation was apparent only at later stages of growth (IRRI, 1981).

Comparing contribution of azolla and blue green algae, Pillai et al. (1980) observed that azolla alone at 6 t ha^{-1} gave 430 kg of extra grain yield ha^{-1} and blue green algae recorded 350 kg ha^{-1}. At the observed level of N response, the overall effect of azolla at 6 t appears to be equivalent to 17 kg N and that of blue green algae to 14 kg N ha^{-1}. Azolla with 25 kg N recorded an additional grain yield response of 890 kg ha^{-1}.

Studies of Srinivasan (1981) revealed the possibility of savings of 25 kg N ha^{-1} when a layer of azolla was incorporated into the soil before planting. He also found that growing azolla without incorporation did not add any appreciable N input to the crop. Experiments at 16 sites in eight countries showed that incorporation of fresh azolla at 20 t with basal application of 30 kg N ha^{-1} as prilled urea produced yield comparable to that with split application of 60 kg N ha^{-1}. Azolla alone applied before or after transplanting produced yields comparable to those with urea at 60 kg N ha^{-1}(IRRI, 1983).

Rao et al. (1983) concluded that yield with 37.5 kg N with 15 t azolla was equal to that with 75 kg N ha^{-1} applied through urea. Kannaiyan et al. (1983) got significant increase in yield due to inoculation of blue green algae, azolla and azospirillum along with fertilizer. Maximum grain yield of 5997 kg ha^{-1} was recorded in blue green algae inoculation with 75 per cent of fertilizer nitrogen. The combined inoculation of these three biofertilizers with 75 per cent and 100 per cent of fertilizers indicate a positive effect of inoculation.

Singh (1977c) reported that a crop of paddy receiving 30 kg fertilizer N and a layer of azolla and 50 kg N with one layer of azolla were better than 50 kg and 80 kg N respectively. Incorporation of one layer of azolla in soil before transplanting increased growth and paddy yield by 12-30 per cent depending on cultivar and season. Govindarajan et al. (1980) reported that plots treated with 70:50:50 kg NPK ha^{-1} and azolla, yielded as well as those with 100:50:50 kg NPK alone indicating that azolla might supplement 25 kg N ha^{-1}. Srinivasan (1980a) concluded that incorporation of azolla a week before transplanting at 10, 20 and 30 t ha^{-1} with N levels at 100 kg gave yields equal to 25, 50 and 75 kg N ha^{-1} respectively.

In a pot culture experiment, with the incorporation of dry azolla at three levels of N, Kaushik and Venkataraman (1981) observed that crop yield was a function of fertilizer N input showing progressive increase from 60 kg N to 100 kg N. Grain and straw yields increased significantly when N was supplemented by dry azolla. At every N level, the effect of azolla supplementation was equal to that of next higher N level without azolla. Uptake also showed significant increase with the application of dried azolla. Siddiqui et al. (1983) claimed that maximum yield increase of 51.3 per cent was obtained in a treatment where azolla had been used in combination with starter dose of mineral N. The increase was 19.1 per cent when azolla had been added as a source of N.

Liu (1979) reviewing the experiments in China reported that fields with azolla as manure increased the rice yield by 600-750 kg ha^{-1}. From the results of 422 field experiments, he concluded that 99 per cent of the experiments gave increased output, the average increase being 18.6 per cent. Cultivation of azolla in rice fields not only increases output but also improves the quality of grains by raising its protein content.

Studies at Madurai indicated that azolla incorporation at transplanting with 30 kg N ha^{-1} gave similar yield that was obtained by 60 kg N ha^{-1}. It was also found that azolla treated plot had higher total N, available N, organic carbon and available P. The uptake was also more in plots receiving azolla (Arunachalam, 1980).

Behra (1982) regarded that azolla incorporated in the form of green manure at the time of puddling is the best way of applying it. Application of 10 t of fresh azolla basally corresponded to 30 kg N ha^{-1}. This gave 34 per cent higher rice yield over the control. Comparing the effect in different seasons, it was found that Rabi planting was more beneficial than kharif planting. Available N were 146, 168, 175 and 165 kg ha^{-1} in plots receiving no azolla, 5 t azolla, 10 t azolla and 60 kg N ha^{-1} respectively.

Rains and Talley (1980) claimed that incorporation of 40 kg N ha^{-1} as dry azolla (*Azolla filiculoides*) in spring 1977 increased the rice yield by 2.0 t ha^{-1}. Results from two years of the trial suggested that upto 56 per cent of the N requirement for rice in California could be supplied by one fallow season crop of azolla. Patel *et al.* (1980) observed that application of 5 t ha^{-1} of azolla alone as basal dose produced a significant yield increase, the mean grain yield response being 38 kg N ha^{-1}, azolla at 10 t resulted in a mean response of 36 kg N ha^{-1}. In general, this dose did not prove significantly better than the lower dose of 5 t ha^{-1}.

Subudhi and Singh (1980) after field trial on azolla suggested that incorporation of azolla at 10 t ha^{-1} increased rice yield by 40 per cent over uninoculated control and was comparable to application of 40 kg N ha^{-1} as ammonium sulphate. Nagaraju et al. (1982) agreed that azolla application resulted in a non-significant increase in grain yield by 4 per cent over green manure and a significant increase by 20 per cent over farm yard manure.

Singh (1982) in a field experiment with various organic manures on an equal N basis (30 kg N ha^{-1}) claimed that fresh *Azolla*, *Eichhornia* sp., *Pistia* sp., *Sesbania* sp., farm yard manure and urea treatments increased grain yield by 46.9, 47.3, 43.9, 40.2, 34.1 and 47.3 per cent over non-fertilized control. There was no significant difference in the tiller number and height among treatments at harvest. In a similar experiment it was observed that root and shoot growth was more in the case of azolla and ammonium sulphate treated plots after 30 days of planting. There was a gradual increase in the weight of roots from 30-90 days after planting and azolla and sesbania treated plots exhibited maximum root growth. Tiller number and plant height also exhibited similar trend.

Experimental data of Beri and Meelu (1983) showed that application of 5 t ha^{-1} of azolla gave rice yield equivalent to 25 kg N ha^{-1}. But in some situations, no significant effect of azolla was obtained. They also found that 50 kg N ha^{-1} through air dry azolla gave substitution of about 40-50 kg N ha^{-1} as inorganic nitrogen. Mathewkutty and Sreedharan (1983) were of the opinion that azolla is an efficient substitute for N fertilizer in sandy soils where there is possibility of vertical and lateral leaching. This may be because azolla releases nitrogen slowly and steadily thereby limiting nitrogen losses.

Kannaiyan (1984) observed that among the organic manures tried, azolla incorporation has recorded higher grain yield followed by lemna, water hyacinth and farm yard manure incorporation. The results have clearly indicated that azolla is effective as an organic manure when compared to other treatments. Oh (1979) found that decomposed compost has little effect as a soil ameliorant, particularly from the view point of soil aggregate formation and plant growth. He further noted that the effect of 7.5 t ha^{-1} of compost, supplementary to chemical fertilizer on paddy yield, decreased with increasing levels of fertilizers. He further observed that when the increase due to compost with no fertilizer was 13.3 per cent it was 9.6 per cent at 40:40:40; 2.8 per cent at 80:80:80 and -0.2 per cent at 160:160:160 kg N, P_2O_5 and K_2O ha^{-1}. Yamamuro (1981) measured the distribution of ^{15}N labelled ammonium fertilizer applied with different amounts of compost. As the quantity of compost increased, the ratio of the N absorbed by rice to the amount applied decreased, and the residual N in the soil increased. Residual N was available to the rice crop in subsequent years.

Subudhi and Singh (1980) found that tiller number in azolla incorporated treatment was superior to that in the other treatments. Kulasooriya and DeSilva (1977) got significant difference in the number of panicles in azolla incorporated treatment.

The urea treatment showed the greatest number of grains panicle^{-1} closely followed by azolla plus fertilizer. The two azolla treatments outyielded the urea treatment in percentage of filled grains. Azolla plus fertilizer registered 133 per cent as many filled grains panicle^{-1} as the control. The urea treatment registered 95 per cent filled grains panicle^{-1}. The azolla treatment might have reduced sterility. The results clearly indicate that azolla has a beneficial effect on yield of rice.

Kannaiyan et al. (1983) reported that plots applied with azolla increased total tillers, productive tillers, plant height and straw yield. The results indicated the positive effect of azolla incorporation on the yield of rice. Siddiqui (1983) observed a positive correlation between number of grains panicle^{-1} and length of panicle.

Singh (1979) reported that analysis of organic carbon after harvest indicated a residual effect in the azolla treatment. There was linear increase from lower to higher doses of incorporated azolla. Although the organic carbon content in the soil of the azolla incorporated treatment was almost the same before the residual study, the azolla incorporated treatment yielded higher. Residues of 5, 10, 15 and 20 t of incorporated azolla increased yield of succeeding crop by 7.4, 23.8, 24.5 and 40.1 per cent respectively over control (Subudhi and Singh, 1980).

Venkataraman (1980) reported that in China, azolla is largely used for the first crop and farmers felt that there is there is residual effect in the second crop of paddy also. Watanabe et al. (1981) stated that growth of rice in the early stages was better in azolla treated plots than in plots without N because of carry over of N from previous azolla crop. Soni and Sikarwar (1983) regarded grain yields of wheat in a rice-wheat sequence were generally higher in treatments receiving a part of N as farm yard manure during Kharif season for rice although the rice crop did not show much of direct response to this treatment.

Kulkarni et al. (1983) revealed that application of 12 t of farm yard manure with 90 kg N to Kharif crop followed by 60 kg ha^{-1} to the Rabi crop could produce a satisfactory yield comparable to 120 kg N, 60 kg P_2O_5 and 60 kg K_2O to Kharif and 60 kg N ha^{-1} to Rabi crop. Haq et al. (1984) recognized that azolla has a beneficial effect on soil structure, soil microflora and micronutrient availability. The effect of azolla may persist longer than nitrogen fertilizers to subsequent crop and its effect may increase overtime to surpass those of commercial nitrogen fertilizers.

It can be summarised that total nitrogen input of azolla in paddy soils are rather variable because they are influenced by agricultural system used, fertilization of the field and presence of soluble nutrients. The overall effect of 5-10 t of azolla appears to be 15-30 kg N ha^{-1}. A combination of azolla with reasonable level of fertilizer seems to be advantageous. Incorporation of azolla before planting is definitely superior to intercropping and burying it at later stages. In addition to the improvement in grain yield, it is also reported to improve the soil physical properties and azolla at higher rates will improve the performance of succeeding crops.

Materials and Methods

III. MATERIALS AND METHODS

The experimental programme consisted of a survey, three field experiments and two pot culture trials which were conducted during 1980 to 1984 at the Regional Agricultural Research Station, Pattambi.

In order to identify the conditions under which azolla grows naturally, a survey was undertaken during the year 1980. For finding out the best time and optimum quantity of inoculum to be applied in the field and geometry of planting rice that favours growth and multiplication of azolla, field experiments were laid out during the second crop season of 1980 and first and second crop seasons of 1981.

Another field trial to evaluate azolla as an organic manure was conducted during the second crop seasons of 1980 and 1981 which was followed by a summer crop of rice to evaluate the residual effect of organic manures.

A pot culture experiment to study the mineralization of azolla after incorporation in the soil was laid out in 1984.

Another pot culture experiment to identify the nutrient requirements for rapid multiplication of azolla was conducted in 1984.

3.1. General experimental conditions

3.1.1. Location and seasons.

Field experiments were laid out in the sandy loam soils of Regional Agricultural Research Station, Pattambi during the second (September-January) and third (January-April) crop seasons of 1980 and first (May-September), second and third crop seasons of 1981. The station is situated at 10°48" N latitude and 76°12" E longitude and 25 m above mean sea level.

3.1.2. Climatic conditions.

The normal climatic conditions prevailed at R.A.R.S., Pattambi (average of ten years from 1970 to 1979) are presented in Appendix I.

The annual normal rainfall is 2696 mm, the major portion of the precipitation is received during June to August. The contribution of rainfall from the south west and north east monsoons and that from summer showers are 1886, 530 and 291 mm respectively. The mean maximum and minimum temperatures during the period are 32.3°C and 22.5°C respectively. March is the hotest month and January is the coolest. Maximum relative humidity of 96.3 per cent at 7 a.m. prevails during July whereas in January it is only 79.3 per cent. Maximum daily sunshine hours (9.8) is recorded during January while the minimum was recorded in the month of July (2.4). Highest evaporation of 7.1 mm is recorded during March while the lowest is in July (3.6 mm).

3.1.3. Climatic condition during crop period.

The crop growth period was from August 1980 to January 1982. The mean monthly data on the meteorological parameters recorded at the meteorological observatory of this station during the 1980-1984 period are presented in appendices II and III. As the actual crop season periods of the years extended only between the standard weeks 23 and 48, weather data pertaining to these periods were specifically calculated for comparison of the year 1980 and 1981. In 1981 crop season, a total of 2934 mm of rainfall was recorded while it was only 2686 mm in 1980. The mean maximum temperatures were 30.8°C and 31.1°C in 1980 and 1981 crop seasons respectively. Relative humidity was higher during 1981 compared to 1980. The mean daily sunshine hours were 5.2 and 4.5 in 1980 and 1981 respectively. Similarly, mean daily evaporation was more in 1980. In general, the weather was more favourable during the 1981 crop season than in 1980.

3.1.4. Cropping history of experimental field.

The cropping sequence of the experimental field during the preceding years before the commencement of the present study was rice-rice-rice. Uniform fertility of the experimental field was attempted by taking rice in the first crop seasons of 1980 and 1981.

3.1.5. Variety.

The rice variety Jaya was used for the experiment. It is derived from a cross between TN-1 and T-141 and was released for cultivation in 1968. The crop takes 125-130 days to mature in first crop season and 115 to 120 days in the second crop season. Jaya has a good yield stability and potential to give a grain yield of 7.5-8.0 t ha^{-1} under optimum conditions of weather and crop management. It has moderate resistance to bacterial leaf blight, tungro virus, blast, stem borer and leaf hoppers (ICAR, 1978; Ram, 1980).

3.1.6. Physical and chemical properties of soil.

The physical and chemical properties of the soils of fields 1 and 2 in which the field experiments were conducted are given in table 3.1.6.1. In field 1, the trial on evaluation of azolla as an organic manure was undertaken. The other two trials viz., time and quantity of azolla inoculum required to be applied in the field and geometry of planting rice in relation to growth of azolla, were laid out in field 2. Composite soil samples collected were analysed for assessing the initial nutrient status of these fields. The soil was sandy loam in field 1 with medium organic carbon and available K and low available P. Texture of the second location was also sandy loam, and was medium in organic carbon, available P and available K.

3.1.7. Layout.

The layout plans of the three field experiments are presented in figures 3.1.7.1, 3.1.7.2 and 3.1.7.3.

3.1.8. Nursery.

A wet rice nursery was prepared in each season as per the recommendations of Kerala Agricultural University (1978).

3.1.9. Land preparation.

The experimental field was wet ploughed thrice, puddled and levelled. Lime was applied at 350 kg ha^{-1} after first ploughing. The plots were laid out and bunds of 30 cm width and height were taken with provision for irrigation channels. The individual plots were again dug, puddled and levelled manually.

Table 3.1.6.1. Physico-chemical properties of the soils of the experimental fields at Pattambi

Properties	Mean value		Method of estimation
	Field 1	Field 2	
Physical properties			
Sand (per cent)	80.98	79.14	International Pipette Method (Piper, 1966)
Silt (per cent)	7.52	8.78	
Clay (per cent)	11.06	11.65	
Textural class	Sandy loam	Sandy loam	
Chemical properties			
Soil reaction (pH) (1:2.5)	5.3	5.5	Potentiometry (Jackson, 1973)
Electrical conductivity (EC mmhos cm^{-1} at 25°C)	0.02	0.02	Conductiometry (Jackson, 1973)
Redox potential (Eh) (mV)	+95	+110	Potentiometry (Jackson, 1973)
Organic carbon (per cent)	1.27	1.45	Walkley and Black's Wet Oxidation (Piper, 1966)
Available N (Per cent)	0.021	0.023	Alkaline permanganate method (Subbiah and Asija, 1956)
Available P (kg ha^{-1})	9.71	15.67	Extraction with Bray No.1 and estimation by calorimetry (Jackson, 1973)
Available K (kg ha^{-1})	184.35	192.52	Extraction with neutral normal ammonium acetate and Flame Photometry (Jackson, 1973)

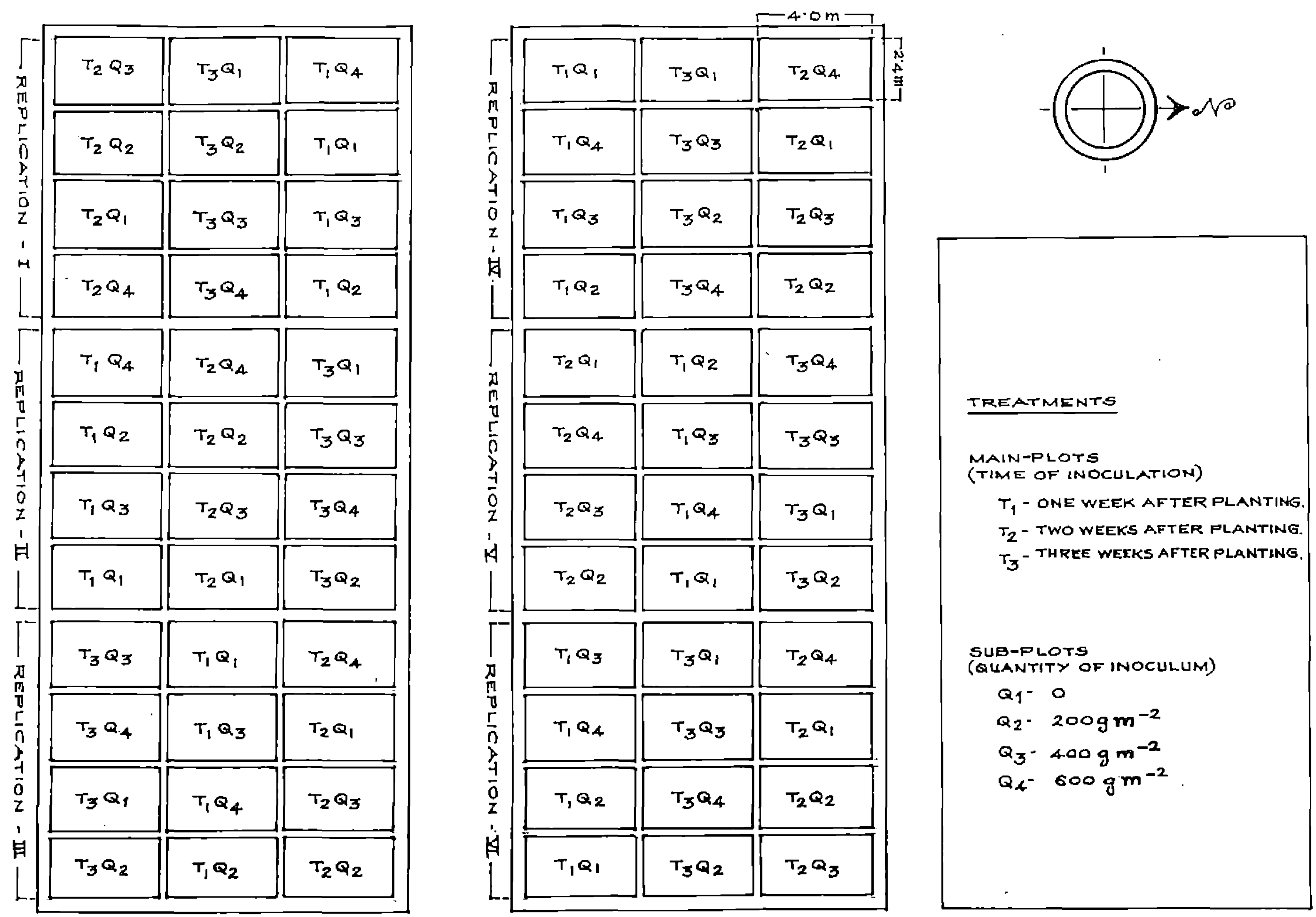
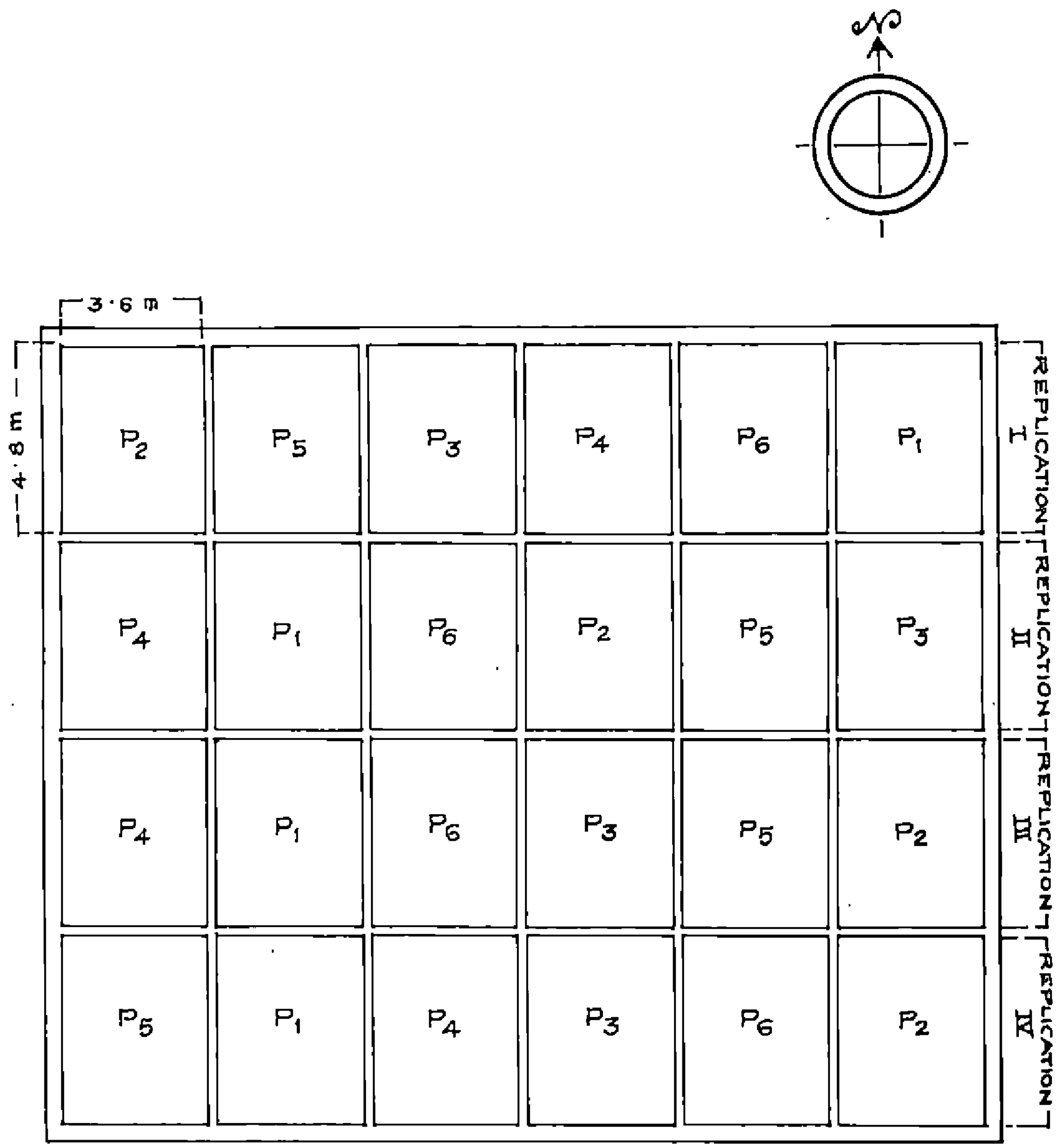


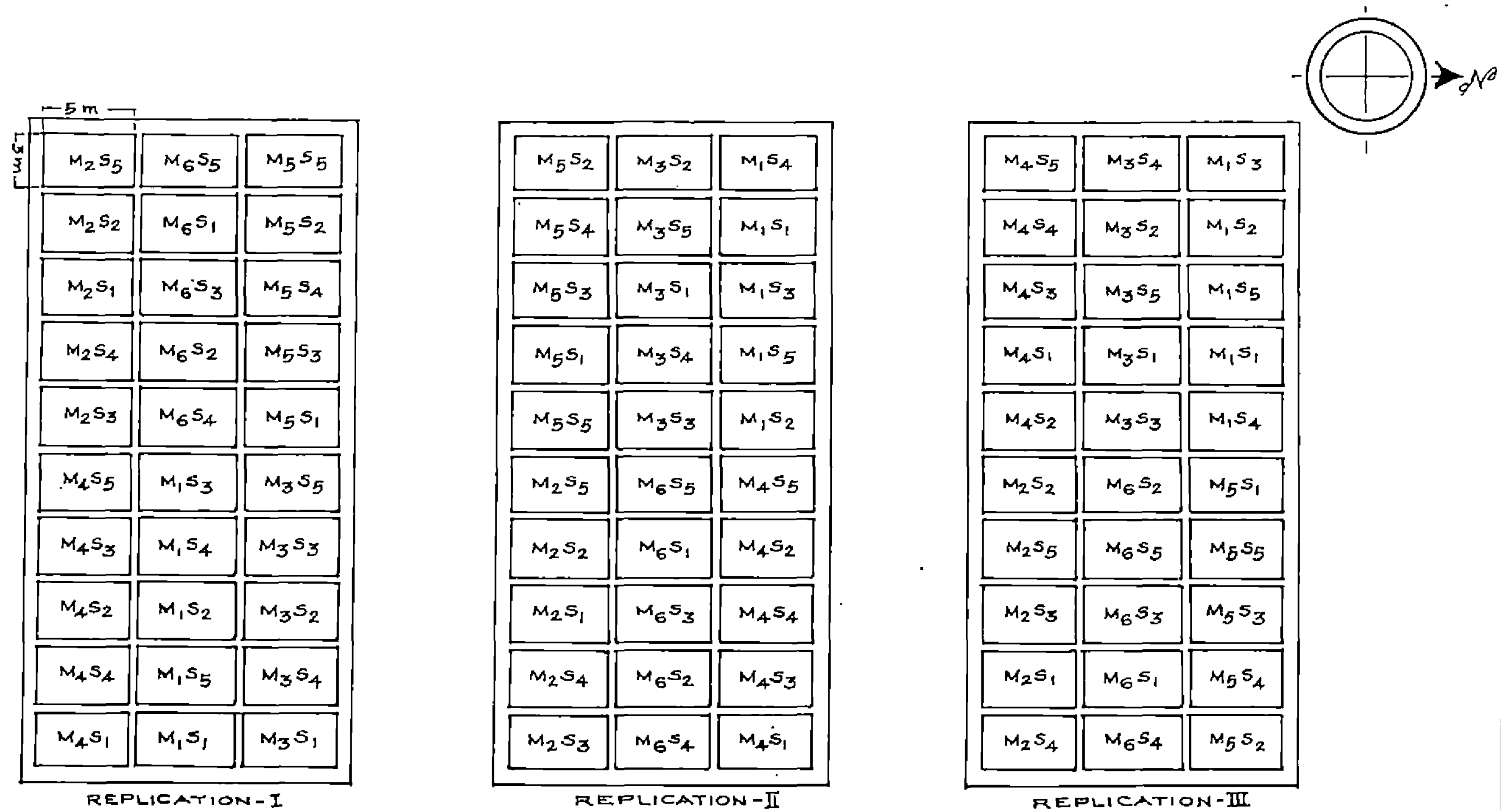
FIG. 3·1·7·1 PLAN AND LAY-OUT OF EXPERIMENT ON TIME OF APPLICATION AND QUANTITY OF INOCULUM ON GROWTH OF AZOLLA.



TREATMENTS

- P_1 - 20 cm x 10 cm EAST-WEST DIRECTION
- P_2 - 20 cm x 10 cm NORTH-SOUTH DIRECTION
- P_3 - 40 cm x 5 cm EAST-WEST DIRECTION
- P_4 - 40 cm x 5 cm NORTH-SOUTH DIRECTION
- P_5 - BULK METHOD (EQUI DISTANT PLANTING)
- P_6 - FALLOW (GROWING AZOLLA WITHOUT RICE)

FIG. 3·1·7·2 PLAN AND LAY-OUT OF THE EXPERIMENT ON GEOMETRY OF PLANTING RICE ON THE GROWTH OF AZOLLA.



TREATMENTS

MAIN-PLOTS (ORGANIC MANURES, t ha^{-1})

- M_1 - CONTROL
- M_2 - CATTLE MANURE - 5·0
- M_3 - GREEN LEAVES - 5·0
- M_4 - AZOLLA - 5·0
- M_5 - AZOLLA - 7·5
- M_6 - AZOLLA - 10·0

SUB-PLOTS ⊗ (FERTILIZER LEVELS)

- S_1 - CONTROL
- S_2 - 25 PER CENT
- S_3 - 50 PER CENT
- S_4 - 75 PER CENT
- S_5 - 100 PER CENT

⊗ DIFFERENT PERCENTAGES OF N, P_2O_5 AND K_2O AT 90:45:45 kg ha^{-1}.

FIG. 3·1·7·3 PLAN AND LAY-OUT OF EXPERIMENT ON EVALUATION OF AZOLLA AS AN ORGANIC MANURE.

3.1.10. Incorporation of organic manures.

Organic manures for individual plots were weighed and applied uniformly before second ploughing. Samples of organic manures were analysed for their nutrient contents.

3.1.11. Fertilizer management.

The recommended fertilizer dose of 90:45:45 kg N, P_2O_5 and K_2O ha^{-1} was followed as per the requirement of treatment schedule. Nitrogen as urea was applied in three splits i.e., 1/2 basal, 1/4 at active tillering and 1/4 at panicle initiation stages. Phosphorus as single superphosphate was applied basally. Potassium was given in two equal splits through muriate of potash basally and at panicle initiation stage. Basal dose of fertilizers was given at the time of last digging.

3.1.12. Transplanting.

Jaya seedlings of 23-25 days old were transplanted in the experimental plots at 33 hills m^{-2} (20 cm x 15 cm) in the first crop season and 50 hills m^{-2} (20 cm x 10 cm) in the second crop season. Summer crop of Thriveni was planted at a population density of 67 hills m^{-2} (15 cm x 10 cm). Two to three seedlings were maintained per hill. Gap filling was done one week after transplanting.

3.1.13. Water management.

Each plot was irrigated separately and independently. A thin film of water was maintained for five days after transplanting. In general 3-5 cm depth of water was maintained during the rest of the crop season with occasional drainage at tillering stage. Irrigation was stopped ten days prior to harvest.

3.1.14. Aftercare.

A hand weeding was given three weeks after transplanting. Lime at 250 kg ha^{-1} was applied uniformly in all plots one week before second top dressing. Prophylactic measures were adopted against pests and diseases attack. Dimacron (250 ml ha^{-1}), Ekalux (1000 ml ha^{-1}) and BHC 10 per cent (25 kg ha^{-1}) were used against pests and Hinosan (500 ml ha^{-1}) against diseases.

3.1.15. Harvesting and threshing.

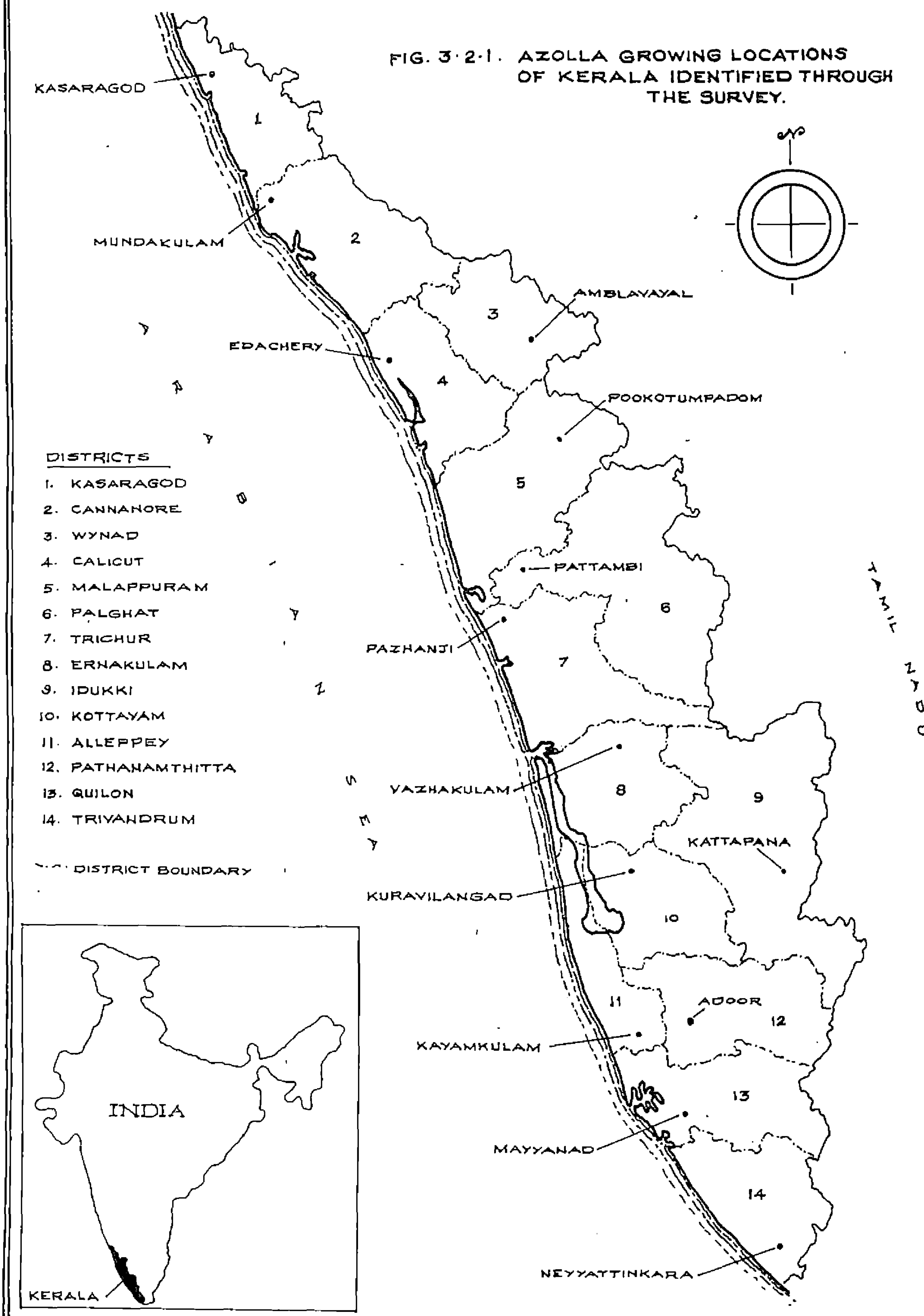
The border plants were harvested first and threshed together subsequently. The crop from each net plot was harvested and threshed separately.

3.2. Technical programme

3.2.1. Survey on the environmental requirement of azolla.

In order to identify the location where azolla grows naturally, a questionnaire along with azolla specimens were supplied to the Junior Agricultural Officers of the Department of Agriculture, Kerala during the year 1980. From the results of preliminary survey (Fig. 3.2.1) three regions i.e., Kayamkulam in Alleppey, Pazhanji in Trichur and Pattambi in Palghat districts, based on the relative coverage of azolla (73, 62 and 13 per cent respectively) were identified for detailed investigations.

FIG. 3·2·1. AZOLLA GROWING LOCATIONS OF KERALA IDENTIFIED THROUGH THE SURVEY.



From each of these three regions, two representative locations where there was satisfactory growth of azolla and a third location where there was no growth, were further selected. Thus, Karuvatta and Kuttitheruvu were the two places where abundant growth of azolla was noticed while Arithalil was the third place having no growth of azolla in the Kayamkulam region. Similarly in Pazhanji region, Pazhanji-1 and Pazhanji-2 were the places of azolla growth while Pazhanji-3 had no growth at all. Three locations were selected from Pattambi also. Two blocks of the Research Station (Block 3 and 5) had some growth of azolla whereas in the third location (Block L), there was no growth at all. From each location, three representative plots were selected for collection of soil, water and azolla samples and the mean values were worked out.

Extent of coverage of azolla in these places was recorded and the quantities of azolla in each of these places were worked out based on the report of Singh (1979).

Weather data of the two regions i.e., Kayamkulam and Pattambi were collected for the year 1980 and presented in appendix III and figures 4.1.5.1 and 4.1.5.2. Temperature at 7 a.m. and 2 p.m. alone could be taken from the third region i.e., Pazhanji as no meteorological observatory was functioning in that area. The period from June to November is designated as azolla growing season while the rest of the period of tho year as non-growing season. Edaphological properties of soil, water and azolla of these locations were monitored as given below.

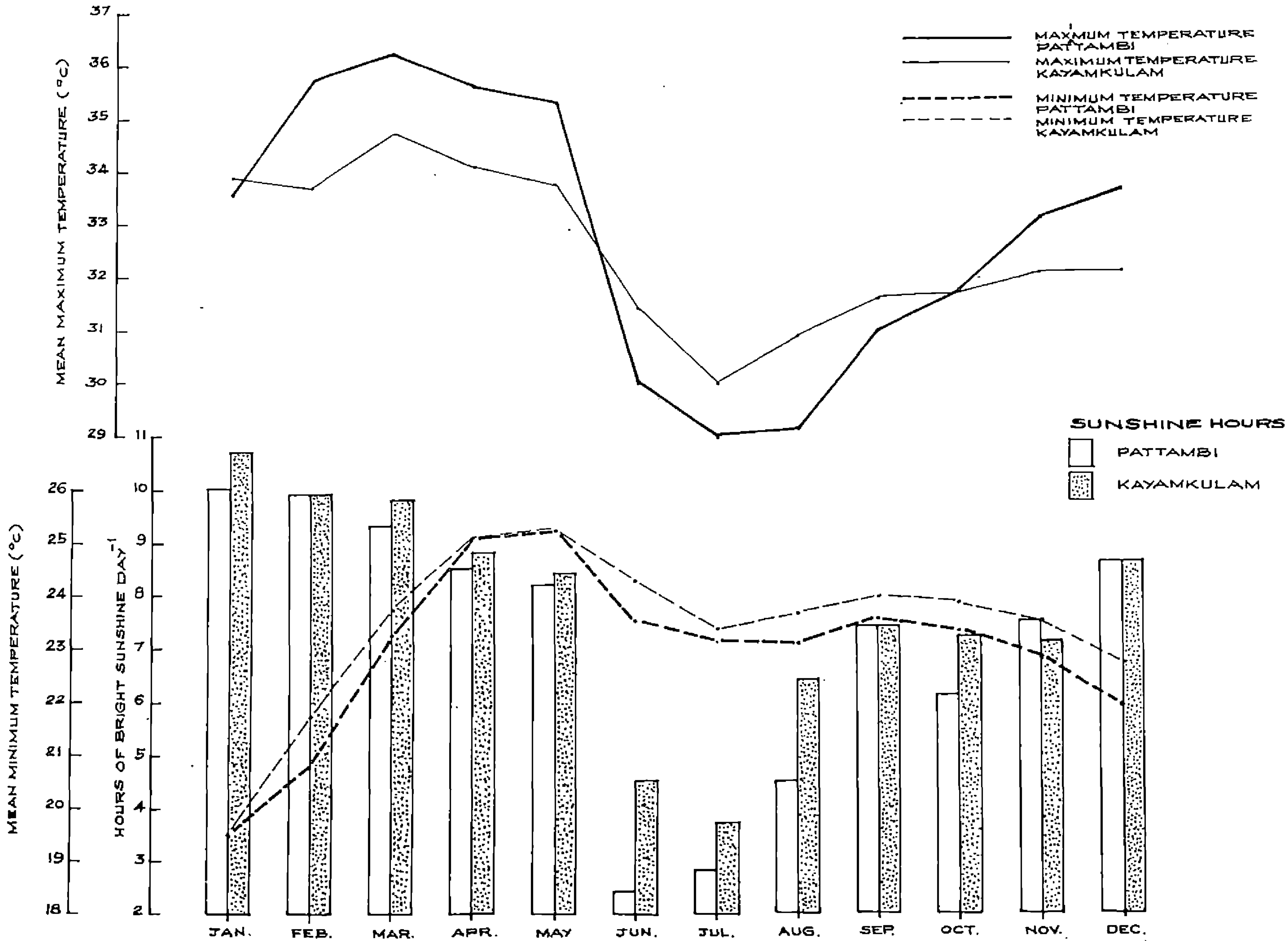


FIG. 4·1·5·1. MEAN MAXIMUM AND MINIMUM TEMPERATURES AND HOURS OF BRIGHT SUNSHINE AT PATTAMBI AND KAYAMKULAM DURING 1980.

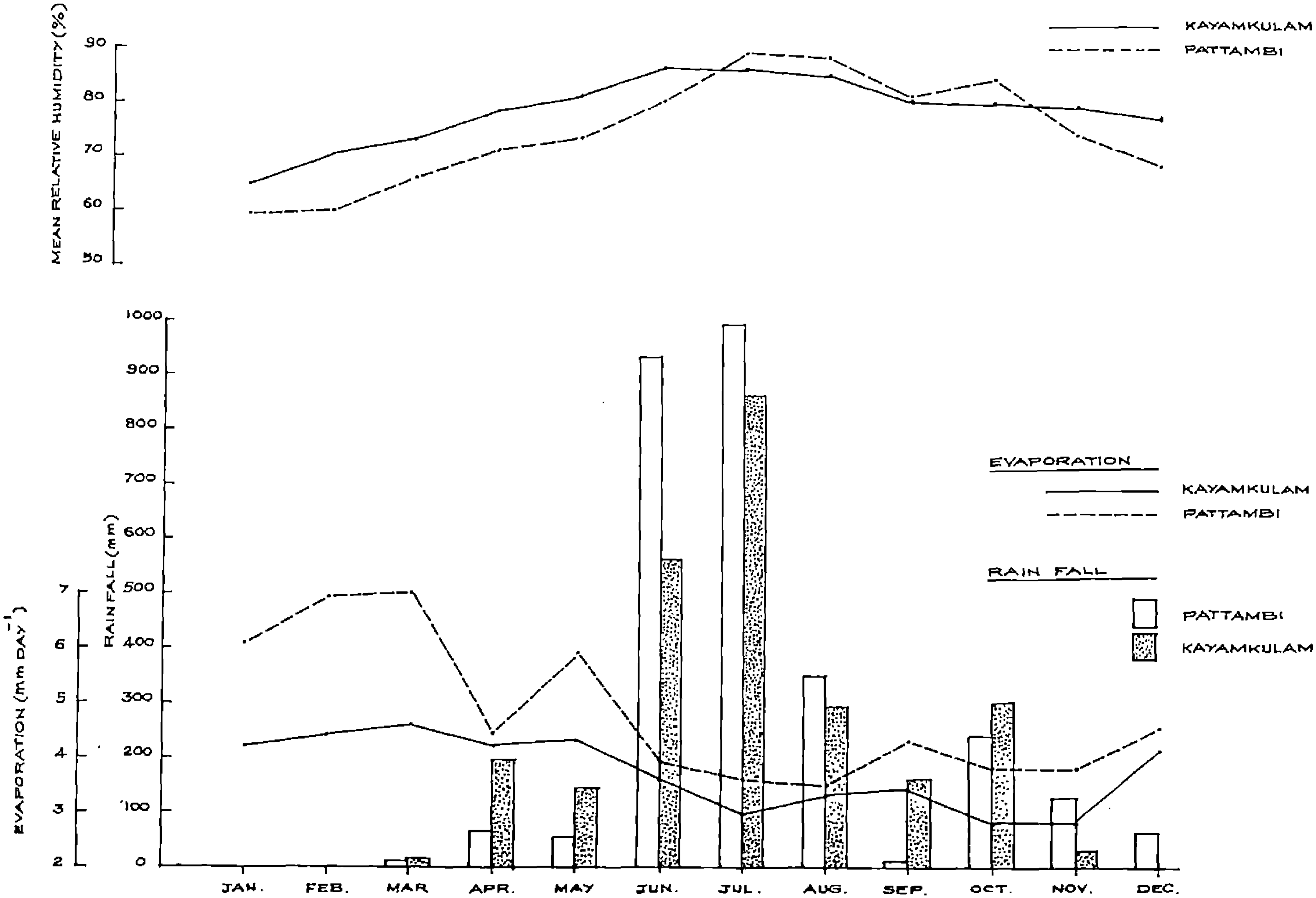


FIG. 4·1·5·2 RAINFALL, MEAN RELATIVE HUMIDITY AND EVAPORATION AT PATTAMBI AND KAYAMKULAM DURING 1980.

3.2.1.1. Soil

Soil samples were analysed for pH, EC and available N, P, K, Ca, Mg, Fe, Mn, Zn and Cu status.

3.2.1.2. Water

Depth of water, nature of inundation, pH, EC, contents of N, P, K, Ca, Mg, Fe, Mn, Zn and Cu were studied.

3.2.1.3. Azolla

Nature of occurrence, dry matter content, and N, P and K contents of azolla were analysed.

3.2.1.4. Weather data

Weekly mean of maximum and minimum temperatures, relative humidity, rainfall and number of rainy days, sunshine hours and evaporation were recorded.

3.2.2. Nutritional requirement of azolla.

Effect of N, P, K, Ca, Mg, Fe and Mn at 20, 20, 40, 40, 40, 2 and 0.5 ppm respectively on the growth, dry matter and N content of azolla were studied for two seasons in a pot culture experiment in completely randomised design in June and September 1984. Effect of each of the elements was studied by missing technique. A treatment without any nutrient (water alone) was also included for comparison.

The investigation was carried out in circular cement pots with an area of 0.1 m^{-2}. The nutrient solution were prepared following the procedures suggested by Yoshida et al. (1976).

3.2.3.1. Main plot treatments

(Time of application of azolla inoculum, after transplanting rice)

t_1 - one week

t_2 - Two weeks

t_3 - Three weeks

3.2.3.2. Sub plot treatments

(Quantity of inoculum)

q_1 - 0 g

q_2 - 200 g m^{-2}

q_3 - 400 g m^{-2}

q_4 - 600 g m^{-2}

Gross plot size - 4.0 m x 2.4 m

Net plot size - 3.6 m x 2.1 m (First crop season)

3.6 m x 2.2 m (Second crop season)

3.2.3.3. Azolla inoculum

Azolla collected from the plots of the Research Station was washed, drained of water, weighed and applied as per the treatment schedule.

The period of study was for three weeks after inoculation and the rate of growth of azolla was measured as described in experiment 3.2.2.

Temperature, pH and EC of water were measured daily at 2 p.m. Hourly measurements of water temperature and light intensity were taken on selected days at weekly intervals. Care was taken to see that the days selected for recording light intensity were clear with no overcasting of sky. Light intensity above the canopy and at the ground surface were measured with an Aplab Lux Meter for each treatment. Grain and straw yields of each of the net plots were recorded.

3.2.4. Geometry of planting rice in relation to growth of azolla and yield of rice.

A field experiment in randomised block design with four replications was laid out in three seasons i.e., second crop season of 1980 and first and second crop seasons of 1981 (Fig. 3.1.7.2). Rice seedlings were planted as shown below.

P_1 - 20 cm x 10 cm spacing with rows in the east-west direction (Plate 2)

P_2 - 20 cm x 10 cm spacing with rows in the north-south direction

P_3 - 40 cm x 5 cm spacing with rows in the east-west direction (Plate 3)

P_4 - 40 cm x 5 cm spacing with rows in the north-south direction

P_5 - Bulk method (equidistant planting) (Plate 4)

P_6 - Fallow (growing azolla without rice) (Plate 5)

Gross plot size - 4.8 m x 3.6 m

Net plot size - 4.4 m x 3.3 m (First crop season)

4.4 m x 3.4 m (Second crop season)

In all the treatments except fallow, the number of hills m^{-2} was kept constant in all the seasons. Azolla inoculu at 0.1 kg m^{-2} was applied uniformly a week after transplanting.

Plate 2. Intercropping of azolla with rice planted at 20 cm x 10 cm in east-west direction

Plate 3. Intercropping of azolla with rice planted at 40 cm x 5 cm in east-west direction

Plate 4. Intercropping of azolla with rice planted in bulk method

Plate 5. Azolla in a fallow plot

Rate of growth of azolla was measured at the end of each week as described in section 3.2.2. (Plate 6).

Temperature, pH and EC of the water were measured daily at 2 p.m. Hourly measurement of water temperature and light intensity above the canopy and at ground surface were measured on selected days at weekly interval. Light transmission ratio (LTR) was calculated by the formula $\frac{T_1}{T_0} \times 100$, where T_0 is the light intensity above the canopy and T_1 light intensity at the ground surface (Yoshida et al., 1976).

After recording the final weight of azolla, samples were analysed for moisture and total nitrogen content. Grain and straw yields of each of the net plot were recorded at harvest.

3.2.5. Mineralization of azolla.

A pot culture experiment in completely randomized design with seven treatments and three replications to study the rate of mineralization of azolla compared to commonly used organic manures was laid out in June 1984 and repeated in September 1984. The treatment details are given below.

T_1 - Azolla at 5 t ha^{-1}

T_2 - Azolla at 10 t ha^{-1}

T_3 - Dry azolla equivalent to fresh azolla at 5 t ha^{-1}

T_4 - Dry azolla equivalent to fresh azolla at 10 t ha^{-1}

T_5 - Cattle manure at 5 t ha^{-1}

T_6 - Green leaves at 5 t ha^{-1}

T_7 - Control

Plate 6. Collection of azolla from the experimental plot to study its growth

The experiment was laid out in circular cement pots with an area of 0.1 m^2. In each pot 20 kg air dried soil was taken and 5 cm water level was maintained during the study period. The organic manures were incorporated and thoroughly mixed with soil. Venga (Pterocarpus marsupium) was the source of green leaves. The nitrogen content of azolla, cattle manure and green leaves used for the study were 4.11, 1.73 and 2.01 per cent respectively. Their dry matter contents were 6.50, 31.10 and 25.28 per cent respectively.

Soil and water samples from each treatment were taken at fortnightly intervals and this was continued till the end of 12th week. Ammoniacal and nitrate nitrogen contents of soil, and water were estimated during this period and expressed as mineralizable nitrogen. In situ measurement of temperature, pH and Eh of soil as well as water was taken at 2 p.m. at fortnightly intervals. Excluding the contribution of nitrogen from soil i.e., subtracting the value of control (T_7) from all the treatments, the percentage of availability of nitrogen at different periods to the quantity of nitrogen initially added through organic manures have been worked out.

3.2.6. Evaluation of azolla as an organic manure.

A field experiment in split plot design with six main plot treatments and five sub plot treatments replicated thrice was laid out in the second crop seasons of 1980 and 1981 (Fig. 3.1.7.3). The residual effect of the treatments was studied during the third crop seasons of 1980 and 1981.

3.2.6.1. Main plot treatments
(Organic manures)

m_1 - Control

m_2 - Cattle manure at 5 t ha^{-1}

m_3 - Green leaves at 5 t ha^{-1}

m_4 - Azolla at 5 t ha^{-1}

m_5 - Azolla at 7.5 t ha^{-1}

m_6 - Azolla at 10 t ha^{-1}

3.2.6.2. Sub plot treatments
(Different percentages of the recommended dose of N, P_2O_5 and K_2O for Jaya i.e., 90:45:45 kg ha^{-1})

s_1 - Control

s_2 - 25%

s_3 - 50%

s_4 - 75%

s_5 - 100%

Gross plot size - 5 m x 3 m

Net plot size - 4.2 m x 2.4 m (First crop season)

4.2 m x 2.6 m (Second crop season)

Glyricidia (*Glyricidia maculata*) was the source of green leaves. Percentage of dry matter and nutrient contents of organic manures are given under.

Organic manure	Dry matter	N	P_2O_5	K_2O
Azolla	5.60	3.36	0.89	1.46
Cattle manure	29.38	1.52	0.35	0.25
Glyricidia	21.08	2.57	0.48	1.42

The summer crop of Thriveni was taken without organic manures and fertilizers to evaluate the residual effect of the treatments.

The contents of N, P and K in rice and uptake at active tillering, panicle initiation and maturity stages were estimated. Available N, P and K contents of soil at the above periods were also estimated in both the years of the trial.

3.3. Methods

3.3.1. Soil analysis.

The soil samples were dried in shade, sieved through 2 mm sieve and used for the following estimations.

The soil pH, EC and Eh were measured following the procedure suggested by Jackson (1973). Walkley and Black's wet oxidation method was followed for the estimation of organic carbon of the soil (Piper, 1966). Total N of the soil was estimated by Macro Kjeldahl method as suggested by Jackson (1973). Available N of soil was estimated by alkaline permanganate method (Subbiah and Asija, 1956). Ammoniacal N was extracted with 10 per cent NaCl (pH 2.5) and estimated by Micro Kjeldahl method. Chromotropic acid method as suggested by Sims and Jackson (1971) was used for estimation of nitrate N of soil. Available P of soil was extracted with Bray No.1 solution and estimated by chlorostannous-reduced molybdophosphoric acid blue colour method as reported by Jackson (1973). Available K, Ca and Mg were extracted with neutral normal ammonium acetate and estimated as per the procedure suggested by Jackson (1973). The contents of Fe, Mn, Zn and Cu were estimated using a Perkin atomic absorption spectrophotometer after extraction with D.T.P.A. as suggested by Lindsay and Norwell (1978).

3.3.2. Analysis of water.

Measurement of EC, pH and Eh of water was made by adopting the procedures employed for their estimation in soil. Ammoniacal N was estimated by Micro Kjeldahl method. Chromotropic acid method was used for estimation of nitrate N. Chlorostannous reduced molybdophosphoric acid blue colour method was used for estimation of the P content of water and the K content was read in a flame photometer. Contents of Ca and Mg were estimated by titration against EDTA and Fe, Mn, Zn and Cu contents were read in an atomic absorption spectrophotometer.

3.3.3. Analysis of plant.

Rice plants collected at active tillering and panicle initiation stages and grain and straw samples collected for recording phytomass production were chemically analysed for N, P and K. Similarly rice grain and azolla plants were analysed for these elements as per the following methods and expressed as per cent over dry matter. The N content was determined by Micro Kjeldahl method and P of triacid digested extract by Vanadomolybdophosphoric yellow colour method as suggested by Jackson (1973). The K content of the extract was read in a flame photometer (Jackson, 1973).

3.3.4. Uptake of N, P and K by rice.

The uptake of N, P and K by rice at active tillering, panicle initiation and maturity stages were computed from their respective elemental concentrations and phytomass. At maturity stage, uptake by grain and straw were calculated separately and added together to get the total uptake.

3.3.5. Growth and yield parameters of rice and azolla.

3.3.5.1. Height of plant and tillers m^{-2}

Observations on the height of plant and total tillers m^{-2} were taken at active tillering, panicle initiation and maturity stages of rice. The number of panicles m^{-2} was noted at maturity stage. Two hill x two hill sampling units, marked in the net plot were taken for recording the observations.

3.3.5.2. Phytomass production

In rice, a two x two hill unit was uprooted and the plants were washed, sundried, oven dried at 70°C for 48 hours and the weight recorded in g m^{-2} at active tillering, panicle initiation and at maturity stages of the crop.

Azolla collected for dry weight determination was washed, excess water drained off and fresh weight recorded. It was sun dried and then oven dried at 70°C for 48 hours for dry weight determination.

3.3.5.3. Leaf area index

Leaf area index was measured at active tillering, panicle initiation and flowering stages. The leaves of plants taken for dry matter production was used for leaf area index measurement, following the procedure given by Yoshida *et al*. (1976).

3.3.5.4. Yield and yield parameters of rice

3.3.5.4.1. Grain yield

After harvesting and threshing, the grains from each net plot were sun dried for three days, winnowed and the grain and chaff were separated. Grain yield was expressed in kg ha^{-1} at 14 per cent moisture.

3.3.5.4.2. Straw yield

For each net plot, the fresh weight of straw was noted and the straw was sun dried for a week, weighed and expressed in kg ha^{-1}.

3.3.5.4.3. Harvest index

Harvest index was computed by the following formula and expressed as percentage.

$$\text{Harvest index (HI)} = \frac{\text{dry grain yield}}{\text{dry grain yield} + \text{dry straw yield}}$$

3.3.5.4.4. Length of panicle

Panicle length from the peduncle node to the tip of the panicle was noted for all the panicles of the four hills collected at maturity for phytomass estimation and the mean values were worked out.

3.3.5.4.5. Number of spikelets $panicle^{-1}$

All the spikelets on each panicle of the four hills collected at maturity were counted and the mean value was taken.

Number of filled grains panicle^{-1}, percentage of filled grains and thousand grain weight were computed as described by Gomez (1972).

3.3.6. Statistical analysis.

The experimental data were statistically analysed by applying the technique of analysis of variance and the significance tested by 'F' test (Snedecor and Cochran, 1967).

3.3.7. Economics.

Cost of production of all the treatment combinations of the experiment on evaluation of azolla as an organic manure was worked out on the basis of the prevailing input cost and market price of grain and straw. The net income ha^{-1} was calculated by deducting the cost of production ha^{-1} from the gross returns ha^{-1}.

Results

IV. RESULTS

The results of the survey conducted in three different regions with field experiments on three aspects viz., time of application and quantity of inoculum and geometry of planting rice in relation to growth of azolla, and evaluation of azolla as an organic manure and two pot culture trials i.e., nutritional requirement and mineralization of azolla compared to other organic manures are presented in this chapter.

4.1. Survey on the environmental requirement of azolla

In order to identify the azolla growing locations in Kerala State and the conditions under which azolla grows well, the edaphic nature of three regions viz., Kayamkulam, Pazhanji and Pattambi were monitored. The available nutrient status of these regions along with the weather paramoters of Kayamkulam and Pattambi for 1980 are presented below.

4.1.1. Texture of soils.

The soils of Kayamkulam region were sandy loam in texture and between the soils of azolla growing and non-growing locations in this region, non-growing location showed higher clay content of 17.8 per cent compared to the mean value of 12.7 per cent in the azolla growing location (Table 4.1.1). Conversely the sand fraction was more in the azolla growing location. In Pazhanji region, the soils which favoured azolla growth were loamy sand in texture with a mean clay per cent of 10.9 while the non-growing location was sandy loam in texture with a clay

Table 4.1.1. Texture of soils of azolla growing and non-growing locations

Location	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Textural class
<u>Kayamkulam region</u>					
G_1 - Karuvatta	41.9	39.4	2.8	13.2	Sandy loam
G_2 - Kuttitheruvu	40.2	42.0	3.2	12.1	Sandy loam
Mean	41.1	40.7	3.0	12.7	
NG - Arithalil	24.5	48.5	5.9	17.8	Sandy loam
<u>Pazhanji region</u>					
G_1 - Pazhanji 1	44.9	36.9	5.0	10.5	Loamy sand
G_2 - Pazhanji 2	42.2	38.2	5.6	11.3	Loamy sand
Mean	43.6	37.6	5.3	10.9	
NG - Pazhanji 3	28.1	44.2	6.6	18.3	Sandy loam
<u>Pattambi region</u>					
G_1 - Block 3	47.0	21.9	12.9	18.2	Sandy loam
G_2 - Block 5	44.9	23.2	8.6	20.5	Sandy clay loam
Mean	46.0	22.6	10.8	19.4	
NG - Block L	26.9	14.3	19.9	36.5	Clay loam
General mean - G	43.6	33.6	6.4	14.3	
General mean - NG	26.5	35.7	10.8	24.2	

Method of estimation,
International Pipette Method (Piper, 1966)
G: Azolla growing location, NG: Non-growing location

content of 18.3 per cent. Here also the proportion of sand was more in the azolla growing locations. In Pattambi region, the two azolla growing locations differed in soil texture, the first location was sandy loam with a clay content of 18.2 per cent while the second one was sandy clay loam in texture, with a clay content of 20.5 per cent. The third location of Pattambi was clay loam in texture and had the highest clay content of 36.5 per cent compared to others. The trend in sand content of azolla growing and non-growing locations were similar to that of Kayamkulam and Pazhanji regions.

Comparison of soils of the three regions revealed that Kayamkulam and Pazhanji were almost similar in soil texture with high content of sand while Pattambi had a higher proportion of clay.

4.1.2. <u>Physico-chemical properties of the soils.</u>

A perusal of the physico-chemical properties of the soils (Table 4.1.2) revealed that there was much variation in soil pH between and within the azolla growing and non-growing locations of the regions. The pH of soil of azolla growing and non-growing locations of Kayamkulam were 5.5 and 4.5 respectively. A similar trend was noticed in Pazhanji also. At Pattambi, no perceptible variation was, however, observed in soil pH (4.7-4.9). The mean pH value of azolla growing area was 5.3 while the non-growing area had a lower pH value of 4.6. Among the locations across the regions favouring azolla growth,

Table 4.1.2. Physico-chemical properties of soils of azolla growing and non-growing locations

Location	pH	EC (mmhos cm^{-1})	Available nutrient (ppm)								
			N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
<u>Kayamkulam region</u>											
G_1 - Karuvatta	5.5	0.48	19.7	12.8	10.5	60.1	24.3	250.5	0.1	0.4	0.7
G_2 - Kuttitheruvu	5.5	0.42	13.5	15.2	9.3	70.4	12.2	289.5	0.2	0.3	0.9
Mean	5.5	0.45	16.6	14.0	9.9	65.3	18.3	270.0	0.2	0.4	0.9
NG - Arithalil	4.5	0.78	4.7	2.4	10.1	100.2	24.3	307.5	0.3	2.9	1.1
<u>Pazhanji region</u>											
G_1 - Pazhanji 1	5.3	0.40	17.3	9.0	8.9	60.2	24.3	312.0	2.2	1.2	1.5
G_2 - Pazhanji 2	5.3	0.39	14.9	9.0	9.3	40.3	24.8	318.0	2.3	0.6	1.5
Mean	5.3	0.40	16.1	9.0	9.1	50.3	24.6	315.0	2.3	0.9	1.5
NG - Pazhanji 3	4.6	0.64	15.7	2.8	8.8	72.0	22.3	350.0	3.8	2.1	1.8
<u>Pattambi region</u>											
G_1 - Block 3	5.0	0.64	19.4	2.8	16.7	100.5	36.5	393.0	6.7	1.8	2.4
G_2 - Block 5	4.9	0.59	16.5	3.8	17.1	80.2	97.3	364.5	4.6	1.3	2.4
Mean	5.0	0.62	18.0	3.3	16.9	90.4	66.9	378.8	5.7	1.6	2.4
NG - Block L	4.7	0.68	17.6	2.8	32.6	260.5	83.2	436.5	7.1	1.9	3.0
General mean - G	5.3	0.49	16.9	8.8	12.0	68.7	36.6	321.2	2.7	1.0	1.6
General mean - NG	4.6	0.70	12.7	2.7	17.2	144.2	43.3	364.7	3.7	2.3	2.0

G : Azolla growing location, NG : Non-growing location

Kayamkulam and Pazhanji had relatively higher pH values than that of Pattambi.

Electrical conductivity of azolla growing and non-growing locations within the three regions also differed considerably. Azolla growing locations had lower EC values compared to non-growing locations and the mean values were 0.49 and 0.70 mmhos cm^{-1} respectively.

The variation in available N content of soil between regions and the locations within the regions, were not substantial. In general the N content of soil favouring azolla growth had higher values compared to non-growing locations.

Available P content of soil varied much within and between regions. When the P content was 2.4 ppm in non-growing location of Kayamkulam, the mean value was 14.0 ppm in the azolla growing locations of that region. The corresponding values of available P in non-growing and growing locations of Pazhanji and Pattambi were 2.8 and 9.0 and 2.8 and 3.3 ppm respectively. When the general mean value of P in azolla growing location was 8.8 ppm, it was only 2.6 ppm in non-growing locations. Among the azolla growing locations of different regions, Kayamkulam had the highest value of 14.0 ppm as against the lowest value of 3.3 ppm in Pattambi.

Azolla growing and non-growing areas did not show much variation in K content of soil except at Pattambi where the non-growing location had a distinctly higher content of available K.

Calcium content of soil varied greatly between locations within and between the regions. The range in Ca content was 65.3 to 100.2 ppm between locations favouring azolla growth and that not favouring the growth of azolla in Kayamkulam, the corresponding values for Pazhanji and Pattambi were 50.3 and 72.0 and 90.4 and 260.5 ppm respectively. The overall mean values of Ca, between azolla growing and non-growing locations were 68.7 and 144.2 ppm respectively.

Within the region, the Mg content of soil varied much at Pattambi, where the Mg content of azolla growing and non-growing locations were 66.9 and 83.2 ppm respectively. When the mean Mg content of locations favouring azolla growth of Kayamkulam was 18.3 ppm, it was 66.9 ppm at Pattambi.

The iron content of soil was quite high in non-growing locations compared to azolla growing locations in all the three regions. With respect to available Fe in soil, the three regions ranked in the following descending order of Pattambi, Pazhanji and Kayamkulam. The overall mean of Fe content for the locations favouring and non-favouring azolla growth were 321.2 and 364.7 ppm respectively.

Manganese, zinc and copper contents of soils followed the same trend as that of iron.

In general, soils which were less acidic, with high content of available P seemed to favour the growth of azolla. Concentration of micronutrients also was relatively less in locations where the azolla growth was better.

4.1.3. Chemical properties of water.

It was observed that pH of water of locations favouring azolla growth varied among the three regions (Table 4.1.3). In general the pH of water of azolla growing location was higher than that of the non-growing location. Among the azolla growing locations, Kayamkulam recorded the highest pH of 6.3 compared to 5.7 at Pattambi.

In all the regions the EC of water favouring azolla growth had lower values compared to non-growing locations. Among the azolla growing locations, Kayamkulam had the lowest value.

Azolla growing locations had in general lower N concentrations in water than the non-growing locations.

Phosphorus content of water, however, differed considerably between locations within the three regions. When the mean concentration of P was 0.03 ppm in Kayamkulam, the third location of Kayamkulam devoid of azolla growth had only traces of P in water. A similar trend was observed in other regions also. Among the three regions Pattambi showed the lowest value.

Potassium contents of water in locations of azolla growth were higher than that of the non-growing areas. Among the regions Kayamkulam registered the highest value (2 ppm).

Ca content did not show a definite trend with azolla growth in different locations of the three regions.

Comparison of mean Mg content of water in azolla growing

Table 4.1.3. Chemical properties of water of azolla growing and non-growing locations

Location	pH	EC (mmhos cm^{-1})	Available nutrient (ppm)					
			N	P	K	Ca	Mg	Fe
<u>Kayamkulam region</u>								
G_1 - Karuvatta	6.3	0.15	1.5	0.02	1.9	10.3	3.7	0.08
G_2 - Kuttitheruvu	6.2	0.10	1.8	0.03	2.0	3.9	3.9	0.09
Mean	6.3	0.13	1.7	0.03	2.0	7.1	3.8	0.09
NG - Arithalil	5.2	0.53	2.1	trace	1.0	10.1	trace	0.21
<u>Pazhanji region</u>								
G_1 - Pazhanji 1	6.0	0.50	2.1	0.05	0.9	7.4	2.4	0.09
G_2 - Pazhanji 2	6.1	0.39	2.4	0.02	1.2	7.6	2.5	0.08
Mean	6.1	0.45	2.3	0.04	1.1	7.5	2.5	0.09
NG - Pazhanji 3	5.1	0.58	2.3	0.01	0.7	3.1	0.5	0.18
<u>Pattambi region</u>								
G_1 - Block 3	5.6	0.51	2.9	0.01	1.3	5.4	1.2	0.51
G_2 - Block 5	5.7	0.54	1.8	0.02	1.8	5.0	1.2	0.52
Mean	5.7	0.53	2.4	0.02	1.6	5.2	1.2	0.52
NG - Block L	5.5	0.57	2.9	trace	1.1	5.0	trace	0.81
General mean - G	6.0	0.37	2.1	0.03	1.6	6.6	2.5	0.23
General mean - NG	5.3	0.56	2.4	0.01	0.9	6.1	0.2	4.00

G : Azolla growing location   NG : Non-growing location locations among the regions revealed that Kayamkulam had the highest value (3.8 ppm) and Pattambi the lowest (1.2 ppm).

In all the regions concentration of Fe in water was lower in locations having azolla growth. Water of locations favouring azolla growth of Kayamkulam region had the lowest value (0.09 ppm) while Pattambi showed the highest value (0.52 ppm). Manganese, zinc and copper contents of water of these regions could not be estimated because of their very low concentration in water.

To sum up the pH of water of location favouring azolla growth was higher than that of non-growing areas. Among the nutrients ostensibly higher contents of P, Ca and Mg in water seemed to favour the growth of azolla.

4.1.4. Dry matter and nutrient contents of azolla.

The percentage of dry matter and nutrient contents of azolla collected from the three regions are given below.

Region	Dry matter	N	P	K
Kayamkulam	6.2	3.39	0.24	1.14
Pazhanji	5.9	3.19	0.35	1.34
Pattambi	6.3	3.24	0.29	1.28

There was not any perceptible variation in dryage and nutritional qualities of azolla from different regions.

4.1.5. Weather parameters.

The survey also envisaged to identify the weather factors favouring azolla growth and was undertaken during the year 1980. The fluctuation in weather parameters of Kayamkulam and Pattambi are presented in appendix III and figures 4.1.5.1 and 4.1.5.2.

The variation in weekly mean maximum temperature at Kayamkulam during the azolla growing season (June-November) was from 29.6 to 32.7°C whereas Pattambi experienced a wider variation from 28.4 to 33.8°C during the period. The mean maximum temperature for Kayamkulam and Pattambi were 31.2 and 30.8°C respectively during the season. The mean maximum temperature for the non-growing season (December-May) were 34.0 and 35.2°C for Kayamkulam and Pattambi respectively and it ranged from 31.4 to 35.2°C at Kayamkulam and from 32.8 to 37.4°C at Pattambi.

Mean minimum temperature during the season varied from 22.8 to 24.8°C at Kayamkulam whereas fluctuations at Pattambi were from 21.9 to 23.9°C. The mean values for the non-growing season were 23.0°C and 22.8°C at Kayamkulam and Pattambi respectively. Pazhanji had the lowest atmospheric temperature both at 7 a.m. (26.0°C) and at 2 p.m. (29.1°C).

Kayamkulam recorded a higher mean relative humidity (7 a.m.) of 95.2 per cent during the season with a variation from 92 to 97 per cent. The mean value for Pattambi during the period was 94.7 per cent and the values fluctuated from

85 to 97 per cent. The mean values for the non-growing period were 91.5 and 87.9 per cent for Kayamkulam and Pattambi respectively. The relative humidity in the afternoon also varied much in the two places. The variation was from 57 to 84 per cent at Kayamkulam while the values fluctuated between 50 and 89 per cent at Pattambi, with mean values of 70.7 and 72.2 per cent respectively. The mean values for the non-growing period in these two places were 54.8 and 45.0 per cent respectively.

Kayamkulam recorded a total rainfall of 1950 mm in 87 rainy days during the season while Pattambi registered 2686 mm in 105 days during the same period. Rainfall during the non-growing period also showed variation. Kayamkulam received a total rainfall of 364.3 mm in 20 rainy days while Pattambi recorded only 253.9 mm in 15 days during the non-growing period.

The sunshine hours fluctuated between 2.3 and 10.6 during the season with a mean value of 5.9 in Kayamkulam whereas it varied from 1.1 to 9.6 in Pattambi and the mean value was 5.2 hr. The mean values for non-growing period for Kayamkulam and Pattambi were 9.5 and 9.1 hr respectively.

Evaporation rates showed wide variation between two places. The mean values for Kayamkulam and Pattambi were 3.4 and 3.9 mm day^{-1} respectively during the azolla growing season. The maximum and minimum values for Kayamkulam were 1.7 and 5.9 mm day^{-1} respectively while the corresponding values were 2.7 and 5.2 mm at Pattambi. During the non-growing season, the mean evaporation was 4.3 mm at Kayamkulam while it was 6.4 mm day^{-1} at Pattambi.

To sum up, it can be seen that the fluctuations in maximum temperature were narrower at Kayamkulam than that at Pattambi. Kayamkulam also recorded higher relative humidity and a well distributed rainfall. Evaporation and variation in sunshine hours were less at Kayamkulam during the period.

4.2. Nutritional requirement of azolla

In order to identify the nutrients required for rapid multiplication of azolla in the field, a pot culture experiment was conducted during July 1984 and it was repeated in August 1984. The data on the effect of each of the elements on the rate of growth, dry matter and N contents of azolla are presented in tables 4.2.1 and 4.2.2 and figure 4.2.1.

The data indicated that at the end of the first week, the treatment receiving no N (X-N) had the maximum growth of azolla of 96.3 g m^{-2} which was significantly superior to other treatments (Table 4.2.1). The percentage increase in yield over the control (X) was 11.6. Omission of P from the nutrient solution (X-P) had resulted in the lowest azolla yield (77.7 g) followed by X-Mg and X-Ca. In the trial repeated in August also a similar trend was observed.

At the end of the second week, in both the trials, the treatment from which N had been omitted, showed maximum growth and X-K ranked second in this respect. Though omission of P had resulted in minimum growth in the first trial and deletion of Mg in the second trial, the yield of azolla in these treatments were statistically on par.

Table 4.2.1. Effect of nutrient deficiency on the growth of azolla

Treatments		Growth of azolla (g m^{-2})							Doubling time (days)	
		Weeks after inoculation						Pooled Mean (Third week)	First trial	Second trial
		First trial			Second trial					
		1	2	3	1	2	3			
T_1	Water alone	83.1	132.6	230.4	87.6	145.7	190.4	210.3	9.5	10.9
T_2	X	86.3	135.4	234.4	88.2	147.4	192.4	213.4	9.4	10.8
T_3	X-N	96.3	143.3	247.2	93.9	153.3	204.5	225.9	9.1	10.3
T_4	X-P	77.7	121.0	185.2	80.5	120.2	157.7	171.2	11.1	12.7
T_5	X-K	87.8	141.0	239.4	88.9	148.4	190.8	215.1	9.3	10.9
T_6	X-Ca	81.8	132.3	219.8	84.5	132.2	173.2	196.5	9.8	11.7
T_7	X-Mg	80.8	123.5	217.5	81.7	117.7	170.3	193.9	9.9	11.9
T_8	X-Fe	88.2	136.1	230.2	86.6	149.3	192.3	211.5	9.5	10.8
T_9	X-Mn	87.3	136.4	232.6	88.4	147.6	197.9	215.3	9.5	10.6
'F' test		*	*	**	*	*	**	*	*	*
S.Em.±		0.49	1.34	2.51	0.48	1.19	0.55	1.32	0.18	0.23
C.D.(0.05)		1.46	3.99	7.46	1.44	3.54	1.65	3.80	0.56	0.71

* Significant at 0.05 level

** Significant at 0.01 level

X = Treatment receiving nutrients such as N, P, K, Ca, Mg, Fe and Mn (control)

Table 4.2.2. Effect of nutrient deficiency on dry matter production and nitrogen content of azolla at three weeks after inoculation

Treatments		Dry matter production (%)		Nitrogen content (%)		
		First trial	Second trial	First trial	second trial	Pooled mean
T_1	Water alone	5.8	5.3	2.6	3.2	2.90
T_2	X	6.1	6.3	4.2	4.1	4.15
T_3	X-N	5.9	6.0	4.0	4.4	4.20
T_4	X-P	6.5	6.8	3.6	3.7	3.65
T_5	X-K	6.0	6.1	4.0	4.5	4.25
T_6	X-Ca	6.2	6.3	4.1	3.8	3.95
T_7	X-Mg	6.3	6.4	3.5	3.6	3.55
T_8	X-Fe	6.1	6.2	4.0	4.1	4.05
T_9	X-Mn	6.0	6.2	4.1	4.1	4.10
'F' test		NS	*	*	*	*
S.Em.±		0.16	0.19	0.10	0.15	0.073
C.D.(0.05)		-	0.58	0.30	0.43	0.230

* Significant at 0.05 level

NS Not significant

X= Treatment receiving all nutrients such as N, P, K, Ca, Mg, Fe and Mn (control)

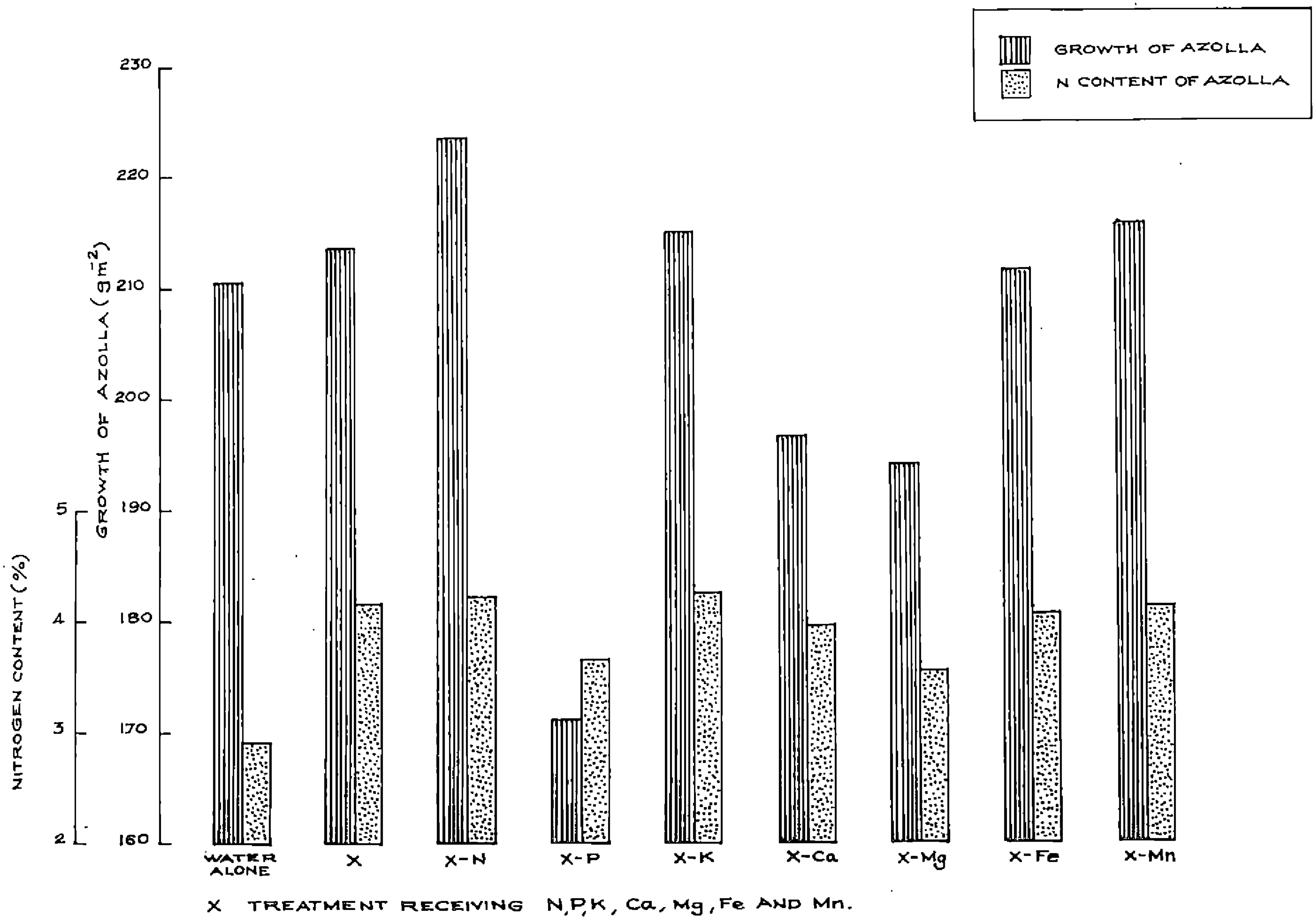


FIG. 4·2·1. EFFECT OF NUTRIENT DEFICIENCY ON GROWTH AND NITROGEN CONTENT OF AZOLLA.

At the end of the third week, growth of azolla was maximum in the treatment devoid of N with a mean yield of 247.2 g m^{-2} in the first trial. The treatment X-K ranked second (239.4 g) which was on par with X (234.4 g) and X-Mn (232.6 g) and superior to other treatments. In the second trial also, a similar trend was observed. Exclusion of P from the nutrient solution had resulted in the lowest yield (157.7 g) followed by X-Mg (170.3 g).

In general, growth of azolla was better in the first trial compared to the second.

A perusal of the pooled data of the two trials for the third week showed significant variation between treatments (Table 4.2.1 and Fig. 4.2.1). Omission of N had resulted in the highest mean yield of 223.4 g m^{-2} which was superior to yields in rest of the treatments. The increase in yield over the control (X) was 4.7 per cent. The treatments X-K, X-Mn, X and X-Fe were on par in yield. Omission of P had resulted in the lowest yield (171.2 g) and percentage reduction over the control was 19.8. Similarly omission of Mg and Ca resulted in yield reductions of 9.1 and 7.9 per cent respectively over the control.

There was slight variation in the dry matter content due to deficiency of nutrients (Table 4.2.2). Maximum dry matter content of 6.5 per cent was for the treatment from which P had been omitted, followed by magnesium deficient plants. Minimum dry weight was noted in the treatment receiving no nutrients (water alone). In the second trial also almost a similar trend was noted except that the differences due to treatments were statistically significant.

In the first trial, the N content of azolla taken at three weeks also showed considerable variation as a function of nutrient supply (Table 4.2.2). The treatment receiving all the nutrients had the highest N content of 4.2 per cent which was on par with X-Mn, X-Ca, X-Fe, X-N and X-K and superior to rest of the treatments. The treatment X-P (3.6 per cent) was on par with X-Mg and superior to the treatment receiving no nutrient. In the second trial X-N recorded the highest N content of 4.4 per cent which was on par with X-K, X, X-Mn and X-Fe and superior to rest of the treatments. The treatment X-Ca, X-P and X-Mg were on par in N content and superior to the treatment receiving water alone.

Pooled analysis of the N content of azolla of the two trials revealed the importance of curtailing N supply to azolla for greater efficiency in biological fixation of atmospheric N_2. The treatment, X-N recorded a value of 4.20 per cent which was on par with X-K, X, X-Mn and X-Fe and superior to rest of the treatments. X-P and X-Mg with low values of 3.65 and 3.55 per cent respectively were inferior in N content to the above treatments. However, azolla grown in water alone recorded the lowest N content of 2.9 per cent which was significantly inferior to that of all other treatments.

Growth rate of azolla in terms of doubling time revealed that in both the trials, the treatment X-N took the minimum number of days with a mean value of 9.7 days. The treatment X-P recorded the maximum mean doubling time of 11.9 days.

In the final analysis it can be seen that omission of N from complete nutrient solution had resulted in significantly higher growth of azolla. Exclusion of K, Mn and Fe could not influence the growth or N content of azolla significantly. Omission of P affected the growth as well as N content significantly. Deletion of Mg and Ca also affected the growth and N content to a lesser extent.

4.3. Time of application and quantity of inoculum on the growth of azolla and yield of rice

In order to study the effect of time of application and quantity of azolla inoculum on the growth of azolla and yield of rice, field trials were laid out in the second crop season of 1980 and first and second crop seasons of 1981. The results of the trials are presented hereunder.

4.3.1. Effect on yield of azolla.

4.3.1.1. Second crop season of 1980

Though there was not much growth of azolla during the second crop season of 1980, in fact there was reduction in the growth of azolla from the first week and the trend lasted till the third week in the case of t_1 (inoculation one week after planting) (Table 4.3.1). But in t_2 (inoculation two weeks after planting) and t_3 (inoculation three weeks after planting) a slight increasing trend was observed after the initial set back. In all the treatments, azolla turned from green to red, 4-6 days after the application of inoculum. Nevertheless, t_3 with azolla yields of 128, 163 and 275 g m^{-2} showed superiority over other treatments in the first, second and third weeks respectively after inoculation (Table 4.3.1). Similarly t_2 was superior to t_1 in the second and third weeks after application.

Quantity of inoculum affected the growth of azolla at all the three stages of observation. The treatment q_3 (400 g inoculum m^{-2}) with a value of 110 g m^{-2} was superior to other treatments in the first week (Table 4.3.1). Nevertheless, q_4 (600 g of inoculum m^{-2}) was on par with q_3 during the second week. At the final stage, q_4 with an azolla yield of 196 g m^{-2} was significantly superior to other two treatments i.e., q_3 and q_2 (200 g of inoculum); q_1 being a treatment receiving no azolla. In all the three weeks, q_3 was found to be superior to q_2.

Interaction between time of application and quantity of inoculum was significant and t_3q_4 with a value of 370 g m^{-2} was superior to all other combinations at the end of the three week period (Fig. 4.3.1.1a).

Figure 4.3.1.1brevealed that there was a steady decline in mean water temperature from the first week to the fifth week after planting. When the mean water temperature at the end of first, second and third weeks after planting for t_1 was 38.2,

Table 4.3.1. Effect of time of application and quantity of azolla inoculum on the yield of azolla (g m^{-2})

Treatment	Weeks after inoculation								
	Second crop 1980			First crop 1981			Second crop 1981		
	1	2	3	1	2	3	1	2	3
<u>Time of inoculation</u>									
t_1 (One week after planting)	39	37	21	162	201	56	328	409	539
t_2 (Two weeks after planting)	41	78	113	453	59	42	284	390	591
t_3 (Three weeks after planting)	128	163	275	261	53	28	388	446	571
'F' test	**	**	**	**	**	**	**	**	**
S.Em ±	2.1	3.1	15.6	6.3	6.3	1.6	3.1	4.1	5.2
C.D.(0.05)	6.3	9.4	46.8	18.7	18.8	5.2	9.3	12.7	16.1
<u>Quantity of inoculum</u>									
q_2 (200 g m^{-2})	66	58	83	156	44	20	157	199	266
q_3 (400 g m^{-2})	110	107	148	305	128	52	355	439	579
q_4 (600 g m^{-2})	103	112	196	416	142	54	490	608	855
'F' test	**	*	**	**	**	**	**	**	**
S.Em.±	2.1	2.1	15.6	6.3	6.3	2.1	3.1	4.1	5.2
C.D.(0.05)	6.2	6.3	46.9	19.6	19.8	6.2	9.3	12.8	15.7

* Significant at 0.05 level
** Significant at 0.01 level

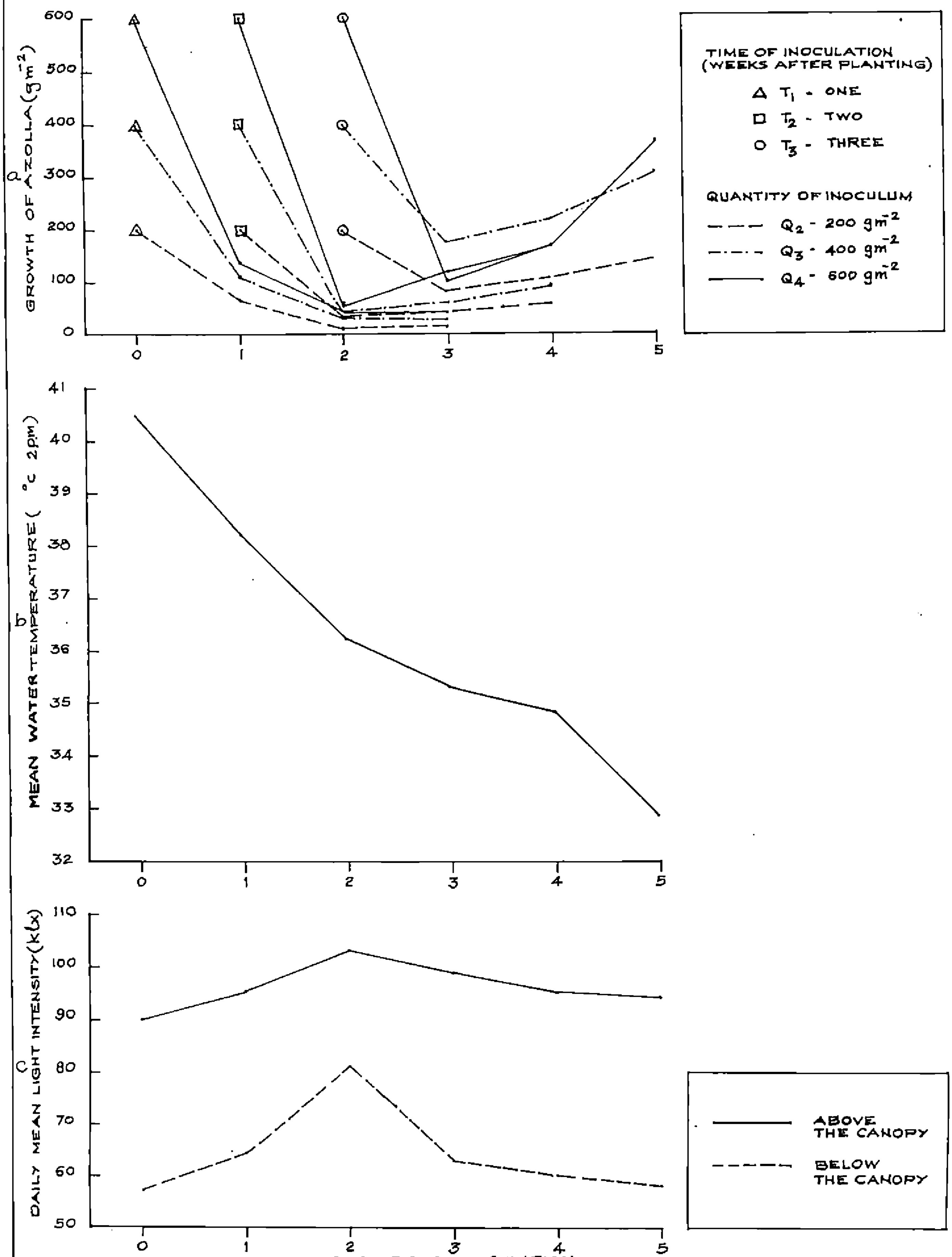


FIG. 4·3·1·1 EFFECT OF TIME OF APPLICATION AND QUANTITY OF INOCULUM ON THE GROWTH OF AZOLLA IN RELATION TO WATER TEMPERATURE AND LIGHT-INTENSITY DURING THE SECOND CROP SEASON OF 1980.

36.2 and 35.3°C respectively, the values for t_2 and t_3 were 36.2, 35.3 and 34.8 and 35.3, 34.8 and 32.8°C respectively.

The daily mean light intensity below the canopy showed an increasing trend from 64 k lx to 81 k lx from the first to the second week after the first inoculation, thereafter it declined (Fig. 4.3.1.1c). The same trend was observed above the crop canopy also.

4.3.1.2. First crop season of 1981

During the first crop season of 1981, t_2 with an azolla yield of 453 g m^{-2} was found to be superior to t_1 and t_3 in the first week after application, but t_1 exerted its superiority at later stages (Table 4.3.1).

Among the quantities of azolla inoculum applied, q_4 with an yield of 416 g m^{-2} was superior to the rest of the treatments in the first week but it was on par with q_3 and superior to q_2 in the other two weeks.

Interaction effect was also significant during the season. Among the combinations, t_2q_4 with a value of 645 g m^{-2} was better than others in the first week (Fig. 4.3.1.2a), but t_1q_4 showed higher yields at later periods.

In the first crop season of 1981, there was a reduction in the growth of azolla during the first week in t_1 followed by an increase during the second week (Fig. 4.3.1.2a). Thereafter the growth of azolla declined in all its subplot treatments. As far as t_2 is concerned q_3 and q_4 showed an increasing

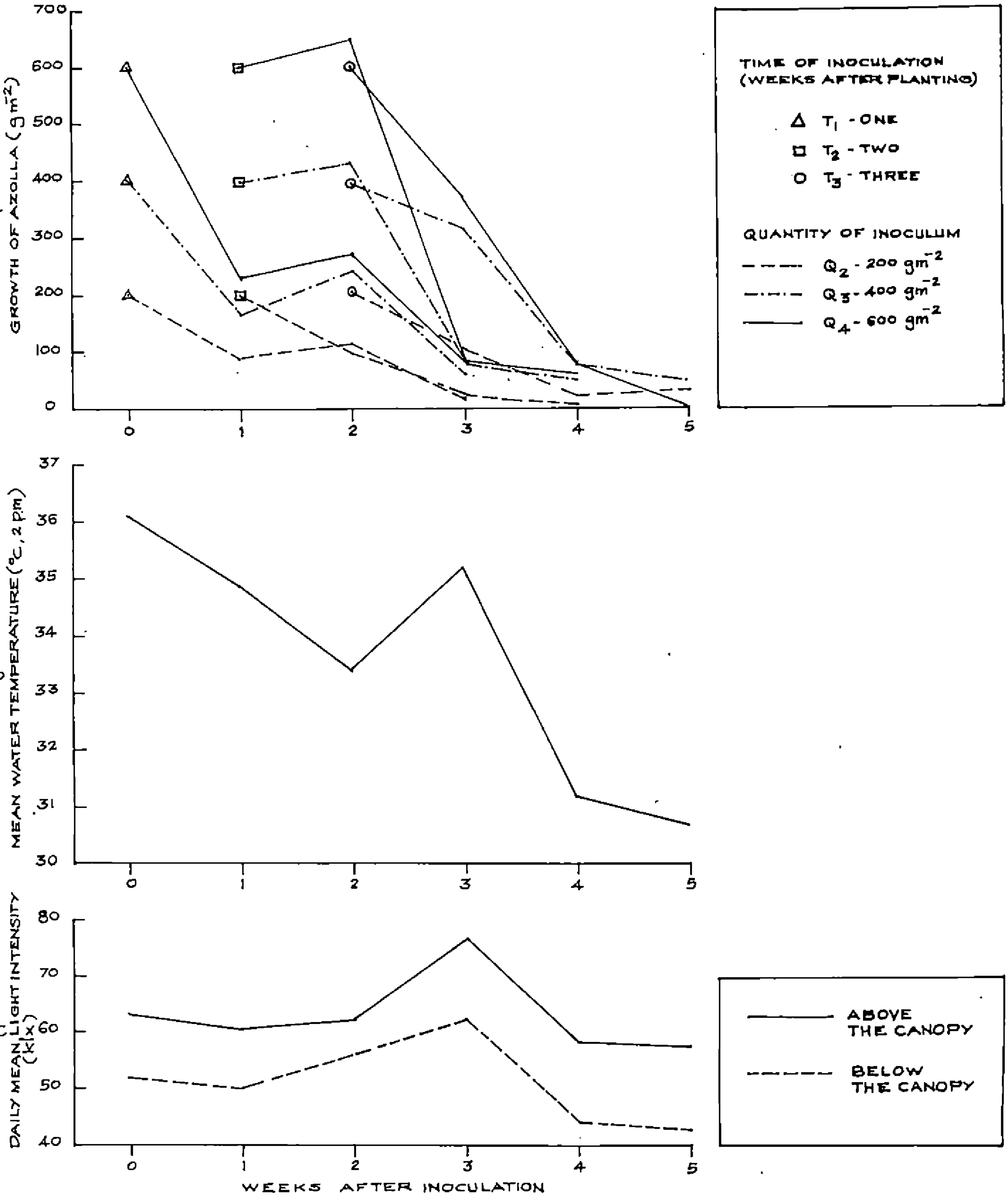


FIG. 4·3·1·2 EFFECT OF TIME OF APPLICATION AND QUANTITY OF INOCULUM ON THE GROWTH OF AZOLLA IN RELATION TO WATER TEMPERATURE AND LIGHT INTENSITY DURING THE FIRST CROP SEASON OF 1981.

trend during the first week followed by a drastic decline. All the t_3 treatments showed a declining trend from the beginning to the end of the study.

Figure 4.3.1.2b showed that the mean water temperature was 36.1°C at the time of inoculation in t_1. Though the value declined to 33.4°C at the end of second week, it showed an increasing trend during the third week. Water temperature at the end of first, second and third weeks after inoculation for t_2 and t_3 were 33.4, 35.2 and 31.2°C and 35.2, 31.2 and 30.7°C respectively.

The daily mean light intensity measurement also showed a similar trend as that of the water temperature with a rise in value from 50 k lx to 62 k lx from first to third week followed by a reduction in values thereafter (Fig.4.3.1.2c).

4.3.1.3. Second crop season of 1981

In the trial of second crop season of 1981, t_3 with values of 388 and 446 g m^{-2} was superior to t_1 and t_2 in azolla growth in the first and second weeks respectively but t_2 with mean yield of 591 g m^{-2} was superior to t_3 and t_1 in azolla yield during the third week (Table 4.3.1).

Among the quantities of azolla inoculum tried, q_4 with values of 490, 608 and 855 g m^{-2} in the first, second and third weeks respectively were superior to q_3 and q_2. In general, q_4 was superior to q_3 and q_2 which were all significantly different from one another.

Interaction between time of application and quantity of inoculum showed significant effect on the growth of azolla (Fig. 4.3.1.3a). The combination t_3q_4 was consistently superior to all other combinations during the first, second and third weeks of the study.

In the first week period, there was decrease in the growth of azolla in all the three times of application eventhough the reduction in t_3 during the first week was not so marked as that of other times of application. From the second week onwards, there was steady growth of azolla which was more marked in t_1 and t_2.

Though the mean water temperature was 35.5°C at the time of inoculation in t_1, the value did not decline remarkably till the end of third week after first inoculation (Fig. 4.3.1.3b). The temperature declined to 33.7°C at the end of fourth week followed by a slight increase during the next week.

The daily mean light intensity below the canopy also showed an increasing trend from 61 k lx to 76 k lx from the first week to the third week after the first inoculation (Fig. 4.3.1.3c).

4.3.2. Effect on yield of rice

Data presented in table 4.3.2 revealed that time of application of azolla inoculum had no effect on grain or straw yields of rice in any of the three seasons tried. But the quantity of inoculum showed significant effect on grain yield.

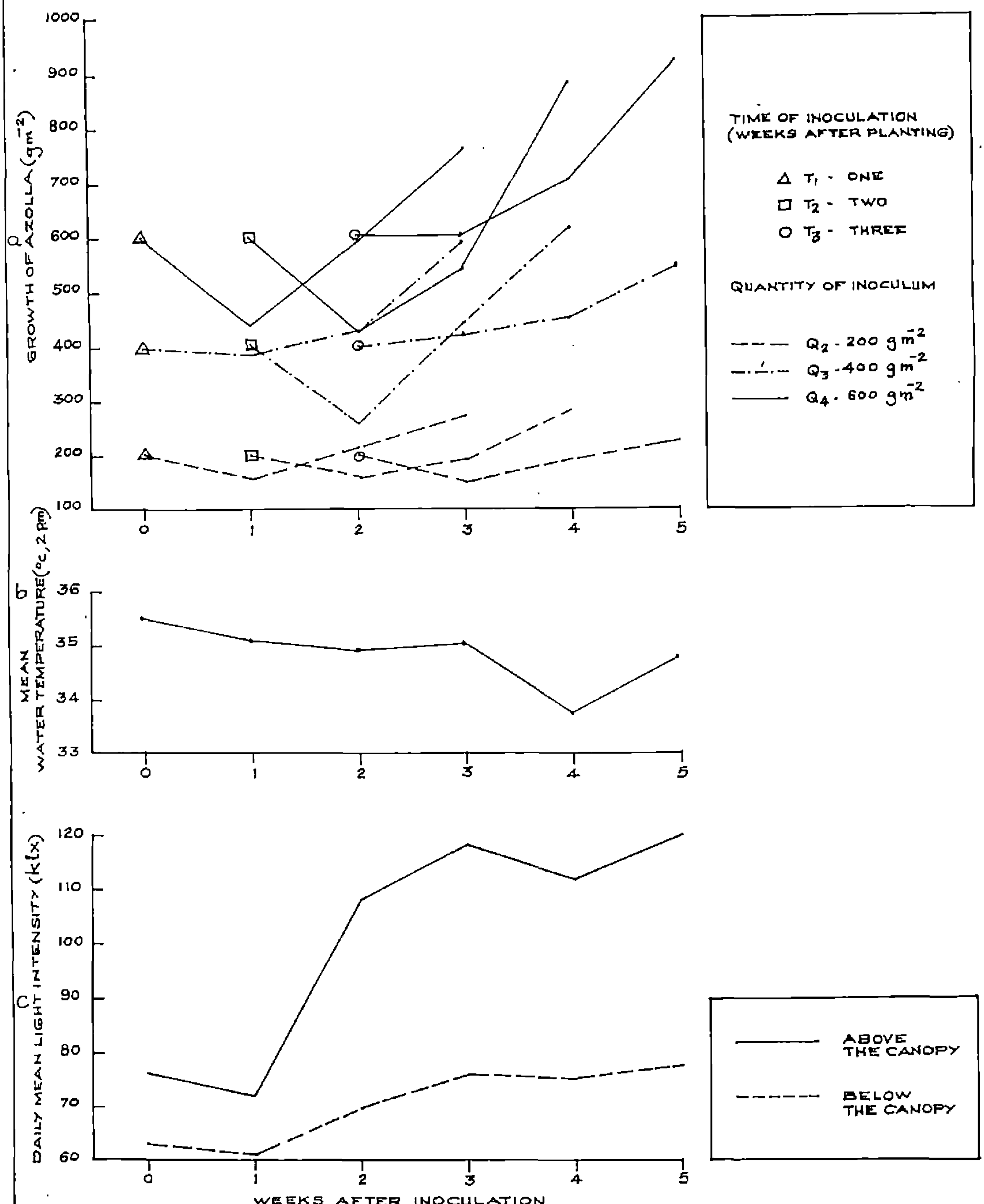


FIG. 4·3·1·3 EFFECT OF TIME OF APPLICATION AND QUANTITY OF INOCULUM ON THE GROWTH OF AZOLLA IN RELATION TO WATER TEMPERATURE AND LIGHT INTENSITY DURING THE SECOND CROP SEASON OF 1981.

Table 4.3.2. Effect of time of application and quantity of azolla inoculum on yield of rice (kg ha^{-1})

Treatment	Season					
	Second crop 1980		First crop 1981		Second crop 1981	
	Grain	Straw	Grain	Straw	Grain	Straw
<u>Time of inoculation</u>						
t_1 (One week after planting)	3575	2892	4827	4375	4798	2724
t_2 (Two weeks after planting)	3506	2981	4809	5359	4920	2951
t_3 (Three weeks after planting)	3613	2718	4840	4379	4850	2853
'F' test	NS	NS	NS	NS	NS	NS
S.Em ±	103.3	125.0	58.6	51.8	77.5	87.4
<u>Quantity of inoculum</u>						
q_1 (No azolla)	3124	2777	4404	3997	4993	2768
q_2 (200 g m^{-2})	3637	3034	4916	4447	4844	2995
q_3 (400 g m^{-2})	3629	2982	4802	4553	4713	2729
q_4 (600 g m^{-2})	3869	3062	5179	4687	4874	2875
'F' test	*	NS	**	**	NS	NS
S.Em.±	112.1	144.3	67.6	59.9	89.5	101.0
C.D.(0.05)	347.7	-	196.3	173.7	-	-

* Significant at 0.05 level
** Significant at 0.01 level
NS Not significant

The treatment q_4 with a grain yield of 3869 kg ha^{-1} was on par with q_3 and q_2 and significantly superior to control (3124 kg) in the second crop season of 1980.

In the first crop season of 1981, quantity of inoculum had significant effect on grain and straw yields of rice. The treatment q_4 with a grain yield of 5179 kg ha^{-1} was superior to others, while q_3 (4802 kg) and q_2 (4916 kg) were on par and superior to control (q_1, 4404 kg). In straw yield, q_4 was on par with q_3 and superior to other treatments.

Interaction between time of application and quantity of inoculum had significant effect on grain and straw yields (Table 4.3.3). Among the combinations, t_3q_4 with a grain yield of 5458 kg ha^{-1} was statistically on par with t_2q_4 (5212 kg) and it was significantly superior to all other combinations. Similar trend was observed in straw yield also.

In the second crop season of 1981, quantity of inoculum could not exert any significant influence on grain or straw yields of rice. But interaction effect was significant on straw yield; t_2q_4 recording the highest straw yield of 3237 kg ha^{-1} during the season.

4.4. Geometry of planting rice in relation to growth of azolla and yield of rice

Effect of geometry of planting rice on the growth of azolla and yield of rice was studied in the second crop season of 1980 and first and second crop seasons of 1981, the results of which are presented below.

Table 4.3.3. Effect of interaction between time of application and quantity of azolla inoculum on yield of rice (kg ha^{-1})

Treatments	First crop 1981								Second crop 1981			
	Grain yield				Straw yield				Straw yield			
	q_1	q_2	q_3	q_4	q_1	q_2	q_3	q_4	q_1	q_2	q_3	q_4
t_1	4686	4947	4810	4866	4259	4470	4369	4402	3018	2848	2688	2341
t_2	4401	4729	4865	5212	4023	4282	4413	4717	2386	3251	2928	3237
t_3	4096	5072	4733	5458	3709	4588	4276	4943	2900	2886	2570	3050
'F' test	*					*				*		
S.Em.±	109.8[a]	117.2[b]				103.7[a]	112.1[b]			161.2[a]	175.1[b]	
C.D.(0.05)	340.1[a]	380.0[b]				301.2[a]	351.3[b]			508.0[a]	579.1[b]	

t_1 One week after planting
t_2 Two weeks after planting
t_3 Three weeks after planting

q_1 No azolla
q_2 Azolla at 200 g m^{-2}
q_3 Azolla at 400 g m^{-2}
q_4 Azolla at 600 g m^{-2}

* Significant at 0.05 level
a For comparing two quantity means at the same level of time mean
b For comparing two time means at the same or different levels of quantity means

At the end of first week during the second crop season of 1980, P_1 (20 cm x 10 cm east-west direction of planting) with an azolla yield of 41 g m^{-2} was on par with P_5 (Bulk method), P_2 (20 cm x 10 cm north-south) and P_3 (40 cm x 5 cm east-west) and significantly superior to P_4 (40 cm x 5 cm north-south) and P_6 (Fallow) (Table 4.4.1 and Fig. 4.4.1a). In the second week, P_1 with an azolla yield of 57 g m^{-2} was on par with P_2 and P_3 and significantly superior to other treatments. At the final stage P_1 was superior to all others in azolla growth.

There was gradual decline in mean water temperature from 41.7°C at the beginning to 35.9°C at the end of three weeks growth period (Fig. 4.4.1b). The decline was almost similar for all the treatments except P_6. Daily mean light intensity showed a slight increase in the second week followed by a decline (Fig. 4.4.1c). The decline was marked for P_2 and P_1. The light and temperature peaks were around 2 p.m. during the second crop season of 1980.

Regarding the effect of geometry of planting on yield of rice, the treatment P_3 recorded the highest grain and straw yields of 4389 and 4781 kg ha^{-1} respectively though the differences in yield between treatments were not statistically significant (Table 4.4.2).

The green colour of azolla turned to red five days after the application of inoculum. This change was noted first in fallow plots (T_6) followed by P_3 and P_4 treatments.

Table 4.4.1. Effect of geometry of planting rice on growth of azolla ($g\ m^{-2}$)

Treatment Geometry of planting	Weeks after inoculation								
	Second crop 1980			First crop 1981			Second crop 1981		
	1	2	3	1	2	3	1	2	3
P_1	41	57	71	55	111	96	177	165	182
P_2	36	50	61	75	110	104	171	148	179
P_3	34	49	59	58	116	93	184	172	160
P_4	26	39	54	53	93	90	166	145	181
P_5	38	47	59	64	158	110	185	167	191
P_6	12	23	40	39	66	55	133	93	68
'F' test	**	**	*	**	**	**	**	**	**
S.Em.$\pm$	2.8	2.9	2.1	3.3	7.3	2.1	3.6	3.6	4.9
C.D.(0.05)	8.7	8.7	6.7	9.8	22.0	6.2	10.8	10.9	14.9

* Significant at 0.05 level

** Significant at 0.01 level

P_1 20 cm x 10 cm east west

P_2 20 cm x 10 cm north south

P_3 40 cm x 5 cm east west

P_4 40 cm x 5 cm north south

P_5 Bulk method

P_6 Fallow

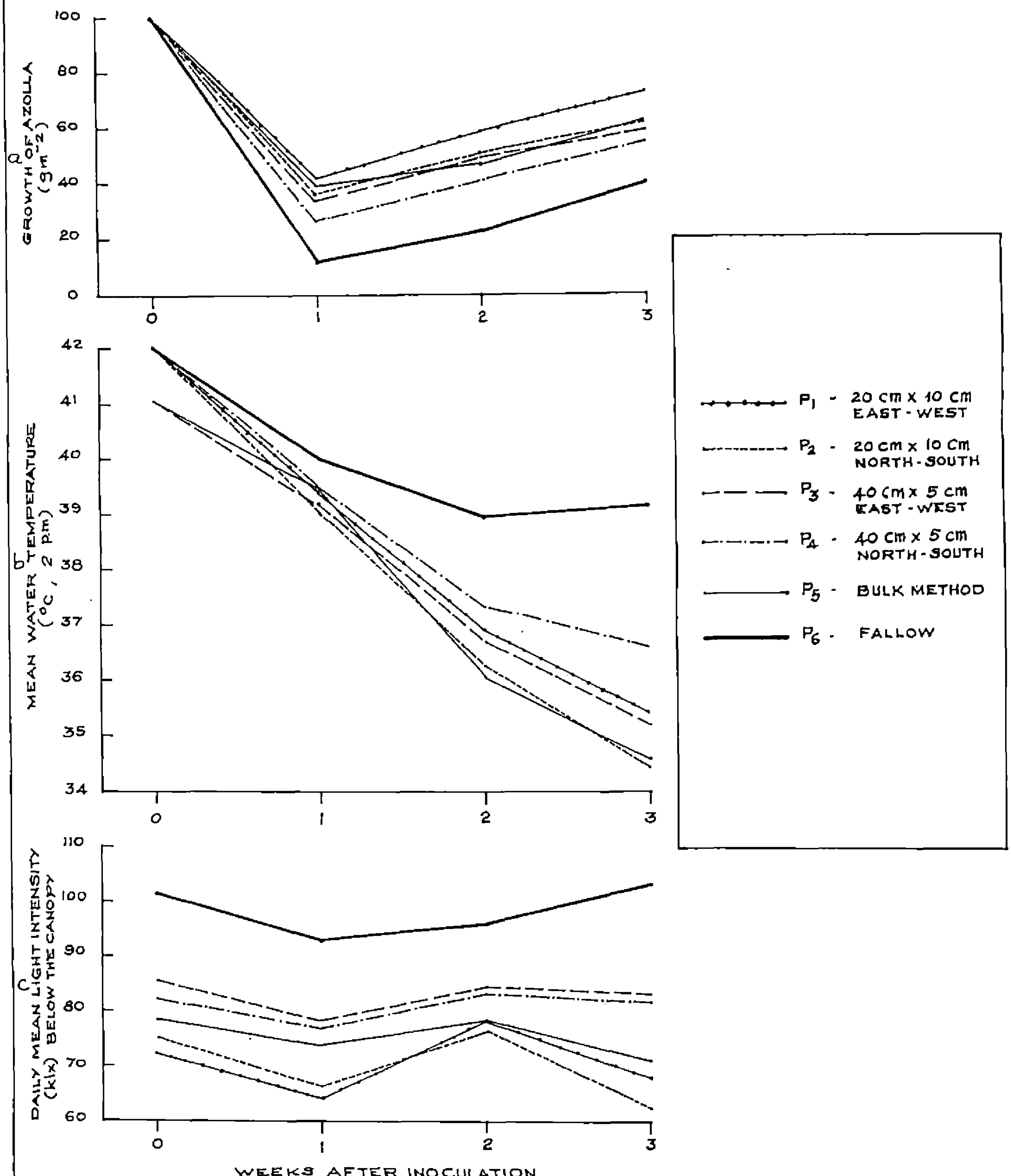


FIG. 4.4.1. EFFECT OF GEOMETRY OF PLANTING RICE ON THE GROWTH OF AZOLLA IN RELATION TO WATER TEMPERATURE AND LIGHT INTENSITY DURING THE SECOND CROP SEASON OF 1980.

Table 4.4.2. Effect of geometry of planting rice on yield of rice

Treatments	Grain yield (kg ha^{-1})			Straw yield (kg ha^{-1})		
	Second crop 1980	First crop 1981	Second crop 1981	Second crop 1980	First crop 1981	Second crop 1981
P_1 20 cm x 10 cm E-W	4002	4738	4775	4459	4461	3340
P_2 20 cm x 10 cm N-S	4323	4601	4673	4411	4344	3124
P_3 40 cm x 5 cm E-W	4389	4691	4334	4781	4407	3137
P_4 40 cm x 5 cm N-S	4329	4396	4612	4449	4129	3373
P_5 Bulk method	3807	4430	4090	4129	4168	2998
'F' test	NS	NS	NS	NS	NS	NS
S.Em.$\pm$	182.2	164.1	155.8	175.6	155.3	139.0

In the first crop season of 1981, P_2 with an azolla yield of 75 g m^{-2} was significantly superior to other treatments at the end of first week after inoculation (Table 4.4.1). In the second week, P_5 with an azolla yield of 158 g m^{-2} was superior to all other treatments. The treatment P_3 (116 g) was on par with P_1 (111 g) and P_2 (110 g).

At the end of three weeks period of the study, P_5 (110 g) and P_2 (104 g) were on par and superior to other treatments. P_1 and P_3 were on par and superior to P_6. The growth of azolla increased till second week followed by a marked decline thereafter (Fig. 4.4.2a).

There was a decrease in mean water temperature from 35.9°C at the beginning to 33.9°C at the end of the second week of inoculation (Fig. 4.4.2b). At the end of third week, it rose to 36.6°C. Among the treatments, P_5 recorded the lowest water temperature (34.3°C) throughout the period of study. A similar trend was observed in light intensity till the end of second week, but in the third week all the treatments except P_5 and P_2 showed an increase.

Azolla cultured in different methods of planting could not exert any significant influence on grain or straw yield of rice in this season also (Table 4.4.2).

At the end of first week during the second crop season of 1981, P_5 (185 g), P_3 (184 g) and P_1 (177 g) were on par in terms of azolla yield and P_5 and P_3 were superior to other

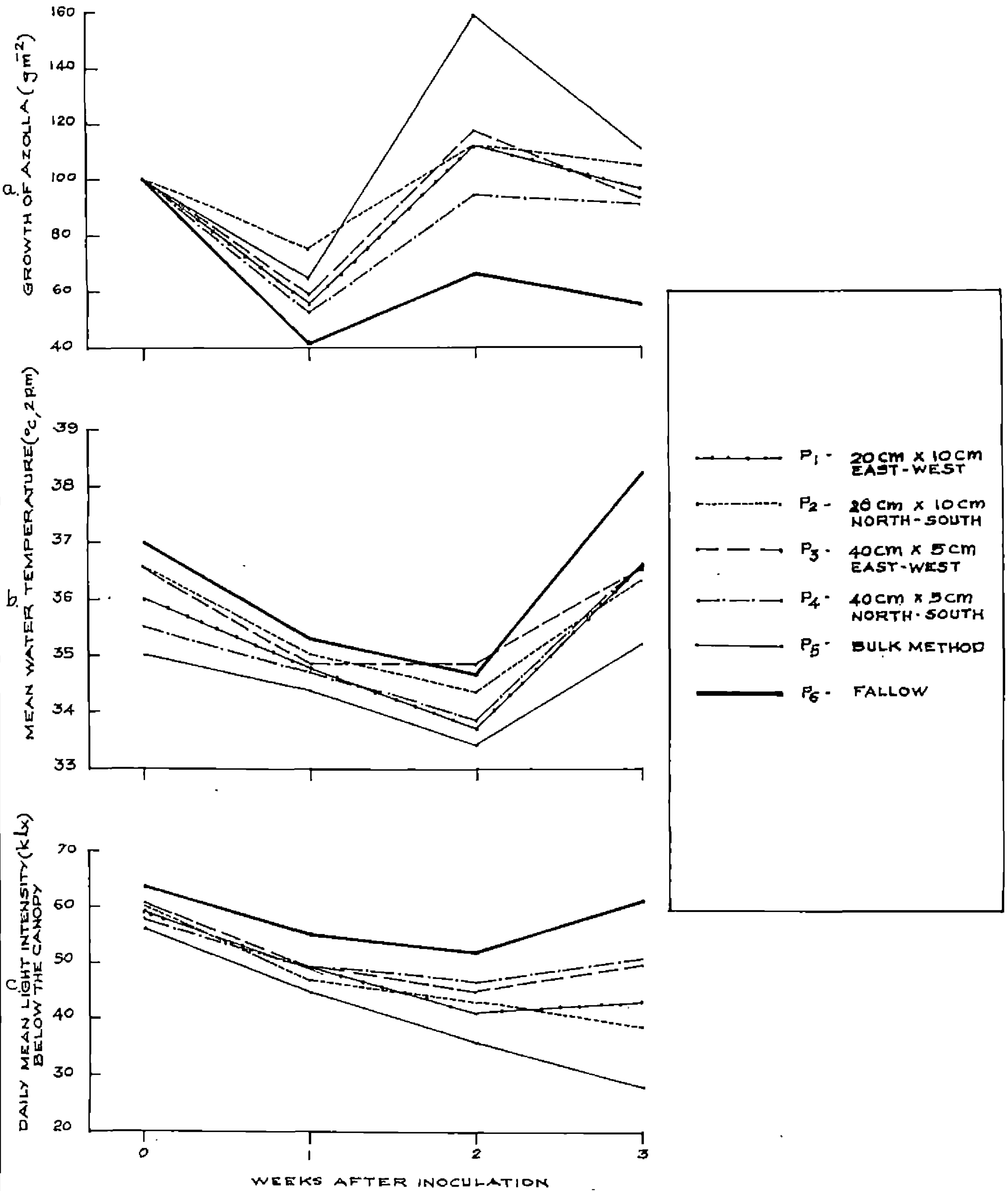


FIG. 4·4·2 EFFECT OF GEOMETRY OF PLANTING RICE ON THE GROWTH OF AZOLLA IN RELATION TO WATER TEMPERATURE AND LIGHT INTENSITY DURING THE FIRST CROP SEASON OF 1981.

treatments except P_1 (Table 4.4.1). In the second week, P_3, P_5 and P_1 were on par in azolla growth and these were superior to rest of the treatments. At the end of three weeks growth period, P_5 (191 g), P_1 (182 g) and P_4 (181 g) were on par in azolla yield. P_5 was found to be significantly superior to P_3 (160 g) and P_6 (68 g).

A perusal of the mean water temperature revealed that P_1 and P_5 showed the lowest value in the second and third weeks of the study (Fig. 4.4.3b). In general, the temperature increased from first week till the beginning of third week. Daily mean light intensity showed an increasing trend till the end of third week, with 61.2, 84.4 and 98.4 k lx in the first, second and third week respectively. Lowest value was for P_1 (70.3 k lx) followed by P_5 (72.4 k lx). Mean daily water temperature also showed lower values for P_1 and P_5 during the period under investigation.

Difference in yield of rice due to the geometry of planting was not significant in this season also.

Over the seasons, azolla growth was better in the second crop season of 1981 followed by first crop season of 1981. The treatment P_1 recorded the highest yield of azolla in the second crop season of 1980, while P_5 showed the highest yield in the first and second crop seasons of 1981. In general the water temperature and light intensity were too high and unfavourable for the growth of azolla during all the three seasons.

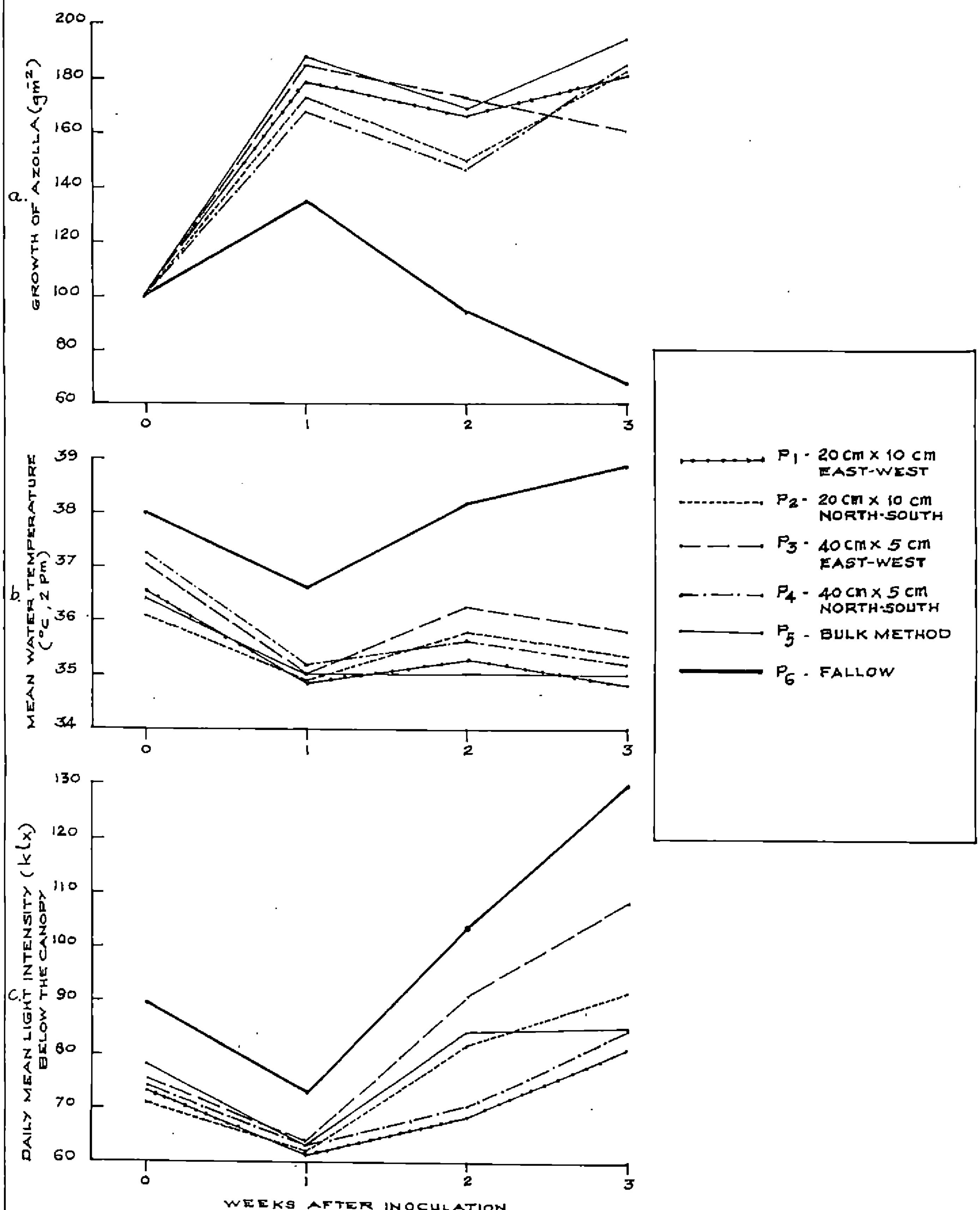


FIG. 4·4·3 EFFECT OF GEOMETRY OF PLANTING RICE ON THE GROWTH OF AZOLLA IN RELATION TO WATER TEMPERATURE AND LIGHT INTENSITY DURING THE SECOND CROP SEASON OF 1981.

4.5. Mineralization of azolla

A study on the mineralization of azolla vis-a-vis commonly used organic manures was conducted during the first and second crop seasons of 1984 and the salient findings are presented below.

4.5.1. Total mineralizable nitrogen.

Figure 4.5.1 on mineralizable nitrogen as influenced by organic manures revealed that application of green leaves at 5 t ha^{-1} recorded the highest value followed by the treatment receiving azolla at 10 t ha^{-1} in the first trial (23.7 ppm and 19.3 ppm respectively). In the second trial also, the same trend was observed but the values were comparatively higher. Assessment of periodwise availability of nitrogen showed the maximum value (21.9 ppm) at the twelfth week after incorporation in the first trial while it was showing the maximum value of 29.8 ppm at the tenth week during the second trial.

Comparison of the two trials in terms of total mineralizable nitrogen revealed that the release was more in the second trial as compared to the first trial (Fig. 4.5.2). Observations recorded on soil and water temperatures pointed out that both the temperatures were higher in the second trial than in the first trial. Study of the figure 4.5.2 revealed that in the first trial both soil and water pH showed a declining trend from second week followed by an increase in the next two fortnights. Thereafter a slight decrease in values were observed.

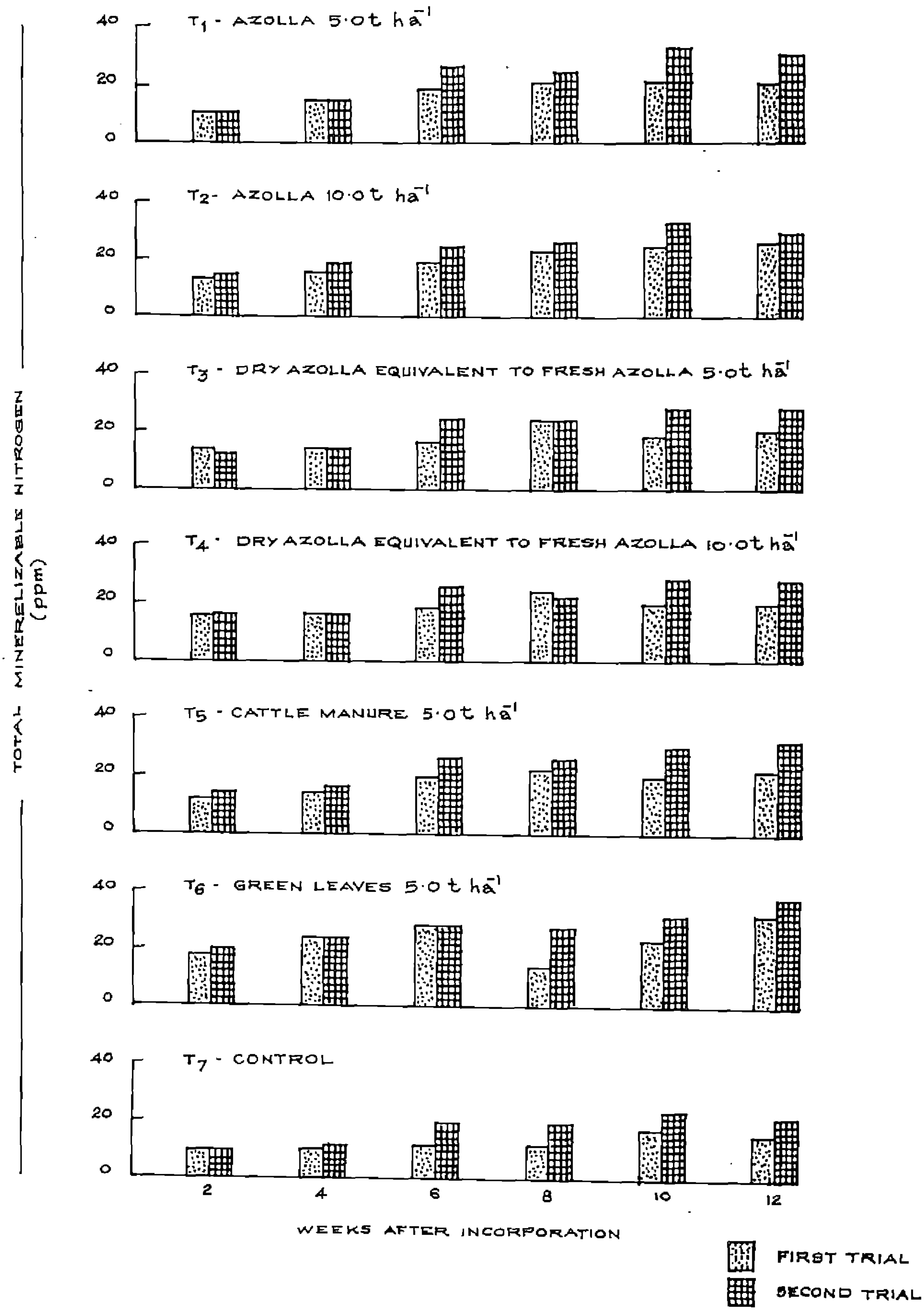


FIG. 4·5·1 EFFECT OF ORGANIC MANURES AND TIME OF INCORPORATION ON THE TOTAL MINERALIZABLE NITROGEN.

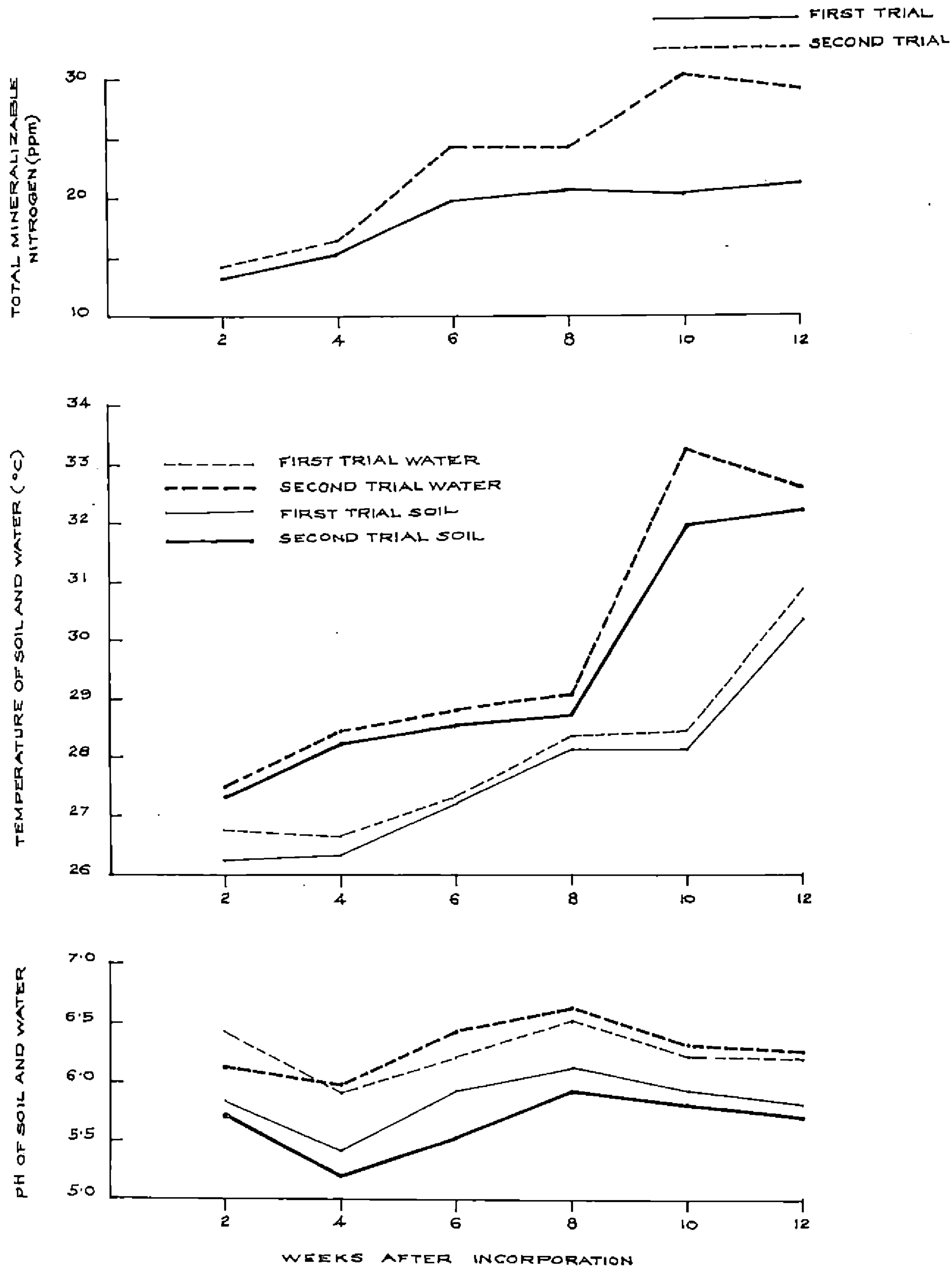


FIG. 4·5·2 EFFECT OF TEMPERATURE AND pH OF SOIL AND WATER ON THE TOTAL MINERALIZABLE NITROGEN.

Similar trend was observed in the second trial also, but the values were slightly higher than that of the first trial.

4.5.2. Ammoniacal nitrogen in soil.

Analysis of the pooled data of the two trials on the performance of each treatment at different periods of sampling revealed that the maximum value (25.3 ppm) of ammoniacal nitrogen for T_1 (azolla at 5 t ha^{-1}) was at tenth week after incorporation (Table 4.5.1). This value was on par with the values observed at twelfth week and significantly higher than that of other periods. For T_2 (azolla at 10 t ha^{-1}) the value observed at tenth week (27.0 ppm) was on par with that of at twelfth week (26.1 ppm), this being significantly higher than that of other values.

Highest value of 22.6 ppm for T_3 (dry azolla equivalent to fresh azolla at 5 t ha^{-1}) was observed at twelfth week. It was on par with the value at tenth and eighth weeks. Similar trend was observed for T_4 (dry azolla equivalent to fresh azolla at 10 t ha^{-1}) but the values at twelfth week was on par with that of earlier three observations and higher than the values at other periods. Similarly T_5 (cattle manure at 5 t ha^{-1}) also recorded the highest value (25.1 ppm) at the twelfth week which was on par with that of earlier two observations. The maximum value of 33.9 ppm for T_6 (green leaves at 5 t ha^{-1}) was also noted at final sampling which was significantly higher than that of the previous observations. For control, value at the fifth sampling was the highest which was on par with that of

Table 4.5.1. Effect of organic manures on ammoniacal nitrogen in soil (ppm)

	Treatments	Weeks after incorporation						Mean
		2	4	6	8	10	12	
	Organic manure, t ha^{-1}							
T_1	Azolla 5	10.4	13.1	20.7	21.8	25.3	23.3	19.1
T_2	Azolla 10	11.3	14.6	19.8	22.5	27.0	26.1	20.2
T_3	Dry azolla equivalent fresh azolla 5	10.5	12.5	18.5	21.5	22.5	22.6	18.0
T_4	Dry azolla equivalent fresh azolla 10	12.2	13.8	21.1	22.3	22.7	23.0	19.2
T_5	Cattle manure 5	10.3	13.2	21.5	22.6	24.5	25.1	19.5
T_6	Green leaves 5	16.0	22.3	26.7	27.2	26.9	33.9	25.5
T_7	Control 0	8.4	9.6	14.9	16.9	18.9	18.7	14.6
	Mean	11.3	14.2	20.5	22.1	24.0	24.7	
	S.Em.±	1.16[a]	0.99[b]	0.61[c]	0.43[d]			
	C.D.(0.05)	3.46[a]	3.09[b]	1.86[c]	1.31[d]			

a For comparison of the same treatment at different periods
b For comparison of different treatments at the same or different periods
c For comparison of treatment means
d For comparison of period means

fourth and sixth sampling and superior to that at the other periods.

Regarding the performance of different treatments at a particular interval, significant variation was noticed at two weeks after incorporation. The treatment T_6 showed the highest value of 16.0 ppm which was significantly better than that of other treatments. At four weeks after incorporation, T_6 was found to be superior to all the other treatments. At the end of sixth week, T_6 maintained its superiority (26.7 ppm). The same trend was observed in the eighth week also. At the end of tenth week, T_2 showed the highest value of 27.0 ppm which was on par with T_6, T_1 and T_5 and superior to rest of the treatments. At final sampling, T_6 recorded the maximum value of 33.9 ppm and it was significantly superior to other treatments.

4.5.3. <u>Nitrate nitrogen in soil.</u>

Pooled data presented in table 4.5.2 on nitrate nitrogen in soil revealed that the values at two weeks after incorporation was the highest for all the treatments except T_5 and significantly superior to values at other periods. Similarly values at fourth week were also superior to values at twelfth week in all the treatments except T_1.

Comparison of treatments at a particular period showed that at two weeks after incorporation, the treatment T_6 recorded the highest value of 0.29 ppm which was on par with that of

Table 4.5.2. Effect of organic manures on nitrate nitrogen in soil (ppm)

Treatments		Weeks after incorporation						Mean
		2	4	6	8	10	12	
<u>Organic manure, t ha^{-1}</u>								
T_1	Azolla 5	0.27	0.15	0.19	0.14	0.12	0.11	0.16
T_2	Azolla 10	0.26	0.17	0.17	0.14	0.12	0.09	0.16
T_3	Dry azolla equivalent to fresh azolla 5	0.27	0.16	0.15	0.13	0.14	0.08	0.16
T_4	Dry azolla equivalent to fresh azolla 10	0.28	0.16	0.12	0.13	0.07	0.08	0.14
T_5	Cattle manure 5	0.23	0.25	0.13	0.17	0.05	0.05	0.15
T_6	Green leaves 5	0.29	0.24	0.19	0.11	0.07	0.07	0.16
T_7	Control 0	0.22	0.14	0.20	0.09	0.05	0.03	0.12
	Mean	0.26	0.18	0.16	0.13	0.09	0.07	
	S.Em.±	0.029[a]	0.023[b]	0.010[c]	0.009[d]			
	C.D.(0.05)	0.090[a]	0.071[b]	0.032[c]	0.030[d]			

a For comparison of the same treatment at different periods

b For comparison of different treatments at the same or different periods

c For comparison of treatment means

d For comparison of period means

other treatments. At the fourth week T_5 was on par with T_6 and superior to all other treatments.

4.5.4. Ammoniacal nitrogen in water.

Pooled data on ammoniacal nitrogen in water presented in table 4.5.3 revealed that the value for T_1 at first sampling (0.74 ppm) was on par with the value at fifth and sixth sampling. For T_2, the value at first sampling (1.21 ppm) was significantly higher than that of other periods. For T_3, the value at first sampling was on par with that of others except at second sampling. In the case of T_4, the value at first sampling (0.78 ppm) was on par with that of fifth and sixth samplings and significantly higher than that of rest of the periods. For T_5 and T_6 the values at first sampling (1.01 and 1.48 ppm respectively) were higher than that of other stages. In the treatment T_7 also the value at first sampling was significantly higher than that of rest of the stages except fifth sampling.

Comparison of treatments at a period showed that T_6 with a value of 1.48 ppm recorded the highest content at first sampling which was found to be superior to rest of the treatments. At the end of sixth week, T_7 registered a value of 0.66 ppm which was significantly higher than that of other treatments. At the eighth and tenth week, the differences between treatments were not significant. At final sampling, T_1 with a value of 0.65 ppm was on par with all the treatments except the control.

Table 4.5.3. Effect of organic manures on ammoniacal nitrogen in water (ppm)

Treatments		Weeks after incorporation						Mean
		2	4	6	8	10	12	
<u>Organic manure, t ha^{-1}</u>								
T_1	Azolla 5	0.74	0.17	0.37	0.37	0.66	0.65	0.49
T_2	Azolla 10	1.21	0.12	0.41	0.49	0.79	0.46	0.58
T_3	Dry azolla equivalent to fresh azolla 5	0.66	0.14	0.41	0.56	0.46	0.64	0.48
T_4	Dry azolla equivalent to fresh azolla 10	0.78	0.09	0.18	0.35	0.54	0.61	0.43
T_5	Cattle manure 5	1.01	0.31	0.37	0.41	0.60	0.53	0.37
T_6	Green leaves 5	1.48	0.12	0.16	0.50	0.88	0.42	0.59
T_7	Control 0	0.94	0.08	0.66	0.40	0.76	0.27	0.52
	Mean	0.83	0.15	0.37	0.44	0.67	0.51	
	S.Em.±	0.090[a]	0.077[b]	0.042[c]	0.036[d]			
	C.D.(0.05)	0.281[a]	0.240[b]	0.132[c]	0.114[d]			

a For comparison of the same treatment at different periods

b For comparison of different treatments at the same or different periods

c For comparison of treatment means

d For comparison of period means

4.5.5. Nitrate nitrogen in water.

Analysis of pooled data (Table 4.5.4) revealed that the treatments performed differently at different periods. For T_1 and T_2, the nitrate nitrogen contents in water were the highest at fourth week after incorporation and these were significantly higher than that of other periods. The values at second week was the next highest which were also superior to that of later periods. For T_3, T_4 and T_5 nitrate nitrogen content was the highest at the end of second week which were on par with that of fourth week and higher than that of other periods. For T_6 and T_7, the values at fourth week were on par with that of second week and significantly better than that of other periods.

Comparison of treatments at different periods revealed that at the second week, T_3 recorded the highest value of 1.26 ppm which was on par with T_4, T_5 and T_2 but higher than that of other treatments. In the fourth week, T_2 showed the highest value (1.39 ppm) but was on par with T_3 and was found to be better than that of rest of the treatments. In other periods, the treatment differences were not significant.

4.5.6. Percentage of nitrogen mineralized at different periods after incorporation.

The quantity of N added through azolla was 13.4 kg ha^{-1} each for T_1 and T_3 and 26.8 kg ha^{-1} each for T_2 and T_4. The values for T_5 and T_6 were 26.9 and 25.4 kg N ha^{-1} respectively.

Comparison of each treatment over the time intervals showed that for T_1, 84.6 per cent of N was available at eight

Table 4.5.4. Effect of organic manures on nitrate nitrogen in water (ppm)

Treatments		Weeks after incorporation						Mean
		2	4	6	8	10	12	
Organic manure, t ha^{-1}								
T_1	Azolla 5	0.74	1.03	0.40	0.47	0.23	0.27	0.52
T_2	Azolla 10	0.99	1.39	0.68	0.40	0.21	0.20	0.65
T_3	Dry azolla equivalent to fresh azolla 5	1.26	1.12	0.49	0.55	0.10	0.07	0.60
T_4	Dry azolla equivalent to fresh azolla 10	1.13	1.01	0.61	0.31	0.09	0.11	0.54
T_5	Cattle manure 5	1.13	1.08	0.69	0.56	0.11	0.15	0.62
T_6	Green leaves 5	0.80	0.88	0.48	0.43	0.10	0.26	0.49
T_7	Control 0	0.50	0.54	0.50	0.48	0.08	0.15	0.38
	Mean	0.94	1.01	0.55	0.46	0.13	0.17	
	S.Em.±	0.111[a]	0.097[b]	0.055[c]	0.042[d]			
	C.D.(0.05)	0.341[a]	0.300[b]	0.172[c]	0.133[d]			

a For comparison of the same treatment at different periods

b For comparison of different treatments at the same or different periods

c For comparison of treatment means

d For comparison of period means

weeks after incorporation (Fig. 4.5.3). Though it increased to 86.3 per cent at the tenth week, the value declined thereafter. The values for T_2 showed an upward trend until the end of twelfth week with a slight decline at the sixth week. In T_3, the values increased till eighth week (78.0 per cent), thereafter the availability decreased markedly (39.5 per cent) followed by an increase in the next fortnight. There was a progressive increase from 33.3 to 50.5 per cent commencing from second week to the end of sixth week in T_4, thereafter the values decreased till tenth week. A similar trend having the highest value of 59.6 per cent at the end of sixth week was also exhibited by T_5. For T_6, 73.5 per cent of N was available at the end of fourth week followed by a decline in the next two fortnights. An increase was noticed from eighth week which attained the peak value (86.0 per cent) at the end of twelfth week.

It is evident from the figure 5.5.6 that at two weeks after incorporation 43.9 per cent of N added was available in T_6 whereas the values for T_1 and T_3 were 34.1 and 37.0 per cent respectively. Higher quantity of azolla (T_2 and T_4) had recorded lower values i.e., 26.0 and 33.3 per cent respectively and the lowest value of 19.1 per cent was recorded by T_5. At the end of fourth week, the highest value of 73.5 per cent was in T_6 and the lowest (35.0 per cent) in T_5. Six weeks after incorporation, 76.0 per cent of N was available for T_1 and 67.2 per cent for T_6. For T_5, 59.6 per cent of N added was

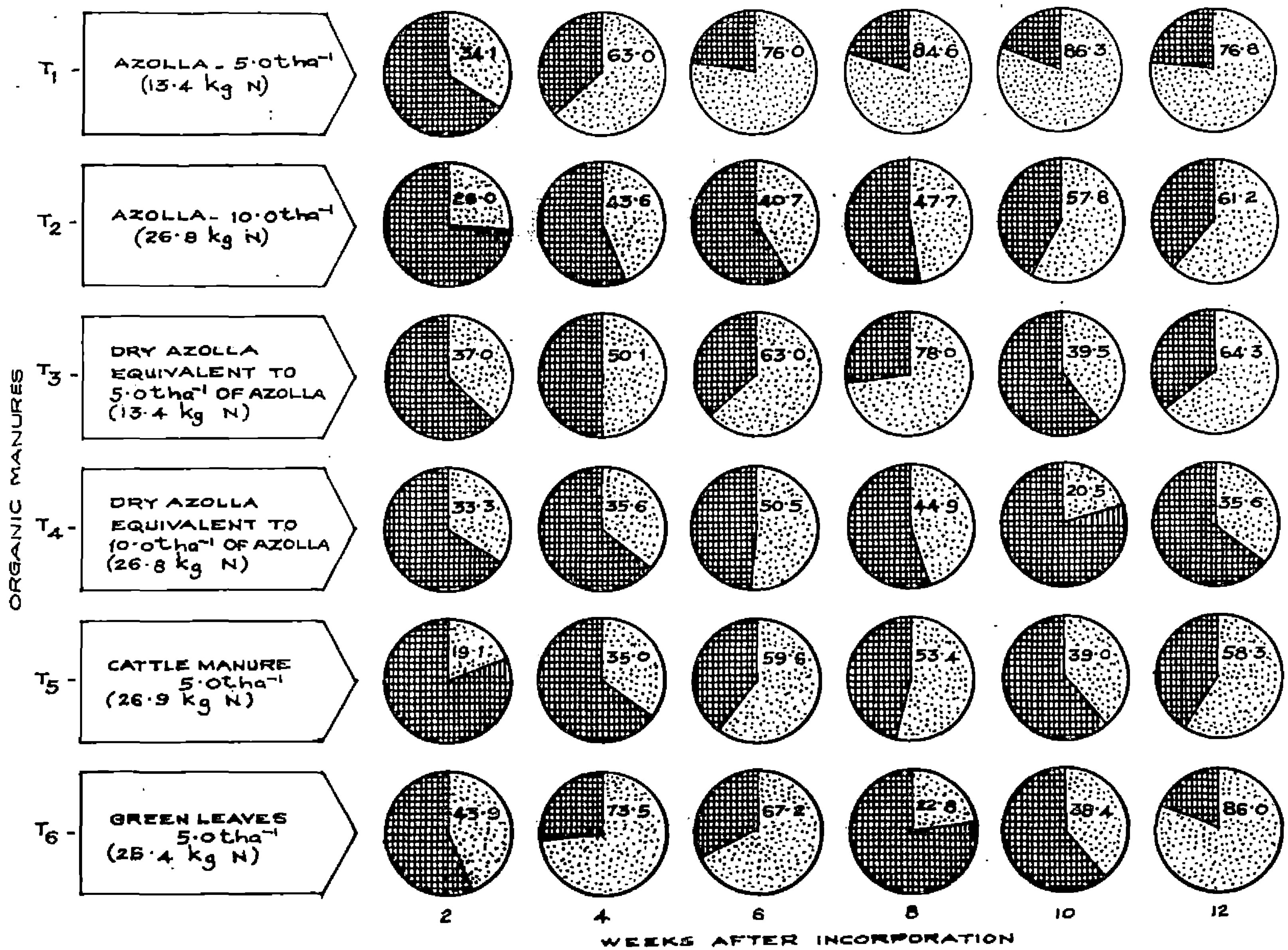


FIG. 4·5·3 EFFECT OF ORGANIC MANURES AND TIME OF INCORPORATION ON THE PERCENTAGE OF MINERALIZABLE NITROGEN.

available at the end of sixth week and T_2 (40.7 per cent) and T_4 (50.5 per cent) recorded lower values for the corresponding period. At the end of eighth week 84.6 per cent of N was available for T_1 followed by T_3 and T_5 (78.9 and 53.4 per cent) respectively. The lower values of 47.7, 44.9 and 22.8 per cent were recorded for the treatment T_2, T_4 and T_6 respectively, T_6 having the lowest among them. At the end of tenth week also T_1 recorded the highest value (83.6 per cent) followed by T_2 (57.8 per cent). There was not much variation between T_3, T_5 and T_6 (38.4-39.5 per cent). T_4 had the lowest value 20.5 per cent. At final sampling 86.0 per cent of N was available in T_6. T_1 ranked second with a percentage of 76.8 followed by T_3 (64.3 per cent) and T_2 (61.2 per cent). T_5 had higher value (58.3 per cent) than T_4 (35.6 per cent).

4.6. Evaluation of azolla as an organic manure

Results of the study on evaluation of azolla as an organic manure conducted in the second crop seasons of 1980 and 1981 are presented below.

4.6.1. Growth attributes of rice.

4.6.1.1. Height of plant

Height of plants did not show any significant difference due to the application of organic manures at any of the stages in 1980 (Table 4.6.1.1). However application of organic manures significantly increased the height at panicle initiation stage in 1981. Treatment receiving green leaves at 5 t ha^{-1}

Table 4.6.1.1. Effect of organic manures and fertilizer levels on height of plant (cm)

Treatments	Stages of crop growth					
	Tillering		Panicle initiation		Maturity	
	1980	1981	1980	1981	1980	1981
Organic manures, t ha^{-1}						
Control 0	19.7	27.6	58.4	60.6	60.5	72.6
Cattle manure 5.0	20.0	26.8	60.2	60.8	63.0	72.0
Green leaves 5.0	20.6	30.5	61.7	65.9	64.6	76.3
Azolla 5.0	19.6	26.9	59.7	62.3	61.8	73.0
Azolla 7.5	20.5	28.2	60.4	62.8	63.3	74.2
Azolla 10.0	20.6	27.8	59.9	60.9	60.2	72.4
'F' test	NS	NS	NS	**	NS	NS
S.Em ±	0.40	0.79	0.93	1.22	1.40	1.58
C.D.(0.05)	-	-	-	3.78	-	-
Fertilizer levels (Percentage of fertilizer dose@)						
0	20.2	26.1	59.0	60.5	59.4	70.1
25	20.4	27.0	58.9	61.2	61.4	73.4
50	20.1	28.8	58.9	61.8	61.9	69.4
75	19.9	28.9	60.2	63.0	64.2	69.7
100	20.3	28.9	63.3	64.6	65.8	76.1
'F' test	NS	*	**	**	**	NS
S.Em. ±	0.33	0.67	0.78	0.81	0.50	2.96
C.D.(0.05)	-	2.11	2.56	2.51	1.62	-

* Significant at 0.05 level
** Significant at 0.01 level
NS Not significant
@ Fertilizer dose N, P_2O_5 and K_2O at 90:45:45 kg ha^{-1}

(65.9 cm) was on par with azolla at 7.5 t ha^{-1} (62.8 cm) and azolla at 5 t ha^{-1} (62.3 cm) but it was statistically superior to rest of the treatments.

The effect due to levels of fertilizers was significantly different at all the stages except at the tillering stage in 1980 and at maturity stage in 1981. Full dose of fertilizers (63.3 cm) was significantly superior to others at panicle initiation stage in 1980 and was on par with 75 per cent of the fertilizer dose at maturity stage in 1980 and at panicle initiation stage in 1981.

4.6.1.2. Tiller production m^{-2}

Data presented in table 4.6.1.2 indicate that tiller production differed significantly as a function of application of organic manures at all the stages of crop growth during 1981. At tillering stage, application of green leaves at 5 t ha^{-1} was on par with azolla at 7.5 t ha^{-1} and 5 t ha^{-1} and superior to rest of the treatments in 1981. At panicle initiation stage, green leaves 5 t ha^{-1} with a tiller count of 264 m^{-2} was significantly superior to other treatments. In terms of total tillers, green leaves 5 t ha^{-1} recorded a tiller count of 290 m^{-2} at maturity stage. This was on par with azolla 7.5 t ha^{-1} and superior to other organic manures tried.

With regard to the effect of fertilizer levels on tiller production, full dose of fertilizer was found to be on par with other levels except control at tillering stage in 1980. But it was significantly superior to other treatments at panicle

Table 4.6.1.2. Effect of organic manures and fertilizer levels on total tillers m^{-2}

Treatments	Stages of crop growth					
	Tillering		Panicle initiation		Maturity	
	1980	1981	1980	1981	1980	1981
Organic manures, t ha^{-1}						
Control 0	281	184	351	230	346	227
Cattle manure 5.0	276	181	364	211	359	236
Green leaves 5.0	296	225	410	264	394	290
Azolla 5.0	300	207	393	229	379	253
Azolla 7.5	313	209	403	240	402	269
Azolla 10.0	294	184	393	210	383	239
'F' test	NS	*	NS	**	NS	*
S.Em. ±	12.0	9.6	18.0	7.4	22.0	10.3
C.D.(0.05)	-	29.9	-	23.0	-	32.2
Fertilizer levels (Percentage of fertilizer dose@)						
0	261	168	323	208	321	221
25	292	193	374	227	370	242
50	287	198	369	227	374	254
75	297	205	401	238	393	267
100	329	227	462	253	427	278
'F' test	**	**	**	**	**	**
S.Em. ±	15.1	5.1	11.0	8.0	11.1	7.8
C.D.(0.05)	47.6	16.0	34.1	24.8	33.9	24.0

* Significant at 0.05 level

** Significant at 0.01 level

NS Not significant

@ Fertilizer dose N, P_2O_5 and K_2O at 90:45:45 kg ha^{-1}

initiation and maturity stages during the year. In 1981, application of full dose of fertilizer was on par with 75 per cent of the dose at panicle initiation and at maturity stages whereas it was superior to other fertilizer levels at tillering stage.

4.6.1.3. Phytomass production m^{-2}

The effect of organic manures on phytomass production was significantly different at tillering stage in 1981 and maturity stages during both the years (Table 4.6.1.3). At tillering stage, application of azolla 7.5 t was on par with green leaves 5 t and azolla 10 t and superior to other treatments. At the maturity stage in 1980, azolla 7.5 t was significantly superior to cattle manure 5 t and control and was on par with other treatments. However, at the maturity stage in 1981, green leaves 5 t with the highest dry matter production of 780 g m^{-2} was on par with azolla 7.5 t (740 g m^{-2}) and superior to others.

The effect of fertilizer levels on phytomass accumulation was significantly different at all the stages in both the years except tillering stage in 1980. At panicle initiation stage in 1980 and tillering stage in 1981, 100 per cent of the fertilizer dose was on par with 75 per cent and superior to rest of the treatments. At panicle initiation stage in 1981, 100, 75 and 50 per cent were on par in dry matter production. But at maturity, 100 per cent of the dose had resulted in significantly higher phytomass production of 755 and 765 g m^{-2} in 1980 and 1981 respectively.

Table 4.6.1.3. Effect of organic manures and fertilizer levels on phytomass production ($g\ m^{-2}$)

Treatments	Stages of crop growth					
	Tillering		Panicle initiation		Maturity	
	1980	1981	1980	1981	1980	1981
Organic manures, $t\ ha^{-1}$						
Control 0	116	131	210	265	500	585
Cattle manure 5.0	136	130	257	262	560	595
Green leaves 5.0	126	173	285	302	580	780
Azolla 5.0	117	115	251	257	570	620
Azolla 7.5	134	190	270	274	605	740
Azolla 10.0	125	162	249	264	585	630
'F' test	NS	*	NS	NS	**	**
S.Em. ±	7.2	13.9	20.0	14.0	14.0	14.1
C.D.(0.05)	-	43.2	-	-	43.2	43.2
Fertilizer levels (Percentage of fertilizer dose@)						
0	122	113	211	231	420	535
25	109	124	245	252	480	630
50	130	150	249	283	530	655
75	124	178	264	280	650	710
100	138	186	298	308	755	765
'F' test	NS	**	**	**	**	**
S.Em. ±	7.1	7.1	12.8	15.2	7.6	5.5
C.D.(0.05)	-	21.9	39.0	47.8	24.0	17.3

* Significant at 0.05 level
** Significant at 0.01 level
NS Not significant
@ Fertilizer dose N, P_2O_5 and K_2O at 90:45:45 kg ha^{-1}

The interaction between the organic manures and fertilizer levels was significant at tillering and maturity stages in 1981 (Tables 4.6.1.4 and 4.6.1.5). At tillering stage, application of azolla at 7.5 t with 100 per cent of the fertilizer dose recorded the highest value of 261 g m^{-2} which was on par with green leaves 5 t with full dose of fertilizer and superior to rest of the treatments. At harvest, azolla 7.5 t with the full dose of fertilizer showed the highest value of 916 g m^{-2} which was significantly superior to rest of the treatments. Phytomass production increased with increasing levels of fertilizer under all organic manure treatments.

4.6.1.4. Leaf area index (LAI)

Application of organic manures influenced the leaf area index (LAI) significantly only at tillering stage in 1981 (Table 4.6.1.6). Green leaves 5 t with LAI of 2.97 was on par with azolla 7.5 t (2.83) and superior to rest of the treatments.

Fertilizer levels also influenced the LAI significantly at all the stages during both the years. At tillering stage, full dose of fertilizer recorded the highest LAI which was superior to other treatments in both the years. At panicle initiation stage in 1980, full dose was significantly superior to others but it was on par with 75 per cent in 1981 al-be-it significantly superior to other treatments. Application of full dose of fertilizer exhibited its superiority in LAI over the other levels of fertilizer at maturity stage in both the years of the trial.

Table 4.6.1.4. Effect of interaction between organic manures and fertilizer levels on phytomass production at tillering stage in 1981 (g m^{-2})

Treatments	Fertilizer levels (Percentage of fertilizer dose@)				
	0	25	50	75	100
<u>Organic manures, t ha^{-1}</u>					
Control 0	82	103	115	170	184
Cattle manure 5.0	88	97	169	126	189
Green leaves 5.0	144	173	166	183	201
Azolla 5.0	91	82	113	118	172
Azolla 7.5	122	152	153	192	261
Azolla 10.0	139	152	160	166	195
'F' test	*				
S.Em. ±	18.1[a]	21.0[b]			
C.D.(0.05)	54.3[a]	64.1[b]			

* Significant at 0.05 level

a For comparison of two fertilizer doses at the same level of organic manure

b For comparison of organic manures at the same or different levels of fertilizers.

@ Fertilizer dose N, P_2O_5 and K_2O at 90:45:45 kg ha^{-1}

Table 4.6.1.5. Effect of interaction between organic manures and fertilizer levels on phytomass production at maturity stage in 1981 (g m^{-2})

Treatments	Fertilizer levels (Percentage of fertilizer dose[@])				
	0	25	50	75	100
Organic manures, t ha^{-1}					
Control 0	427	533	567	663	729
Cattle manure 5.0	440	551	587	668	738
Green leaves 5.0	744	754	770	793	843
Azolla 5.0	504	619	623	673	685
Azolla 7.5	562	705	728	792	916
Azolla 10.0	534	616	657	670	686
'F' test	*				
S.Em. ±	17.8[a]	20.7[b]			
C.D.(0.05)	58.5[a]	67.1[b]			

* Significant at 0.05 level

a For comparison of two fertilizer doses at the same level of organic manure

b For comparison of organic manures at the same or different levels of fertilizers

@ Fertilizer dose N, P_2O_5 and K_2O at 90:45:45 kg ha^{-1}

Table 4.6.1.6. Effect of organic manures and fertilizer levels on leaf area index of rice

Treatments	Stages of crop growth					
	Tillering		Panicle initiation		Maturity	
	1980	1981	1980	1981	1980	1981
Organic manures, $t\ ha^{-1}$						
Control 0	2.07	2.04	2.68	2.62	3.46	2.76
Cattle manure 5.0	2.46	2.01	4.11	2.76	3.49	2.97
Green leaves 5.0	2.33	2.97	4.49	3.81	4.03	3.97
Azolla 5.0	2.14	2.11	3.87	2.98	4.02	2.98
Azolla 7.5	2.46	2.83	4.16	3.30	4.22	3.90
Azolla 10.0	2.40	2.10	3.74	2.95	3.59	2.72
'F' test	NS	**	NS	NS	NS	NS
S.Em. ±	0.201	0.180	0.430	0.272	0.330	0.350
C.D. (0.05)	-	0.581	-	-	-	-
Fertilizer levels (Percentage of fertilizer dose@)						
0	1.86	1.84	2.56	2.57	2.58	2.44
25	2.03	2.35	3.67	2.92	3.21	2.90
50	2.23	2.26	3.98	3.11	3.67	3.04
75	2.31	2.43	3.95	3.34	4.35	3.57
100	2.84	2.85	5.21	3.84	5.21	4.47
'F' test	**	**	**	**	**	**
S.Em. ±	0.143	0.121	0.260	0.202	0.230	0.183
C.D. (0.05)	0.471	0.343	0.840	0.662	0.761	0.603

** Significant at 0.01 level

NS Not significant

@ Fertilizer dose N, P_2O_5 and K_2O at 90:45:45 kg ha^{-1}

Data presented in table 4.6.1.7 showed that interaction between organic manures and fertilizer levels was significant at tillering stage in 1981. At this stage, LAI values of 3.61 and 3.35 were recorded for application of green leaves 5 t and azolla 7.5 t respectively at 25 per cent of the fertilizer dose. These values were on par with those at full dose of fertilizers for the two organic manures.

4.6.2. <u>Yield and yield attributes</u>.

4.6.2.1. <u>Grain yield</u>

The data presented in table 4.6.2.1 indicated that the differences in grain yield due to the application of organic manures were statistically significant in both the years. In 1980, azolla 7.5 t with a grain yield of 3179 kg ha^{-1} was on par with azolla 10 t (2963 kg), green leaves 5 t (2981 kg) and cattle manure 5 t (2945 kg). However, it was superior to other treatments. Control registered the lowest yield of 2554 kg ha^{-1} which was significantly inferior to all other treatments. In 1981, green leaves 5 t with a grain yield of 3752 kg ha^{-1} was significantly superior to all the other treatments. Similarly azolla 7.5 t was superior to the rest of the treatments.

Fertilizer levels also influenced the grain yield significantly in both the years of the trial. The maximum grain yields of 3858 and 3681 kg ha^{-1} in 1980 and 1981 respectively were recorded with 100 per cent of the fertilizer dose and significantly superior to all other levels.

Interaction effect of organic manures and fertilizer levels

Table 4.6.1.7. Effect of interaction between organic manures and fertilizer levels on leaf area index at tillering stage in 1981

Treatments	Fertilizer levels (Percentage of fertilizer dose[@])				
	0	25	50	75	100
<u>Organic manures, t ha^{-1}</u>					
Control 0	1.04	1.49	2.36	2.44	2.87
Cattle manure 5.0	1.34	1.75	2.36	2.42	2.50
Green leaves 5.0	2.32	3.61	3.26	3.10	3.58
Azolla 5.0	1.97	1.67	2.16	2.25	2.51
Azolla 7.5	2.33	3.35	3.12	2.94	3.43
Azolla 10.0	2.02	2.26	2.21	2.49	2.52
'F' test	*				
S.Em. ±	0.251[a]	0.292[b]			
C.D. (0.05)	0.821[a]	0.934[b]			

* Significant at 0.05 level

a For comparison of two fertilizer doses at the same level of organic manure

b For comparison of organic manures at the same or different levels of fertilizers

@ Fertilizer dose N, P_2O_5 and K_2O at 90:45:45 kg ha^{-1}

Table 4.6.2.1. Effect of organic manures and fertilizer levels on yield and harvest index of rice

Treatments	Yield kg ha^{-1}						Harvest index	
	Grain			Straw				
	1980	1981	Pooled	1980	1981	Pooled	1980	1981
Organic manures, t ha^{-1}								
Control 0	2554	2816	2685	2460	2973	2717	51.3	48.5
Cattle manure 5.0	2945	3010	2978	2649	2896	2773	52.8	50.8
Green leaves 5.0	2981	3752	3367	2829	4063	3446	51.2	47.9
Azolla 5.0	2877	3012	2945	2849	3151	3000	51.2	48.5
Azolla 7.5	3179	3483	3331	2839	3870	3355	53.1	47.4
Azolla 10.0	2963	3121	3042	2696	3159	2928	53.7	49.5
'F' test	*	**	*	NS	*	*	NS	*
S.Em. ±	93.3	74.6	58.2	88.7	73.9	56.6	0.94	0.55
C.D.(0.05)	293.9	235.0	176.1	-	232.8	170.2	-	1.74
Fertilizer levels (Percentage of fertilizer dose@)								
0	2116	2573	2345	1931	2742	2337	52.4	48.3
25	2472	3059	2766	2372	3189	2781	51.9	49.0
50	2896	3219	3058	2492	3306	2899	53.2	49.3
75	3210	3434	3322	3183	3604	3394	50.7	48.6
100	3858	3681	3770	3624	3919	3772	52.1	48.7
'F' test	**	**	*	**	**	*	NS	NS
S.Em.±	53.4	50.8	36.3	60.8	54.1	41.2	0.72	0.56
C.D.(0.05)	166.3	153.4	111.0	186.7	168.2	123.1	-	-

* Significant at 0.05 level
** Significant at 0.01 level
NS Not significant
@ Fertilizer dose N, P_2O_5 and K_2O at 90:45:45 kg ha^{-1}

was significant in 1981 (Table 4.6.2.2). Among the combinations, azolla 7.5 t with full dose of fertilizer recorded the highest grain yield of 4166 kg ha^{-1} which was on par with green leaves 5 t with full dose of fertilizer and significantly superior to rest of the combinations.

Pooled analysis of grain yield for the two years (Table 4.6.2.1) revealed that green leaves 5 t with a grain yield of 3367 kg ha^{-1} was on par with azolla 7.5 t (3331 kg) and superior to rest of the treatments. The lowest yield was recorded in control (2685 kg) which was significantly inferior to rest of the treatments. The increase in grain yield for the treatments, cattle manure 5 t, green leaves 5 t, azolla 5, 7.5 and 10 t over the control were 10.9, 25.4, 9.7, 24.1 and 13.3 per cent respectively.

With respect to fertilizer levels, grain yield increased significantly from the lowest to the highest level.

The pooled interaction effect of organic manures and fertilizer levels, presented in figure 4.6.2.1, revealed that azolla 7.5 t with full dose of fertilizer recorded the highest grain yield of 4181 kg ha^{-1} which was significantly superior to all other combinations.

Full dose of fertilizer alone (3589 kg) was on par with azolla 10 t with full dose of fertilizer (3656 kg), azolla 7.5 t and 5 t with 75 per cent of fertilizer (3657 kg and 3432 kg respectively) green leaves 5 t with 50 per cent of fertilizer dose (3441 kg) and cattle manure 5 t with full dose of fertilizer (3625 kg).

Table 4.6.2.2. Effect of interaction between organic manures and fertilizer levels on grain yield of rice in 1981 (kg ha^{-1})

Treatments	Fertilizer levels (Percentage of fertilizer dose[@])				
	0	25	50	75	100
<u>Organic manures, t ha^{-1}</u>					
Control 0	1970	2594	2755	3199	3563
Cattle manure 5.0	2504	2716	3024	3258	3533
Green leaves 5.0	3490	3722	3684	3743	3953
Azolla 5.0	2270	2980	2907	3496	3409
Azolla 7.5	2683	3374	3508	3683	4166
Azolla 10.0	2519	2965	3436	3224	3460
'F' test	*				
S.Em. ±	123.8[a]	128.5[b]			
C.D.(0.05)	376.5[a]	396.8[b]			

* Significant at 0.05 level

a For comparison of two fertilizer doses at the same level of organic manure

b For comparison of organic manures at the same or different levels of fertilizers

@ Fertilizer dose N, P_2O_5 and K_2O at 90:45:45 kg ha^{-1}

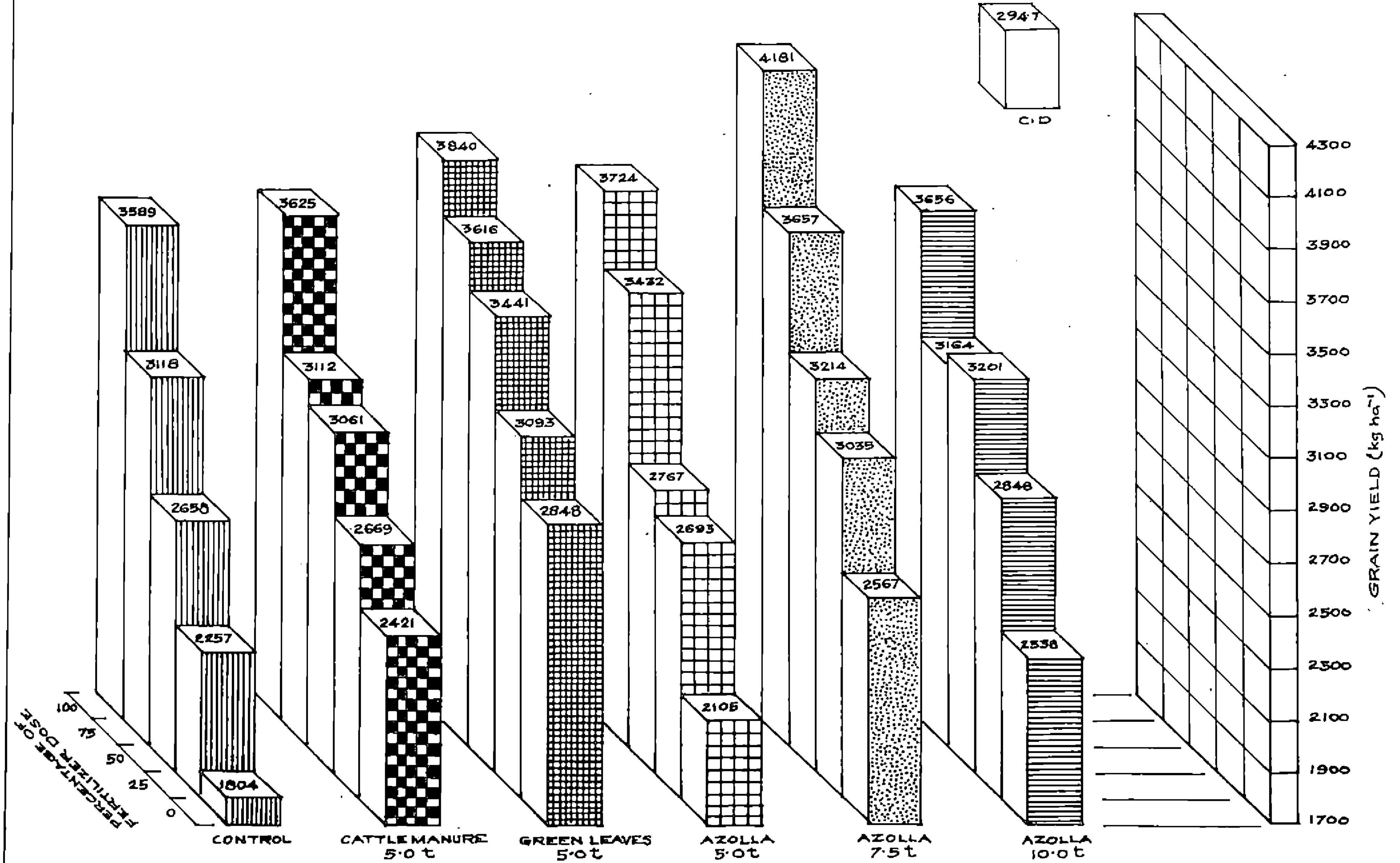


FIG. 4·6·2·1 EFFECT OF INTERACTION BETWEEN ORGANIC MANURES AND FERTILIZER LEVELS ON GRAIN YIELD OF RICE (POOLED DATA).

4.6.2.2. Straw yield

Organic manures significantly influenced the straw yield in 1981 (Table 4.6.2.1). Application of green leaves 5 t and azolla 7.5 t had recorded straw yields of 4063 and 3870 kg ha^{-1} respectively and these treatments were on par and were significantly superior to rest of the treatments. Azolla 10 t and 5 t were on par in straw yield.

Regarding the effect of fertilizer levels on straw yield, similar trend as that of grain yield was observed except that 50 per cent of the fertilizer dose were on par with 25 per cent in both the years.

Interaction effect of organic manures and fertilizer levels on straw yield was significant in 1981. Among the combinations, azolla 7.5 t with full dose of fertilizer recorded the highest yield of 4939 kg ha^{-1} which was superior to all the other combinations (Table 4.6.2.3).

Pooled analysis of the straw yield for the two years (Table 4.6.2.1) revealed that among the organic manures, green leaves 5 t had recorded the highest yield of 3446 kg ha^{-1} which was on par with azolla 7.5 t and superior to the rest of the treatments. Azolla 5 t was on par with azolla 10 t and superior to the rest of the treatments.

Among the fertilizer levels, application of full dose of fertilizer recorded the highest yield of 3772 kg ha^{-1} which was superior to all the lower levels.

Table 4.6.2.3. Effect of interaction between organic manures and fertilizer levels on straw yield of rice in 1981 (kg ha^{-1})

Treatments	Fertilizer levels (Percentage of fertilizer dose[@])				
	0	25	50	75	100
<u>Organic manures, t ha^{-1}</u>					
Control 0	2240	2685	2888	3372	3678
Cattle manure 5.0	1843	2739	2800	3313	3786
Green leaves 5.0	3988	3731	3973	4151	4470
Azolla 5.0	2716	3205	3239	3313	3279
Azolla 7.5	2888	3623	3718	4182	4939
Azolla 10.0	2773	3151	3218	3293	3360
'F' test	*				
S.Em.±	133.2[a]	140.7[b]			
C.D.(0.05)	412.3[a]	435.0[b]			

* Significant at 0.05 level

a For comparison of two fertilizer doses at the same level of organic manure

b For comparison of organic manures at the same or different levels of fertilizers

@ Fertilizer dose N, P_2O_5 and K_2O at 90:45:45 kg ha^{-1}

The pooled interaction effect of organic manures and fertilizer levels presented in figure 4.6.2.2 revealed that application of azolla at 7.5 t with full dose of fertilizer recorded the highest straw yield of 4328 kg ha^{-1} which was on par with green leaves 5 t with full dose of fertilizer (4181 kg) and significantly superior to all other combinations.

Control with full dose of fertilizer (3615 kg) was comparable to azolla 10 t with full dose of fertilizer (3360 kg), azolla 7.5 and 5 t with 75 per cent of the dose (3836 and 3456 kg respectively), green leaves 5 t with 50 per cent of the dose (3346 kg) and cattle manure 5 t with full dose of fertilizer (3616 kg).

4.6.2.3. Harvest index

Organic manures influenced the harvest index significantly only in 1981 trial (Table 4.6.2.1). Application of cattle manure 5 t recorded the highest harvest index of 50.8 per cent which was on par with azolla 10 t (49.5 per cent) and superior to others. Fertilizer levels did not show any significant influence on harvest index.

Interaction effect of organic manures and fertilizer levels was significant in 1981 (Table 4.6.2.4). Cattle manure 5 t with no fertilizer recorded the highest harvest index of 55.7 per cent which was on par with cattle manure 5 t with 50 per cent of fertilizer dose and superior to all others. With green leaves 5 t, application of 25 per cent of fertilizer dose recorded the highest value of harvest index while azolla 7.5 t recorded the

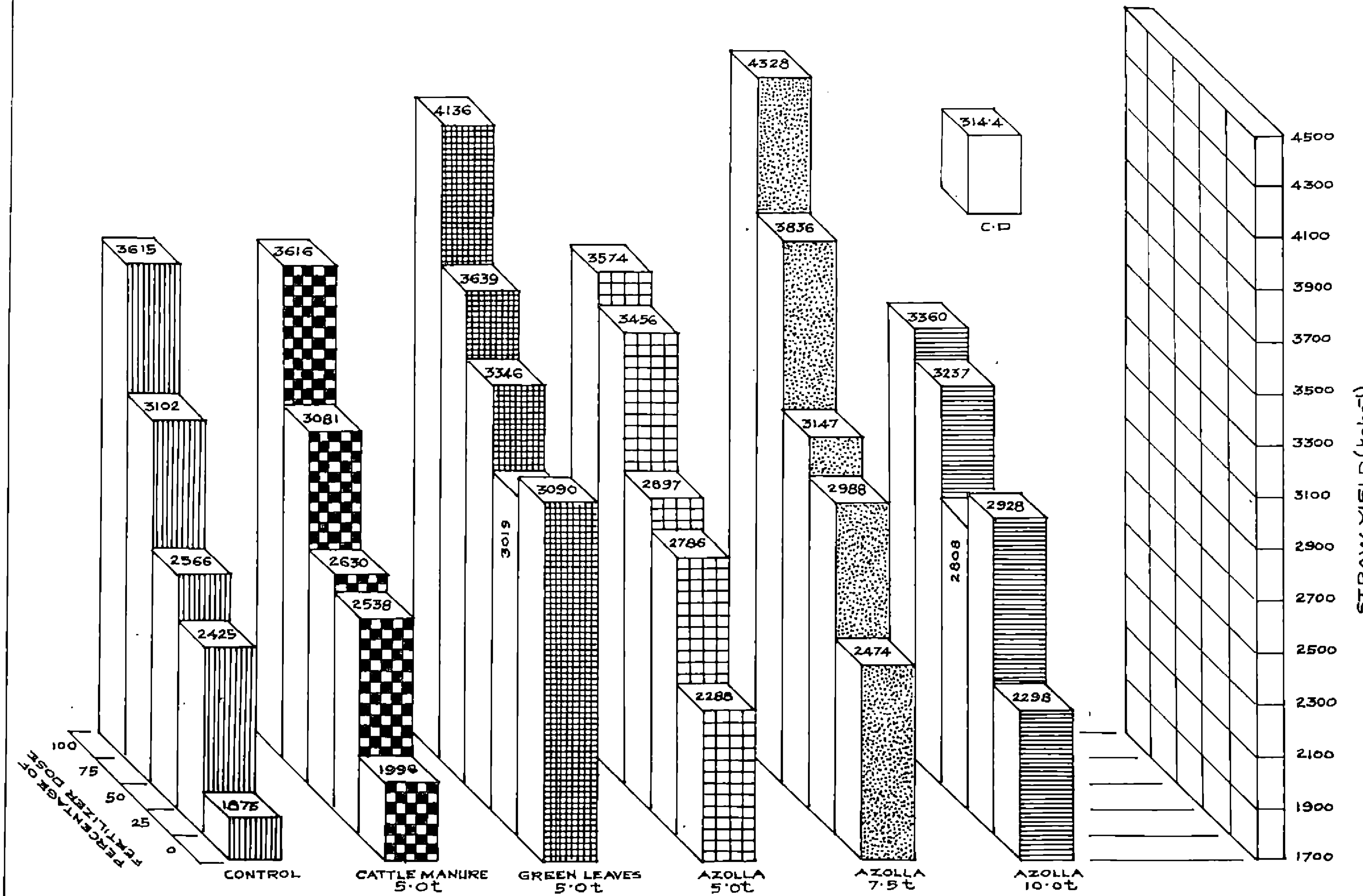


FIG. 4·6·2·2 EFFECT OF INTERACTION BETWEEN ORGANIC MANURES AND FERTILIZER LEVELS ON STRAW YIELD OF RICE (POOLED DATA)

Table 4.6.2.4. Effect of interaction between organic manures and fertilizer levels on harvest index of rice in 1981 (%)

Treatments	Fertilizer levels (Percentage of fertilizer dose[@])				
	0	25	50	75	100
<u>Organic manures, t ha^{-1}</u>					
Control 0	46.9	49.0	48.8	48.6	49.1
Cattle manure 5.0	55.7	49.9	51.8	48.2	48.4
Green leaves 5.0	46.5	50.5	48.1	47.6	46.9
Azolla 5.0	45.1	48.1	47.2	51.4	50.8
Azolla 7.5	48.1	48.4	48.4	46.3	50.0
Azolla 10.0	47.4	48.3	51.7	49.4	50.8
'F' test	*				
S.Em. ±	1.27[a]	1.26[b]			
C.D.(0.05)	3.93[a]	3.93[b]			

* Significant at 0.05 level

a For comparison of two fertilizer levels at the same level of organic manure

b For comparison of organic manures at the same or different levels of fertilizers

@ Fertilizer dose N, P_2O_5 and K_2O at 90:45:45 kg ha^{-1}

maximum value (50.0) with full dose of fertilizer. When the value was highest for azolla 5 t at 75 per cent of the fertilizer dose, it was highest (51.7 per cent) for azolla 10 t at 50 per cent of fertilizer dose.

4.6.2.4. Number of panicle m^{-2}

Organic manures influenced the number of panicle m^{-2} significantly only in 1981 (Table 4.6.2.5). Green leaves 5 t with 248.0 panicle m^{-2} was on par with azolla 7.5 t (231.0) and superior to other treatments.

Fertilizer levels affected this character in both the years. In 1980, application of full dose of fertilizer recorded the highest number of 385.5 panicle m^{-2} which was superior to other levels tried. However in 1981, 100 per cent of fertilizer dose was on par with 75 per cent and was superior to other treatments.

4.6.2.5. Length of panicle

There was no perceptible variation in panicle length due to the application of organic manures in both the years (Table 4.6.2.5). However application of fertilizers affected this character significantly. The length of panicle for the treatment receiving 100 per cent of fertilizer dose was 20.0 cm, this being superior to others in 1980. But in 1981, all the fertilizer treatments were on par and superior to unfertilized control.

4.6.2.6. Number of spikeletspanicle^{-1}

The number of spikelets panicle^{-1} was not significantly

Table 4.6.2.5. Effect of organic manures and fertilizer levels on yield attributes of rice

Treatments	Number of panicles m^{-2}		Length of panicle (cm)		Number of spikelets $panicle^{-1}$	
	1980	1981	1980	1981	1980	1981
Organic manures, t ha^{-1}						
Control 0	306.5	199.5	17.9	20.7	58.8	80.5
Cattle manure 5.0	324.5	201.5	17.7	20.7	56.1	84.5
Green leaves 5.0	348.5	248.0	20.9	21.4	60.1	83.9
Azolla 5.0	342.5	211.0	20.2	20.8	57.8	87.0
Azolla 7.5	360.5	231.0	18.4	21.3	62.1	90.3
Azolla 10.0	338.5	199.5	18.1	21.1	53.9	80.2
'F' test	NS	**	NS	NS	NS	NS
S.Em. ±	17.50	7.50	0.58	0.45	2.47	3.24
C.D.(0.05)	-	23.00	-	-	-	-
Fertilizer levels (Percentage of fertilizer dose@)						
0	281.5	187.0	17.8	19.9	47.0	76.8
25	334.5	208.5	17.8	21.1	58.8	82.3
50	328.0	219.5	18.0	21.1	58.1	84.7
75	354.5	222.0	18.3	21.2	58.4	89.0
100	385.5	238.5	20.0	21.7	58.1	89.2
'F' test	**	**	**	**	**	*
S.Em. ±	8.80	5.50	0.46	0.31	2.06	2.86
C.D.(0.05)	28.00	17.50	1.31	0.96	6.43	8.43

* Significant at 0.05 level
** Significant at 0.01 level
NS Not significant
@ Fertilizer dose N, P_2O_5 and K_2O at 90:45:45 kg ha^{-1}

(contd.)

Table 4.6.2.5 contd.

Treatments	Filled grains panicle^{-1}		Percentage of filled grains		Thousand grain weight (g)	
	1980	1981	1980	1981	1980	1981
<u>Organic manures, t ha^{-1}</u>						
Control 0	43.3	60.8	74.2	76.1	25.3	27.1
Cattle manure 5.0	41.9	66.1	74.9	78.2	25.1	27.6
Green leaves 5.0	44.4	62.3	74.1	73.9	25.8	28.4
Azolla 5.0	42.1	67.0	72.3	77.1	25.3	28.0
Azolla 7.5	44.4	68.8	71.5	76.2	26.3	28.6
Azolla 10.0	41.6	61.3	74.4	76.9	25.7	28.3
'F' test	NS	NS	NS	NS	NS	*
S.Em. ±	2.32	3.71	2.05	1.92	0.39	0.30
C.D. (0.05)	-	-	-	-	-	0.93
<u>Fertilizer levels</u> (Percentage of fertilizer dose@)						
0	42.5	56.2	74.8	73.5	25.1	26.8
25	42.8	61.4	73.9	74.7	25.9	27.8
50	43.8	65.0	75.4	77.5	25.8	28.5
75	43.5	70.8	72.0	79.4	25.3	28.2
100	42.0	68.7	71.7	77.0	25.7	28.7
'F' test	NS	**	NS	*	NS	**
S.Em. ±	2.01	2.52	2.05	1.26	0.03	0.31
C.D. (0.05)	-	7.48	-	3.88	-	0.89

* Significant at 0.05 level
** Significant at 0.01 level
NS Not significant
@ Fertilizer dose N, P_2O_5 and K_2O at 90:45:45 kg ha^{-1}

influenced by organic manures in any of the years (Table 4.6.2.5). However, fertilizer levels affected this character significantly. All the fertilizer levels were on par and superior to unfertilized control in 1980 and 1981 trials.

4.6.2.7. Number of filled grains panicle^{-1}

Application of organic manures did not influence the number of filled grains panicle^{-1} significantly in any of the years (Table 4.6.2.5). However, it was significantly affected by fertilizer levels in 1981. The higher three levels were on par and were superior to other levels tried.

4.6.2.8. Percentage of filled grains panicle^{-1}

Percentage of filled grain did not differ significantly due to the application of organic manures (Table 4.6.2.5) whereas fertilizer treatments influenced this character significantly in 1981; 50 per cent was on par with 75 and 100 per cent of the fertilizer dose and was superior to rest of the treatments.

4.6.2.9. Thousand grain weight

Data presented in table 4.6.2.5 indicated that application of organic manures influenced the thousand grain weight significantly in 1981. Azolla 7.5 t with a value of 28.6 g was on par with azolla 10 t (28.3 g), green leaves 5 t (28.4 g) and azolla 5 t (28.0) and superior to rest of the treatments. Fertilizer levels also affected this character significantly in 1981. Regarding the effect of fertilizer levels, 100 per cent of the dose was on par with 50 and 75 per cent and was superior to others.

4.6.3. Content of nutrients and their uptake by rice.

4.6.3.1. Nitrogen content in rice

Nitrogen content in rice did not vary significantly due to the application of organic manures in any of the stages or years (Table 4.6.3.1). However, fertilizer levels caused significant differences in N content at tillering and panicle initiation stages in 1980. At tillering stage, all the treatments which received fertilizer were on par and superior to unfertilized control. At panicle initiation stage, 100 per cent of the fertilizer dose was found to be superior to lower levels. Fertilizer levels influenced N content of straw in both the years. Application of full dose of fertilizer was on par with 75 per cent and superior to other treatments in 1980 and 1981.

4.6.3.2. Phosphorus content in rice

At all the stages, except the maturity stage in 1980, the P content of plant was not statistically significant. At this stage, significant differences were observed only in P content of grain. Cattle manure 5 t (0.24 per cent) was on par with green leaves 5 t (0.21 per cent) and significantly superior to others at this stage (Table 4.6.3.2). Fertilizer levels could not bring about any significant difference in P content, at any of the stages.

Table 4.6.3.1. Effect of organic manures and fertilizer levels on nitrogen content in rice (%)

Treatments	Stages of crop growth							
	Tillering		Panicle initiation		Maturity			
					Grain		Straw	
	1980	1981	1980	1981	1980	1981	1980	1981
Organic manures, t ha^{-1}								
Control 0	1.82	1.77	1.59	1.12	1.12	1.08	0.59	0.73
Cattle manure 5.0	2.04	1.81	1.65	1.14	1.23	1.13	0.63	0.82
Green leaves 5.0	2.00	1.79	1.62	1.19	1.13	1.08	0.60	0.88
Azolla 5.0	1.97	1.74	1.62	1.13	1.12	1.10	0.66	0.90
Azolla 7.5	1.96	1.81	1.68	1.26	1.09	1.17	0.60	0.86
Azolla 10.0	1.82	1.77	1.62	1.18	1.16	1.19	0.61	0.76
'F' test	NS	NS	NS	NS	NS	NS	NS	NS
S.Em.±	0.110	0.041	0.042	0.043	0.042	0.051	0.029	0.082
C.D.(0.05)	-	-	-	-	-	-	-	-
Fertilizer levels (Percentage of fertilizer dose@)								
0	1.76	1.68	1.35	1.17	1.09	1.21	0.54	0.72
25	2.00	1.80	1.55	1.17	1.18	1.08	0.58	0.75
50	1.97	1.76	1.55	1.17	1.14	1.02	0.60	0.79
75	1.97	1.90	1.75	1.17	1.12	1.14	0.65	0.93
100	2.08	1.80	1.94	1.18	1.17	1.17	0.70	0.94
'F' test	*	NS	**	NS	NS	NS	**	**
S.Em.±	0.060	0.061	0.052	0.030	0.031	0.052	0.020	0.031
C.D.(0.05)	0.181	-	0.149	-	-	-	0.068	0.101

* Significant at 0.05 level
** Significant at 0.01 level
NS Not significant
@ Fertilizer dose N, P_2O_5 and K_2O at 90:45:45 kg ha^{-1}

Table 4.6.3.2. Effect of organic manures and fertilizer levels on phosphorus content in rice (%)

Treatments	Stages of crop growth							
	Tillering		Panicle initiation		Maturity			
					Grain		Straw	
	1980	1981	1980	1981	1980	1981	1980	1981
Organic manures, t ha^{-1}								
Control 0	0.19	0.20	0.14	0.14	0.14	0.18	0.14	0.14
Cattle manure 5.0	0.25	0.19	0.24	0.16	0.24	0.19	0.16	0.14
Green leaves 5.0	0.22	0.21	0.18	0.15	0.21	0.18	0.15	0.14
Azolla 5.0	0.23	0.19	0.23	0.15	0.17	0.17	0.16	0.15
Azolla 7.5	0.26	0.19	0.17	0.17	0.15	0.18	0.15	0.13
Azolla 10.0	0.23	0.21	0.13	0.16	0.15	0.18	0.14	0.14
'F' test	NS	NS	NS	NS	**	NS	NS	NS
S.Em. ±	0.019	0.010	0.028	0.010	0.012	0.012	0.009	0.009
C.D. (0.05)	-	-	-	-	0.039	-	-	-
Fertilizer levels (Percentage of fertilizer dose@)								
0	0.23	0.20	0.19	0.15	0.18	0.18	0.15	0.14
25	0.21	0.20	0.17	0.15	0.18	0.19	0.14	0.14
50	0.24	0.21	0.19	0.15	0.17	0.18	0.15	0.14
75	0.24	0.21	0.19	0.15	0.18	0.18	0.16	0.14
100	0.24	0.19	0.18	0.16	0.18	0.18	0.16	0.14
'F' test	NS	NS	NS	NS	NS	NS	NS	NS
S.Em. ±	0.008	0.009	0.008	0.010	0.010	0.005	0.007	0.006
C.D. (0.05)	-	-	-	-	-	-	-	-

** Significant at 0.01 level

NS Not significant

@ Fertilizer dose N, P_2O_5 and K_2O at 90:45:45 kg ha^{-1}

4.6.3.3. Potassium content in rice

Organic manures did not influence the K content of rice in any of the stages except at maturity stage in 1980 (Table 4.6.3.3). At maturity stage, K content of straw alone was affected by the application of organic manures. Cattle manure 5 t (1.37 per cent) was significantly superior to rest of the treatments in this respect. Regarding fertilizer levels, K content at panicle initiation stage in 1980 showed significant difference, 100 per cent was on par with 75 and 50 per cent of the fertilizer dose and was significantly superior to other treatments.

4.6.3.4. Nitrogen uptake by rice

Table 4.6.3.4 on N uptake by rice revealed that organic manures significantly influenced the uptake at maturity stage in 1980 and tillering, panicle initiation and maturity stages in 1981. At maturity stage in 1980, the organic manure treatments were on par in N uptake and superior to the control. At tillering stage in 1981, azolla 7.5 t (34.2 kg) was on par with green leaves 5 t (30.2 kg) and azolla 10 t (29.4 kg) but was superior to others. At panicle initiation stage, green leaves 5 t was on par with azolla 7.5 t and azolla 10 t and was superior to other treatments. At the maturity stage in 1981, azolla 7.5 t (77.2 kg) was on par with green leaves 5 t (76.0 kg) and both were superior to others.

Fertilizer levels influenced the N uptake at all the stages except panicle initiation stage in 1981. At tillering

Table 4.6.3.3. Effect of organic manures and fertilizer levels on potassium content in rice (%)

Treatments	Stages of crop growth							
	Tillering		Panicle initiation		Maturity			
					Grain		Straw	
	1980	1981	1980	1981	1980	1981	1980	1981
Organic manures, t ha^{-1}								
Control 0	1.09	1.17	1.08	1.06	0.40	0.49	1.01	1.19
Cattle manure 5.0	1.27	1.19	1.15	1.11	0.43	0.49	1.37	1.20
Green leaves 5.0	1.40	1.23	1.24	1.24	0.44	0.48	1.17	1.30
Azolla 5.0	1.27	1.14	1.03	1.02	0.41	0.48	1.16	1.13
Azolla 7.5	1.26	1.14	1.12	1.10	0.41	0.49	1.03	1.23
Azolla 10.0	1.12	1.12	1.12	1.04	0.41	0.49	1.04	1.23
'F' test	NS	NS	NS	NS	NS	NS	**	NS
S.Em.±	0.071	0.020	0.059	0.058	0.009	0.005	0.042	0.039
C.D.(0.05)	-	-	-	-	-	-	0.130	-
Fertilizer levels (Percentage of fertilizer dose@)								
0	1.23	1.16	1.05	1.14	0.42	0.50	1.10	1.20
25	1.23	1.12	1.06	1.03	0.42	0.49	1.15	1.16
50	1.23	1.17	1.13	1.10	0.41	0.48	1.08	1.23
75	1.19	1.20	1.16	1.08	0.42	0.48	1.11	1.26
100	1.29	1.17	1.21	1.13	0.42	0.48	1.13	1.21
'F' test	NS	NS	*	NS	NS	NS	NS	NS
S.Em.±	0.041	0.020	0.035	0.032	0.008	0.009	0.030	0.018
C.D.(0.05)	-	-	0.109	-	-	-	-	-

* Significant at 0.05 level
** Significant at 0.01 level
NS Not significant
@ Fertilizer dose N, P_2O_5 and K_2O at 90:45:45 kg ha^{-1}

Table 4.6.3.4. Effect of organic manures and fertilizer levels on nitrogen uptake by rice (kg ha^{-1})

Treatments	Stages of crop growth					
	Tillering		Panicle initiation		Maturity	
	1980	1981	1980	1981	1980	1981
<u>Organic manures, t ha^{-1}</u>						
Control 0	20.4	19.3	33.5	25.3	43.9	53.6
Cattle manure 5.0	26.6	23.4	43.3	26.3	50.9	59.0
Green leaves 5.0	25.2	30.2	46.4	36.3	48.6	76.0
Azolla 5.0	22.6	20.2	40.8	29.3	50.8	61.2
Azolla 7.5	26.4	34.2	46.1	34.7	52.3	77.2
Azolla 10.0	23.7	29.4	40.4	31.4	52.8	62.0
'F' test	NS	*	NS	*	*	**
S.Em. ±	1.79	2.36	2.36	1.82	1.47	2.86
C.D.(0.05)	-	7.44	-	6.71	4.59	9.29
<u>Fertilizer levels</u>						
(Percentage of fertilizer dose@)						
0	21.5	18.4	28.4	27.9	34.2	52.4
25	21.8	22.3	38.4	29.4	41.7	56.7
50	25.6	26.6	38.1	31.1	45.9	59.5
75	24.1	32.8	46.2	32.8	56.8	75.0
100	27.9	33.9	57.4	34.4	71.0	80.5
'F' test	*	**	**	NS	**	**
S.Em.±	1.45	1.54	1.53	1.66	1.49	2.41
C.D.(0.05)	4.46	4.74	4.74	-	4.69	7.43

* Significant at 0.05 level
** Significant at 0.01 level
NS Not significant
@ Fertilizer dose N, P_2O_5 and K_2O at 90:45:45 kg ha^{-1}

stage in 1980, 100 per cent of the fertilizer dose was on par with 75 per cent and 50 per cent and was superior to other lower levels. Use of full dose of fertilizer was superior to rest of the treatments at panicle initiation and maturity stages in 1980. At tillering and maturity stages in 1981, 100 per cent was on par with 75 per cent and both were superior to others.

4.6.3.5. Phosphorus uptake by rice

Data presented in table 4.6.3.5 indicated that P uptake was significantly influenced by the application of organic manures at maturity stage in 1980 and at tillering and maturity stages in 1981. At maturity stage in 1980, cattle manure 5 t (10.9 kg) was on par with azolla 7.5 t (9.6 kg) and green leaves 5 t (10.0 kg) in P uptake and superior to others. At tillering stage in 1981, green leaves 5 t (3.6 kg) was on par with azolla 7.5 t (3.6 kg) and azolla 10 t (3.4 kg) and superior to rest of the treatments. At maturity stage in 1981, green leaves 5 t (12.7 kg) was on par with azolla 7.5 t (12.0 kg) and was superior to others.

Fertilizer levels influenced P uptake by rice significantly at all the stages except tillering stage in 1980. At panicle initiation stage in 1980, 100 per cent was on par with 75 per cent and 50 per cent of the dose and was superior to others in P uptake. At maturity stage, full dose was superior to rest of the treatments. In 1981, 100 per cent was on par with 75 per cent in all the three stages of observation.

Table 4.6.3.5. Effect of organic manures and fertilizer levels on phosphorus uptake by rice (kg ha^{-1})

Treatments	Stages of crop growth					
	Tillering		Panicle initiation		Maturity	
	1980	1981	1980	1981	1980	1981
<u>Organic manures, t ha^{-1}</u>						
Control 0	2.1	2.6	3.0	3.3	6.6	10.2
Cattle manure 5.0	3.6	2.6	6.2	4.2	10.9	9.9
Green leaves 5.0	2.9	3.6	5.2	4.6	10.0	12.7
Azolla 5.0	2.6	2.1	5.7	3.9	8.6	9.0
Azolla 7.5	3.5	3.6	4.5	4.6	9.6	12.0
Azolla 10.0	2.8	3.4	3.4	4.1	8.5	10.4
'F' test	NS	*	NS	NS	**	*
S.Em. ±	0.29	0.19	0.35	0.25	0.38	0.45
C.D.(0.05)	-	0.87	-	-	1.82	1.65
<u>Fertilizer levels</u> (Percentage of fertilizer dose@)						
0	2.1	2.3	4.1	3.5	6.6	8.5
25	2.4	2.4	4.2	4.0	7.5	10.4
50	3.1	3.1	4.9	4.0	8.6	11.0
75	3.2	3.6	4.9	4.3	10.4	11.7
100	3.2	3.5	5.3	4.7	12.2	12.7
'F' test	NS	**	*	*	**	**
S.Em.±	0.26	0.17	0.32	0.35	0.35	0.42
C.D.(0.05)	-	0.49	0.91	0.99	0.99	1.21

* Significant at 0.05 level
** Significant at 0.01 level
NS Not significant
@ Fertilizer dose N, P_2O_5 and K_2O at 90:45:45 kg ha^{-1}

4.6.3.6. Potassium uptake by rice

Potassium uptake due to organic manures was significantly different at all the stages, except tillering and panicle initiation stages in 1980 (Table 4.6.3.6). At maturity stage in 1980, green leaves 5 t (48.1 kg) was on par with azolla 7.5 t (46.1 kg), azolla 5 t (44.9 kg) and cattle manure 5 t and was significantly superior to others. However, at tillering stage in 1981, azolla 7.5 t was on par with green leaves 5 t and azolla 10 t and was superior to rest of the treatments. At panicle initiation stage in 1981, green leaves 5 t (37.5 kg) was on par with cattle manure 5 t (30.9 kg) and was superior to other treatments. At maturity stage in 1981, green leaves 5 t (71.1 kg) was on par with azolla 7.5 t and both were significantly superior to other treatments.

Fertilizer levels resulted in significant differences in K uptake at all the stages in both the years of the trial. Full dose of fertilizer was significantly superior to rest of the treatments at all the stages in 1980. The treatment receiving 100 per cent of the dose was on par with 75 per cent and superior to others in K uptake at all the stages in 1981.

The interaction effect due to organic manures and fertilizer levels was significant on K uptake at tillering stage in 1981 and the highest K uptake of 30.3 kg ha^{-1} was for the treatment receiving azolla 7.5 t with 75 per cent of fertilizer dose (Table 4.6.3.7).

Table 4.6.3.6. Effect of organic manures and fertilizer levels on potassium uptake by rice (kg ha^{-1})

Treatments	Stages of crop growth					
	Tillering		Panicle initiation		Maturity	
	1980	1981	1980	1981	1980	1981
<u>Organic manures, t ha^{-1}</u>						
Control 0	11.8	15.3	22.7	25.1	36.5	49.8
Cattle manure 5.0	17.2	15.4	27.8	30.9	46.6	53.6
Green leaves 5.0	17.6	21.3	34.2	37.5	48.1	71.1
Azolla 5.0	14.3	15.8	28.7	26.3	44.9	51.9
Azolla 7.5	16.9	21.6	28.6	30.0	46.1	65.3
Azolla 10.0	13.9	18.3	27.1	26.7	41.7	54.7
'F' test	NS	*	NS	*	*	**
S.Em.±	1.01	1.72	1.50	2.22	2.32	1.87
C.D.(0.05)	-	5.34	-	6.99	6.27	5.99
<u>Fertilizer levels</u> (Percentage of fertilizer dose@)						
0	13.1	13.2	21.4	26.5	34.9	47.1
25	13.5	13.9	25.4	27.4	37.0	55.4
50	15.0	17.1	27.8	28.6	39.6	56.5
75	14.9	21.3	30.9	29.9	50.8	63.8
100	18.3	21.6	35.4	33.7	57.3	65.8
'F' test	**	**	**	*	**	**
S.Em. ±	0.87	0.83	1.27	1.28	1.95	1.42
C.D.(0.05)	2.63	2.60	3.91	4.15	6.03	4.33

* Significant at 0.05 level

** Significant at 0.01 level

NS Not significant

@ Fertilizer dose N, P_2O_5 and K_2O at 90:45:45 kg ha^{-1}

Table 4.6.3.7. Effect of interaction between organic manures and fertilizer levels on potassium uptake by rice at tillering stage in 1981 (kg ha^{-1})

Treatments	Fertilizer levels (Percentage of fertilizer dose@)				
	0	25	50	75	100
<u>Organic manures, t ha^{-1}</u>					
Control 0	9.3	11.2	12.5	18.6	16.3
Cattle manure 5.0	10.2	13.2	20.1	21.2	19.7
Green leaves	17.6	20.9	22.5	21.2	24.3
Azolla 5.0	9.8	11.1	13.5	13.8	19.7
Azolla 7.5	14.2	16.8	18.3	30.3	28.4
Azolla 10.0	18.3	14.2	18.2	18.5	22.3
'F' test	*				
S.Em.±	1.91[a]	2.52[b]			
C.D.(0.05)	6.30[a]	7.81[b]			

* Significant at 0.05 level

a For comparison of two fertilizer levels at the same level of organic manure

b For comparison of two organic manures at the same or different levels of fertilizers.

@ Fertilizer dose N, P_2O_5 and K_2O at 90:45:45 kg ha^{-1}

The interaction between organic manures and fertilizer levels was significant at maturity stage in 1981 (Table 4.6.3.8) and azolla 7.5 t with full dose of fertilizer had the highest K uptake of 82.2 kg ha^{-1} which was on par with that of green leaves 5 t with 75 per cent and 100 per cent of fertilizer dose.

4.6.4. Available nutrients in soil.

4.6.4.1. Available N in soil

Application of organic manures influenced the available N content in soil significantly at maturity stage in 1980 (Table 4.6.4.1). Cattle manure 5 t and azolla 10 t were on par in available N content but superior to rest of the treatments.

Fertilizer levels were found to influence the N content at maturity stage in 1980 and panicle initiation stage in 1981. At maturity stage in 1980, 75 per cent of the fertilizer dose was on par with all the treatments except that receiving 25 per cent of the fertilizer dose. At panicle initiation stage in 1981 50 per cent of fertilizer dose was on par with 25 per cent and superior to rest of the treatments.

4.6.4.2. Available P in soil

Data presented in table 4.6.4.2 revealed that differences due to organic manures on available P content of soil were statistically significant at panicle initiation stage in 1980. Azolla 10 t (28.8 kg) was significantly superior to other treatments in this respect.

Table 4.6.3.8. Effect of interaction between organic manures and fertilizer levels on total potassium uptake by rice at maturity stage in 1981 (kg ha^{-1})

Treatments	Fertilizer levels (Percentage of fertilizer dose[@])				
	0	25	50	75	100
<u>Organic manures, t ha^{-1}</u>					
Control 0	38.1	40.9	49.5	55.1	53.2
Cattle manure 5.0	41.3	60.0	49.6	64.6	62.8
Green leaves 5.0	66.6	67.8	67.5	78.1	73.5
Azolla 5.0	49.3	49.5	50.7	63.8	56.5
Azolla 7.5	51.6	62.2	62.7	67.6	82.2
Azolla 10.0	45.8	52.0	59.0	58.8	57.6
'F' test	*				
S.Em. ±	3.58[a]	3.62[b]			
C.D.(0.05)	10.62[a]	11.23[b]			

* Significant at 0.05 level

a For comparison of two fertilizer levels at the same level of organic manure

b For comparison of two organic manures at the same or different levels of fertilizers

@ Fertilizer dose N, P_2O_5 and K_2O at 90:45:45 kg ha^{-1}

Table 4.6.4.1. Effect of organic manures and fertilizer levels on available nitrogen in soil (kg ha^{-1})

Treatments	Tillering		Panicle initiation		Maturity	
	Stages of crop growth					
	1980	1981	1980	1981	1980	1981
Organic manures, t ha^{-1}						
Control 0	273.5	228.7	205.4	215.7	293.2	204.7
Cattle manure 5.0	290.5	244.8	207.6	223.6	371.6	206.3
Green leaves 5.0	290.9	245.3	215.3	235.9	305.1	204.7
Azolla 5.0	281.1	259.4	217.9	224.4	297.7	212.1
Azolla 7.5	286.3	267.0	213.7	227.8	284.9	201.8
Azolla 10.0	275.5	242.8	221.5	232.7	345.4	209.7
'F' test	NS	NS	NS	NS	*	NS
S.Em.±	13.48	3.94	6.36	8.38	18.60	8.13
C.D.(0.05)	-	-	-	-	58.6	-
Fertilizer levels (Percentage of fertilizer dose@)						
0	245.1	270.1	208.8	224.0	335.3	205.6
25	254.7	269.9	208.8	233.6	300.6	213.5
50	260.1	290.8	223.3	248.2	330.6	206.5
75	250.0	252.2	214.8	224.2	355.7	202.3
100	250.0	253.6	212.4	221.9	330.6	204.5
'F' test	NS	NS	NS	*	*	NS
S.Em.±	3.61	10.12	5.40	5.78	12.28	4.37
C.D. (0.05)	-	-	-	18.19	36.8	-

* Significant at 0.05 level

NS Not significant

@ Fertilizer dose N, P_2O_5 and K_2O at 90:45:45 kg^{-1}

Table 4.6.4.2. Effect of organic manures and fertilizer levels on available phosphorus in soil (kg ha^{-1})

Treatments	Stages of crop growth					
	Tillering		Panicle initiation		Maturity	
	1980	1981	1980	1981	1980	1981
<u>Organic manures, t ha^{-1}</u>						
Control 0	14.5	15.5	20.9	15.7	20.5	13.2
Cattle manure 5.0	14.7	13.3	23.4	16.9	22.5	14.7
Green leaves 5.0	18.6	13.7	23.3	18.4	21.2	17.7
Azolla 5.0	16.5	10.7	23.1	17.3	22.7	15.2
Azolla 7.5	18.8	14.0	25.1	17.9	20.0	17.4
Azolla 10.0	16.7	14.2	28.8	18.4	22.6	14.8
'F' test	NS	NS	**	NS	NS	NS
S.Em.±	1.07	1.61	0.79	0.91	1.58	1.28
C.D.(0.05)	-	-	2.50	-	-	-
<u>Fertilizer levels</u> (Percentage of fertilizer dose@)						
0	15.7	12.2	24.2	17.2	20.6	14.7
25	16.7	13.1	24.6	17.3	21.3	15.3
50	17.0	13.1	25.5	17.9	21.6	15.0
75	17.4	13.2	25.3	18.0	22.3	17.1
100	16.5	15.2	26.1	18.5	22.1	16.4
'F' test	NS	**	NS	NS	NS	*
S.Em.±	0.80	0.42	0.51	0.40	0.59	0.53
C.D.(0.05)	-	1.20	-	-	-	1.70

* Significant at 0.05 level

** Significant at 0.01 level

NS Not significant

@ Fertilizer dose N, P_2O_5 and K_2O at 90:45:45 kg ha^{-1}

The effect due to fertilizer levels was significant at tillering and maturity stages in 1981. At tillering stage, full dose was found to be significantly superior to others whereas at maturity, 75 per cent was on par with 100 per cent and superior to others in available P content in soil.

4.6.4.3. Available K in soil

Neither organic manures nor fertilizer levels could make any significant difference in the available K content of soil (Table 4.6.4.3).

4.6.5. Residual effect of organic manures and fertilizer levels.

The data presented in table 4.6.5.1 on residual effect of organic manures in terms of grain yield of succeeding crop was observed to be statistically significant only in summer season of 1981-82. The treatment receiving azolla 10 t with a grain yield of 2644 kg ha^{-1} was on par with that receiving azolla 5 t (2509 kg) and was superior to others. The effect of organic manures on straw yield of succeeding crop was not significant in any of the years.

Fertilizer levels also influenced the grain and straw yields of succeeding crop in 1981-82. The fertilizer level at 75 per cent of the recommended dose was on par with 100 per cent and control and was superior to rest of the treatments. Regarding straw yield, the treatment receiving 75 per cent of the fertilizer dose had the maximum straw yield of 2084 kg ha^{-1}. It was on par with control but was significantly superior to the other treatments.

Table 4.6.4.3. Effect of organic manures and fertilizer levels on available potassium in soil (kg ha^{-1})

Treatments	Stages of crop growth					
	Tillering		Panicle initiation		Maturity	
	1980	1981	1980	1981	1980	1981
<u>Organic manures, t ha^{-1}</u>						
Control 0	130.3	128.7	79.0	100.7	160.7	142.1
Cattle manure 5.0	152.4	145.8	90.7	106.4	166.1	169.4
Green leaves 5.0	134.2	163.3	112.2	101.1	182.9	167.1
Azolla 5.0	121.7	154.5	90.1	150.4	179.9	146.6
Azolla 7.5	131.9	148.4	87.1	115.7	165.6	145.9
Azolla 10.0	138.9	147.3	89.3	114.9	171.0	154.8
'F' test	NS	NS	NS	NS	NS	NS
S.Em.±	11.95	6.00	5.39	7.06	1.98	8.76
C.D.(0.05)	-	-	-	-	-	-
<u>Fertilizer levels</u> (Percentage of fertilizer dose@)						
0	126.4	131.3	90.4	112.7	168.8	156.4
25	130.6	147.2	95.1	113.6	176.0	160.6
50	133.9	146.1	91.4	113.7	175.1	155.7
75	123.6	162.3	90.2	123.6	178.4	156.4
100	126.7	152.4	98.4	110.6	182.0	162.6
'F' test	NS	NS	NS	NS	NS	NS
S.Em.±	5.9	5.9	3.3	6.4	5.6	5.4
C.D.(0.05)	-	-	-	-	-	-

NS Not significant

@ Fertilizer dose N, P_2O_5 and K_2O at 90:45:45 kg ha^{-1}

Table 4.6.5.1. Effect of organic manures and fertilizer levels on yield of succeeding crop of rice (kg ha^{-1})

Treatments	Grain yield		Straw yield	
	Summer crop 1980-81	Summer crop 1981-82	Summer crop 1980-81	Summer crop 1981-82
<u>Organic manures, t ha^{-1}</u>				
Control 0	2454	2439	1979	1960
Cattle manure 5.0	2335	2452	1901	1934
Green leaves 5.0	2277	2365	1873	1904
Azolla 5.0	2378	2509	1909	2034
Azolla 7.5	2260	2328	1851	1941
Azolla 10.0	2419	2644	1988	1975
'F' test	NS	*	NS	NS
S.Em.±	43.6	43.4	37.2	38.5
C.D.(0.05)	-	161.4	-	-
<u>Fertilizer levels</u> (Percentage of fertilizer dose@)				
0	2319	2473	1875	1994
25	2343	2371	1927	1867
50	2400	2402	1970	1937
75	2367	2546	1893	2084
100	2341	2486	1920	1908
'F' test	NS	*	NS	**
S.Em.±	39.8	36.7	33.9	32.1
C.D.(0.05)	-	112.8	-	99.9

* Significant at 0.05 level
** Significant at 0.01 level
NS Not significant
@ Fertilizer dose N, P_2O_5 and K_2O at 90:45:45 kg ha^{-1}

Interaction effect of organic manures and fertilizer levels on grain yield was also significant during summer season of 1981-82. Highest yield of 2682 kg ha^{-1} was for the treatment receiving azolla 7.5 t with 75 per cent fertilizer dose (Table 4.6.5.2).

4.6.6. <u>Output-input ratio</u>.

Analysis of the output-input ratio (Fig. 4.6.2.3) revealed that the treatment receiving full dose of fertilizer alone recorded the highest ratio of 2.09 closely followed by the treatment receiving azolla at 7.5 t ha^{-1} with full dose of fertilizer, ~~ranked third in this respect (1.88)~~. The treatment receiving neither organic manure nor fertilizer showed the lowest ratio of 1.25. Addition of green leaves alone at 5 t had resulted in a ratio of 1.60.

Table 4.6.5.2. Effect of interaction between organic manures and fertilizer levels on grain yield of succeeding crop of rice in 1981-82 (kg ha^{-1})

Treatments	Fertilizer levels (Percentage of fertilizer dose[@])				
	0	25	50	75	100
<u>Organic manures, t ha^{-1}</u>					
Control 0	2454	2315	2586	2255	2661
Cattle manure 5.0	2355	2174	2416	2435	2298
Green leaves 5.0	2263	2345	2459	2087	2230
Azolla 5.0	2536	2476	2330	2353	2196
Azolla 7.5	1981	2265	2134	2682	2238
Azolla 10.0	2323	2481	2474	2388	2426
'F' test	*				
S.Em.±	88.8[a]	96.2[b]			
C.D.(0.05)	277.5[a]	302.6[b]			

* Significant at 0.05 level

a For comparison of two fertilizer doses at the same level of organic manure

b For comparison of two organic manures at the same or different levels of fertilizers

@ Fertilizer dose N, P_2O_5 and K_2O at 90:45:45 kg ha^{-1}

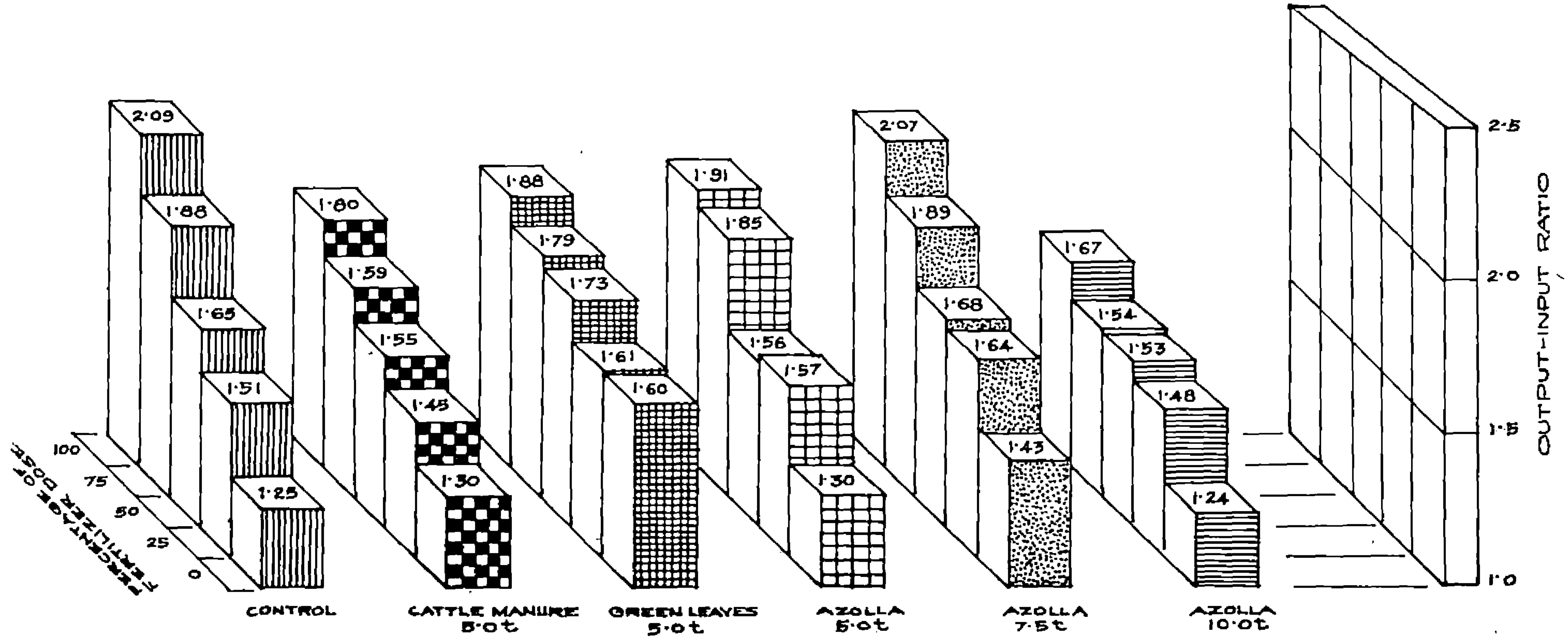


FIG. 4·6·2·3 OUT PUT - IN PUT RATIO OF THE EXPERIMENT ON EVALUATION OF AZOLLA AS AN ORGANIC MANURE.

Discussion

V. DISCUSSION

The results of the survey conducted in three different regions, with field investigations on three aspects, viz., time of application and quantity of inoculum and geometry of planting rice on the growth of azolla and evaluation of azolla as an organic manure and two pot culture trials, i.e., nutritional requirement and mineralization of azolla compared to other organic manures are discussed in this chapter.

5.1. Survey on the environmental requirement of azolla

Out of the survey conducted, it is evident that in general, soils of azolla growing locations had lower content of clay compared to non-growing areas. This is confirmed by the physical analysis of the soils from the azolla growing and non-growing locations found in Kayamkulam, Pazhanji and Pattambi regions. The azolla growing locations had 12.7, 10.9 and 19.4 per cent clay which is about 0.25 times lesser than the values, 17.8, 18.3 and 36.5 per cent of the non-growing locations respectively in the above mentioned regions (Table 4.1.1). It has also been found that the availability of exchangeable cations and anions is more in soils with less clay content (Brady, 1970). This is further supported by the chemical analysis of water at these locations. A high content of available nutrients is found in water samples of azolla growing locations. Though the locations favouring azolla growth had lower contents of available nutrients in their soils, the proportions of nutrients released into water were high, compared to soils having higher content of clay (Tables 4.1.2 and 4.1.3). Among the locations favouring the growth of azolla, Pattambi had higher percentage of clay (19.4 per cent). It was noted that the extent of coverage of azolla at Pattambi was only 13 per cent compared to 62 and 73 per cent at Pazhanji and Kayamkulam regions respectively. Thus it may be inferred that low release of essential nutrients required for azolla growth may be one of the factors limiting spread of azolla in these locations. This corroborates the findings of Pillai et al. (1980).

Soil and water pH of the azolla growing locations were high compared to non-growing locations (Tables 4.1.2 and 4.1.3). According to Brady (1970), one of the outstanding physiological characteristics of the soil solution, is its reaction. The fixation of P, Fe and Al is most serious when the soil pH is below 5.0. When the soil reaction is held within a range of 6.0 to 7.0, toxicity of Fe, Al and Mn can satisfactorily be suppressed at the same time, availability of P and other nutrients is assured unless these elements are decidedly lacking in the soil. Bori and Meelu (1983) observed that occurrence of 5-10 cm of standing water having a neutral pH is one of the most important inputs for proper growth of azolla.

With regard to the nutritional status of the soils, azolla growing locations at Kayamkulam, Pazhanji and Pattambi regions had 14.0, 9.0 and 3.3 ppm of available P compared to 2.4, 2.8 and 2.8 ppm respectively in the non-growing locations. The same trend was observed in P content of water also. The high content of P in Kayamkulam and Pazhanji locations, may probably be due to the relatively higher pH coupled with the lower content of clay. Importance of P in the nutrition of azolla is well recognized. Subudhi and Watanabe (1981) observed that for growth of azolla, the threshold concentration of P in azolla appeared to be 0.2 to 0.3 per cent below that growth was proportional to P content. Lumpkin and Plucknett (1982) and Watanabe and Ramirez (1984) reported that in most paddy systems, P is the most common element limiting the growth of azolla.

In the case of potassium content of water, the non-growing location showed very low value (Table 4.1.3). An inverse relation in the available K content in soil and water could be observed which may probably be due to its association with clay content. Several workers (Singh, 1979; Lumpkin and Plucknett, 1982) had observed the significant effect of K on the growth of azolla.

The mean calcium content of water of locations favouring the growth of azolla at Kayamkulam region was 7.1 and at Pazhanji it was 7.5 ppm. Pattambi had lower value (5.2 ppm). Thus the growth of azolla at these regions also showed a decreasing trend from Kayamkulam to Pattambi. However, the Ca content of soil presented a reverse picture. This may be due to the fact that the lower content of clay in Kayamkulam and Pazhanji locations may be favouring release of nutrients though their contents in soil are comparatively low. Becking (1979) and Singh (1979) also reported that Ca deficiency had more pronounced effect on growth and N fixation of azolla. The higher contents of Ca in water of the azolla growing locations of Kayamkulam and Pazhanji regions may be favouring its growth in these locations.

Magnesium content of soil followed the same trend of calcium. Water of azolla growing location contained higher content of this element. The importance of Mg in the nutrition of azolla is evident from table 4.2.1. Similar observations were made by Watanabe (1977) and Becking (1979).

There was an increase in the iron content of soils of azolla growing locations at Pattambi compared to that of Kayamkulam (Table 4.1.2). The non-growing locations had a higher content of iron in all the three regions. The low pH of soil may be favouring its solubilization and resulting in higher content of available iron in these soils. The iron content of water also depicted the same trend. Therefore it can be assumed that Fe content is not a limiting factor in these soils but its higher content can lead to toxicity problems as evident from poor or no growth of azolla. In such soils it is also probable that the high Fe content has got a depressing effect on P availability.

In general, Mn, Zn and Cu contents of the soil of both azolla growing and non-growing tracts were very low (Table 4.1.2). However, it appears that these elements _per se_ do not limit the growth, since extremely small quantities, would suffice for the proper growth and development of the fern. Corroboratory results were reported by Lumpkin and Plucknett (1982).

Apart from the nutrient supplying capacity of the soil and water, the climatological parameters also exerted a decisive role on the growth and development of azolla. Among the meteorological parameters, temperature, rainfall, relative humidity, sunshine hours and evaporation are important (Lumpkin and Plucknett, 1982). It may be noted that the extent of coverage of azolla at Kayamkulam, Pazhanji and Pattambi were 73, 62 and 13 per cent respectively. The fluctuation in maximum and minimum temperature during the azolla growing and non-growing season were wider at Pattambi than that of Kayamkulam (Appendix III and Fig. 41.5.1 and 4.1.5.2).

Similarly maximum temperature during the non-growing period was higher at Pattambi (Appendix III). On the effect of pre-season soil drying on blue green algal population, Roger and Kulasooriya (1980) observed that under a long dry spell, spores of heterocystous blue green algae constituted more than 95 per cent of the potential flora as against 30 per cent for a short dry spell.

With regard to relative humidity among the three regions, Kayamkulam was relatively more favourable (Appendix III) (92-97 per cent during the forenoon). According to the report of FAO (1979) the optimum relative humidity to azolla growth is between 85-90 per cent.

Similarly rainfall distribution was more even at Kayamkulam (Fig. 4.1.5.2). Heavy rainfall at Pattambi especially during the early growth period of azolla hinders its growth and development due to wave action and turbulence as reported by Ashton (1974). In the non-growing season, Kayamkulam recorded a pre-monsoon rainfall to the tune of 364.3 mm in 20 rainy days, as against 253.9 mm in 16 days period at Pattambi. This rainfall is useful for the germination of spores. The reports of Gurunathan and Sreerangasami (1983) also corroborated this fact.

Thus it can be concluded that the higher pH, with proper availability of P, Ca and Mg coupled with sufficiency of other nutrients, may be the soil factors favouring azolla growth at Kayamkulam and Pazhanji. Comparatively cooler climate at these places may be the other factor encouraging its spread in these regions.

5.2. Nutritional requirement of azolla

The azolla grown in water without any addition of nutrients was inferior in growth as well as in nitrogen content. The yield was reduced by 7.9 per cent while N content by 31.8 per cent over the control which may be attributed to the inadequacy of nutrients particularly P, Mg and Ca (Tables 4.2.1 and 4.2.2 and Fig. 4.2.1). Azolla grown in water showed yellowing and its intensity increased with the advancement of growth period. The general reduction in yield and N content of these treatments may be attributed to low fresh weight, low number of algal cells in the frond cavities and low rate of N_2 fixation (IRRI, 1976).

However, omission of N, K, Fe and Mn from the complete nutrient solution did not affect the growth of azolla, as the yield in these treatments were comparable with that receiving all the nutrients. Similarly, in N content of azolla also, these treatments were comparable with that of the control receiving all the nutrients. Though these elements are reported to be essential for the growth of azolla (Olsen, 1970; Becking, 1979; Liu, 1979), omission of these elements from the nutrient solution did not exert any significant influence on the growth of azolla. This is due to the fact that the water used for the trial contained N, K, Fe and Mn at 1.8, 1.5, 0.16 and 0.07 ppm respectively which may be sufficient for meeting its requirements.

Solution culture investigations on the nutrient requirement of azolla revealed that P is the most essential element for its growth and development. Exclusion of P from the solution has reduced the yield by 19.8 per cent and N content by 14.1 per cent over the control. It may be remembered that water used for the trial contained only 0.01 ppm P. The survey conducted to identify the reasons for luxurient growth in certain places also revealed that azolla growth was maximum in areas where the P content of water was the highest.

In aerobic condition heterocyst frequency in Azolla filiculoides has been shown to be related to acetylene reduction activity (Hill, 1975) and the frequency of heterocyst decreased in P deficient azolla (Subudhi and Watanabe, 1981). Acetylene reduction activity in these P deficient fronds may be ATP limited, since ATP synthesis is much affected by P application. P deficiency and high temperature reduce N_2 fixing activity of the symbiont by different mechanism (Tung and Watanabe, 1983) and in green algae, the deficiency of P has been shown to result in a decreased rate of photosynthesis. Many workers have stressed the role of P in the growth of azolla (Subudhi and Watanabe, 1981; Lumpkin and Pluckmett, 1982 and Watanabe and Ramirez, 1984). Perusal of the data revealed that the dry matter per cent was maximum in P deficient treatment. The moisture content of azolla is related to the sufficiency or deficiency of nutrients as reported by Aziz and Watanabe (1983). It may also be noted that this treatment took maximum time for doubling and it can be concluded that the P contained in the water was insufficient for its proper growth and development. The results corroborate the findings of Aziz and Watanabe (1983).

Omission of Mg from the nutrient solution resulted in a yield reduction of 9.1 per cent and N content by 16.5 per cent over the control. The water used for the trial contained only 0.9 ppm Mg. The insufficient quantity of this element in water coupled with its essentiality might have caused the reduction in the growth and N content. Becking (1979) observed that Mg deficiency caused a reduction in fresh weight by 82 per cent and total N content by 77 per cent over the control. Similar were the findings of Watanabe _et al_. (1977).

Though the water used for this study possessed a Ca content of 5.2 ppm, its elimination from the nutrient solution had resulted in a yield reduction to the tune of 7.9 per cent and N content by 7.1 per cent. This clearly points out that the content of Ca in water may be insufficient to meet the requirement. Agarwala and Sharma (1976) explained the role of Ca in cellular organization and in the assimilation of N. Becking (1979) observed that Ca deficient plants had a fresh weight of only nine per cent of that of normal plants and total N content was reduced to 50 per cent of that of plants receiving the complete solution. The results of the present study agree with that of Liu (1979).

In general the increase in yield of azolla over the three weeks period was 3.4 to 4.5 fold. Between the trials the performance in the first trial was better than that of the other. It could be attributed to the fluctuations in the water and air temperature. Weather during the first trial was comparatively favourable than the other (Appendix II). The lower growth rate observed in the second trial may be due to the higher water temperature. This is in accordance with the reports of Watanabe et al. (1977) and Lumpkin and Pluckmett (1982).

5.3. Time of application and quantity of inoculum on the growth of azolla and yield of rice

To elicit on the influence of time of application and quantity of inoculum vis-a-vis planting rice, three experiments were conducted during the second crop season of 1980 and first and second crop seasons of 1981.

In the second crop season of 1980, t_3 (inoculation three weeks after planting) registered its superiority in azolla growth over the other two times of application, i.e., t_2 and t_1 (inoculation two weeks and one week after planting respectively) (Table 4.3.1).

Growth of azolla decreased in the order: three weeks after planting > two weeks after planting > one week after planting. The result differs from the findings of Sreenivasan (1980a), Govindarajan et al. (1980) and Kannaiyan et al. (1983). This difference can be explained based on the unfavourable weather conditions particularly water temperature prevailed during the early periods after inoculation (Fig. 4.3.1.1b). The weekly mean temperature recorded at 2 p.m. at the time of inoculation was 36.2°C in t_3 whereas it was 38.2 and 40.5°C respectively for t_2 and t_1, mainly influenced by the rice crop canopy. The daily mean light intensity below the canopy followed similar trend and it was more favourable for t_3 than for t_2 and t_1. Optimum temperature for growth of azolla is 22-30°C and when the temperature exceeds 32°C reddish brown discolouration appears and azolla growth is affected (FAO, 1979). Tuan and Thuyet (1979) found that when the temperature at 14 hours rose to 30°C, azolla turned reddish and at 35°C it began to die.

Stressing the effect of solar radiation, Ashton (1974) reported that growth rate of azolla increased with increasing light intensity to a maximum of 50 per cent sunlight i.e., about 49 k lx. Optimum solar energy for the growth of azolla is 26-50 k lx (FAO, 1979).

Thus it can be assumed that the unfavourable water temperature and solar radiation prevailed during the early five weeks period after planting resulted in poor growth in t_1 and t_2. An improvement in growth observed at the third week after inoculation of t_3 made it superior over other times of application.

Quantity of azolla inoculum also affected the growth of azolla significantly, q_4 recorded the maximum yield of azolla followed by q_3 and q_2 which were all significantly different from one another. Interaction effect of time and quantity of inoculum was also statistically significant and t_3q_4 produced the highest yield of azolla which was better than other combinations (Fig. 4.3.1.1a).

In general the azolla growth was not satisfactory during the second crop season of 1980 mainly because of higher temperature.

In the first crop season of 1981, t_2 was found to be superior in azolla growth compared to others during the first week after application of inoculum. The treatment t_1 had the lowest fluctuation in water temperature compared to t_2 and t_3. A perusal of the figure 4.3.1.2b shows that water temperature was comparatively favourable during the second and fourth week after the first inoculation. Light intensity during the growth period followed the same pattern of temperature. The decline in growth in t_1 during the first week may be due to the transfer of azolla growing in a favourable condition to a quite unfavourable situation. But a favourable condition in the second week caused an increase in growth for this treatment. Moreover, the treatment t_1 experienced relatively minimum fluctuation in water temperature compared to t_2 and t_3.

Though t_2 had the benefit of more favourable temperature during the first week of growth, a rise in temperature during the second week might have destroyed the inoculum affecting its further growth. Thus t_2 could exhibit superior growth tendency only at the end of first week after its application.

For t_3, the rise in temperature and light intensity in the week of inoculation might have destroyed the quantity of inoculum applied as a result there was no significant growth eventhough the water temperature and light intensity were comparatively favourable during the later periods.

As the conditions were not congenial for the multiplication of azolla, the quantities of inoculum could not exert any significant influence on the growth during the first crop season of 1981 also. The interaction between time of application and quantity of inoculum was significant and t_1q_4 was superior to other combinations probably due to overall favourable effect coupled with higher quantity of inoculum used in this combination.

In the second crop season of 1981, t_3 with azolla yields of 388 g m^{-2} in the first week and 446 g m^{-2} in the second week was found to be superior to the azolla yields of t_1 and t_2 for the corresponding periods.

A perusal of the figure 4.3.1.3b revealed that the water temperature was around 35.1°C throughout the period of growth in t_1. But in the case of t_2, the last week was comparatively favourable as the weekly mean value of water temperature declined and this made this treatment to be superior in azolla growth to t_3 in the last week. For t_3, the water temperature was relatively favourable compared to other two times of inoculation. The temperature declined from 35.0°C at the first week to 33.7°C at the end of second week followed by an increase to 34.7°C. Light intensity below the canopy also showed an almost similar trend as that of water temperature except in the later stages. This fall in values may be due to the canopy coverage at later periods. But the rise in water temperature at the third week period affected its growth and made it inferior to that of t_2 in the third week after inoculation.

Among the different quantities of inoculum tried, q_4 with values of 490, 608 and 855 g m^{-2} was superior in all the three weeks of study. The treatment q_3 was found to be better than q_2. Under unfavourable conditions, higher quantity of inoculum was found to be better since even after a considerable loss, the survived azolla acted as the starting inoculum when the climatic conditions became favourable.

The experiments confirmed the significant influence of water temperature and light intensity. Growth of azolla in the comparatively favourable period and reduction in growth during unfavourable conditions shows that weather factors influenced the growth of azolla in these seasons.

Among the three seasons, second crop season of 1981 was relatively more favourable for the growth of azolla. This season exhibited relatively lower water temperature coupled with least fluctuations compared to other seasons, which contributed to the better growth of azolla during the season.

5.4. Geometry of planting rice in relation to growth of azolla and yield of rice

At the end of the three weeks growth period in 1980, P_1 (20 cm x 10 cm east-west direction of planting) resulted in the highest growth of azolla (71 g m^{-2}) followed by P_2 (20 cm x 10 cm north-south) and P_5 (Bulk method) (Table 4.4.1). The treatment P_6 (fallow) was found to be inferior to all the other treatments. Relatively low water temperature and high light interception might have favoured these treatments to have a better growth compared to others (Fig. 4.4.1).

There was reduction in growth in all the treatments in the first week probably because of the drastic effect of very high temperature though it was showing a declining trend.

There was increase in growth from the second week onwards and this period corresponds to a fall in water temperature and light intensity. The decline was because of the reduction in atmospheric temperature coupled with the shading of plants in the later stages.

Weather conditions during the period of study were quite unfavourable for the growth of azolla.

In general, growth of azolla was minimum in the fallow plots compared to others. This may be due to the deleterious effect of high temperature and light intensity during the period. In plots planted with rice, the unfavourable effects are alleviated through the interception of solar radiation by the rice canopy. This is indicated from the observation that daily mean light intensity in the first, second and third weeks after the application of inoculum were 64.2, 78.0 and 67.9 k lx in P_1 and the corresponding values for P_6 were 92.8, 96.0 and 102.6 k lx respectively. The mean water temperature at 2 p.m. declined from 39.4°C at the end of first week to 35.4°C at the end of the third week in P_1, the corresponding values for control were 40.0 and 39.1 respectively. Thus the water temperature and light intensity were quite unfavourable for the growth of azolla. The result supports the findings of Goss (1973), Ashton (1974) and Lumpkin and Plucknett (1982).

At the end of the three week period in the first crop season of 1981, P_5 with azolla growth of 110 g m^{-2} was on par with P_2 (104 g m^{-2}) and superior to other methods of planting. The weekly mean water temperatures at the end of first, second and third week after inoculation for P_5 were 34.4, 33.4 and 35.2°C respectively. The corresponding values for P_6 were 35.0, 34.6 and 38.2°C. The daily mean light intensity also showed a similar trend (Fig. 4.4.2c). The mean percentage of light interception in P_5 and P_2 were 35.3 and 22.6 respectively. It can be seen that P_5 had recorded the lowest water temperature and light intensity values compared to others. Even under unfavourable condition, the lower values of water temperature and light intensity caused by shading of plants might have enhanced the growth of azolla in this treatment.

Growth of azolla declined in all the treatments, during the third week period of the study. Water temperature showed a corresponding increase in all the treatments. Light intensity showed an increase in fallow plots. But in planted plots, the values remained almost constant in all but P_5 where it declined. This may be due to overshading of plants in P_5.

At the end of the study in second crop season of 1981, P_5 with an azolla yield of 191 g m^{-2} was on par with P_1 (182 g m^{-2}) and P_4 (181 g m^{-2}) and significantly superior to P_3 (Table 4.4.1). The mean water temperature at the end of first, second and third week for P_5 were 36.7, 34.4 and 35.1°C, whereas the corresponding values for P_4 and P_6 were 37.3, 35.0 and 36.0 and 37.5, 36.7 and 38.8°C respectively (Fig. 4.4.3b).

The mean percentage of light interception for P_5, P_1 and P_4 were 33.5, 35.3 and 29.0 respectively. Thus the water temperature and light intensity were comparatively lower which enabled better growth in these treatments.

A reduction in growth of azolla was observed in all the treatments in the second week after inoculation. The period corresponds to the increase in water temperature and light intensity. These unfavourable conditions might have affected the growth of azolla during the period. There was slight increase in growth when the temperature began to decline. This trend clearly shows that it is the climatic factors that controlled the growth of azolla in these seasons.

In all the seasons when light and water temperature increased, there was browning of azolla from green colour. This was first noticed in fallow plots followed by P_3 and P_4. Holst (1977) observed that under natural condition, azolla symbiosis is affected by air and water temperature and light quantity. Plant material exposed to direct sun was red pigmented and senesced when air and water temperature exceeded 25°C. (Plate 7).

Geometry of planting intercepted the solar radiation differently at different seasons. In the second crop season P_5 (bulk method) followed by P_1 seemed to be better in intercepting light whereas in the first crop season P_5 followed by P_2 appeared to be better.

As the sun will be moving slantingly towards south at the time of planting during the second crop season, 20 cm x 10 cm with east-west direction of planting would intercept the light to a greater extent. North-south direction is probably better than east-west direction during the first crop season since there is more direct incidence of solar radiation during the early weeks in the season. Lumpkin and Plucknett (1982) were of the opinion that the orientation of rows is important and it will vary according to season. In tropical regions where high temperature is a problem, it has been suggested

Plate 7. Azolla turned from green to brown under high solar radiation and temperature

that rice rows be oriented in a north-south direction so that direct sunlight will only penetrate the canopy for a short period each day.

To conclude, it has been found that climatic factors imposed strong restrictions on the survival and growth of azolla during the experimental periods of all the seasons. The slight amelioration in temperature and solar radiation induced by the presence of the rice crop could improve the growth of azolla. Among the different methods, bulk method of planting of rice (equidistant planting) could exert a favourable influence on the growth of azolla even under the unfavourable weather conditions.

5.5. Mineralization of azolla

A pot culture study on the mineralization of azolla in comparison with other organic manures was undertaken during 1984 and the results are discussed here.

Through the incorporation of azolla at 5 t ha^{-1}, 13.4 kg N was added to the soil and at the end of four weeks 63.0 per cent of nitrogen initially added was available (Fig. 4.5.3). Within a period of six and eight weeks after incorporation, 76.0 and 84.6 per cent of nitrogen of azolla was mineralized. Only after tenth week, the percentage of availability of nitrogen in this treatment began to decline. Thus it can be seen that a substantial portion of nitrogen in azolla 5 t was available within a reasonable period of time and this was reflected in the different fractions of nitrogen especially the ammoniacal nitrogen of soil (Table 4.5.1). One of the reasons for faster availability of nitrogen from azolla 5 t may be due to its narrow C:N ratio (11:1). Because of the succulence, fresh azolla decomposes faster than dry azolla (Behra, 1982). The reasonable quantity of azolla added (5 t) may be another reason for its steady availability during the twelve week period of study. At this level there was no much immobilization of nitrogen unlike the other treatments. The results are in line with the findings of Behra (1982), Lumpkin and Plucknett (1982) and Ito and Watanabe (1985).

The steady supply of nitrogen from azolla 5 t has some practical significance. Four weeks after incorporation 63.0 per cent of nitrogen was available and this period corresponds to tillering stage of medium duration rice. The period of maximum nitrogen availability coincides with the panicle initiation stage. This was evident in the yield and yield attributes of rice (Table 4.6.2.5). The results corroborate the findings of Pande (1979).

Green leaves contributed nitrogen to the tune of 25.4 kg when it was incorporated at 5 t ha^{-1}. Estimation of different components of nitrogen of soil as well as water revealed that this treatment had the highest values in most of the samplings. The data on percentage of availability of nitrogen at different periods showed that the release of nitrogen was faster from green leaves as 43.9 per cent of total nitrogen added was available in two weeks after incorporation and 73.5 per cent within a short span of four weeks which agrees with the report of ICAR (1964). The faster availability in this treatment may be due to the quicker decomposition of the succulent green leaves with high nitrogen content.

The initial maximum availability of nitrogen from green leaves (73.5 per cent) coincides with tillering stage of rice facilitating higher tiller production. This was also reflected in the field experiment and the treatment receiving green leaves at 5 t ha^{-1} had significantly higher total tillers and panicles m^{-2} which were comparable to azolla 7.5 t only (Tables 4.6.1.2 and 4.6.2.5). But the decreasing availability in the next three fortnights observed may be due to the immobilization of nitrogen already released. As the easily decomposable plant materials are depleted within four weeks and the non-availability of suitable substrate coupled with the higher microbial population may be the reasons for the reduction in nitrogen availability during these periods. Thus it is seen that the reproductive phase of rice may not be benefited as in the case of tillering stage. It is seen that 86.0 per cent of total nitrogen added was available at twelve weeks after incorporation. As this period coincides with the grain filling stage, the nitrogen may be useful for improving the quality of grains.

Though 26.9 kg of nitrogen was added by incorporating cattle manure at 5 t ha^{-1}, the result revealed that cattle manure was comparatively slow in nitrogen release. This was clear from the fact that only 19.1 per cent of total nitrogen added was available, two weeks after incorporation which was the lowest among the treatments tried. This trend continued till the end of the fourth week. Even after six weeks, only 59.6 per cent of nitrogen added was available. This may be due to the fact that the cattle manure is composed of fibrous plant materials which had undergone digestion once in the rumen of animals. Hence whatever easily decomposable materials present in the manure undergo mineralization at a faster rate in the beginning while the harder materials disintegrate only slowly. This slower rate of decomposition may be due to the wide C:N ratio it had (30:1). Another reason for slow release of nitrogen from cattle manure may be that it had a good load of microbial population and the easily decomposable substrate might have been used for their body build up and proliferation and the nitrogen thus fixed would be available only at a later period. The decline in nitrogen availability at eighth and tenth week after incorporation may be due to immobilization of nitrogen by microbes as reported by Yoshida and Padre (1977). The higher availability at twelfth week (58.3 per cent) confirms the observation that the harder materials give way to decomposition process and the nitrogen temporarily immobilized is released slowly to the soil system. In the field experiment the late availability of nitrogen in the treatment receiving cattle manure at 5 t ha^{-1} was reflected in thousand grain weight. But the general performance of rice receiving cattle manure 5 t was inferior to that of azolla 7.5 t or green leaves 5 t.

Though fresh azolla is faster in release of nitrogen, the increase in quantity from 5 t to 10 t decreased the percentage of availability of nitrogen. It is evident from the figure 4.5.6 that at all the periods, the treatment receiving azolla 10 t had low values, compared to azolla 5 t. It is clear from the fact that only 47.7 per cent of total nitrogen added was available even at the end of eight weeks period. It may be noted that the percentage of availability went on increasing till the final sampling except for a slight decline at the end of the sixth week period. Though 26.8 kg nitrogen was added by the incorporation of azolla at 10 t ha^{-1}, release of different fractions of nitrogen was not proportional to the quantity of nitrogen initially added. Thus when the quantity of azolla was increased, the percentage of availability decreased.

One of the reasons for slow availability may be that the lignin content (18-24 per cent) as reported by Lian <u>et al.</u> (1981) may be affecting the mineralization process significantly. According to Bundy and Bremner (1973) 2-methoxy and 2,6-dimethoxy-benzoquinon which are formed during the decomposition of lignin inhibit urease activity.

Immobilization of part of the nitrogen released may be another reason for slow availability of nitrogen in this treatment. As there was not much variation in the total nitrogen content of soil, the increase in the nitrogen availability as period advanced on, may be because of the fact that part of the nitrogen immobilized by microbes are released to the soil system. The results confirm the findings of Bandyopadhyay and Bandyopadhyay (1983). Increased pressure of mineralized ammonium in soil might have caused fixation of part of this fraction through entrapment in lattice of clay minerals as reported by Saha and Mukhopadhyay (1983). Thus it can be assumed that higher addition of lignin per unit area coupled with the immobilization and fixation of nitrogen might have affected the release of nitrogen in this treatment.

When dry azolla equivalent to 5 t was added, the percentage availability of nitrogen was lower than that of fresh azolla applied at the same rate at all periods except first sampling. Due to drying, azolla becomes hard and hence it decomposes only slowly. It was clear from the lower availability of nitrogen from dry azolla (5 t) as compared to that of fresh material. The result agrees with the reports from International Rice Research Institute (IRRI, 1976). Ito and Watanabe (1985) found that fresh azolla released 2.5 times more ammoniacal nitrogen from its body than dry azolla. The result indicates the necessity of applying dry azolla well in advance so that the maximum availability of nitrogen coincides with peak nitrogen needs of rice. The higher availability of nitrogen from dry azolla two weeks after incorporation may be due to the mineralization of a small amount of easily decomposible substances that remained after drying as reported by Behra (1982).

Through the incorporation of dry azolla equivalent to 10 t of fresh azolla ha^{-1}, 26.8 kg of nitrogen was added to soil, but the availability was not proportional to the quantity of nitrogen initially added. Only 50.5 per cent of nitrogen was available at three fortnights after its incorporation and this was the maximum availability recorded for this treatment during the study. The reasons for slow availability may be the drying effect and the higher addition of lignin at the higher quantity of azolla incorporated into soil.

Comparative analysis of rate of mineralization of organic manures during the two trials revealed the faster mineralization during the second trial (Fig. 4.5.2). With regard to temperature and pH of soil and water, higher values were recorded during the second trial. This phenomenon brings out the influence of temperature on mineralization as observed by Cho and Ponnamperuma (1971). There was a decline in pH values as depicted in figure 4.5.2. from the second to fourth week after incorporation. The decline in pH is due to the accumulation of CO_2 during the initial stages (IRRI, 1964). Then there was a gradual increase in pH values, the rate of which being higher in the second trial, corresponding to higher rate of mineralization during the period.

5.6. Evaluation of azolla as an organic manure

In order to evaluate azolla as an organic manure, field investigations were undertaken during the years 1980 and 1981. The salient findings are discussed in the ensuing section.

5.6.1. Effect of organic manures on growth and yield of rice.

Analysis of grain yield as influenced by organic manures for the two years revealed that green leaves at 5 t ha^{-1} was on par with azolla at 7.5 t ha^{-1} and superior to rest of the treatments (Table 4.6.2.1). Azolla 10 t, cattle manure 5 t and azolla 5 t ha^{-1} were on par in grain yield and all were significantly superior to control.

Application of green leaves at 5 t ha^{-1} resulted in grain and straw yields of 3367 and 3446 kg ha^{-1} respectively. The increases in yield of grain and straw over the control (no organic manure) were 25.4 and 26.8 per cent respectively. The higher yields can be due to the faster and more availability of nutrients in this treatment (Fig. 4.5.3). This is in agreement with the report of ICAR (1964). It may be noted that glyricidia when incorporated at 5 t ha^{-1} contributed 27.1 kg N, 5.1 kg P_2O_5 and 14.9 kg K_2O and the result of the mineralization study revealed that 73 per cent of the nitrogen was available within four weeks after incorporation. Thus the faster availability of nutrients together with their higher contents, might have facilitated this treatment to perform better compared to other treatments except azolla at 7.5 t.

Superiority of green leaves was manifested in growth and yield attributes of rice. According to Matsushima (1976) the four primary yield components or determinants in rice are the number of panicles per unit area, the number of spikelets per panicle, percentage of filled grains per panicle and thousand grain weight. With regard to height of plant and total and productive tillers at maturity, green leaves 5 t and azolla 7.5 t were on par and significantly superior to other treatments (Tables 4.6.1.1, 4.6.1.2, 4.6.2.5). In length of panicle, number of spikelets panicle^{-1} and the percentage of filled grains panicle^{-1}, it was comparable with azolla 7.5 t (Table 4.6.2.5). In thousand grain weight this treatment (28.4 g) was better than cattle manure 5 t (Table 4.6.2.5). The uptake of N at maturity was comparable with azolla 7.5 t and superior to others (Table 4.6.3.4). Similar trend was observed in P and K uptake also (Tables 4.6.3.5 and 4.6.3.6).

Application of azolla at 7.5 t ha^{-1} had resulted in a grain yield of 3331 kg ha^{-1} which was 24.1 per cent more than that of the control (Table 4.6.2.1). The increase in straw yield over the control was 23.5 per cent. The nutrients N, P_2O_5 and K_2O at 14.1, 3.9 and 6.1 kg respectively were added by the incorporation of azolla at 7.5 t ha^{-1}. Mineralization study on azolla revealed that there was a continuous release of nitrogen from azolla (Fig. 4.5.3). Pande (1979) reported that about half of nitrogen in azolla was mineralized within three weeks after water logging and 2/3 after 6-8 weeks of flooding. Moreover, azolla has a beneficial effect on soil microflora and nutrient availability as reported by Haq _et al._ (1984). Thus the faster release of nutrients and their higher contribution might have resulted in better yields in this treatment. The result confirms the findings of Rains and Talley (1979).

The superiority of azolla 7.5 t was noticed in the yield attributes and nutrient uptake. In total and productive tillers, it was significantly superior to all other treatments except green leaves 5 t (Tables 4.6.1.2 and 4.6.2.5). Thousand grain weight was the highest for this treatment (Table 4.6.2.5). In number of spikelets panicle^{-1} and filled grains panicle^{-1}, this treatment recorded the highest values (Table 4.6.2.5). The uptake of N, P_2O_5 and K_2O for this treatment was 77.2, 12.0 and 65.3 kg ha^{-1} respectively in 1981 which was comparable with that of green leaves 5 t and superior to the rest of the treatments.

Azolla 10 t, cattle manure 5 t and azolla 5 t were on par in grain yield. The increases in yield of these treatments over the control were 13.3, 10.9 and 9.7 per cent respectively. Azolla 10 t and azolla 5 t were on par in straw yield.

Through the incorporation of azolla at 5 t, 9.4 kg N, 2.5 kg P_2O_5 and 4.1 kg K_2O were added ha^{-1}. Mineralization study on azolla revealed that azolla was faster in release of nitrogen and within a period of eight weeks, 85 per cent of the nitrogen added through 5 t of azolla, was available (Fig.4.5.3). Though the contribution of nutrients was less compared to cattle manure, the steady supply throughout the growth period of rice has made it comparable with that of cattle manure.

The incorporation of azolla at 10 t ha^{-1}, added 18.8 kg N, 5.0 kg P_2O_5 and 8.2 kg K_2O ha^{-1}. In grain and straw yields, it was comparable with azolla 5 t and inferior to azolla 7.5 t. In growth and yield attributes and in uptake of nutrients, the same trend was noted in this treatment. The poor performance at the highest rate of azolla application may be due to accumulation of lignin to toxic level which affected the decomposition processes. Lian et al. (1981) noticed that azolla was higher in lignin content (18-24 per cent) as a result of which the decomposition and nitrogen liberation would be slower. The usual lignin degradation products such as 2-methoxy and 2,6-dimethoxybenzoquinon inhibited urease activity and nitrification processes (Bundy and Bremner, 1973). Another possible explanation is the negative relation between the amount of nitrogen incorporated as azolla and the proportion of nitrogen available to rice crop (Rains and Talley, 1979; Wen, 1984). The poor response of azolla 10 t may also be due to the immobilization of part of the nitrogen added.

Incorporation of cattle manure 5 t could bring about only 10.9 per cent increase in yield over the control (Table 4.6.2.1) though 22.3 kg N, 5.1 kg P_2O_5 and 3.6 kg K_2O ha^{-1} were added to soil through its incorporation. Among the organic manures, this treatment had the lowest straw yield. The poor performance by this treatment was manifested in the yield parameters and nutrients' uptake also.

Though higher quantities of nutrients were added through 5 t of cattle manure, the results showed that the present crop could not benefit much from it. Mineralization study revealed that percentage of nitrogen released was lowest in cattle manure incorporated treatment (Fig. 4.5.3). Even at the end of the twelve week period, only 58 per cent of the total nitrogen added through cattle manure was available. This may be one of the reasons for lower yield in this treatment. Observation of Soni and Sikarwar (1983) confirms this fact. They found that grain yield of wheat in a rice-wheat sequence was higher in the treatment receiving a part of nitrogen as cattle manure for *kharif* rice although the rice crop did not show much of direct response to this treatment.

Effect of organic manures on harvest index was significant in the year 1981 (Table 4.6.2.1) and cattle manure 5 t had the highest value (50.8 per cent) followed by azolla 10 t. Perusal of the grain and straw yield data revealed that these treatments had lower grain yield compared to azolla 7.5 t and green leaves 5 t. Azolla 7.5 t and green leaves 5 t had significantly better yields than cattle manure 5 t and straw yields for these two treatments were slightly higher than that of grain which resulted in lower harvest index values. Mineralization study of organic manures revealed that availability of nitrogen from cattle manure 5 t and azolla 10 t were slow compared to green leaves 5 t and azolla 5 t. Thus, under limited supply of nutrients, more of the available nutrients were used for grain than straw production in the treatments receiving cattle manure 5 t and azolla 10 t. This is further proved by the fact that harvest index was the highest (55.7 per cent) for cattle manure

5 t with no fertilizer (Table 4.6.2.4). But the value decreased as the percentage of fertilizer dose increased and at full dose of fertilizer, the value was comparable with green leaves 5 t and azolla 7.5 t.

Residual effect of organic manures in influencing the grain yield of succeeding crop was significant in the summer crop of 1981-82 (Table 4.6.5.1). The treatment receiving azolla at 10 t ha^{-1} had the highest yield of 2644 kg ha^{-1}. It was on par with azolla 5 t and superior to other treatments. This indicate that part of the nutrients supplied through azolla might have been left in the soil, as a result, the performance of succeeding crop could be improved due to the residual effect. The beneficial effect on azolla on the succeeding crops was reported by Subudhi and Singh (1980). They found that residue of 5, 10, 15 and 20 t of incorporated azolla ha^{-1} increased the yield of succeeding rice crop by 7.7, 23.8, 24.5 and 40 per cent respectively over the control. Haq *et al.* (1984) were of the view that azolla had beneficial effect on soil structure, soil microflora and micronutrient availability and the effect of azolla may persist longer than chemical fertilizers.

5.6.2. Effect of fertilizer levels on growth and yield of rice.

Fertilizer levels significantly influenced the grain and straw yields of rice. Application of full dose resulted in the highest grain yield of 3770 kg ha^{-1} which was 60.8 per cent higher than that of the control (Table 4.6.2.1). The corresponding yield increases for 25, 50 and 75 per cent of the fertilizer doses were 18.0, 30.4 and 41.7 per cent respectively. In straw yield also almost a similar trend was observed. Application of full dose had resulted in 61.4 per cent increase over the control.

The increase in grain and straw yields is due to the availability of nutrients and this was manifested in all the yield contributing factors. In 1980, full dose of fertilizers had resulted in significantly higher tiller counts (total as well as productive) whereas in 1981, it was on par with 75 per cent and superior to the rest of the treatments (Tables 4.6.1.2 and 4.6.2.5). Regarding the length of panicle, 100 per cent of fertilizer dose was superior to the lower levels in 1980 (Table 4.6.2.5). Such a superiority was observed in phytomass production and leaf area index also (Tables 4.6.1.3 and 4.6.1.6). The uptake of N, P_2O_5 and K_2O by rice was also highest in this treatment (Tables 4.6.3.4, 4.6.3.5 and 4.6.3.6). The favourable effect of full dose of fertilizer on growth and yield parameters had resulted in higher grain and straw yields at this level. The results corroborate the findings of Kaushik and Venkataraman (1981).

With regard to the residual effect of fertilizers on grain yield of succeeding rice, the treatment receiving 75 per cent of the fertilizer dose was on par with that of full dose and control in summer crop of 1981-82 (Table 4.6.5.1). The significantly higher yield at the higher levels of fertilizers might be due to the residual effect of applied fertilizers in these treatments. The better performance of succeeding crop in the control treatment might be due to the fact that soil nutrients had not been exploited fully by the current crop under this treatment as revealed by poor yield and uptake of nutrients (Tables 4.6.2.1, 4.6.3.4, 4.6.3.5 and 4.6.3.6). As a result, the succeeding crop was in an advantageous position compared to other treatments which received different levels of fertilizers.

5.6.3. <u>Effect of interaction between organic manures and fertilizer levels on the growth and yield of rice</u>.

The effect of fertilizer levels varied significantly with different organic manures in grain and straw yields. Among the interactions between organic manures and fertilizer levels, the highest grain yield of 4181 kg ha^{-1} was obtained at azolla 7.5 t with full dose of fertilizer (Fig. 4.6.2.1). At this level it was even better than green leaves 5 t though in terms of nutrient contribution, green leaves was superior to azolla 7.5 t. This may be due to the favourable effect of azolla as reported by Singh (1977c) and Haq <u>et al</u>. (1984). In straw yield, azolla 7.5 t with full dose of fertilizer was comparable with green leaves 5 t with full dose and was superior to all other combinations (Fig. 4.6.2.2).

The treatment without any organic manure showed significant increase in grain yield at each higher level of fertilizer and the yield with full dose of fertilizer was the highest (Fig. 4.6.2.1). The increase in grain yield at 25, 50, 75 and

100 per cent of the fertilizer dose over the control (no fertilizer) was 25.1, 47.3, 72.8 and 98.9 per cent respectively. Similar trend was observed in straw yield also.

Cattle manure 5 t with full dose of fertilizer was significantly better than that of the lower levels. The increases in yield over the control (no fertilizer) were 49.7 and 81.2 per cent for grain and straw yields respectively. The yields were comparable to the treatment with full dose of fertilizer without organic manure. This may be due to slower release of nutrients as revealed by the mineralization study. Application of cattle manure 5 t alone had resulted in an increase in yield to the tune of 34.2 per cent over the absolute control. The results corroborate the findings of Oh (1979).

Green leaves 5 t with full dose of fertilizer had resulted in a grain yield of 3840 kg ha^{-1} which was comparable with that of 75 per cent of fertilizer dose. In the case of straw yield, full dose (4136 kg) was significantly better than lower levels. Application of green leaves 5 t alone resulted in 57.9 and 64.8 per cent increase in grain and straw yields respectively. over the control. The higher content of nutrients with faster availability as revealed by the mineralization study (Fig.4.5.3) coupled with supplementation of chemical fertilizers had enabled this treatment to perform better. The favourable effect of this treatment on growth and yield attributes was also conspicuous.

Grain yield of azolla 5 t supplemented with chemical fertilizers increased with the application of higher levels of fertilizer and was the maximum with the highest dose (3724 kg). Straw yield seemed to be stabilized at 75 per cent of fertilizer dose. The increase in grain and straw yields for azolla 5 t alone over the control was 16.7 and 22.2 per cent respectively. Grain and straw yields obtained with 75 per cent of fertilizer dose was comparable with the treatment receiving full dose of fertilizers alone thereby indicating a saving of 25 per cent of fertilizer dose. The steady supply of nutrients from azolla together with the supplementation from chemical fertilizers, enhanching the uptake of nutrients and yield parameters, might have contributed much for a better performance by this treatment. Beri and Meelu (1983) also found that application of azolla at 5 t ha^{-1} gave rice yield equivalent to 25 kg N ha^{-1}

Incorporation of azolla 7.5 t had resulted in higher grain and straw yields at all the levels of fertilizer tried. Azolla 7.5 t with full dose of fertilizer recorded the highest grain yield of 4181 kg ha^{-1} which was superior to all the other combinations. The increase in grain yield over the control with full dose was 16.5 per cent. The increases in grain yield at 25, 50, 75 and 100 per cent of fertilizer dose over control (azolla 7.5 t alone) were 18.2, 25.2, 42.5 and 62.9 per cent respectively. In straw yield also, azolla 7.5 t with full dose of fertilizer had recorded the highest yield of 4328 kg ha^{-1}. Application of azolla 7.5 t alone resulted in an increase of 32.1 per cent over absolute control. The better performance of this treatment may be due to the quicker availability of nutrients as reported by Behra (1982) coupled with its higher contribution of nutrients. The favourable effect was noticed in all growth parameters, yield attributes and uptake of nutrients.

Azolla 7.5 t with 75 per cent of fertilizer dose was comparable to the treatment receiving full dose of fertilizer alone, thereby resulting in a saving of 25 per cent of the fertilizer dose. Arunachalam (1980) got similar result due to the incorporation of azolla. Kaushik and Venkataraman (1981) also found that at every nitrogen level, the effect of azolla supplementation was equal to 20 kg nitrogen ha^{-1}.

Azolla 10 t with full dose of fertilizer had significantly higher yield (3656 kg) as compared to lower levels. Application of azolla 10 t alone had resulted in an yield increase of 29.6 per cent over the absolute control. Grain yield at azolla 10 t with full dose of fertilizer was comparable to the treatment with full dose of fertilizer alone. The comparatively poor performance of this treatment was reflected in growth, nutrient uptake and yield attributes of rice. In total and productive tillers, it was quite inferior to azolla 7.5 t. Similarly in length of panicle, number of spikelets per panicle and filled grains per panicle, it had recorded lower values. In harvest index, percentage of filled grains $panicle^{-1}$ and thousand grain weight, this treatment was comparable with azolla 7.5 t or green leaves 5 t which might be the reason for obtaining the present yield. Though 18.8, 5.0 and 8.2 kg N, P_2O_5 and K_2O respectively were added through azolla at 10 t ha^{-1}, the result revealed that part of the nutrients was not available for the present crop. High lignin content of azolla at this level as reported by Lian et al. (1981) might have affected the decomposition process and even the release of nitrogen from urea of added fertilizers.

Among the interactions between organic manures and fertilizer levels, the highest grain yield of 4181 kg ha^{-1} was obtained at azolla 7.5 t with full dose of fertilizer. Grain yield with the application of full dose of fertilizer alone was comparable with green leaves 5 t with 50 per cent of fertilizer dose, azolla 7.5 and 5.0 t with 75 per cent of fertilizer dose, cattle manure 5 t and azolla 10 t with full dose of fertilizer. This clearly points out the possibility of saving chemical fertilizers to the tune of 50 per cent when green leaves 5 t is used and a saving of 25 per cent when azolla 7.5 t or 5 t is used as green manure. Thus, when highest yield is the objective, application of azolla at 7.5 t with full dose is the best combination. If saving in fertilizer at a reasonable yield of 3600 kg ha^{-1} is the choice, green leaves 5 t with 50 per cent of fertilizer dose or azolla 5 t with 75 per cent fertilizer dose can be adopted.

5.6.4. Effect of organic manures and fertilizer levels on the economics of rice production.

The maximum output-input ratio of 2.09 was recorded by the treatment receiving full dose of fertilizer alone which was followed by 2.07 in the treatment receiving azolla at 7.5 t ha^{-1} with full dose of fertilizer (Fig. 4.6.2.3). The decrease in the output-input ratio in the treatment receiving azolla at 7.5 t ha^{-1} with full dose of fertilizer was due to the high cost of organic manure though this treatment recorded significantly higher grain yield than the treatment receiving full dose of fertilizer alone.

Though the maximum output-input ratio of 2.09 was for the treatment receiving the full dose of fertilizer alone, this cannot be given as a recommendation since it could be detrimental to crop production in the long run. Thus a combination of azolla at 7.5 t with full dose of fertilizer (with a ratio of 2.07) becomes a suitable combination for getting the maximum output. Even at the rate of 5 t ha^{-1}, azolla seems to be better than green leaves in terms of output-input ratio.

All these discussions have the following limitations. Influence of wage rate is very high and varying in treatments where cattle manure, green leaves and azolla are involved. In the case of fertilizer treatments, cost of fertilizers will not be subject to this much of fluctuation. More favourable changes can be expected when green leaves or azolla is produced *in situ*. In times to come, where better varieties and management techniques for higher biomass production and quality improvement of azolla are achieved, it can be expected that output-input ratio of azolla application will still be improved. Availability of organic manures, especially green leaves, is on the decrease. *In situ* growing of green manure crop, takes more than six weeks but azolla can be multiplied in three weeks' time. This point should also be considered while the output ratio of azolla treatments are evaluated.

5.7. Future line of work

In the present investigation it was observed that Kayamkulam area has the maximum natural growth of azolla. As this area has a very specific cropping sequence of rice-rice-sesamum, it appears necessary to verify whether different summer crops have any effect on the growth of azolla during the first crop season by influencing the mineral nutrient status of soil.

Nutritional studies with the objective of improving the quality of azolla which can ultimately help us in reducing the quantity of azolla to be used, need further elaborate study. Trials to find out whether growth regulators have any influence on increasing the biomass production or quality of azolla is also worth trying.

Collection and evaluation of different types of azolla for identifying such types which are resistant to higher temperature as experienced in Kerala is desirable.

Mineralization aspect of azolla, both as fresh as we.. as dry materials, needs more elaborate study.

As the data from the mineralization study on three forms of organic manures (cattle manure, green leaves and azolla) have indicated different patterns of release of nitrogen, detailed studies with combinations of these three organic manures in different proportions appear to be necessary. Such studies can be expected to throw light on the possibility of efficient use of smaller quantity of azolla available and also assure steady supply of nutrients to the rice plant.

Summary

VI. SUMMARY

In order to identify the conditions under which azolla grows well and to work out the management practices for its utilization in rice production, a survey work, three field experiments and two pot culture studies were undertaken at the Regional Agricultural Research Station, Pattambi from 1980 to 1984.

The survey work included detailed investigation on soil, water and weather parameters at three regions; Kayamkulam having the highest growth of azolla, Pattambi with the least growth and Pazhanji which comes in between. The field experiment to find out the best time and optimum quantity of azolla inoculum consisted of three times of application (one, two and three weeks after planting) and four quantities (0, 200, 400 and 600 g m^{-2}) of application. The experiment for identifying the best method of planting rice, favouring maximum growth of azolla had six treatments (20 x 10 cm and 40 x 5 cm spacing each in east-west and north-south directions, bulk method and fallow).

The experiment for evaluating azolla as an organic manure consisted of six mainplot treatments (cattle manure 5 t, green leaves 5 t, azolla 5, 7.5 and 10 t ha^{-1} and control). There were five subplot treatments (0, 25, 50, 75 and 100 per cent of the recommended dose of 90:45:45 kg N, P_2O_5 and K_2O ha^{-1}). Besides, two pot culture experiments were also undertaken. One of the pot culture trials was aimed at studying the effect of

N, P, K, Ca, Mg, Fe and Mn on the growth and nitrogen content of azolla. The second pot culture study was on the mineralization of azolla compared to commonly used organic manures (Azolla 5 t and 10 t, dry azolla equivalent to 5 t and 10 t of fresh azolla, cattle manure 5 t and green leaves 5 t ha^{-1} and control).

The salient findings of the investigations are summarised below:

1. Soils of azolla growing locations had a lower content of clay compared to non-growing location and among the three regions, Kayamkulam which recorded the highest growth of azolla and the lowest clay content. Soils of azolla growing locations had higher pH values and available P contents. Among the three regions, soils of Kayamkulam had the highest P content and pH value. Concentration of available K, Ca, Mg, Fe, Mn, Zn and Cu and Ec values were relatively lower in areas where azolla growth was maximum. Nitrogen content did not vary much among the different regions.

2. A similar trend was noticed in pH, EC value and P content of water of azolla growing locations. Contents of K, Ca and Mg were higher in water that favoured growth of azolla. Contents of Mn, Zn and Cu were in traces in both azolla growing and non-growing locations.

3. Fluctuation in mean maximum temperature was narrower at Kayamkulam during the azolla growing and non-growing periods.

The mean minimum temperature was slightly higher at Kayamkulam than at Pattambi in both azolla growing and non-growing locations. Kayamkulam had higher mean relative humidity values in the forenoon and afternoon and narrower fluctuation than Pattambi. A higher rainfall during the non-growing season followed by a well distributed rainfall during azolla growing season as experienced at Kayamkulam was found to be favourable for azolla growth at Kayamkulam. Evaporation rate was lower at Kayamkulam than Pattambi both during the non-growing and azolla growing periods.

4. Omission of nitrogen from the nutrient solution resulted in significantly higher yield of azolla and the increase over control (receiving all the nutrients) was 4.1 per cent.

5. Elimination of P affected the growth of azolla most and the percentage of reduction over the control was 19.8. Omission of Mg and Ca also resulted in a reduction of 9.1 and 7.9 per cent respectively over the control. Exclusion of K, Mn and Fe did not affect the growth of azolla.

6. Maximum dry matter content was for the treatment from which P had been omitted followed by Mg excluded treatment. Minimum dry weight was noted in the treatment receiving no nutrient (water alone).

7. Omission of N resulted in a N content of 4.2 per cent. Exclusion of P, Ca and Mg reduced the N content significantly. Azolla grown in water alone had the lowest N content of 2.9 per cent.

8. Growth of azolla was maximum in the N excluded treatment which recorded the lowest doubling time of 9.7 days. The doubling time was also found to be affected by higher water temperature.

9. From the point of view of higher azolla yield, the best time of application of azolla was found to be different for the first and second crop seasons. While azolla inoculation at one week after planting was better for the first crop, inoculation at three weeks after planting was found to be better in the second crop season.

10. Under conditions of higher temperature and light intensity as in Pattambi, a higher quantity of inoculum at 600 g m^{-2} was found to be superior irrespective of the seasons.

11. Quantities of inoculum had significant influence on the yield of rice. Inoculation at 600 g m^{-2} recorded the highest grain and straw yields. Time of application did not influence the yield significantly.

12. Under a low inoculation rate of 100 g m^{-2}, one week after planting, bulk method seems to be the best among the different methods of planting rice studied. Solar radiation below the canopy and water temperature were the lowest under this system of planting. At this level and time of application of azolla, the different methods of planting did not influence the grain and straw yields significantly.

13. At 5 t ha^{-1} both fresh azolla and dry azolla were found to compare well with cattle manure and green leaves at

5 t ha^{-1} with regard to N released from sixth week to eighth week after incorporation.

14. At the level of 5 t ha^{-1}, the peak percentage of N availability from fresh azolla, dry azolla, cattle manure and green leaves were found to be 86.6 at eighth week, 78.9 at eighth week, 59.6 at sixth week and 86.0 at twelfth week after incorporation, respectively.

15. Both in the case of fresh and dry azolla, a higher level of 10 t ha^{-1} was found to slightly reduce and prolong the release of N compared to 5 t ha^{-1}.

16. At both the levels of application, fresh azolla was found to be slightly superior to dry azolla with respect to the release of nitrogen.

17. With medium duration variety Jaya, application of azolla at 7.5 t ha^{-1} as a substitute for organic manures like cattle manure 5 t or green leaves 5 t was found to be possible without affecting the grain as well as straw yields. This treatment was statistically on par with green leaves 5 t which was superior to all the other treatments and significantly superior to cattle manure 5 t. Though azolla at 5 t and 10 t ha^{-1} were inferior to azolla 7.5 t and green leaves 5 t ha^{-1}, they were on par with cattle manure at 5 t ha^{-1}.

18. Under a system where medium duration rice varieties are cultivated giving a N, P_2O_5 and K_2O dose of 90:45:45 kg ha^{-1} over a basal application of cattle manure at 5 t ha^{-1},

substitution of cattle manure by azolla either at 5 t or 7.5 t ha^{-1} resulted in a saving of 25 per cent of fertilizer dose.

19. When yield increase is the objective and not the saving in fertilizer cost, substitution of cattle manure or green leaves at 5 t ha^{-1} by azolla at 7.5 t ha^{-1} is found to be promising for medium duration rice variety. Among the combinations tried, it was found that the treatment receiving azolla at 7.5 t ha^{-1} with the full dose of fertilizer recorded the highest grain yield as well as straw yield, it being significantly superior to all other treatment combinations in grain yield.

20. Application of azolla at 7.5 t and 5 t ha^{-1} with full dose of fertilizer gave output-input ratios of 2.07 and 1.91 respectively while green leaves at 5 t ha^{-1} with full dose of fertilizer showed an output-input ratio of 1.88. Thus, even at a lower level of 5 t ha^{-1}, azolla can be a substitute for green leaves at 5 t ha^{-1}.

21. From an assessment of the residual effect of organic manures in terms of grain yield of succeeding unmanured crop, it was seen that application of azolla at 10 t ha^{-1} was significantly superior to green leaves as well as cattle manure at 5 t ha^{-1}.

22. Analysis of the yield attributes shows that superiority of green leaves 5 t and azolla 7.5 t over cattle manure 5 t in grain yield has been brought about through higher tiller production and thousand grain weight.

23. Analysis of growth parameters and the uptake studies appear to show that the superiority of the treatment receiving azolla at 7.5 t or green leaves 5 t over cattle manure 5 t was through higher number of tillers m^{-2}, a better leaf area index at tillering stage, a higher phytomass production and higher uptake of N, P and K by the plant.

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* Original not seen

Appendices

Appendix I

Normal mean monthly meteorological data at Pattambi*

Months	Parameters							
	Temperature (°C)		Rainfall (mm)	Rainy days	Relative humidity (%)		Hours of bright sunshine	Evaporation (mm day^{-1})
	Maximum	Minimum			7 a.m.	2 p.m.		
January	33.2	19.7	0.5	0.2	79.3	35.9	9.8	6.3
February	34.9	20.9	2.8	0.5	84.5	35.9	9.6	6.6
March	36.6	23.2	16.3	1.2	87.5	39.4	9.4	7.1
April	35.4	24.4	89.5	5.0	89.7	51.5	8.8	6.5
May	33.3	24.2	170.5	8.5	92.3	60.6	7.1	5.5
June	30.2	22.8	577.0	20.7	95.5	76.8	3.9	4.5
July	28.4	22.5	677.0	24.2	96.3	81.7	2.4	3.6
August	29.1	22.7	424.0	29.2	95.8	79.8	4.2	3.7
September	30.6	23.0	208.0	12.2	95.0	69.9	6.2	4.5
October	31.4	23.9	265.0	11.2	95.0	68.3	6.3	3.8
November	31.9	22.3	262.0	10.5	92.5	61.1	6.9	4.4
December	32.9	21.0	3.2	0.5	83.7	48.6	8.9	5.3

* Average of ten years from 1970 to 1979

Appendix II

Mean monthly meteorological data at Pattambi

Months	Normal 1970-'79	Rainfall (mm)							
		Actual				Deviation from normal			
		1980	1981	1982	1984	1980	1981	1982	1984
January	0.5	0	0	0	14.0	-0.5	-0.5	-0.5	+13.5
February	2.8	0	0	0	14.8	-2.8	-2.8	-2.8	+12.0
March	16.3	12.4	62.0	2.0	18.0	-3.9	+45.7	-14.3	+ 1.7
April	89.5	66.0	66.0	45.0	80.0	-23.5	-23.5	-44.5	-9.5
May	170.5	49.6	176.7	192.2	66.5	-120.9	+6.2	+21.7	-104.0
June	577.0	930.0	1122.0	-	864.0	+353.0	+545.0	-	+287.0
July	677.0	992.0	542.5	-	692.1	+315.0	-134.5	-	+15.1
August	424.0	353.4	647.9	-	229.9	-70.6	+223.9	-	-194.1
September	208.0	14.1	348.0	-	70.6	-193.9	+140.0	-	-137.4
October	265.0	238.7	257.3	-	314.8	-26.3	-7.7	-	+49.8
November	262.0	132.0	96.0	-	38.4	-130.0	-166.0	-	-223.6
December	3.2	58.9	0	-	17.6	+55.7	-3.2	-	+14.4
		Mean rainy days							
January	0.2	0	0	0	1	-0.2	-0.2	-0.2	+0.8
February	0.5	0	0	0	1	-0.5	-0.5	-0.5	+0.5
March	1.2	2	1	0	3	+0.8	-0.2	-1.2	+1.8
April	5.0	7	6	1	8	+2.0	+1.0	-4.0	+3.0
May	8.5	4	5	10	7	-4.5	-3.5	+1.5	-1.5
June	20.7	26	27	-	27	+5.3	+6.3	-	+6.3
July	24.2	30	18	-	25	+5.8	-6.2	-	+0.8
August	29.2	22	23	-	19	-7.2	-6.2	-	-10.2
September	12.2	9	20	-	8	-3.2	+7.8	-	-4.2
October	11.2	13	12	-	15	+1.8	+0.8	-	+3.8
November	10.5	8	7	-	2	+7.5	-3.5	-	-8.5
December	0.5	2	0	-	1	+1.5	-0.5	-	+0.5

(contd.)

Appendix II (contd.)

Months	Normal 1970-79	Mean relative humidity at 7 a.m.(%)							
		Actual				Deviation from normal			
		1980	1981	1982	1984	1980	1981	1982	1984
January	79.3	80.0	82.0	81.0	80.7	+0.7	+2.7	+1.7	+1.4
February	84.5	87.0	83.0	92.0	81.7	+2.5	-1.5	+7.5	-2.8
March	87.5	89.0	87.0	91.0	87.8	+1.5	-0.5	+3.5	+0.3
April	89.7	91.0	90.0	89.0	92.4	+1.3	+0.3	-0.7	+2.7
May	92.3	90.0	91.0	91.0	90.4	-2.3	-1.3	-1.3	-1.9
June	95.5	96.0	97.0	-	94.1	+0.5	+1.5	-	-1.4
July	96.3	96.0	96.0	-	95.4	-0.3	-0.3	-	-0.9
August	95.8	96.0	96.0	-	94.5	+0.2	+0.2	-	-1.3
September	95.0	95.0	96.0	-	94.1	0	+1.0	-	-0.9
October	95.0	96.0	95.0	-	89.0	+1.0	0	-	-6.0
November	92.5	90.0	92.0	-	90.4	-2.5	-0.5	-	-2.1
December	83.7	85.0	84.0	-	87.3	+1.3	+0.3	-	+3.6
		Mean relative humidity at 2 p.m. (%)							
January	35.9	36.9	41.0	39.1	49.5	+1.0	+5.1	+3.2	+13.6
February	35.9	33.4	31.9	31.4	41.2	-2.5	-4.0	-4.5	+5.3
March	39.4	42.0	37.4	43.3	45.6	+2.6	-2.0	+3.9	+6.2
April	51.5	50.0	51.2	48.3	60.0	-1.5	-0.3	-3.2	+8.5
May	60.6	56.2	57.7	54.3	54.6	-4.4	-2.9	-6.3	-6.0
June	76.8	80.3	83.2	-	88.4	+3.5	+6.4	-	+11.6
July	81.7	82.3	77.2	-	78.4	+0.6	-4.5	-	-3.3
August	79.8	79.1	77.3	-	73.2	-0.7	-2.5	-	-6.6
September	69.9	67.6	72.8	-	69.8	-2.3	+2.9	-	-0.1
October	68.3	71.2	71.4	-	68.0	+2.9	+3.1	-	-0.3
November	61.1	58.8	59.3	-	54.8	-2.3	-1.8	-	-6.3
December	48.6	51.0	43.8	-	49.8	+2.4	-4.8	-	+1.2

(contd.)

Appendix II (contd.)

Months	Mean maximum temperature (°C)								
	Normal 1970-79	Actual				Deviation from normal			
		1980	1981	1982	1984	1980	1981	1982	1984
January	33.2	33.5	33.7	34.1	33.2	+0.3	+0.5	+0.9	0
February	34.9	35.7	35.8	36.2	35.0	+0.8	+0.9	+1.3	+0.1
March	36.6	36.2	37.0	36.6	35.8	-0.4	+0.4	0	-0.8
April	35.4	35.6	36.1	36.4	34.7	+0.2	+0.7	+1.0	-0.7
May	33.3	35.3	34.5	34.9	35.7	+2.0	+1.2	+1.6	+2.4
June	30.2	30.0	28.7	-	29.1	-0.2	-1.5	-	-1.1
July	28.4	29.0	29.6	-	28.4	+0.6	+1.2	-	0
August	29.1	29.1	29.0	-	28.9	0	-0.1	-	-0.2
September	30.6	31.0	29.9	-	30.1	+0.4	-0.7	-	-0.5
October	31.4	31.7	31.2	-	30.1	+0.3	-0.2	-	-1.3
November	31.9	33.1	32.3	-	32.4	+1.2	+0.4	-	+0.5
December	32.9	33.6	33.5	-	32.6	+0.7	+0.6	-	-0.3
	Mean minimum temperature (°C)								
January	19.7	19.5	21.1	20.4	22.0	-0.2	+1.4	+0.7	+2.3
February	20.9	20.7	21.1	21.1	23.8	-0.2	+0.2	+0.2	+2.9
March	23.2	23.2	23.5	23.5	23.8	0	+0.3	+0.3	+0.6
April	24.4	25.1	25.3	25.2	24.6	+0.7	+0.9	+0.8	+0.2
May	24.2	25.2	24.6	24.8	25.6	+1.0	+0.4	+0.6	+1.4
June	22.8	23.5	23.3	-	22.9	+0.7	+0.5	-	+0.1
July	22.5	23.1	23.5	-	23.0	+0.6	+1.0	-	+0.5
August	22.7	23.1	23.3	-	23.2	+0.4	+0.6	-	+0.5
September	23.0	23.5	23.7	-	23.1	+0.5	+0.7	-	+0.1
October	23.9	23.3	23.4	-	22.0	-0.6	-0.5	-	-1.9
November	22.3	22.8	22.3	-	22.5	+0.5	0	-	+0.2
December	21.0	21.9	21.4	-	19.5	+0.9	+0.4	-	-1.5

(contd.)

Appendix II (contd.)

Months	Duration of bright sunshine (hr day^{-1})								
	Normal 1970-79	Actual				Deviation from normal			
		1980	1981	1982	1984	1980	1981	1982	1984
January	9.8	10.0	9.7	10.0	8.0	+0.2	-0.1	+0.2	-1.8
February	9.6	9.9	9.9	9.9	8.3	+0.3	+0.3	+0.3	-1.3
March	9.4	9.3	9.5	9.3	7.4	+0.1	+0.1	-0.1	-2.0
April	8.8	8.5	8.7	9.1	7.3	-0.3	-0.1	+0.3	-1.5
May	7.1	8.2	7.8	7.3	9.3	+1.1	+0.7	+0.2	+2.2
June	3.9	2.4	1.7	-	2.1	-1.5	-2.2	-	-1.8
July	2.4	2.8	4.0	-	3.1	+0.4	+1.6	-	+0.7
August	4.2	4.5	3.3	-	5.4	+0.3	-0.9	-	+1.2
September	6.2	7.4	4.6	-	6.1	+1.2	-1.6	-	-0.1
October	6.3	6.1	5.5	-	6.0	-0.2	-0.8	-	-0.3
November	6.9	7.5	7.2	-	7.2	+0.6	+0.3	-	+0.3
December	8.9	8.6	9.0	-	9.0	-0.3	+0.1	-	+0.1
	Evaporation (mm day^{-1})								
January	6.3	6.1	5.8	6.4	5.0	-0.2	-0.5	+0.1	-1.3
February	6.6	6.9	6.6	6.2	5.2	+0.3	0	-0.4	-1.4
March	7.1	7.0	6.9	7.0	4.8	-0.1	-0.2	-0.1	-2.3
April	6.5	4.4	6.2	7.2	3.9	-2.1	-0.3	+0.7	-2.6
May	5.5	5.9	6.2	5.6	5.1	+0.4	+0.7	+0.1	-0.4
June	4.5	3.9	3.5	-	0.8	-0.6	-1.0	-	-3.7
July	3.6	3.6	3.9	-	0.7	0	+0.3	-	-2.9
August	3.7	3.5	3.8	-	1.8	-0.2	+0.1	-	-1.9
September	4.5	4.3	4.3	-	3.3	-0.2	-0.2	-	-1.2
October	3.8	3.8	4.3	-	2.2	0	+0.5	-	-1.6
November	4.4	3.8	3.9	-	3.6	-0.6	-0.5	-	-0.8
December	5.3	4.5	5.4	-	3.7	-0.8	+0.1	-	-1.6

Appendix III

Mean weekly meteorological data at Pattambi and Kayamkulam during 1980

Standard week	Azolla growing season: Temperature (°C) Maximum PTB*	Maximum KYLM*	Minimum PTB	Minimum KYLM	Standard week	Non-growing season: Temperature (°C) Maximum PTB	Maximum KYLM	Minimum PTB	Minimum KYLM
23	29.5	31.6	23.1	23.6	1	33.4	33.6	19.8	20.4
24	31.6	32.7	23.9	24.8	2	33.4	34.2	20.4	19.7
25	32.6	30.7	23.5	24.2	3	33.3	34.3	19.9	19.1
26	28.9	30.7	23.1	24.0	4	33.7	33.4	17.8	19.0
27	28.5	31.0	23.1	23.2	5	34.0	33.4	20.1	22.9
28	28.8	29.6	23.2	23.2	6	35.1	34.1	20.2	20.7
29	29.5	29.6	23.4	23.6	7	35.0	33.8	20.6	20.1
30	27.3	29.9	22.9	22.8	8	37.0	33.4	20.7	21.3
31	29.4	30.1	23.2	23.5	9	36.3	34.0	23.0	23.5
32	29.5	31.6	23.1	23.7	10	35.9	34.0	23.3	23.6
33	28.4	30.0	22.8	23.3	11	35.9	34.6	22.8	23.3
34	28.9	30.6	23.3	23.7	12	37.4	34.9	23.1	23.3
35	29.8	31.1	23.4	23.6	13	36.1	35.2	24.2	24.2
36	29.7	31.0	23.7	23.9	14	36.1	33.5	23.8	23.8
37	31.0	32.0	23.8	23.6	15	35.6	34.5	26.3	26.0
38	31.6	32.0	23.1	23.7	16	35.8	34.5	25.1	24.9
39	31.9	31.4	23.5	24.2	17	35.0	34.5	25.0	25.0
40	31.3	31.1	23.8	24.1	18	35.2	33.7	24.8	25.2
41	32.3	31.0	23.2	24.3	19	35.6	34.0	25.3	25.1
42	32.2	30.9	23.7	24.2	20	35.7	34.2	25.3	25.4
43	31.6	31.8	23.5	23.6	21	35.2	34.5	25.6	25.7
44	33.8	32.2	21.9	23.4	22	32.9	32.3	24.4	24.6
45	33.8	32.7	22.4	23.3	49	33.3	32.4	21.9	22.6
46	32.2	31.9	23.5	23.8	50	34.0	32.7	23.0	23.0
47	32.8	32.0	22.8	23.5	51	32.8	32.0	21.6	22.8
48	33.2	32.6	22.3	23.1	52	33.1	31.4	21.2	22.2
Mean	30.8	31.2	23.2	23.7		35.2	34.0	22.8	23.0

* PTB - Pattambi   * KYLM - Kayamkulam

(contd.)

Appendix III (contd.)

Standard week	Azolla growing season: Rainfall: Quantity (mm) PTB	KYLM	Number of rainy day PTB	KYLM	Standard week	Non-growing season: Rainfall: Quantity (mm) PTB	KYLM	Number of rainy day PTB	KYLM
23	338.7	218.6	6	7	1	-	-	-	-
24	53.2	32.6	5	3	2	-	-	-	-
25	215.3	151.3	7	4	3	-	-	-	-
26	306.1	157.8	7	6	4	-	-	-	-
27	330.1	142.4	7	5	5	-	-	-	-
28	252.4	170.4	6	7	6	-	2.4	-	-
29	155.8	102.8	7	5	7	-	-	-	-
30	155.6	122.6	7	5	8	-	-	-	-
31	48.2	32.2	5	2	9	-	-	-	-
32	83.8	29.7	2	1	10	-	-	-	-
33	136.2	136.2	7	7	11	4.6	-	1	-
34	73.0	66.8	5	6	12	-	-	-	-
35	32.6	20.4	5	3	13	6.3	12.2	1	1
36	13.5	40.6	3	1	14	36.8	69.6	3	3
37	-	4.6	-	1	15	-	5.4	-	1
38	85.2	24.0	1	2	16	12.0	38.4	2	1
39	37.8	66.8	4	4	17	48.4	41.0	2	2
40	46.4	66.8	4	3	18	5.0	34.2	1	2
41	127.4	57.8	5	3	19	2.4	45.2	-	2
42	25.4	29.8	2	1	20	10.4	35.2	1	3
43	37.0	193.2	2	4	21	26.6	-	1	-
44	-	13.8	-	1	22	101.4	62.7	3	5
45	31.0	4.8	2	1	49	105.8	-	1	-
46	75.8	12.9	4	4	50	-	29.0	-	-
47	25.8	-	2	-	51	2.2	11.0	-	-
48	-	12.2	-	1	52	-	1.3	-	-
Total	2686.0	1950.0	105	87		253.9	346.3	16	20

PTB - Pattambi KYLM - Kayamkulam (contd.)

Appendix III (contd.)

Standard week	Azolla growing season				Standard week	Non-growing season			
	Relative humidity (%)					Relative humidity (%)			
	Forenoon		Afternoon			Forenoon		Afternoon	
	PTB	KYLM	PTB	KYLM		PTB	KYLM	PTB	KYLM
23	96	96	79	75	1	85	92	41	47
24	96	92	69	70	2	72	86	36	37
25	95	97	83	81	3	78	92	35	34
26	97	96	89	81	4	86	91	33	42
27	97	96	82	76	5	88	79	42	50
28	96	95	83	78	6	84	91	36	45
29	97	96	80	84	7	87	89	32	45
30	97	95	84	75	8	89	91	22	49
31	95	95	73	70	9	92	93	44	60
32	95	96	80	74	10	93	91	47	56
33	97	96	84	78	11	91	93	40	51
34	96	96	82	76	12	83	94	33	55
35	95	96	72	73	13	89	92	50	53
36	96	95	76	65	14	91	94	53	64
37	94	96	63	61	15	91	93	54	61
38	94	94	62	63	16	90	92	48	62
39	95	95	68	72	17	94	92	52	61
40	95	93	72	69	18	90	94	55	66
41	97	96	68	70	19	90	94	57	66
42	94	95	75	75	20	90	95	54	68
43	97	95	67	66	21	89	93	52	61
44	94	95	50	60	22	93	95	73	76
45	90	95	57	57	49	93	95	55	60
46	93	95	65	68	50	88	92	51	65
47	89	95	60	63	51	82	91	54	64
48	85	93	53	59	52	78	95	46	55
Mean	94.7	95.2	72.2	70.7		87.9	91.5	45.0	54.8

PTB - Pattambi KYLM - Kayamkulam

(contd.)

Appendix III (contd.)

Standard week	Azolla growing season				Standard week	Non-growing season			
	Hours of bright sunshine		Evaporation (mm day^{-1})			Hours of bright sunshine		Evaporation (mm day^{-1})	
	PTB	KYLM	PTB	KYLM		PTB	KYLM	PTB	KYLM
23	1.1	2.6	4.1	4.3	1	10.0	10.2	5.0	3.8
24	5.8	8.7	4.4	3.7	2	10.1	10.7	7.0	4.2
25	1.7	3.6	3.1	4.5	3	10.4	11.0	6.6	4.6
26	1.6	3.2	2.8	1.7	4	9.8	10.7	6.1	4.0
27	3.1	4.9	4.5	4.3	5	8.9	8.5	5.7	4.3
28	2.0	2.3	3.7	5.9	6	10.1	9.4	6.8	4.7
29	4.1	2.4	4.1	2.5	7	9.8	10.7	6.7	4.3
30	2.5	4.8	3.2	2.8	8	10.4	10.9	7.5	4.6
31	2.7	4.2	2.8	3.1	9	9.7	10.1	6.9	4.2
32	5.6	8.4	4.2	3.6	10	9.7	8.6	6.8	4.4
33	2.4	2.5	3.4	2.9	11	8.8	10.1	6.7	4.5
34	4.7	6.8	3.7	3.1	12	10.0	10.7	7.1	5.0
35	5.6	5.2	3.7	2.9	13	9.5	9.7	7.3	4.3
36	6.3	7.2	4.0	3.8	14	8.9	8.2	5.9	3.6
37	8.2	9.6	4.3	3.7	15	8.7	9.3	5.9	4.1
38	9.1	8.6	5.2	4.2	16	7.6	8.2	6.6	4.6
39	6.3	5.8	4.1	2.8	17	8.4	9.4	6.7	5.0
40	6.3	5.6	3.6	3.0	18	8.6	8.8	5.8	3.7
41	5.2	3.9	4.7	2.2	19	9.1	9.6	6.3	4.6
42	4.3	4.5	2.7	2.9	20	8.8	9.4	6.2	4.1
43	6.4	7.8	4.0	2.7	21	9.3	9.5	6.5	4.2
44	9.6	9.2	4.6	3.1	22	4.0	5.1	5.1	4.2
45	8.5	10.6	4.0	3.0	49	9.3	9.8	3.8	3.1
46	5.4	6.0	3.6	3.0	50	9.0	9.3	4.2	3.1
47	7.1	6.4	3.6	2.4	51	8.2	7.8	4.4	3.0
48	8.9	9.0	4.3	3.0	52	7.6	7.6	5.2	2.5
Mean	5.2	5.9	3.9	3.4		9.1	9.5	6.4	4.3

PTB - Pattambi KYLM - Kayamkulam

Appendix IV

Cost of cultivation of rice ha^{-1}

	Pair @ Rs.50/-	Men @ Rs.25/-	Women @Rs.18/-	Amount Rs.
Preparatory cultivation				
Trimming and repairing bunds	-	10	-	250.00
Ploughing (thrice), puddling and levelling with tractor (12 hr at Rs.60 hr^{-1})	-	-	-	720.00
Total	-	10	-	970.00
Seeds and sowing				
Cost of 70 kg seeds at Rs.3 kg^{-1}	-	-	-	210.00
Ploughing (thrice) and levelling	2	-	-	100.00
Taking beds, sowing seeds and plant protection including cost of chemicals	-	1	-	50.00
Uprooting seedlings	-	-	6	108.00
Transporting and spreading seedlings	-	2	-	50.00
Planting	-	-	30	540.00
Total	2	3	36	1058.00
After cultivation				
Weeding	-	-	30	540.00
Spraying (thrice)	-	6	-	150.00
Ekalux, 1.0 l at Rs.94 l^{-1}	-	-	-	94.00
Dimacron, 0.25 l at Rs.196 l^{-1}	-	-	-	49.00
B.H.C. 50%, 2.5 kg at Rs.13 kg^{-1}		-	-	32.50
Hinosan, 0.5 l at Rs.199 l^{-1}	-	-	-	99.50
Dithane M 45, 2.5 kg at Rs.55 kg^{-1}		-	-	137.50
Liming material, 250 kg at Rs.0.67 kg^{-1}	-	-	-	167.50
Application of lime	-	1	-	25.00
Total	-	7	30	1295.00

(contd.)

Appendix IV (contd.)

	Pair @ Rs.50/-	Men @Rs.25/-	Women @ Rs.18/-	Amount Rs.
Harvesting and processing				
Harvesting	-	-	30	540.00
Transporting and threshing	-	15	-	375.00
Drying and cleaning paddy and drying straw	-	2	5	140.00
Total	-	17	35	1055.00
Total cultivation charge without the application of organic manure or fertilizers	2	37	101	4378.00
Cost of fertilizers and their application charge				
Urea, 195 kg at Rs.2.45 kg^{-1}	-	-	-	477.75
Mussorie phosphate, 189 kg at Rs.0.75 kg^{-1}	-	-	-	141.75
Muriate of potash, 72 kg at Rs.1.50 kg^{-1}	-	-	-	108.00
Transporting and application of fertilizers	-	2	-	50.00
Total	-	2	-	777.50
Total cultivation charge including cost of full dose of fertilizer	2	39	101	5155.50
Cost of organic manures and their application charge				
Cattle manure 5 t at Rs.150 t^{-1}		-	-	750.00
Green leaves 5 t at Rs.200 t^{-1}		-	-	1000.00
Azolla 5 t at Rs.100 t^{-1}		-	-	500.00
Application of organic manure (5 t)		5	-	125.00
Additional cost of transporting, threshing and cleaning paddy consequent to increase in yield due to the application of full dose of fertilizer		6	3	204.00
Local rate of grain and straw- Grain Rs.2 kg^{-1} Straw Re.1 kg^{-1}				

ECOPHYSIOLOGY OF AZOLLA AND ITS MANAGEMENT FOR RICE PRODUCTION

By

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ABSTRACT OF A THESIS

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ABSTRACT

In order to explore the agronomic potential of azolla for rice production, an investigation entitled 'Ecophysiology of azolla and its management for rice production' was carried out at the Regional Agricultural Research Station, Pattambi, during the years 1980 to 1984 with the following objectives:

1. To study the influence of environmental conditions on the growth and establishment of azolla.
2. To assess the nutritional requirement of azolla.
3. To find out the time of application and optimum quantity of azolla inoculum required for growing it as an intercrop with rice.
4. To identify the geometry of planting rice favouring the multiplication of azolla in the field.
5. To study the rate of mineralization of azolla compared to other organic manures.
6. To evaluate azolla as an organic manure and explore the possibility of reducing the fertilizer requirement of rice by the use of azolla.

Based on a preliminary survey, three regions showing high, medium and low natural growth of azolla i.e., Kayamkulam, Pazhanji and Pattambi respectively were identified.

The field experiment to find out the best time and optimum quantity of azolla inoculum consisted of three times of

application, one, two and three weeks after planting and four quantities of inoculum, 0, 200, 400 and 600 g m^{-2}. The experiment for identifying the best method of planting rice favouring maximum growth of azolla had six treatments (20 cm x 10 cm and 40 cm x 5 cm spacing each in east-west and north-south directions, bulk method and fallow).

The experiment for evaluating azolla as an organic manure consisted of six mainplot treatments i.e., cattle manure 5 t, green leaves 5 t, azolla 5, 7.5 and 10 t ha^{-1} and control. There were five subplot treatments (0, 25, 50, 75 and 100 per cent of the recommended dose of 90:45:45 kg N, P_2O_5 and K_2O ha^{-1}). Besides, two pot culture experiments were also undertaken. One of the pot culture trials was aimed at for studying the effect of N, P, K, Ca, Mg, Fe and Mn at 20, 20, 40, 40, 40, 2 and 0.5 ppm respectively on the growth and nitrogen content of azolla. The second pot culture study was on the mineralization of azolla compared to the most commonly used organic manures i.e., azolla 5 t and 10 t, dry azolla equivalent to 5 t and 10 t of fresh azolla, cattle manure 5 t and green leaves 5 t ha^{-1} and control.

Soils of azolla growing locations had lower contents of clay compared to non-growing locations and among the three regions, Kayamkulam which recorded the highest growth of azolla had the lowest clay content. Soils of azolla growing locations had higher pH values and available P contents. A similar trend was noticed in pH, EC value and P content of water of azolla growing location. Contents of K, Ca and Mg were higher in the water that favoured the growth of azolla. Fluctuation in mean maximum temperature was narrower at Kayamkulam during the azolla growing and non-growing periods. Kayamkulam had higher mean relative humidity value and narrower fluctuation than that of Pattambi. A higher rainfall during the non-growing season followed by a well distributed rainfall during the azolla growing season as experienced at Kayamkulam, was found to be favourable for the growth of azolla.

Elimination of P affected the growth of azolla most and the percentage of reduction over the control was 19.8. Omission of Mg and Ca also resulted in a reduction of 9.1 and 7.9 per cent respectively over the control. Omission of nitrogen resulted in a N content of 4.2 per cent. Exclusion of P, Ca and Mg reduced the N content of azolla significantly. Azolla grown in water without the addition of any nutrient had the lowest N content of 2.9 per cent.

From the point of view of higher azolla yield, the best time of application of azolla was different for the first and second crop seasons. While azolla inoculation at one week after planting was better for the first crop, inoculation at three weeks after planting was found to be better in the second crop season. A higher quantity of inoculum at 600 g m^{-2} was found to be superior to lower levels irrespective of the seasons.

Under a low inoculation rate of 100 g m^{-2}, one week after planting, bulk method seems to be the best among different methods of planting rice studied. Solar radiation below the canopy and water temperature were the lowest under this system of planting.

Results of the mineralization study showed that at 5 t ha^{-1}, fresh and dry azolla were found to compare well with cattle manure and green leaves at 5 t ha^{-1} in relation to N release from sixth week to eighth week. At the level of 5 t ha^{-1}, the peak percentage of N availability from fresh azolla, dry azolla, cattle manure and green leaves were found to be 86.6 at eighth week, 78.9 at eighth week, 59.6 at sixth week, 86.0 at twelfth week after incorporation,respectively. Both in the case of fresh and dry azolla, a higher level of 10 t ha^{-1} was found to slightly reduce and prolong the release of N compared to 5 t ha^{-1}. At both levels of application, fresh azolla was found to be slightly superior to dry azolla regarding the rate of release of N.

Under a system where medium duration rice varieties are cultivated giving a N, P_2O_5 and K_2O dose of 90:45:45 kg over a basal application of cattle manure at 5 t ha^{-1}, substitution of cattle manure by azolla either at 5 t or 7.5 t ha^{-1} can result in a saving of 25 per cent of fertilizer dose. When yield increase is the objective and not the saving in fertilizer cost, substitution of cattle manure or green leaves at 5 t ha^{-1} by azolla at 7.5 t ha^{-1} is found to be promising for medium duration rice variety. Among the combinations tried, the treatment receiving azolla at 7.5 t ha^{-1} with full dose of fertilizer recorded the highest grain yield as well as straw yield, it being significantly superior to all other treatment combinations in grain yield. Application of azolla at 7.5 t and 5 t ha^{-1} with full dose of fertilizer gave output-input ratios of 2.07 and 1.91 respectively while green leaves at 5 t ha^{-1} with full dose of fertilizer showed an output-input ratio of 1.88. Thus, even at a lower level of 5 t ha^{-1}, azolla can be a substitute for green leaves at 5 t ha^{-1}. From an assessment of the residual effect of organic manures in terms of grain yield of succeeding unmanured crop, it was seen that application of azolla at 10 t ha^{-1} was significantly superior to green leaves as well as cattle manure at 5 t ha^{-1}.