STUDIES ON THE INTERACTIVE EFFECTS OF WATER REGIMES, WEED CONTROL TREATMENTS AND NITROGEN LEVELS IN DIRECT-SEEDED RICE

By

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This is to certify that the thesis entitled "Studies on the interactive effects of water regimes, weed control treatments and nitrogen levels in direct-seeded rice" submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Agronomy of the Post-Graduate School, Indian Agricultural Research Institute, New Delhi, is a record of bonafide research carried out by Sri B. Mohan Kumar under my supervision and no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been duly acknowledged.

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CHAPTER I

INTRODUCTION

The exploitation of hybrid vigour and repatterning of canopy architecture led to the evolution of a new generation of high yielding, photoinsensitive crop varieties in the recent past. The availability of these improved varieties has brought about radical changes in the cropping system of the country. The north-western plain of India is well endowed with abundant solar energy and assured irrigation. To harness these natural resources more efficiently, rice is fastly replacing many of the non-remunerative crops and emerging as the principal *kharif* crop of this tract.

Though rice-wheat rotation is already popular with the farmers of north and north western India, many of the technological hurdles still remain unresolved. Because of the limitations of labour availability during the peak farming seasons, the practice of transplanting becomes quite difficult. On the other hand, terrific weed competition makes dry seeding a losing proposition. Thus as an alternative, direct seeding on puddled soil holds considerable promise.

One of the major technological problems in this context, is the extremely low efficiency of applied nitrogen. It is paradoxical that the conditions that favour the better growth and yield of rice also accelerate the losses of nitrogen. The problem is aggravated by the lighter soil texture which is the major characteristic of the north-west Indian upland rice soils. In this context a study conducted at the IARI, revealed that the apparent recovery of applied nitrogen was 52.2 per cent for the transplanted crop, but it was only 38.4 per cent for direct seeded rice (Prasad and Prasad, 1980). Weed competition is a cardinal factor responsible for the low nitrogen use efficiency associated with direct-seeded crop. Under weedy conditions, the weeds deprive the crop of nitrogen to the extent of 64 per cent of the normal uptake (Kakati, 1976).

Water regimes play a dominant role in the emergence and the type of weed flora. Severe weed infestation concomittantly results in increased evapo-transpiration and decreased water use efficiency. In addition to this, water regimes are equally important in deciding the extent of nitrogen losses through ammonia volatilization, nitrification-denitrification and leaching.

These factors *viz.* nitrogen, water and weeds do not only act independently, rather they strongly interact with each other. Lot of work in this direction has been done and useful information has been obtained for the heavy clay soils of the traditional rice growing areas in north-eastern and southern India. Nevertheless, these results per se are not applicable to the non-traditional rice growing areas. Moreover, very meagre work has been reported from this tract on these aspects.

In view of the above facts, an experiment on the interaction of water regimes, weed control treatments and nitrogen levels on direct-seeded rice was planned with the following objectives:

1. to study the response to nitrogen and the extent of yield reduction due to crop-weed competition under different systems of water-management and weed control.

2. to understand the nutrient uptake pattern, apparent recovery and assimilation of nitrogen

as influenced by nitrogen levels, weed control treatments and water regimes.

3. to estimate the nutrient losses due to weeds. and

4. to explore the possibility of economising the fertilizer use in rice by taking recourse to weed control through herbicides.

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CHAPTER II

REVIEW OF LITERATURE

In this chapter an attempt has been made to review the important research findings pertaining to the direct seeded cultivation of rice. However, in certain cases where references are extremely scanty, literature on transplanted lowland rice is also incorporated.

2.1. Direct-seeding of Rice

The direct-seeding practices include broadcasting or drilling pre-germinated seeds on a puddled bed, drilling or broadcasting on dry soil and dibbling in dry soil (Pillai, 1958). Stand establishment is often poor under direct-seeding because of poor land preparation, high temperature (that occur in the tropics), weed competition and poor weed control (De Datta, 1981).

However, under ideal conditions, it is possible to obtain similar high grain yields with rice transplanted or direct-seeded in puddled soil. (Mahapatra, 1969; Mabbayad and Obordo, 1970; Singh et al., 1973c; Hukkeri and Sharma, 1980). To obtain high yields with direct seeded rice, precise water management (water depths controlled with irrigation and drainage), good weed control and optimum fertilizer management are necessary (De Datta, 1981).

The process of puddling, the mechanical reduction in the apparent specific volume of soil (Bodman and Rubin, 1948) forms an integral component of the wet seeding system. Land puddling results in marked increase in rice yields through improved weed control, establishment of a reduced soil condition which improves soil fertility and fertilizer management and reduced percolation losses of water (De Datta and Barker, 1978; Wickham and Singh, 1978; Reddy and Hukkeri, 1979; Dayanand and Singh, 1980; Villegas, 1980).

2.2. Weed Control in Direct-seeded Rice

2.2.1. Weed flora and their biology

In direct-seeded rice generally and in the dry seeded crop particularly, weed competition is very severe; because the crop and weed seeds germinate simultaneously and the weeds being more vigorous smother the crop (Moody and Mukhopadhyay, 1982).

A wide spectrum of weeds are infesting the rice fields (Parker and Fryer, 1975; De Datta, 1978; Noda, 1980; Kim *et al.*, 1981; De Datta, 1981; Chisaka and Noda

1983; Smith, 1983). Cyperaceae and Graminae are the two predominant weed families. Most of the weeds possess the C_4 photosynthetic pathway and provide a troublesome existence for the C_3 rice crop. Dicot weeds are comparatively less in number and many of them belong to the families of Scrophulariaceae, Compositae and Lythraceae (Shankar, 1971; Matsunaka, 1983). Of all these weeds, Echinochloa crus-galli and its various sub-species are the common and the most difficult to control followed by Eleocharis acicularis (De Datta, 1979; Noda, 1980). A striking example of morphological and phenological resemblance is found in the rice mimic Echinochloa crus-galli var. oryzicola. Comparative studies of growth, development and pattern of phenotypic variations of cultivated rice, E. crus-galli var. oryzicola and var. crus-galli demonstrated that oryzicola is more similar to rice than to its close relative (Barrett, 1981).

Yamagishi et al. (1978) studying the neighbor effects between rice and E. crusgalli observed that in both rice and E. crus-galli, the reproductive effort tended to decrease at high densities, but at different rates. Assemat and Oka (1980) found that the aggressiveness of E. crus-galli was highest at low densities of rice. The reproductive effort also increased with increasing density of the weed, while in rice it decreased. Similarly, E. colona produced more tillers than rice and yielded about 42000 seeds plant^{-1} (Mercado and Talatala, 1977; Mercado et al., 1978; Pons, 1980).

2.2.2. Losses due to weed competition

The overall effect of crop-weed competition is a reduction in the economic as well as biological yield of rice. The potential loss in rice production for India on account of weeds is estimated to be around Rs. 375 x 10^7 (PAI, 1975). The corresponding figure for USA is \$ 205 x 10^6 which accounts a 17 per cent reduction annually (Smith, 1979; Chandler, 1981).

Crops and weeds compete for the same resources - nutrients, water and light. In addition weeds release certain compounds into the environment which may affect growth, nutrient uptake, photosynthesis, respiration and conductance of xylem tissues (Rice, 1979). The competition between the rice crop and weeds depend on a number of factors such as the weed species, type of rice culture, method of planting and cultural practices (BRRI, 1977; De Datta, 1979; IRRI, 1980; Iwata and Takeyanagi, 1980a, 1980b; Ghobrial, 1981; Sarkar and Moody, 1981; Smith, 1983).

Yield reduction in upland paddy due to weed competition was as high as 90 per cent (Ghosh et al., 1977). According to Kumar and Gill (1982) loss in rice yield due to weeds in direct-seeded rice under puddled conditions ranges from 10 to 70 per cent.

Reduction in grain yield was caused by decreases in tiller number, panicle number, panicle length, crop growth rate, leaf area index, rate of ripening and light transmission (Sierra and Mercado, 1975; Cabello, 1979; Kim et al., 1979; Guh et al., 1980; Iwata and Takayanagi, 1980a; 1980b). The reduction in panicle number per unit area due to weed competition was 37 per cent, number of filled grains per panicle by 13 per cent and 1000-grain weight by 4 per cent (Ghobrial, 1981).

2.2.3. Critical stages in crop-weed competition

The rice crop suffers more due to weed competition during the early stage i.e. 20 days after sowing. The longer the competition period and earlier it begins, larger was the reduction in yield (Carson, 1975; Pereiro, 1975; Nair et al., 1976; Ghosh et al., 1977; Dubey et al., 1977; Murakami et al., 1978; Varughese and Nair, 1980; Ghobrial, 1981; Moody, 1981a). According to Wells and Cebradilla(1981) the critical period was from 2 to 9 weeks after sowing of upland rice.

Naidu and Bhan (1980) suggested that for maximum yields in drilled rice, the plots should be kept weed free for the first 45 days. Corroboratory results were obtained by Kolhe and Mittra (1981). It can be concluded that weed competition is extremely severe in direct-sown rice. The magnitude of yield reduction due to weed competition depends on the stage of the crop, nature of weeds and their intensity.

2.2.4. Weed-fertilizer interactions

The extensive literature on the subject has been reviewed recently (Zimdahl, 1980; Moody, 1981b). Hence, only the recent reports are considered here.

2.2.4.1. Nutrient removal by weeds

Weeds have a large requirement for nutrients and their tissues have higher mineral nutrient content than crop plants (Alkamper, 1976; Pons and Utomo, 1979). Crops plus weeds from an unweeded area absorb about the same amount of nitrogen as the crop from a weed free plot (Shahi et al. 1979; Moorthy and Dubey, 1979; Nanjappa and Krishnamurthy, 1980). Weeds also grow faster than crop plants and thus absorb the available nutrients earlier resulting in a deprivation of nutrients for the crop plants. Therefore, poor soil fertility, often seriously limits crop production because of the relatively greater weed growth at low levels of soil fertility which requires a substantial proportion of nutrients available in the soil (Iruthayaraj, 1981; Ahmed and Moody, 1981; Moody, 1981b).

Regarding nutrient removal by weeds, the figures reported by various workers (Kakati and Mani, 1977; Moorthy and Dubey, 1979; Nanjappa and Krishnamurthy, 1980) vary tremendously (7.3 - 62.1 kg N ha^{-1}; 0.8 - 20 kg P ha^{-1} and 27.5 - 64.8 kg K ha^{-1} for wet seeded rice) depending on the nature of weed flora, soil and water management practices etc. Moody (1981b) summarised these reports and suggested that weeds growing in association with wet-seeded rice remove approximately 27.0, 6.6 and 44.8 kg ha^{-1} of N, P and K respectively.

2.2.4.2. Fertilizer use efficiency

Addition of fertilizers to weedy plots do not compensate for the yield losses. Without weed control, increase in rates of N results in no increase in grain yield (Long and Alkamper, 1978; Hoque and Akanda, 1979; Henrich, 1981). In fact, higher fertility levels often cause proportionately greater weed growth and crop yield reduction, because weeds are more efficient in taking the applied nutrients (Alkamper and Do van Long, 1978; Rajan and Mahapatra, 1980). The relative growth rate of weeds, weed number and weed weight increased with application of fertilizers particularly nitrogen (Kim and Moody, 1980; Sarkar and Ghosh, 1980). Thus, in heavily infested fields fertilizer application will have the opposite effect and stimulates weed growth to such an extent that the crop plants will consequently suffer severe damage (Saefuddin *et al.*, 1978; Olofintoye, 1980; Polthanee, 1980; Ahmed and Moody, 1981; Pillai, 1981).

2.2.5. Interaction between water regimes and weed control treatments

The emergence of weeds and the types of weeds are functions of soil moisture content. Under dryland conditions total weed population is higher than irrigated conditions (Suzuki *et al.*, 1975). According to Iruthayaraj (1981) soil saturation and alternate flooding not only failed to control weed growth, but stimulated its growth. *Echinochloa crus-galli*, a hygrophytic weed, emerges and grows best at soil moisture of 80 per cent of the water holding capacity. Emergence and growth becomes increasingly poor with increased submergence; when water depth reaches 10-15 cm *E. crus-galli* stops growing and most of the plants die (Bhan, 1983; Podkin *et al.*, 1983). The efficiency of pre-emergence herbicide depended on soil moisture conditions after application. When applied to dry bed and/or dry conditions immediately following application, the effectiveness was markedly low (Mann and Rick, 1979). In the case of foliar applied herbicides, a decrease in soil moisture content resulted in a reduction in the amount of herbicide translocated to the growing point (Amarlal and Dos, 1980; Okafor, 1980).

It can be concluded that the fertilizer use efficiency solely depends on the intensity of weed infestation which in turn depends on the water management practices. Better water management not only controls weed emergence but also improves the herbicidal efficiency. However, weed control through water control is not only expensive, but also inefficient.

2.2.6. Chemical control of weeds in direct-seeded rice

2.2.6.1. Pre-emergence herbicides : Butachlor (N-butoxy methyl - α - chloro - 2', 6' - diethylacetanilide

Butachlor introduced by Monsanto Co. of USA in 1969, belongs to the anilides and gives pre-emergence contro of annual grasses and certain broad-leaf weeds in rice. Regarding the spectrum of activity, butachlor controls the predominant rice weeds, *Echinochloa crus-galli*, *E. colona*, *Panicum sp.*, *Fimbristylis miliacea*, perennial sedges such as *Cyperus rotundus* and grasses such as *Cynodon dactylon* (Paul and Jacob, 1977; Pillai *et al.*, 1977; Mohamed Ali *et al.*, 1977; Moorthy and Dubey, 1981).

Gunasena and Arceo (1981) found that a rate of 1 kg a.i. ha^{-1} was sufficient to control most of the weed species in a direct sown rice field. Other workers observed that a rate of 0.5 kg ha^{-1} applied 3 days after sowing along with one hand weeding would suffice to keep the weeds under check (Hoque et al., 1978; IRRI, 1982). According to a large number of workers butachlor at the rate of 2 kg a.i. ha^{-1} gave excellent control of grass weeds and was an economic alternative to hand weeding (Singh and Chauhan, 1978; Schiller and Indhaphun, 1979; Mukhopadhyay and De, 1979; Sabio et al., 1980; Tasic et al., 1980; Ahmed and Hoque, 1981; Mukhopadhyay and Mondal, 1981; Ahmed and Islam, 1983).

Butachlor, like other members of the chloroacetamides are indirect inhibitors of cell division in higher plants due to blocking of some regulatory or biosynthetic step needed for the normal cell division to occur; and thereby inhibiting seed germination (Fedtke, 1982). The exact mechanism, however, is not known.

Toxicity to rice

The phytotoxic effects on rice were of very minor nature (Ryang, 1974). Mohamed Ali et al. (1977) reported that even though there was an initial 5 per cent killing of rice seedlings when butachlor (1 kg a.i. ha^{-1}) was applie

6 days after sowing, the seedlings recovered later on. Tolerance of rice to the chemical is a function of the rate, time and genetic factors of the cultivar. Ahmed and Moody (1979) reported that rice plant is moderately tolerant to butachlor when applied 12 days after emergence. The phytotoxic symptoms at high rates of butachlor include reduction in plant height, culm length, fresh weight, dry weight, number of leaves, root elongation and in some cases death of seedlings (Guh and Kwon, 1975; Utomo and Mercado, 1980; Noriel, 1981). Ahmed and Hoque (1981) found that at 2 kg ha^{-1}, the stand count of rice was significantly reduced (43 per cent) and despite excellent weed control, yields were significantly lower than the three times hand weeded plot.

2.2.6.2. Post-emergence herbicides : Bentazone (3-isopropyl)-(1 H)-benzo - 2, 1, 3-thiadiazin-4-one 2,2-dioxide)

Bentazone, a heterocyclic compound, was introduced by BASF in 1968 for the post-emergence control of certain broad-leaved weeds. Bentazone gives good control of a large number of broad-leaf weeds in direct-sown rice, particularly *Portulaca oleracea*, *Amaranthus viridis* and sedges, *Cyperus esculentus* and *Scirpus compactus* (Weerd, 1977; Santos and Cruz, 1979; Akobundu, 1981; Gulidov and Volkotrub, 1981; Menck, 1983).

The optimum stage for application of bentazone was worked out to be 3-5 leaf stage (Luis and Weerd, 1974, 1976; Santos and Cruz, 1979). Most workers found that a rate of 1 kg a.i. ha^{-1} or more could give good control of dicot weeds in rice (Ulug, 1978; Besold, 1978; Santos and Cruz, 1979). However, a dose of 3-6 kg ha^{-1} was required to control Scirpus compactus (Gulidov and Volkotrub, 1981).

The herbicide is absorbed through the foliage and is primarily a photosynthetic inhibitor blocking the electron transport system between photosystem I and II. (Silk et al., 1980). Lichtenthaler et al. (1980) reported that bentazone not only blocked the photosynthetic electron transport, but also had additional effects on cell metabolism. It induced the formation of shade type chloroplasts with a different ultrastructure and phenyl lipid composition. It also induced the formation of broader and higher number of thylakoids (Buschmann et al., 1980; Meier and Lichtenthaler, 1980, 1981; Meier et al., 1980). Selectivity is determined by the degree of uptake, translocation and detoxification (Retzlaff and Hamm, 1977; Suwanketnikom et al., 1978; Borner, 1979; Retzlaff et al., 1979; Fedtke, 1982).

2.2.6.3. Propanil (3',4'-dichloropropionanilide)

Propanil belongs to the anilides and marketed by a number of firms, is active against both annual grass and broad-leaved weeds. It was found effective against *Rottboellia exaltata*, *Echinochloa crus-galli*, *Oryza punctata*, *E. colona*, *Cyperus rotundus*, *Paspalum* sp. *Phyllanthus niruri*, *Eclipta erecta*, *Cynodon dactylon*, *Ammannia baccifera* etc. Control of barnyard grass (*Echinochloa* sp.) is the major use of propanil the world over (Ghosh, 1976, 1977; Singh et al., 1982b; De Datta and Herdt, 1983).

Singh and Singh (1976-77) evaluated Stam F-34 (1.6 - 4 kg a.i. ha^{-1}) in direct-sown rice under puddled conditions and found that a dose of 2.4 kg ha^{-1} provided the best weed control. Similar reports were also made by Mercado and Razon (1977-78), Kaushik and Mani (1978), Upadhyay and Choudhary (1979), Borgochain and Upadhyay (1980), Kolhe and Mittra (1981); Kannaiyan et al. (1981), Singh and Sharma (1981) and Barbiker (1982).

Absorption is mainly through the foliage and acts through the inhibition of Hill reaction of photosynthesis (Silk et al., 1980). Propanil is a potent inhibitor of photosynthetic electron flow at the 'diuron site' (Daniell et al., 1981). At higher concentrations it also adversely affected cyclic photophosphorylation and the chloroplast membrane (Fedtke, 1982).

Resistance of rice plants to propanil has been traced to an enzyme 'aryl acylamidase' which rapidly hydrolyses the herbicide (Ray and Still, 1975; Matsunaka and Aoyama, 1981). Though selective to rice, in propanil treated rice leaves, there was a temporary decrease in dry weight, pigments, protein and photosynthetic products. However, there was complete recovery in 4-5 days (Daniell et al., 1981). Xiang (1982) on the other hand, observed an increased photosynthetic rate in propanil (0.5 per cent) treated rice flag leaf at the beginning of grain filling.

In the final analysis, a number of herbicides are available for rice weed control; the mode of action in most cases is not exactly known. The rate, time and efficiency depends on a number of factors such as the nature and intensity of weed flora, soil and water management practices etc. That is to say such studies are mostly situation specific.

2.3. Water Management in Rice

Rice is a semi-aquatic species and most ecotypes grow and yield best in submerged or 'wet paddy' conditions. A major part of irrigation water in tropical Asia goes to rice production, but the efficiency of on-farm use may average as low as 30 per cent in the areas well supplied with water (Tomar and O'Toole, 1980). In India, although 45 per cent of the irrigation water is diverted to rice, yet it covers only 38 per cent of the total cultivated area under rice? leaving 62 per cent rainfed (CSE, 1982). Thus the vast irrigated and rainfed rice growing regions of the tropical Asia, with their current low water use efficiency illustrate the potential for improved water management on an unparalled scale.

2.3.1. Water requirement and consumptive use

There are only a few reports available on the water requirement of upland direct-sown rice. Some of the reports on transplanted rice indicated varying amounts ranging from 962 mm to 1615 mm depending on crop duration and location (Pande, 1963; Mallick and Das, 1966). Chowdhury and Singh (1968) have found that for direct-seeded main season paddy crop (NP-130) irrigation and total water requirements were 390 and 989 mm respectively. These figures appear to be low as compared to the findings of Nayak (1970) who reported that the water requirement of upland drilled rice ranged from 1643 to 2166 mm depending upon the method of water management and Wann (1978) who calculated the daily water requirement for the rice crop between 15-25 mm. Similarly, Hukkeri and Sharma (1980) working on a sandy clay loam soil of Delhi found that the average water requirement for direct-sown rice varied from 1640 mm to 2620 mm depending upon the water management practice. Similar observations were also reported by Singh *et al.* (1980).

Ghildyal and Tomar (1976) reported that evapotranspiration (ET) was greatest during early growth and declined as growth advanced under conditions when levels of incident solar radiation remained constant. According to them, ET losses ranged from 511-825 mm. Crop transpiration was found to vary with canopy development and reached 3-4 mm day^{-1} at maximum tillering and 5-7 mm day^{-1} at heading (Tomar and O'Toole, 1979, 1980; Ghildyal, 1983).

It is clear from the above mentioned findings that values for water use varied widely depending on climatic factors, duration, management practices and even the methods used to estimate water use of rice. Therefore, the figures obtained in one cultural system may not represent another.

2.3.2. Continuous submergence

The advantages of a submerged cultural system for rice growth and yield are well documented : improved weed control, nutrient availability and root activity, regulation of temperature and pH, algal fixation of atmospheric N_2, increased photosynthetic efficiency by reflecting solar radiation etc. (Yoshida, 1981). The following section entails a brief review of the recent papers on direct-seeded rice in this regard.

The various yield components such as number of panicles hill^{-1}, number of grains panicle^{-1}, plant height and 1000 grain weight were favourably influenced by continuous submergence (Reddy and Hukkeri, 1979; De Datta, 1981). Waterlogging increased growth and yield of direct-seeded rice compared with rice grown under conditions of alternate wetting and drying (Biswas and Mahapatra, 1979; Panda et al., 1979; Reddy and Hukkeri, 1979; Hukkeri and Sharma, 1980; Sandhu et al., 1980; Khind and Ponnamperuma, 1981).

Soil submergence greatly influences the availability of nutrients to the rice plant as a result of the decrease in soil pH and redox potential (Eh) (Biswas and Mahapatra, 1980; Sonar and Ghugare, 1982). It improves the availability of P, K, Ca, Mg, Fe and Mn and decreases that of Si, S, Cu and Zn (Yoshida, 1981; Jones et al., 1982).

2.3.3. Alternate flooding and drying

Although there are many advantages for land submergence, it is often uneconomical because of the high water requirement. Moreover, many workers have observed no significant difference between continuous flooding and alternate flooding and drying provided there is no water stress during the critical stages (Yadav, 1972, 1974; Tanaka, 1976; Biswas and Mahapatra, 1979; Reddy and Hukkeri, 1979). There are two critical stages in the ontogeny of the rice plant when submergence is essential: tillering and panicle primordial initiation to flowering (Vamadevan and Dastane, 1973; Sahu and Rao, 1974; Rajput, 1979).

Bhan and Padwal (1976) in trials with direct-sown rice on a light textured soil found that there was no significant difference in yields between irrigation at 0.1 bar tension and submergence to 5 cm water depth. Similar results were also reported by Subramanian and Rajagopalan (1979), Mali and Varade (1981) and Snitwongse and Jirathana (1981).

Subramanian et al. (1978) observed that irrigation at hairline crack stage (0.3 bar) was not only as good as submergence but also resulted in 41 per cent saving of irrigation water and a high water use efficiency (WUE) of 52 kg paddy ha cm^{-1} of water. A considerable increase in WUE (as high as 49 per cent) was reported in the case of intermittent submergence over continuous flooding (Krishnamurthy, 1978; Hukkeri and Sharma, 1980; Jha et al., 1981).

It can be summarised that land submergence is a wasteful practice and result in low WUE. A considerable amount of water can be saved by a proper combination of moisture tension, its duration and growth stages.

2.3.4. Effect of soil water regimes on the physico-chemical properties of the soil

Water regimes tremendously influence the nitrogen turnover in the soil. Many workers have shown that decomposition of organic matter and nitrification are stimulated by alternate wetting and drying the soil (Gooding and Mc Calla, 1945; Stanford and Smith, 1972; Stanford and Epstein, 1974; Reddy and Patrick, 1975; Rosswal 1982; Savant and De Datta, 1982).

Water regimes also play a cardinal role in deciding the extent of nitrogen losses through different processes. For instance, NH_3 volatilization is the principal loss mechanism in a flooded system, whereas denitrification holds the key for the alternate flooding and drying condition.

2.3.4.1. Ammonia volatilization

Nitrogen in the flooded-soil ecosystem occurs in inorganic and organic forms. At any given time, NH_4^+ predominates in the inorganic N pool; it comes from the mineralization of organic N, which supplies nearly 60 per cent of the N requirement of the rice crop (Reddy and Patrick, 1976, 1978) and the application of fertilizers. De Datta and Craswell (1982) studying the NH_4^+ dynamics of wetland soils reported that NH_4^+ - N is stable under reduced conditions. Nitrification proceeds at a much slower rate in flooded soil system than in a drained soil system (Franco and Munns, 1982) resulting in the accumulation of NH_4^+-N. Iruthayaraj and Morachan (1980a,b) reported that NH_3 volatilization accounted 7.9 per cent of applied N under soil saturation, whereas, it was only 5.5 per cent with 5 cm submergence. NH_3 volatilization is a pH dependant process. In flooded soils planted to rice, NH_3 volatilization was hitherto not considered an important mechanism of N loss. However, high pH conditions in flood water can develop during sunlight hours as a result of an imbalance between photosynthesis and respiration of algae and aquatic macrophytes. Under these conditions pH of the water column can increase by 2 to 3 units during mid day when the photosynthetic process is actively withdrawing CO_2 from the system. When urea or ammoniacal fertilizers are applied to the surface of these systems, significant volatilization losses were observed (Lyster et al., 1980; Reddy, 1982; De Datta et al., 1983).

2.3.4.2. Nitrification-denitrification

Nitrification - denitrification reactions are known to occur simultaneously in flooded soil - ecosystems. The widely cited Mitsui's model assumed that nitrification takes place at the 'reduction layer' underlying the oxidation layer. The NO_3^- formed in the aerobic soil layer is leached down to the reduced zone where it is denitrified (Reddy and Patrick, 1980a). Further NO_3^-s are also present in the oxygen zone in rhizosphere adjacent to the rice roots (Reddy, 1982). And there is a facultatively anaerobic ecotype of nitrite bacterium that lives in close associatio with denitrifying bacteria and both are active at the same locus in the oxidation and reduction layers (Zhou and Chen, 1983). Thus it can proceed under both oxidized and reduced soil conditions.

In a soil subjected to alternate flooding and drying, nitrification can occur when the soil is drained and then the accumulated NO_3^- be denitrified upon flooding (Reddy, 1982). Zhou and Chen (1983) reported that 35-52 per cent of the organic and inorganic nitrogen supplied to rice is lost due to denitrification as determined by isotopic N^{15} technique.

However, these findings per se are not applicable to soil-plant systems. Results obtained by Craswell and Vlek (1979a) albeit from studies using only short drying cycles, indicated that intermittent flooding did not promote N losses in soil-plant systems. Furthermore, Craswell and Vlek (1979b) and Vlek and Craswell (1979) have been unable to demonstrate any significant loss of N via denitrification (less than 5 per cent) in a continuously flooded soil-plant system. Intermittent flooding of soil planted to rice did not increase the loss of N (Sahrawat, 1981; Fillery and Vlek, 1982). However, denitrification appeared to be an important mechanism in continuously flooded fallow soils, accounting for the loss of approximately 40 per cent of the applied N^{15} (Fillery and Vlek, 1982).

It is concluded that the aeration status of the soil had a marked effect on organic matter breakdown. Losses of urea-N from continuously flooded soils or intermittently flooded soils planted to rice are less likely to be caused by denitrification than by volatilization of NH_3. Denitrification losses proceeded uninhibited in fallow soils because of the elimination of plant roots as an active competitor with the denitrifiers for any NO_3^- formed in the soil.

2.4. Nitrogen

Crop yield is influenced often decisively, by the extent to which the plants' requirement for N can be met. This varies greatly from crop to crop and from soil to soil and from one climate to another (Greenwood, 1976, 1982).

The yield increases obtained by N fertilizers are mostly interpreted as N being a substrate for the synthesis of organic N compounds - proteins which are constituents of protoplasm and chloroplasts. In addition, the nutritional status in N can also be looked at from the hormonal view in so far as N stimulates meristematic growth and cytokinin biosynthesis (Yoshida and Oritani, 1974; Beringer, 1980).

2.4.1. Crop response to nitrogen

rop response often depended on several factors, but chiefly on the crops demand for N, influence of soil physical conditions on root proliferation, distribution of roots, NO_3^- and water relative to one another (Greenwood, 1982). There are several reports on direct-seeded rice which highlight the fact that yield and dry matter accumulation increased due to addition of N fertilizers (Socorro et al., 1978; Samui et al., 1979; Singh et al., 1979; Kumar and Sharma, 1980; Ghobrial, 1980, 1982; Lian, 1980; Saif and Rana, 1980; Upadhyay and Pathak, 1981; Heenan and Lewin, 1982; Singh et al., 1982a).

The response of rice yield to N can be attributed to the response of the individual yield components : panicle density, spikelet number, maturity ratio and 1000 grain weight (Vlek et al., 1979). Increased panicle number, leaf area index, leaf area duration and N uptake were also reported by many workers (Clarete and Mabbayad, 1978; Murthy and Murthy, 1978; Rai and Murthy, 1979;

Stone and Steinmetz, 1979; Wilson and Mengel, 1980; Hoque and Khan, 1981). It was found that higher levels of N had a marked effect on delaying leaf senescence and thereby maintaining active photosynthesis during the ripening phase (Chow, 1980; Yoshida, 1981).

2.4.2. <u>Nitrogen efficiency</u>

Singh and Modgal (1979a) working on upland rainfed rice reported that on an average the crop removed 61 kg N ha^{-1} and nearly 15 per cent of the total accumulated N was absorbed upto tillering, 50 per cent upto panicle initiation and 85-90 per cent upto heading. N supply was found to increase significantly the N uptake (Singh and Modgal, 1978, 1979b; Reddy and Patrick, 1980b; Moore *et al.*, 1981; Prasad and Prasad, 1983).

The productive efficiency is primarily dependant on the environmental factors particularly climate (Murayama, 1979; Silva, 1980; Silva and Stutte, 1980; Fagi and De Datta, 1981), fate of N in lowland soils (Mikkelsen and De Datta, 1979), N supplying capacity of the soil (Hauck, 1979), time and method of application (Pillai and De, 1979; IRRI, 1980).

Numerous N-response experiments have shown that the recovery of fertilizer N applied to the rice crop seldom exceeds 30-35 per cent. Even with best agronomic practices and strictly controlled conditions, it is never more than 60-65 per cent (Vlek et al., 1979; Craswell and De Datta, 1980; Clark, 1981; De Datta, 1981; Wang et al., 1981).

It has been concluded by Yoshida (1981) that there are two peaks in the partial production efficiency for grain in rice. The N absorbed at the early stage is used to produce more straw than grain and vice-versa at later stages. Moderate or low levels of N topdressed about 20 days prior to heading (panicle fertilizer) had a high production efficiency.

The efficiency of utilization for grain production in the tropics is about 50 kg rough rice per kg N absorbed (Yoshida, 1981) or 15-25 kg rice per kg N applied (Prasad and De Datta, 1979). Kemmler (1980) from experiments in farmers' fields in India reported that the yield increase per kg N accounted to 9.6 kg rice.

In the final analysis, N fertilizers increase grain and protein yields. However, recovery of applied N to rice is extremely low. Though recovery of fertilizer N is not a goal in itself, the desired increase in grain yield is a function of both N absorption and the efficiency at which it is translocated into the grains. Regarding the partial production efficiency, delay in application of

N increased fertilizer utilization and grain N content, but it was considered that early application was also needed to ensure vegetative development during early growth.

2.4.3. Nitrogen metabolism

Rice plants are adapted to reductive soil conditions in submerged soils where NH_3 is the major and stable form of N (Malvolta, 1954). However, NO_3^- is the predominant form in upland soils, and even in submerged soils, NO_3^- is reported to be present in the oxidized layer and rhizosphere (Rajale and Prasad, 1974).

Several workers have reported the adaptive formation of nitrate reductase in young rice seedlings. Tang and Wu (1957) first reported the presence of NR (nitrate reductase) in 5 day old rice seedlings. According to Sasakawa and Yamamoto (1977) NR in 21 day old rice shoots was much higher than those in barley and soybean. However, Rao et al. (1979) observed that the in vivo NR activity (NRA) in Pusa 33 rice seedlings grown under lowland conditions was low as compared to other cereals grown under aerobic conditions.

2.4.3.1. Regulation of nitrate assimilation

Regulation of NO_3^- reduction is achieved by changing the activities of the nitrate reductase (NR) enzyme.

It is usually regarded as a substrate inducible enzyme (Beevers and Hageman, 1969, 1972; Hewitt, 1975; Hewitt *et al.*, 1976; Srivastava, 1980; Guerrero *et al.*, 1981; Franco and Munns, 1982). In most land plants, the induction of NR is closely related to the supply of NO_3^- and environmental conditions such as light, nutrient supply, temperature, pH, CO_2 and O_2 tensions, water potential etc. (Shaner and Boyer, 1976a; Chantarotwong *et al.*, 1976; Sasakawa and Yamamoto, 1978; Misra *et al.*, 1980; Naik *et al.*, 1982). Not only NO_3^- uptake, but translocation to the site of reduction from the storage pool also appears to play a critical role in the control of NO_3^- reduction. However, species differ in their relationship of NRA to NO_3^- uptake (Steer, 1981).

The antagonistic effect of NH_4^+ on NO_3^- assimilation with regard to the synthesis of the enzymes of NO_3^- reducing system is evident. However, just as in the case of NO_3^- enhancement of NRA, little is known about the underlying mechanism of these effects. NH_4^+ or certain aminoacids are reported to prevent the NO_3^- induced increase in NRA (Oaks, 1979). However, there are exceptions to this NH_4^+ repression of NRA. Srivastava and Metha (1983) reported that NRA is induced by NH_4^+ in bean and maize leaves both in the presence or absence of NO_3^-. They suggested that NH_4^+ either directly or through some other molecules induces the synthesis of an active NR molecule. Simultaneously, it mobilizes endogenous NO_3^- out of the storage pool which activates the inactive NR molecule. Alternatively, increased reductant supply (NADH) in the presence of NH_4^+ or increase in enzyme synthesis through the induction of cytokinins was proposed by these workers.

It can be concluded that rice plants can utilize both NH_4^+- N and NO_3^- - N. NO_3^- reduction principally takes place in the leaves. The process is controlled by a number of environmental factors of which NO_3^- supply and light are the principal ones.

2.5. Water Stress Effects on Growth and Development of Rice

About one-third of the world's potentially arable land suffers from an inadequate supply of water and in most of the remaining areas crop yields are periodically reduced by drought (Kramer, 1980). The various physiological, morphological and biochemical responses to desiccation are a reduction in photosynthesis, impaired translocation of photosynthates, floral development and pollination, decrease in leaf water potential, reduction in cell turgor, stomatal closure, impaired leaf enlargement, leaf senescence, accumulation of proline and abscissic acid and a reduction in NO_3^- assimilation.

Several reviews have appeared recently on this (Begg and Turner, 1976; Boyer, 1976; Hanson and Nelsen, 1980; Hanson and Hitz, 1982; Parsons, 1982; Passioura, 1982).

There are several reports of drought effects on rice cultivars (O'Toole et al., 1978; Corsini, et al., 1979; Hirasawa and Ishihara, 1979; O'Toole and Moya, 1979; Cutler et al., 1980a-d; Yoshida et al., 1981; Gueye and Renard, 1982). Rice resists poorly to water stress and limitations of water vapour exchanges by stomatal clos and leaf rolling followed a fall in the water potential (Renard and Alluri, 1981; Nayek et al., 1982).

As a result of the increased resistance to CO_2 entry, the photosynthetic process is retarded. Consequently dry matter accumulation, grain yield and grain weight decreased drastically, whereas sterility percentage of spikelets went up (Singh and Sahrawat, 1981; O'Toole and Moya, 1981; Ghosh et al., 1982). Stomatal conductance to CO_2 exchange was found linearly proportional to the magnitude of stomatal conductance (Morison and Gifford, 1983).

2.5.1. NO_3^- assimilation under water stress

NRA is sensitive to water status of plants and is inhibited when the water potential of plants decline

(Beevers and Hageman, 1969; Morilla et al., 1973; Mali and Metha, 1977). The inhibition was due to a direct effect of water potential on enzyme activity (Morilla et al., 1973) or a possible inactivation of the enzyme under stress (Sinha and Nicholas, 1981).

Shaner and Boyer (1976a,b) working with maize hypothesised that the decreased movement of NO_3^- into the induction site of the enzyme from the storage pool is the cause of the low NRA under water stress. Lahiri (1980) found that water and NO_3^- followed a uniform rate of uptake and a decrease in transpiration decreased both water and NO_3^- uptake. Hence, a low level of NO_3^- in the induction site may result in low NRA.

O'Toole and Baldia (1982) found that transpiration rate, the most sensitive parameter under water stress, and nutrient uptake were highly correlated. Sub-optimal N nutrition sensitizes stomata to water stress, causing stomatal closure at a higher water potential than normal. Low N also promotes abscissic acid accumulation in leaves and stomatal closure (Trewavas, 1981; Radin et al., 1982).

2.5.2. Proline accumulation

A range of amino acids accumulate to a greater or lesser degree in different organisms during an episode of water stress. But the most frequent and extensive response in most plants is an increase in the concentration of the imino acid, proline (Singh *et al.*, 1972, 1973a; 1973b; Aspinall *et al.*, 1973; Aspinall and Paleg, 1981).

Mali and Metha (1977) reported that in a drought tolerant rice cultivar, free proline accumulated to the extent of 5.4 fold under stress whereas it was only 1.2 fold in a drought susceptible cultivar. Proline accumulation in the leaves of stressed rice plants, thus was positively correlated with drought resistance (Chu and Li, 1979).

The various functions attributed to such an accumulation are (i) osmoregulation (2) protection of biopolymers (3) conservation of energy and amino groups and (4) as a sink of soluble N (Aspinall and Paleg, 1981; Huber and Eder, 1982). However, the adaptive significance of such an accumulation under water stress has not been very clear. During senescence of rice leaves also, it was observed that proline content increased (Stewart and Hanson, 1980; Kao, 1981; Wang *et al.*, 1982). Therefore, proline accumulation in water stressed leaf tissue is a deleterious consequence of internal water deficit and hence drought tolerant genotypes should accumulate less proline than susceptible ones under identical conditions.

To sum up, among the environmental variables affecting plant growth, water stress is one of the most important. An episode of water stress induces several responses in the rice plant. Decrease in NRA and increase in free proline are prominent among them.

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CHAPTER III

MATERIALS AND METHODS

The experiments were conducted in field and pots. The objective of the field trial was to study the interactive effects of nitrogen with weed control treatments in direct seeded rice (*Oryza sativa* L.), under two systems of water management. The pot culture experiment was undertaken to investigate the growth and nitrogen assimilation in rice plants as affected by moisture regimes.

3.1. Field Studies

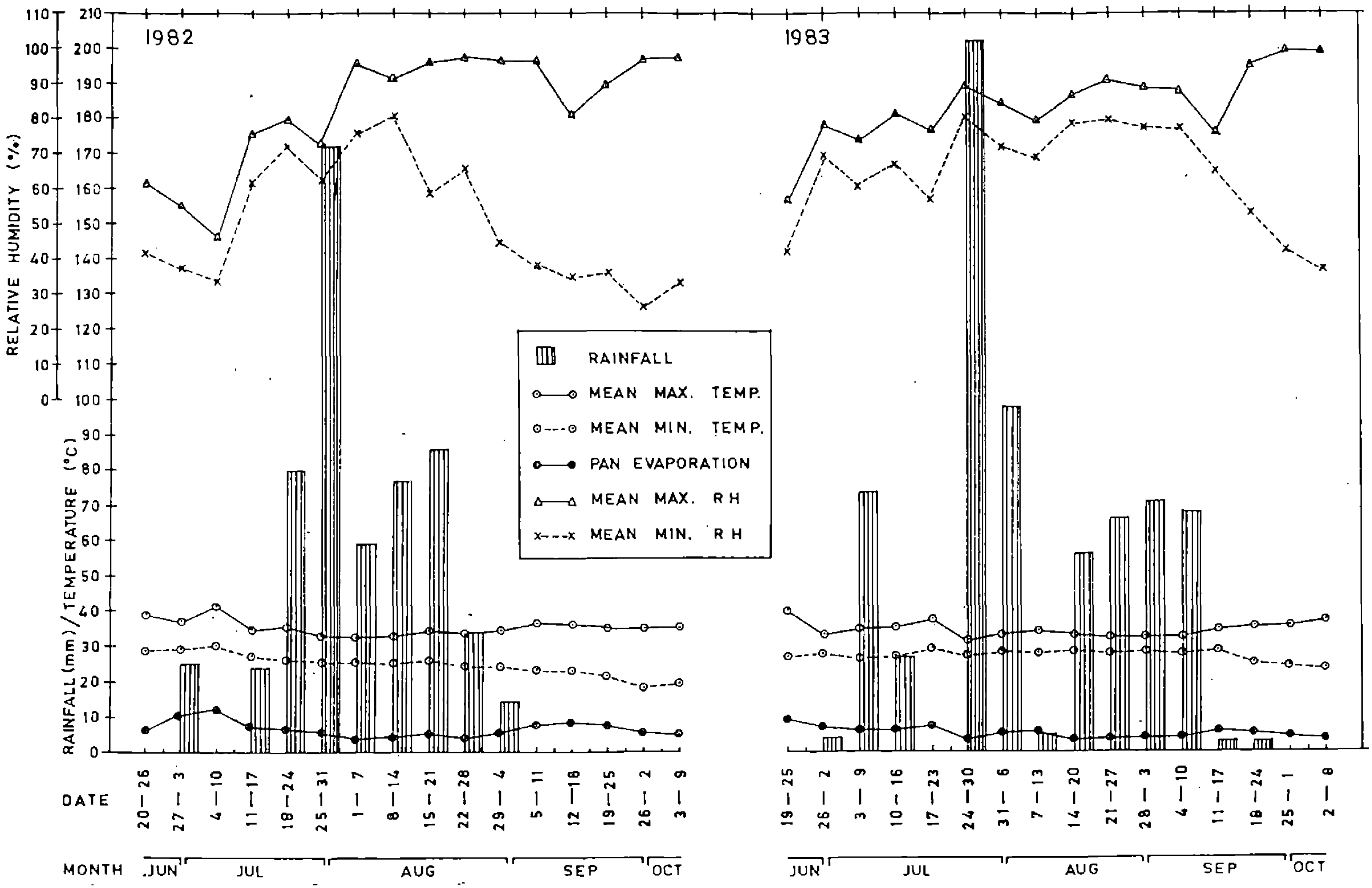
3.1.1. Location

The field studies were conducted on a sandy clay-loam soil of the Main Block 14-C of the Indian Agricultural Research Institute Farm, New Delhi (77°12'E, 28°40'N, 228.6 m altitude) during the *kharif* seasons of 1982 and 1983.

3.1.2. Climate and weather conditions

Delhi has a sub-tropical semi-arid climate with hot dry summers and cold winters. The mean annual precipitation is around 710 mm (average of past 30 years), most of which is received from July to September. Mean weekly weather data in respect of some of the important meteorological parameters recorded at the meteorological observatory of the

FIG. 1. METEOROLOGICAL DATA FOR THE CROP SEASONS.



Water Technology Centre, IARI are presented in Fig. 1 and Appendix I.

The total rainfall received from June to October were 676.3 mm in 1982 and 730.1 mm in 1983. The rainfall pattern was normal during 1982. However, the year 1983 was characterised by a higher amount of precipitation as well as a larger number of rainy days; 41 as against 31 in the preceding year. The mean minimum relative humidity was low and the pan evaporation rate was higher in the 1982 crop season compared to that of the 1983.

3.1.3. Cropping history of the field

The cropping sequence of the experimental field for the three preceding years of the commencement of the present study was rice followed by wheat. The experimental field was made uniform from the fertility standpoint by taking wheat in the *rabi* season without fertilizer application both in 1981-82 and 1982-83.

3.1.4. Rice cultivar : Pusa 33

Pusa 33 is one of the short duration varieties (105 days) of rice having high yield potential. It is developed from the cross between Improved Sabarmati and Ratna. The variety is characterised by highly synchronous tillering habit, early seedling vigour, slow leaf senescence and good grain quality.

3.1.5. Physico-chemical characteristics of the soil

The physico-chemical characteristics of the soil are given in Table 1. The soil is sandy clay-loam in texture with moderate water-holding capacity and bulk density ranging from 1.48 to 1.52 g cm^{-3}. The soil was low in nitrogen content and medium in available phosphorus and potassium status.

3.1.6. Ground water table

The periodical fluctuations in ground water _____ of the experimental site were measured at weekly intervals (Fig. 2 and Appendix II). It ranged from 223 cm to 40 cm from the ground level in 1982. The corresponding figures were 220 cm to 36 cm in the subsequent year.

3.1.7. Soil moisture characteristics

Composite soil samples from five locations at soil depths of 0-15, 15-30 and 30-60 cm were air dried and ground to pass through a 2 mm sieve. The soil moisture characteristic were determined with a pressure plate - pressure membrane apparatus and presented in Fig. 3a-c.

3.1.8. Layout

The experiment was laid out in a split plot design

FIG. 2. DEPTH TO GROUND WATER TABLE DURING THE CROP PERIOD.

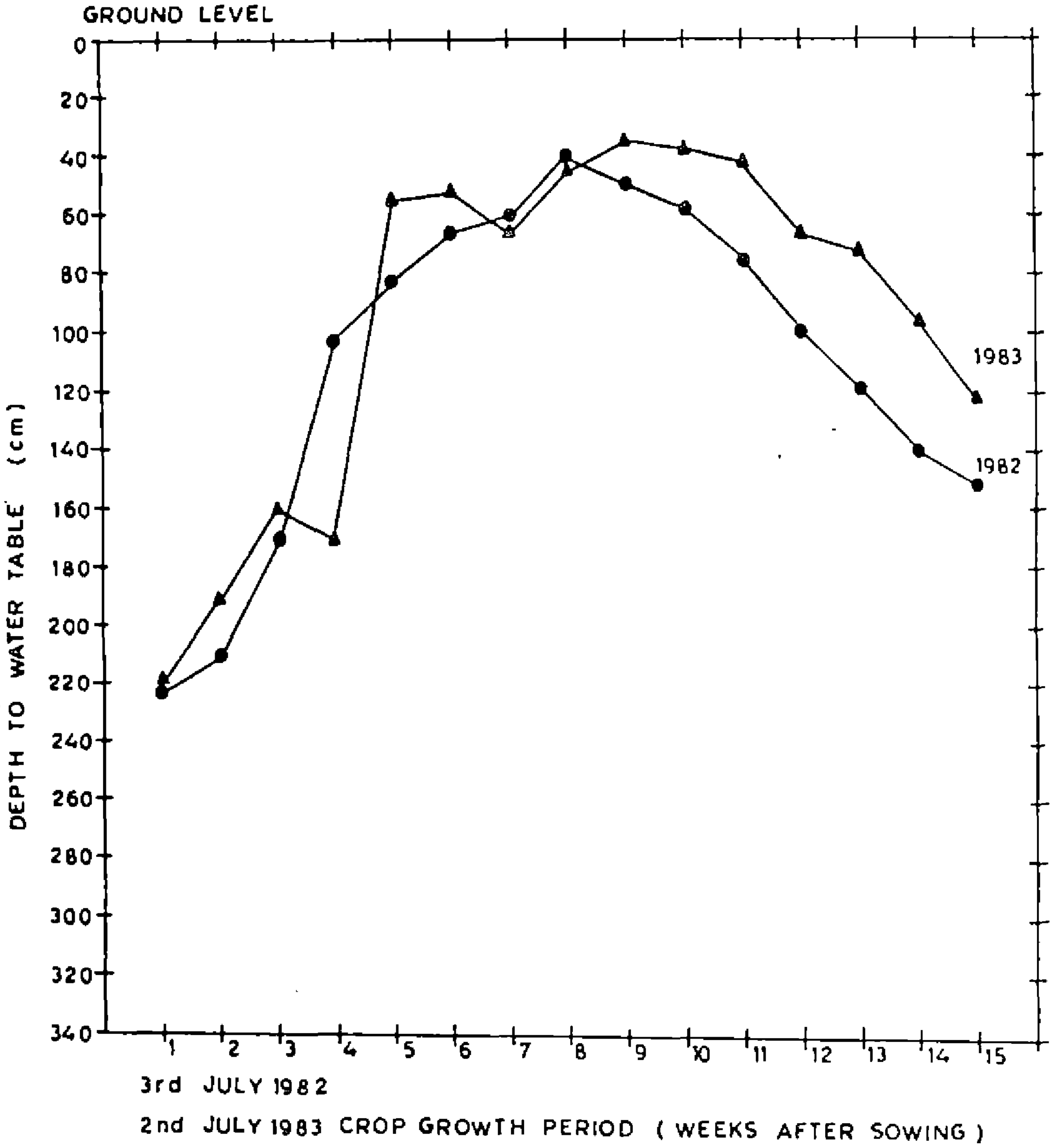


Table 1. Physico-chemical properties of the soil

A. Mechanical composition (Hydrometer Method : Bouyoucos, 1962)

Constituent	Percentage
Sand	51.2
Silt	22.2
Clay	26.6
Textural class	Sandy clay loam

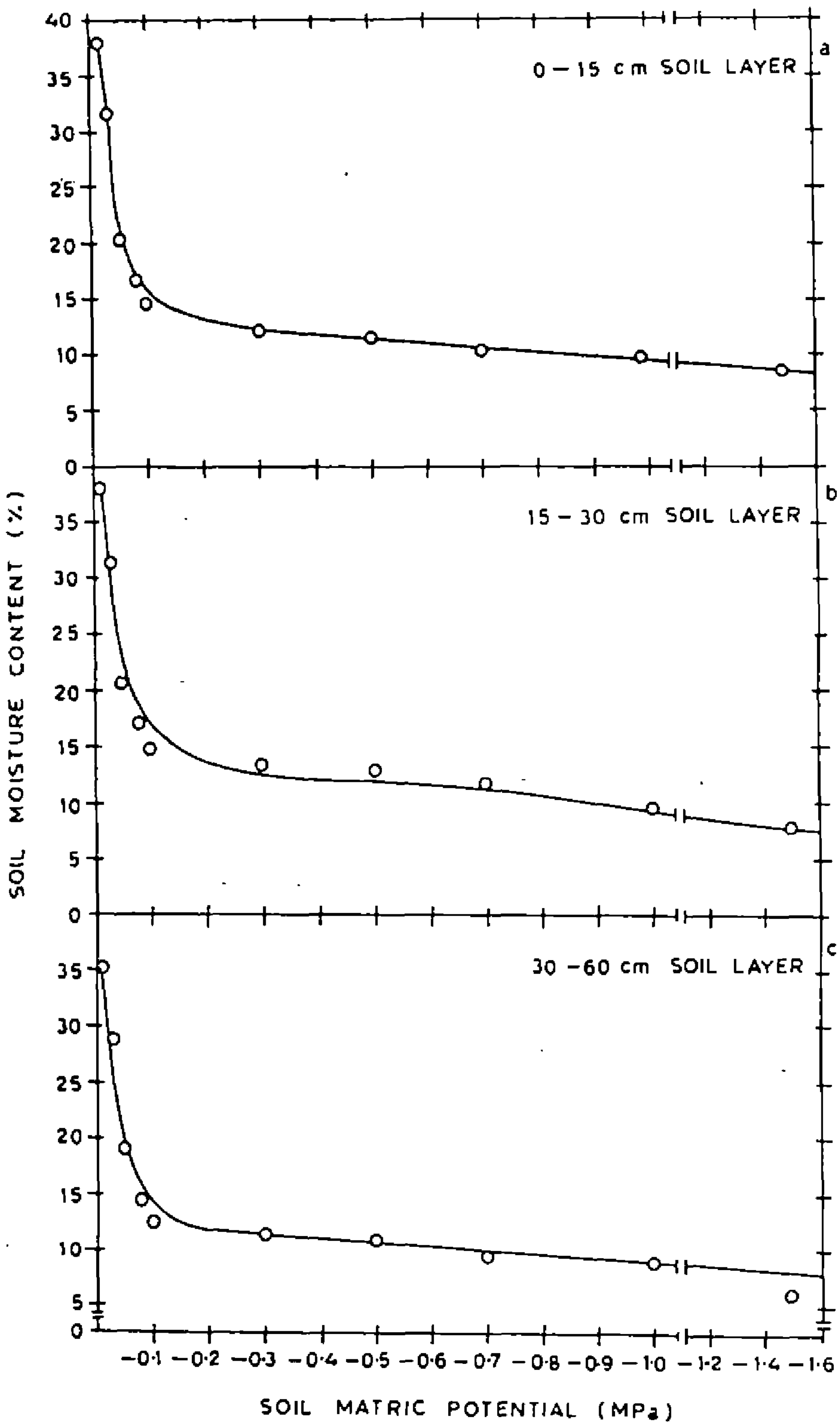
B. Physical properties

Properties	Soil depth (cm)			Method used
	0-15	15-30	30-60	
Field capacity (% w/w)	18.65	18.04	17.65	Field method (Colman, 1944)
Permanent wilting (% w/w)	8.32	7.50	6.02	15 atm. tension value (Richards and Weaver, 1943)
Bulk density ($g\ cm^{-3}$)	1.48	1.52	1.51	Core Sampler (Bodman, 1942)

C. Chemical composition

Particulars	Content	Method used
Organic carbon (%)	0.47	Walkley and Black method (Jackson, 1967)
Total nitrogen (%)	0.043	Modified Kjeldahl method (Jackson, 1967)
Available phosphorus ($kg\ ha^{-1}$)	21.20	Olsen's method (Olsen, 1954)
Available potassium ($kg\ ha^{-1}$)	178.60	Flame photometric method (Jackson, 1967)
pH (1:2.5 soil:water)	7.4	Elico pH meter (Piper, 1950)
EC (mmhos cm^{-1} at 25°C)	0.47	Solubridge method (Piper, 1950)

FIG.3. SOIL MOISTURE CHARACTERISTIC CURVES.



with three replications, the details of which are presented below.

Main plot treatments :	6 (2 water regimes x 3 weed control treatments)
Sub-plot treatments :	4 (nitrogen levels)
Total number of plots :	72
Gross plot size:	10 m x 2 m
Net plot size:	8 m x 1.4 m

3.1.9. Details of treatments

A. Main plot treatments

(i) Soil moisture regimes

i_1 : Continuous flooding (7-0 cm)

i_2 : Alternate flooding and drying (0-0.02 MPa)

(ii) Weed control treatments

w_0 : Weedy check (no weeding)

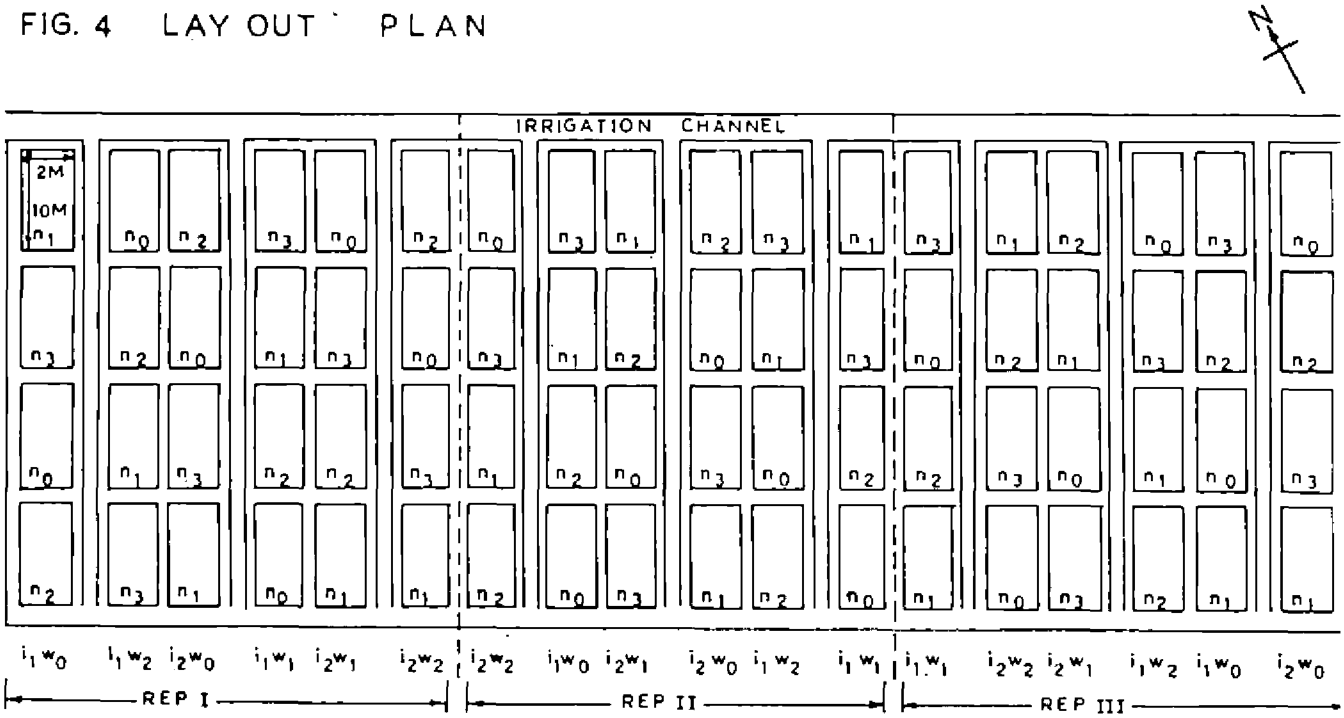
w_1 : Butachlor 1 kg a.i. ha^{-1} (Formulation : Machete 5 G of Monsanto Ltd. India, @ 20 kg ha^{-1})

w_2 : (1982) - Bentazone 1 kg a.i. ha^{-1} (Formulation : Basagran - 48% of BASF @ 2.08 l ha^{-1})

w_2 : (1983) - Bentazone 1 kg a.i. ha^{-1} + Propanil 2.0 kg a.i. ha^{-1} (Formulation : Stam F-34 - 35% of Rhom and Hass @ 5.70 l ha^{-1})

The weed control treatments in 1982 consisted of weedy check, butachlor and bentazone. However, in the subsequent year the bentazone treatment was supplemented with

FIG. 4 LAY OUT PLAN



TREATMENTS

A. MAIN PLOT (i x w)

(i) SOIL MOISTURE REGIMES

i_1 — CONTINUOUS FLOODING

i_2 — ALTERNATE FLOODING AND DRYING (0-0.02MPa)

(ii) WEED CONTROL TREATMENTS

w_0 — WEEDY CHECK

w_1 — BUTACHLOR (1 kg ai ha^{-1})

w_2 — BENTAZONE (1 kg ai ha^{-1}) IN 1982 AND BENTAZONE (1 kg ai ha^{-1}) + PROPANIL (2.0 kg ai ha^{-1}) IN 1983.

B. SUB PLOT (NITROGEN)

n_0 — NO NITROGEN

n_1 — 50 kg N ha^{-1}

n_2 — 100 kg N ha^{-1}

n_3 — 150 kg N ha^{-1}

propanil to control the predominantly grassy weed flora since bentazone alone failed to control this group of weeds in the first year.

The w_1 and w_2 treatments were hand weeded once around the 40th day of sowing in both the years.

B. Sub-plot treatments

Nitrogen levels (N kg ha^{-1})

n_0	-	0
n_1	-	50
n_2	-	100
n_3	-	150

3.1.10. Scheduling of irrigation

Strong ridges were made around the individual plots. Tensiometers (vacuum guage type) were installed at a depth of 15 cm in all the alternate flooding and drying plots to measure the soil moisture tension. Tensiometers were read daily in the morning (0700 h to 0800 h) and irrigation was applied as soon as the tension reached the pre-designated level. Approximately 5 cm of water was applied at each irrigation through a 7.62 cm Parshall Flume installed at the head of the experimental field.

3.1.11. Method of herbicide application

Pre-emergence application of butachlor was done four days after sowing. Machete granules weighed for individual plots were taken in polyethylene bags and thoroughly mixed with about 1/2 kg dry soil. The mixture was then applied uniformly over the entire plot. A thin film of water was present at the time of application.

Post-emergence herbicides were applied 20 days after sowing. In the first year, when only bentazone was tried, the desired amount of the chemical was diluted with water at the rate of approximately 800 l ha^{-1} and sprayed with a foot sprayer having a fan type nozzle. In the subsequent year, both bentazone and propanil were mixed in required quantities with water at the same rate and sprayed. Care was taken to avoid spray-drift.

3.1.12. Fertilizers and fertilizer application

Nitrogen was given as urea in three equal splits (1) a week after seeding (2) tillering and (3) panicle initiation stages. Superphosphate and muriate of potash were applied at 30 kg each of P_2O_5 and K_2O at the time of final land preparation.

3.1.13. Seeds and sowing

Eighty kg of pre-germinated seeds (by soaking for approximately 24 h in water and then keeping in a wet gunny bag for another 48 h under shade) were drilled per hectare into the twice puddled and levelled beds, using a seed drill in the first year of experimentation. However, in the subsequent year seeds were broadcast onto the puddled beds because the drilling operation was found not only cumbersome but also it did not give higher yield as compared to the broadcast sown crop (Singh, unpublished).

The plots were irrigated similarly for about the first 15 days and then the irrigation schedule was commenced.

3.1.14. Calendar of operations

Some important cultural operations other than irrigation are given in Table 2. The details of irrigation are presented in Appendix III.

3.1.15. Sampling technique

Samples were taken from the pre-designated sample zones on either side of the plot excluding the border rows. Crop and weed samples were periodically collected from these sample zones. Every time, plants were taken from an area of 0.5 m^2 (0.25 m^2 each at two locations) in each plot.

3.1.16. Studies on weeds (weed population and dry weight)

Weed counts were taken from an area of 0.5 m^2 in each plot on 35, 70 and 100 days after sowing. The weeds

Table 2. Calendar of operations

Operation	Date	
	1982	1983
Discing and levelling	16.6.82	10.6.83
Preparing the layout, main bunds, channels etc.	18.6.82	13.6.83
Flooding the field and puddling	21.6.82	14.6.83
Puddling, application of basal dose of P_2O_5 and K_2O	28.6.82	22.6.83
Seeding	28.6.82	22.6.83
Application of butachlor	3.7.82	27.6.83
Preparation of sub-plots	6.7.82	28.6.83
Application of first dose of nitrogen	5.7.82	30.6.83
Irrigation schedule (Given in Appendix II)		
Application of post-emergence herbicides	17.7.82	12.7.83
Nitrogen top dressing	26.7.82 16.8.82	19.7.83 10.8.83
Hand weeding w_1 and w_2 treatments	6.8.82	1.8.83
Harvesting, threshing, cleaning etc.	11-15.10.82	5-10.10.83

removed from this area were dried to constant weights at 70°C in an oven and converted to g m^{-2}.

3.1.17. Studies on rice

Growth parameters: The plant height was measured from five random plants at tillering, flowering and maturity stages. The plants from two locations (0.25 m^2 each) in the sample zone of each plot were harvested at the above phenological stages, dried to constant weights at 70°C and expressed as g m^{-2}. The total number of tillers and the ear-bearing tillers were also counted from an area of 0.5 m^2 and the values computed for one m^2.

Yield and yield attributes: The net plots were harvested separately after cutting and removing the border and sample zones. The grain from the individual plots were cleaned, sundried and weighed. The results were expressed on 14 per cent moisture basis. Straw was sun-dried for 4 days and weighed separately.

Panicle characters such as length of panicle, total number of spikelets per ear and number of grains per ear were taken from 10 randomly selected ears. The weight of 1000 grains was recorded using Numigral Seed Counter (Tecator, Sweden).

Harvest index was calculated as follows:

HI = Y(econ.)/Y(biol), where, HI = Harvest index, Y(econ.) is the economic yield and Y(biol) is the biological yield

3.1.18. Chemical analyses

Rice and weed samples collected from individual plots at tillering, flowering and maturity (harvest) were separately analysed for nitrogen (Kjeldahl method), phosphorus (Vanadomolybdo phosphoric yellow colour method) and potassium (Flame photometry) contents (Jackson, 1967; Prasad, 1982).

3.1.19. Chlorophyll content of rice leaves

The chlorophyll content in fully expanded upper rice leaves was determined at the panicle initiation stage as per the method suggested by Arnon (1949).

3.1.20. Nutrient uptake and crude protein content

Nitrogen, phosphorus and potassium uptake by the rice crop and weeds and also the crude protein content in hulled rice were computed from their respective elemental concentration. The factor used for deriving protein content was 6.25.

3.1.21. Apparent recovery of applied fertilizer nitrogen

Apparent recovery of applied nitrogen was calculated by the difference method using expression : Apparent recovery (%) = (N_f - N_c) x 100/N applied kg ha^{-1}, where N_f and N_c are nitrogen uptake kg ha^{-1} in fertilized and control plots respectively.

3.1.22. Water requirement and water use efficiency

Water requirement for different irrigation treatments was obtained by adding effective rainfall (80 per cent of the total rainfall received, Dastane, 1974) to the amount of water used in the experiment. Water use efficiency was calculated by dividing grain yield with the respective water requirement for different treatments.

3.2. Pot culture Studies

3.2.1. Plant material and culture

Rice cultivars Pusa 33 (drought susceptible) and Pusa 312 (derivative of the cross between Pusa 2-21 and N 22, drought tolerant) seeds were sown in porcelain pots (24 cm dia and 25 cm deep) in a green house. Twenty seeds were sown in each pot containing approximately 6.5 kg sandy clay-loam soil (physico-chemical characteristics of the soil are described in the previous section). Superphosphate and muriate of potash were mixed with the soil at the rate of 50 mg each of P_2O_5 and K_2O kg^{-1} of the soil before filling the pots.

The experiment was conducted during the summer season of 1983 (March to June). The meteorological data are given in Appendix I. Seeds were sown on 14.3.1983 and the pots were uniformly watered for the first 15 days.

Thereafter irrigations were given as per the treatment schedule.

3.2.2. Treatments

The treatments consisted of combinations of 2 cultivars, 3 levels of nitrogen and 5 water regimes each replicated thrice.

Cultivars

v_1 : Pusa 33

v_2 : Pusa 312

Nitrogen levels (mg kg soil^{-1})

n_0 : 0

n_1 : 100

n_2 : 200

Nitrogen was given as an aqueous solution (3.67%) of urea twice at 15 and 45 days after sowing.

Moisture regimes

m_1 : Submergence to saturation

m_2 : 0-0.025 MPa soil moisture tension

m_3 : 0-0.05 MPa soil moisture tension

m_4 : 0-0.075 MPa soil moisture tension

m_5 : 0-0.10 MPa soil moisture tension

Water application was scheduled using tensiometer (Gauge type) installed in each pot except the m_1 treatment. Water was applied as and when the pre-designated soil moisture tensions were reached. Irrigations were limited to once a day in the morning. Visual symptoms of water stress such as wilting and leaf rolling were very common in the drier treatments. Consequent to the prolonged water stress throughout the growth period, the severely stressed plants (m_3, m_4 and m_5) did not produce any panicles even after 100 days, when the experiment was terminated.

3.2.3. Sampling

Sampling was done between 0800 h to 0900 h. At each sampling date, composite samples consisting of one plant each from all the three replicates were used for measuring leaf area, dry weight, *in vivo* nitrate reductase activity (NRA) and free proline content in the leaves. The shoots were wrapped in moist muslin cloth and brought to the laboratory.

3.2.4. Biochemical Assays : In vivo Nitrate Reductase Activity (NRA)

The *in vivo* NRA in the uppermost three fully expanded leaves was determined by the method of Klepper *et al.* (1971) and Hageman and Huckleby (1971) with some modification (Nair and Abrol, 1977). The amount of nitrate reduced was determined by the method suggested by Evans and Nason (1953).

Determination of free proline in rice leaves

Free proline content of rice leaves was determined by the method of Bates (1973).

3.2.5. Leaf area, dry weight and plant height

The leaf area of 3 sample plants from each treatment was measured periodically using an Automatic Leaf Area Meter (Model 3100, Li-cor). The leaves and stalks of the above plants were oven dried to constant weights at 70°C and weights recorded. Plant height was obtained by measuring 5 plants in each pot and then computing their mean.

3.2.6. Nutrient uptake and concentration

The procedure adopted is given in the previous section.

3.3. Statistical analysis

The data relating to each character were analysed statistically by applying the technique of Analysis of Variance and the significance tested by 'F' test (Cochran and Cox, 1957). The data on weed population showed considerable variation and hence were subjected to square root transformation before analysis. Treatment means computed from the original values are also provided along with the transformed values. Response equations for grain production as a function of nitrogen levels were fitted for different weed control treatments.

3.4. Economics

Costs of production of all treatment combinations were worked out on the basis of the prevailing input cost and market price of grain and straw. The net income per hectare was calculated by deducting the cost of production per hectare from the gross returns per hectare.

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CHAPTER IV

RESULTS

The experimental findings are presented in this chapter; data pertaining to the field experiment are followed by that -° the green house studies.

4.1. Rice

4.1.1. Growth characters of rice

4.1.1.1. Plant height (cm)

The data on plant height at various phenological stages are given in Table 3. The two water regimes failed to exert any significant influence on the height of rice plants at any stage in the ontogeny of the crop in both the years. The weed control treatments also behaved in a similar fashion, except for the tillering and maturity stages in 1983. It is seen that the mean height of the rice plants in the weedy plots was more than the chemical treated ones in the beginning. But subsequently this advantage in terms of increased plant height was not evident. In other words, the plants in the weedy check had a lower stature than those in the herbicide treatments at all subsequent observations.

Increase in the level of nitrogen significantly enhanced the plant height. At maturity stage, however, the

Table 3. Plant height and tiller number as affected by water regimes, weed control treatments and nitrogen levels

Treatments	Height of plants (cm)						Tiller number (m-2)			
	Tillering stage		Flowering stage		Maturity		Total		Effective	
	1982	1983	1982	1983	1982	1983	1982	1983	1982	1983
Water regimes										
Continuous flooding	37.7	37.6	66.0	75.3	76.3	79.9	235.6	212.4	200.2	180.8
Alternate flooding and drying	37.2	38.0	67.7	73.8	76.2	80.7	220.8	217.1	180.3	178.6
'F' test	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S.Em ±	0.5	0.9	1.1	0.7	1.0	1.6	7.6	4.9	6.7	4.9
CD (0.05)	-	-	-	-	-	-	-	-	-	-
Weed control treatments										
Weedy check	38.0	41.2	64.9	75.4	75.4	75.6	178.3	122.7	143.6	101.1
Butachlor	37.0	36.4	66.8	74.5	76.6	84.2	299.2	277.0	264.7	226.0
Bentazone	37.2	-	64.9	-	76.8	-	207.0	-	162.4	-
Bentazone + Propanil	-	35.8	-	73.8	-	81.2	-	244.5	-	212.0
'F' test	NS	*	NS	NS	NS	*	**	**	**	**
S.Em ±	0.6	1.1	1.4	0.9	1.2	1.9	9.3	6.0	8.2	6.0
CD (0.05)	-	3.5	-	-	-	6.0	29.2	18.9	25.7	19.0
Nitrogen (kg ha^{-1})										
0	36.6	34.4	60.3	71.0	75.2	78.7	197.1	152.6	159.2	126.4
50	35.6	36.6	63.4	73.2	76.7	80.0	223.9	186.8	187.0	160.7
100	38.6	38.5	66.4	76.6	76.1	81.5	243.2	259.0	205.7	216.9
150	38.1	41.7	71.3	77.6	77.0	81.1	248.5	260.6	209.1	215.0
'F' test	**	**	**	**	NS	NS	**	**	**	**
S.Em ±	0.6	0.3	1.3	0.9	1.0	0.9	7.6	8.2	6.5	8.1
CD (0.05)	1.7	0.7	3.7	2.6	-	-	21.9	23.6	18.7	23.2

differences between nitrogen levels were not significant, though a general increasing trend was visible even at that stage in both years.

4.1.1.2. Total number of tillers m^{-2}

Observations recorded on the total number of tillers at the panicle emergence stage are summarised in Table 3. The number of tillers were in general higher in the year 1982. Irrigation treatments failed to have any significant influence on the tiller number in either of the crop seasons.

Among the weed control treatments, application of butachlor produced significantly more tillers (299.2 and 277.0 compared to 178.3 and 122.7 in the weedy check respectively in 1982 and 1983). Bentazone was found to be statistically at par with the weedy check in 1982. However, in the subsequent year when it was supplemented with propanil, there was a substantial increase in the tiller number per unit area.

Nitrogen application significantly increased the number of tillers in both the years. Nevertheless, the treatments receiving 50 and 100 kg N ha^{-1} in 1982 and 100 and 150 kg ha^{-1} in both the years were found to be statistically at par, though each of these nitrogen levels was considerably superior to the no nitrogen treatment.

The interaction between weed control treatments and nitrogen levels was significant in both the years (Table 4). In the first year, butachlor manifested the nitrogen effect on tiller number; while both butachlor and bentazone plus propanil combination displayed an increasing trend in tiller number with increasing levels of nitrogen in the subsequent year. There was absolutely no response to nitrogen in the weedy check in both the seasons and the bentazone alone plots in the first year.

4.1.1.3. <u>Effective number of tillers m^{-2}</u>

It is quite clear from the Table 3 that the irrigation treatment had no marked influence on the number of effective tillers m^{-2}. As far as the weed control treatments are concerned, butachlor consistently registered the highest number of effective tillers m^{-2} (264.7 and 226.0 as against 143.6 and 101.1 in the weedy check respectively in 1982 and 1983). Bentazone was unable to benefit this component as it was at par with the weedy check. But bentazone when combined with propanil had a marked stimulatory effect.

Increasing levels of nitrogen enhanced the number of effective tillers m^{-2} albeit the doses 100 and 150 kg N ha^{-1} were statistically at par. The interaction between nitrogen levels and weed control treatments was significant in both the years (Table 5). In the year 1982, among the

Table 4. Total number of tiller m^{-2} as affected by the interaction between weed control treatments and nitrogen levels

Weed control treatments	Nitrogen (kg ha^{-1}) 0	50	100	150
1982				
Weedy check	174.3	176.2	189.2	173.3
Butachlor	226.5	278.3	332.5	359.5
Bentazone	190.3	217.2	207.8	212.7
1983				
Weedy check	107.7	117.9	157.0	108.2
Butachlor	175.3	262.7	326.3	343.9
Bentazone + Propanil	174.8	179.8	293.8	329.6

	1982 S.Em ±	1982 CD (0.05)	1983 S.Em ±	1983 CD (0.05)
For comparing nitrogen means at the same level of weed control	13.2	37.9	14.2	40.8
For comparing weed control treatment means at the same level of nitrogen	14.7	43.9	13.7	40.0

Table 5. Effective number of tillers m^{-2} as affected by the interaction between weed control treatments and nitrogen levels

Weed control treatments	Nitrogen (kg ha^{-1}) 0	50	100	150
1982				
Weedy check	143.3	139.8	152.3	139.0
Butachlor	176.5	247.0	302.2	333.0
Bentazone	157.7	174.2	162.7	155.2
1983				
Weedy check	79.5	101.0	136.3	87.8
Butachlor	150.6	231.1	261.7	260.7
Bentazone + Propanil	149.0	150.0	252.7	296.4

	1982 S.Em ±	1982 CD (0.05)	1983 S.Em ±	1983 CD (0.05)
For comparing nitrogen means at the same level of weed control	11.3	32.4	14.0	40.0
For comparing weed control treatments means at the same level of nitrogen	12.7	38.0	13.5	39.6

weed control treatments, the synergistic effect of nitrogen was visible only with butachlor. There was 40, 71 and 89 per cent increase over no nitrogen with the first, second and third increments of nitrogen respectively. In the subsequent year, butachlor as well as bentazone plus propanil exhibited similar complementary effect on promoting the effective tiller number per unit area. The increase in number of effective tillers was to the extent of 53, 74 and 73 per cent respectively with the first, second and third increments of nitrogen in the butachlor plots. Similarly, second and third increment of nitrogen resulted in an increase of 70 and 99 per cent respectively in the bentazone plus propanil treatment. However, weedy check and bentazone failed to have any positive effect on the effective number of tillers m^{-2} with increasing levels of nitrogen.

4.1.1.4. Phytomass accumulation (g m^{-2}) at various stages of growth

The summary of the data on phytomass yield of the rice crop at various phenological stages such as tillering, flowering and maturity are presented in Table 6. It shows that the water management treatments did not have any marked effect on this parameter at any of the stages.

Among the weed control treatments, the weedy check invariably was the least efficient in this respect. On the

Table 6. Phytomass accumulation (g m^{-2}) by rice as affected by water regimes, weed control treatments and nitrogen levels

Treatments	Phases of crop growth					
	Tillering		Flowering		Maturity	
	1982	1983	1982	1983	1982	1983
<u>Water regimes</u>						
Continuous flooding	57.3	51.0	370.6	271.1	804.5	728.5
Alternate flooding and drying	56.1	49.7	363.9	271.5	760.9	749.0
'F' test	NS	NS	NS	NS	NS	NS
S.Em ±	2.6	3.3	10.4	8.1	20.3	37.5
CD (0.05)	-	-	-	-	-	-
<u>Weed control treatments</u>						
Weedy check	51.6	25.2	334.3	187.5	720.0	356.2
Butachlor	66.3	63.0	443.1	327.1	948.5	971.6
Bentazone	52.3	-	324.3	-	678.1	-
Bentazone + Propanil	-	62.8	-	299.3	-	888.5
'F' test	*	**	**	**	**	**
S.Em ±	3.2	4.1	12.8	9.9	24.9	45.9
CD (0.05)	10.0	12.8	40.3	31.1	78.3	144.6
<u>Nitrogen (kg ha^{-1})</u>						
0	33.6	33.2	248.0	216.9	663.5	493.3
50	51.3	42.1	330.9	253.3	707.9	714.7
100	66.4	62.3	441.1	305.8	862.8	850.7
150	75.5	63.7	449.0	309.1	896.7	896.3
'F' test	**	**	**	**	**	**
S.Em ±	2.6	2.9	17.3	10.7	36.1	43.6
CD (0.05)	7.4	8.4	49.6	30.7	103.7	125.1

contrary, the butachlor treatment consistently registered the highest amount of phytomass throughout the ontogeny of the crop. It was significantly superior to bentazone in the year 1982, nevertheless at par with bentazone plus propanil combination in the succeeding year.

Application of nitrogen significantly increased the phytomass accumulation at all growth stages in both the years (896.7 and 896.0 g m^{-2} in 150 kg N ha^{-1} as against 663.5 and 493.3 g m^{-2} in the no nitrogen treatment respectively in 1982 and 1983, at maturity). However, the difference between the higher levels of nitrogen (100 and 150 kg N ha^{-1}) was not significant at any of the stages in the two years except the tillering phase in 1982. Similarly, the difference between no nitrogen control and 50 kg N ha^{-1} was not significant at maturity in the same year.

The interaction between weed control treatments and nitrogen levels was significant at tillering and flowering in the second year and at maturity in both the years. The data pertaining to the tillering phase presented in Table 7 reveal that with butachlor and bentazone plus propanil, additional increments of nitrogen markedly increased the phytomass accumulation albeit, the higher levels of nitrogen (100 and 150 kg N ha^{-1}) were at par.

The phytomass production was almost static over the entire range of 0 to 150 kg N ha^{-1} in the weedy check. A similar trend was noticed in the subsequent stages also (Tables 8 and 9).

The interaction between water regimes and nitrogen levels also assumed significance at the maturity phase of the crop in the year 1982. The beneficial effect of nitrogen on boosting the phytomass production was evident only in the continuously flooded plots (Table 10), where phytomass yield increased from 624.3 g m^{-2} in the no nitrogen control to 1006.3 g m^{-2} in the 150 kg N ha^{-1} plots.

4.1.2. Chlorophyll content (mg g fr wt^{-1}) of rice leaves

The data presented in Table 11 reveal that the magnitude of change in rice leaf chlorophyll content at panicle initiation stage as a function of water regimes and weed control treatments is quite meagre. Chlorophyll 'a', 'b' and total chlorophyll, however, increased with increasing levels of nitrogen. The increase in total chlorophyll content was to the tune of 43 per cent in the 150 kg N ha^{-1} treatment over no nitrogen.

4.1.3. Yield attributes

The data collected on various yield attributes are given in Table 12.

Table 7. Phytomass accumulation by rice (g m^{-2}) at tillering stage as affected by the interaction between weed control treatments and nitrogen levels (1983)

Weed control treatments	Nitrogen (kg ha^{-1})			
	0	50	100	150
Weedy check	23.9	23.8	28.8	24.5
Butachlor	39.8	54.4	72.8	85.2
Bentazone + Propanil	36.1	48.3	85.5	81.5

	S.Em ±	CD (0.05)
For comparing nitrogen means at the same level of weed control	5.1	14.6
For comparing weed control treatment means at the same level of nitrogen	6.0	18.0

Table 8. Phytomass accumulation by rice (g m^{-2}) at flowering stage as affected by the interaction between weed control treatments and nitrogen levels (1983)

Weed control treatments	Nitrogen (kg ha^{-1})			
	0	50	100	150
Weedy check	172.3	191.4	199.5	186.7
Butachlor	230.8	303.7	389.5	384.3
Bentazone + Propanil	247.7	264.8	328.2	356.4

	S.Em ±	CD (0.05)
For comparing nitrogen means at the same level of weed control	18.5	53.1
For comparing weed control treatment means at the same level of nitrogen	18.8	55.4

Table 9. Phytomass accumulation by rice ($g\ m^{-2}$) at maturity as affected by interaction between weed control treatments and nitrogen levels

Weed control treatments	Nitrogen ($kg\ ha^{-1}$)			
	0	50	100	150
1982				
Weedy check	642.5	654.8	796.5	792.5
Butachlor	664.3	899.0	1022.8	1208.0
Bentazone	683.8	570.0	769.0	689.5
1983				
Weedy check	359.2	319.0	416.8	329.7
Butachlor	616.2	980.8	1059.7	1229.7
Bentazone + Propanil	504.5	844.2	1075.6	1129.7

	1982		1983	
	S.Em ±	CD(0.05)	S.Em ±	CD (0.05)
For comparing nitrogen means at the same level of weed control	62.6	179.5	75.5	216.7
For comparing weed control treatment means at the same level of nitrogen	59.6	174.0	80.0	236.6

Table 10. Phytomass accumulation ($g\ m^{-2}$) by rice at maturity as affected by the interaction between water regimes and nitrogen levels (1982)

Water regimes	Nitrogen ($kg\ ha^{-1}$)			
	0	50	100	150
Continuous flooding	624.3	692.7	894.7	1006.3
Alternate flooding and drying	702.7	723.2	830.8	787.0

	S.Em ±	CD (0.05)
for comparing nitrogen means at the same level of irrigation	51.1	146.6
For comparing irrigation means at the same level of nitrogen	48.7	142.1

Table 11. Chlorophyll content (mg g fr.wt^{-1}) of rice leaves at panicle initiation stage as affected by water regimes, weed control treatments and nitrogen levels

Treatments	Chlorophyll a	Chlorophyll b	Total Chlorophyll
Water regimes			
Continuous flooding	2.207	0.802	3.023
Alternate flooding and drying	2.404	0.853	3.273
Weed control treatments			
Weedy check	2.247	0.854	3.116
Butachlor	2.462	0.850	3.327
Bentazone + Propanil	2.207	0.778	3.000
Nitrogen (kg ha^{-1})			
0	1.831	0.634	2.477
50	2.375	0.889	3.279
100	2.422	0.855	3.292
150	2.593	0.932	3.543

4.1.3.1. Length of panicle (cm)

The panicle length was influenced by moisture regimes in the year 1982. The continuously flooded water régime registered a significantly higher length of panicle over alternate flooding and drying during that season. The weed control treatments also depicted notable difference on this parameter in the year 1983. The butachlor treated plots produced significantly longer panicles (21.8 cm) as against those (20.2 cm) in the weedy check.

Nitrogen application had a marked influence on this parameter. Additional increments of this element resulted in considerably longer panicles. However, the difference between two consecutive levels remained mostly non-significant in both the years.

The interaction between weed control treatments and nitrogen levels was significant in the year 1983 (Table 13). Increasing the doses of nitrogen was found to increase the length of panicles both in the butachlor and bentazone plus propanil treatments. However, the magnitude of increase was more in the former (14 and 6 per cent in the butachlor and bentazone plus propanil treatments respectively over the range 0 to 150 kg N ha^{-1}).

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

Irrigation levels had no significant effect on the number of spikelets $panicle^{-1}$ in either of the years.

Table 12. Yield attributed as affected by water regimes, weed control treatments and nitrogen levels

Treatments	Panicle length (cm) 1982	Panicle length (cm) 1983	Number of spikelets per panicle 1982	Number of spikelets per panicle 1983	Number of grains per panicle 1982	Number of grains per panicle 1983	Thousand grain weight (g) 1982	Thousand grain weight (g) 1983
Water regimes								
Continuous flooding	21.1	20.8	112.1	93.5	95.1	89.7	18.7	18.8
Alternate flooding and drying	20.6	20.9	111.6	99.5	91.6	90.1	18.2	19.1
'F' test	*	NS	NS	NS	NS	NS	*	NS
S.Em ±	0.1	0.3	2.1	4.2	2.2	4.3	0.1	0.2
CD (0.05)	0.4	-	-	-	-	-	0.3	-
Weed control treatments								
Weedy check	21.1	20.2	109.7	87.1	91.1	77.4	18.6	19.1
Butachlor	20.8	21.8	114.5	107.5	96.1	97.9	18.6	18.7
Bentazone	20.6	-	111.3	-	92.8	-	18.2	-
Bentazone + Propanil	-	20.5	-	103.3	-	94.3	-	19.1
'F' test	NS	*	NS	*	NS	*	NS	NS
S.Em ±	0.2	0.4	2.6	5.2	2.7	5.3	0.1	0.2
CD (0.05)	-	1.1	-	16.4	-	16.6	-	-
Nitrogen (kg ha^{-1})								
0	20.6	20.2	105.2	82.6	86.9	71.5	18.5	19.0
50	20.5	20.7	107.1	102.2	88.9	93.3	18.5	18.8
100	21.3	21.0	115.2	105.1	96.1	96.5	18.5	19.0
150	21.1	21.5	119.9	107.3	101.5	98.2	18.2	18.9
'F' test	*	**	**	**	**	**	NS	NS
S.Em ±	0.2	0.2	2.8	3.4	2.7	3.6	0.1	0.1
CD (0.05)	0.5	0.6	7.9	9.7	7.9	10.3	-	-

Table 13. Length of panicle (cm) as affected by the interaction between weed control treatments and nitrogen levels (1983)

Weed control treatments	Nitrogen (kg ha^{-1})			
	0	50	100	150
Weedy check	20.2	20.3	20.1	20.2
Butachlor	20.3	21.3	22.2	23.2
Bentazone + Propanil	19.9	20.3	20.8	21.1

	S.Em ±	CD (0.05)
For comparing nitrogen means at the same level of weed control	0.36	1.04
For comparing weed control treatments means at the same level of nitrogen	0.47	1.42

But the weed control treatments were found to have a prominent effect on this parameter in the year 1983. Butachlor registered the highest number of spikelets panicle^{-1} (107.5). Nevertheless, it was at par with the bentazone plus propanil combination (103.3).

There was a steady and consistent increase in the spikelet number with increasing levels of applied nitrogen in both the years. However, at higher levels the difference between the means was not significant.

4.1.3.3. <u>Number of grains panicle^{-1}</u>

The trend was similar to that of total spikelet number panicle^{-1}. Water regimes were unable to manifest any decisive impact on this yield component. Regarding the herbicide treatments, the differences were significant only in the second year when butachlor (97.9) and bentazone plus propanil (94.3) were superior to the weedy check (77.4) in terms of grain number panicle^{-1}.

The stimulatory effect of nitrogen in boosting the grain number panicle^{-1} is distinctly evident from the data. The number of filled spikelets per panicle increased with additional increments of nitrogen (0 to 150 kg ha^{-1}) from 86 to 101 in the year 1982 and from 71 to 98 in the succeeding year. However, the differences between the higher levels were not very evident in both the seasons.

4.1.3.4. Thousand grain weight (g)

None of the treatments displayed any phenomenal influence on thousand grain weight except the water regimes in the first year of experimentation (1982). The continuously flooded moisture regime resulted in a significantly higher grain weight over the alternately flooded and dried treatment.

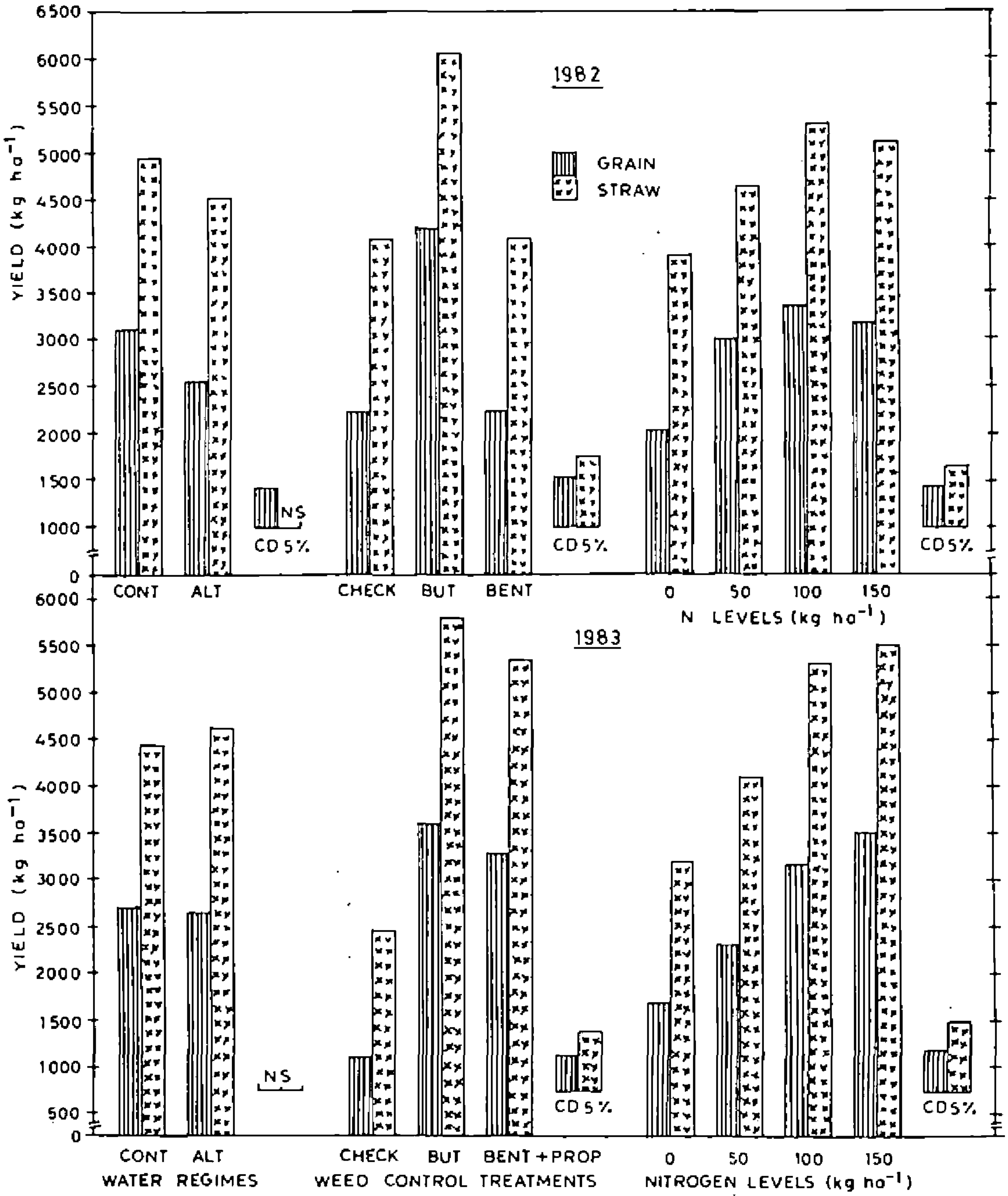
4.1.4. Grain Yield, Straw Yield and Harvest Index

4.1.4.1. Grain yield

The data on grain yield are presented in Table 14 and Fig. 5. Continuous submergence has significantly increased the grain yield over alternate flooding and drying in the year 1982. However, there was no much difference between the two water regimes in the subsequent year.

Grain yield was significantly affected by the weed control treatments. In the year 1982, application of butachlor resulted in 87 per cent increase in grain yield over the weedy check. The difference between the weedy check and bentazone applied plots, however, was negligible. In the succeeding year also, butachlor maintained the lead with 36.12 q ha^{-1} (227 per cent higher over the control). The combination of bentazone and propanil also recorded significantly higher yield (33.14 q ha^{-1}) as compared to that obtained in the control plot (11.03 q ha^{-1}).

FIG. 5 GRAIN AND STRAW YIELDS OF RICE AS INFLUENCED BY WATER REGIMES WEED CONTROL TREATMENTS AND NITROGEN LEVELS.



(CONT. Continuous and ALT. Alternate submergence, CHECK- Weedy check BUT - Butachlor BENT - Bentazone and PROP - Propanil).

Table 14. Grain (paddy)yield, straw yield and harvest index as affected by water regimes, weed control treatments and nitrogen levels

Treatments	Grain ($q\ ha^{-1}$)		Straw ($q\ ha^{-1}$)		Harvest index	
	1982	1983	1982	1983	1982	1983
Water regimes						
Continuous flooding	31.08	26.97	49.47	44.44	0.3721	0.3638
Alternate flooding and drying	25.63	26.56	45.28	46.30	0.3610	0.3422
'F' test	*	NS	NS	NS	NS	*
S.Em ±	1.39	0.97	1.94	1.73	0.0068	0.0060
CD (0.05)	4.37	-	-	-	-	0.0188
Weed control treatmen						
Weedy check	22.33	11.03	40.77	24.58	0.3477	0.3011
Butachlor	41.86	36.12	60.55	57.98	0.3998	0.3788
Bentazone	22.36	-	40.81	-	0.3521	-
Bentazone + Propanil	-	33.14	-	53.56	-	0.3790
'F' test	**	**	**	**	**	**
S.Em ±	1.70	1.19	2.37	2.12	0.0084	0.0073
CD (0.05)	5.35	3.74	7.47	6.67	0.0264	0.0230
Nitrogen ($kg\ ha^{-1}$)						
0	20.36	17.15	38.92	32.18	0.3381	0.3482
50	29.90	23.23	46.62	41.29	0.3824	0.3543
100	33.42	31.78	52.85	53.29	0.3770	0.3424
150	31.73	34.90	51.12	54.73	0.3686	0.3671
'F' test	**	**	**	**	**	NS
S.Em ±	1.45	1.54	2.27	2.61	0.0077	0.0092
CD (0.05)	4.17	4.42	6.50	7.48	0.0222	-

Nitrogen levels profoundly influenced the grain yield in both the years. In 1982, the first increment of 50 kg nitrogen increased the rough rice yield by about 9 q ha^{-1}, while the second increment boosted it further by 4 q ha^{-1}. However, any additional increment of nitrogen was unable to increase the yield level any more. The response at this stage tended to be quadratic. In the next year, the corresponding figures for yield increments were 6 and 8 q ha^{-1} for the first and second increments of nitrogen respectively. The third increment (from 100 to 150 kg N ha^{-1}) in 1983 pushed up the grain production still further unlike in the previous year. But the differences were found to be statistically non significant.

The interaction between weed control treatments and nitrogen levels was significant in both the years. In 1982, grain yield increased consistently due to additional increments of nitrogen only in the butachlor treated plots, producing 53.13 q ha^{-1} at 150 kg N ha^{-1}. The grain yield remained more or less unchanged over the entire range of 0 to 150 kg N ha^{-1} both in bentazone and weedy check plots. In fact, there was a diminishing trend in grain yield at the highest level compared to the previous doses in both these treatments. Nevertheless, these reductions were not significant. In the subsequent year, the trend was slightly different. Both in butachlor and bentazone plus propanil treated plots, nitrogen response was quite evident upto 150 kg N ha^{-1} (50.04 and 44.35 q ha^{-1} respectively). The increase in yield obtained in the butachlor plot with increments of nitrogen was strictly linear whereas in the bentazone plus propanil treatment it tended to be quadratic. In the weedy plots there was absolutely no beneficial effect from applied nitrogen.

The response equations for nitrogen with different weed control treatments were fitted (Fig. 6). In 1982, the response was quadratic, while in the succeeding year a linear response was obtained except for the weedy check. The equations are:

<u>1982</u>

Butachlor : $Y = 23.090 + 0.4538\ x - 0.001744\ x^2$

Bentazone : $Y = 16.037 + 0.19824\ x - 0.000976\ x^2$

Weedy check : $Y = 22.065 + 0.0796\ x - 0.000652\ x^2$

Overall : $Y = 20.4005 + 0.24371\ x - 0.001123\ x^2$

<u>1983</u>

Butachlor : $Y = 21.666 + 0.19272\ x$

Bentazone+ Propanil : $Y = 19.4475 + 0.1825\ x$

Weedy check: $Y = 11.45 - 0.0092\ x + 0.000032\ x^2$

Overall : $Y = 17.495 + 0.1326\ x$

The economic optimum doses of nitrogen for 1982 worked out to be 119.06, 81.34, 30.78 and 90.94 kg N ha^{-1}

Table 15. Grain (paddy) yield (q ha^{-1}) as affected by interaction between weed control treatments and nitrogen levels

Weed control treatments	Nitrogen (kg ha^{-1}) 0	50	100	150
1982				
Weedy check	21.88	24.99	22.92	19.53
Butachlor	21.88	45.05	47.40	53.13
Bentazone	17.32	19.66	29.95	22.53
1983				
Weedy check	11.93	9.63	12.29	10.31
Butachlor	21.36	31.38	41.70	50.04
Bentazone + Propanil	18.16	28.68	41.35	44.35

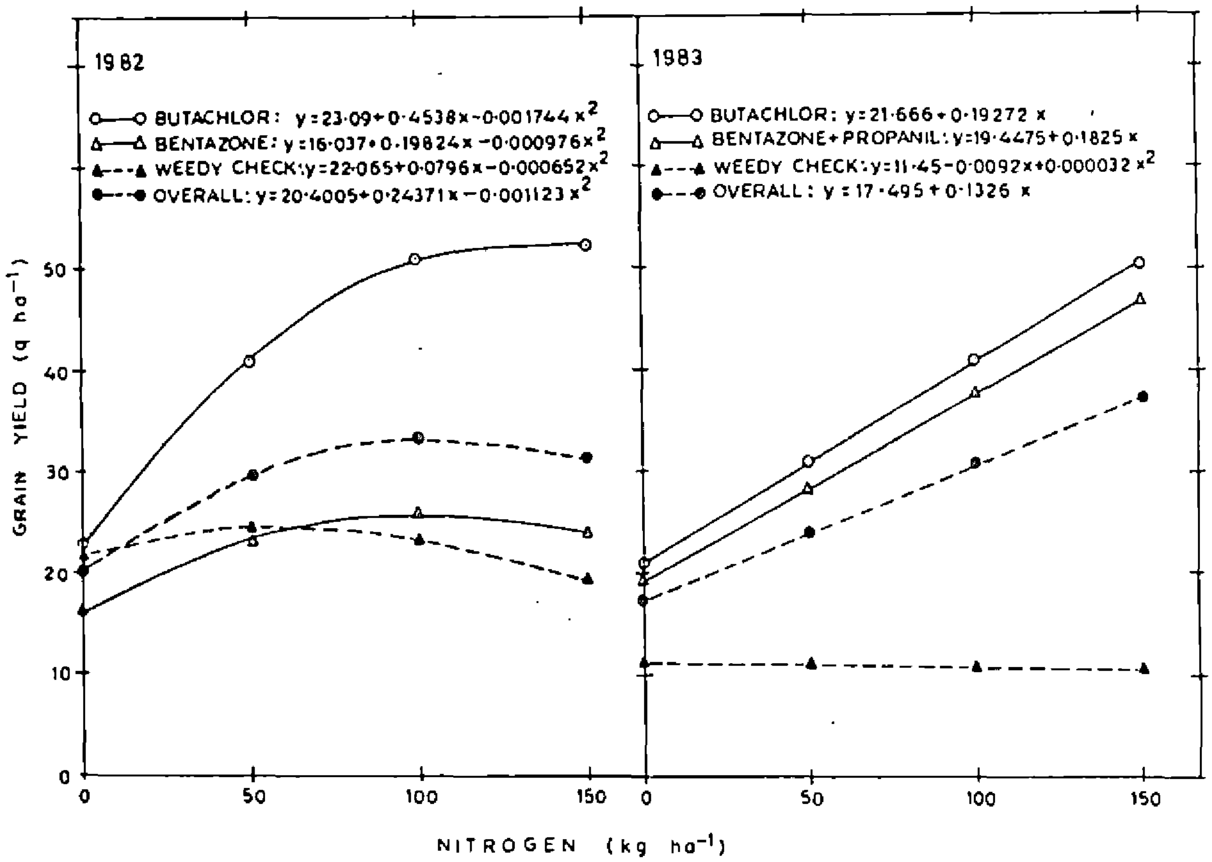
	1982 S.Em ±	1982 CD(0.05)	1983 S.Em ±	1983 CD (0.05)
For comparing nitrogen means at the same level of weed control	2.51	7.22	2.67	7.68
For comparing weed control treatment means at the same level of nitrogen	2.76	8.22	2.60	7.65

Table 16. Straw yield (q ha^{-1}) as affected by the interaction between weed control treatments and nitrogen levels

Weed control treatments	Nitrogen (kg ha^{-1}) 0	50	100	150
1982				
Weedy check	40.71	42.25	40.96	39.17
Butachlor	42.92	60.04	66.63	72.61
Bentazone	33.15	37.56	50.96	41.57
1983				
Weedy check	23.99	22.27	29.39	22.65
Butachlor	40.26	54.47	64.27	72.92
Bentazone + Propanil	32.29	47.13	66.22	68.62

	1982 S.Em ±	1982 CD (0.05)	1983 S.Em ±	1983 CD (0.05)
For comparing nitrogen means at the same level of weed control	3.92	11.27	4.51	12.95
For comparing weed control treatment means at the same level of nitrogen	4.14	12.27	4.44	13.03

FIG. 6. RESPONSE OF RICE TO NITROGEN AS AFFECTED BY WEED CONTROL TREATMENTS.



for butachlor, bentazone, weedy check and overall effects respectively. The paddy yield at the respective optimum nitrogen levels, were 52.41, 25.71, 23.90 and 23.28 q ha^{-1}.

4.1.4.2. Straw yield

The data on straw yield are presented in Table 14 and Fig. 5. The water regimes did not have any pronounced effect on this parameter in any of the seasons, whereas, the weed control treatments significantly influenced the straw yield in both the years. In the year 1982, butachlor was significantly superior to bentazone and weedy check even though the latter two were at par. The increase in straw yield with butachlor was to the tune of 48.5 per cent over these treatments. Butachlor, in the succeeding year registered 136 per cent increase in the straw yield over weedy check. However, butachlor and bentazone plus propanil were statistically similar during that season.

Nitrogen application favoured straw production both in 1982 and 1983 seasons. Additional increments of this nutrient resulted in a steady enhancement in straw weight. The difference in yield level due to 50, 100 and 150 kg N ha^{-1} was however, not significant in the first year. Similarly, the levels 100 and 150 kg N ha^{-1} were at par in the subsequent year. Regarding the magnitude of increase with various increments of nitrogen, the first increment resulted in 8 q ha^{-1} higher straw yield over no nitrogen control, whereas the next increment produced 6 q ha^{-1} over 50 kg N ha^{-1} in the year 1982. The corresponding figures for the succeeding year were 9 and 12 q ha^{-1}.

The interaction between weed control treatments and nitrogen levels assumed significance (Table 16). The response to nitrogen application was visible only in the butachlor treated plots during the first year. The combination of butachlor and 150 kg N ha^{-1} produced the highest straw yield of 73 q ha^{-1}. This was markedly superior to all other combinations except the 100 kg N ha^{-1} with butachlor. A similar trend was observed in the succeeding year also. However, the combinations of nitrogen with butachlor were at par with those of nitrogen and bentazone plus propanil.

4.1.4.3. <u>Harvest index</u>

The data on harvest index as affected by the various treatments are presented in Table 14. Irrigation failed to influence this component in the year 1982. However, in the subsequent year, the continuously flooded treatment turned out to be superior (6 per cent) to the alternately flooded and dried one.

Weed control treatments showed a marked effect on this parameter in both the years. Butachlor had a clear superiority over both the remaining treatments in 1982. In the next year, however, butachlor and bentazone plus propanil combination were at par and both were significantly superior to weedy check.

Difference due to the nitrogen levels touched the level of significance only in the first year. However, during that year also no marked variation was observed over the entire range of 50 to 150 kg N ha^{-1}. The interaction effect of weed control treatments and nitrogen levels was significant in both the years (Table 17). There was a consistent increase in harvest index with every additional increment of nitrogen in the butachlor treated plots in the year 1982. In the succeeding year, the same trend was depicted both by butachlor as well as bentazone plus propanil treated plots. The weedy check, however, portrayed an altogether different picture. Here the harvest index not only showed any appreciable increase but it actually declined and this is true for both the years.

4.1.5. <u>Nitrogen concentration (%) in rice plant at various stages of growth</u>

Table 18 depicts the data on nitrogen content of rice (whole plant) at tillering and flowering as well as grain and straw at maturity, as affected by the various treatments. It seems that water regimes did not have any marked effect on the nitrogen content of rice plant at any of the phenological stages studied.

Table 17. Harvest index as affected by the interaction between weed control treatments and nitrogen levels

Weed control treatments	Nitrogen (kg ha^{-1})			
	0	50	100	150
1982				
Weedy check	0.3404	0.3725	0.3448	0.3331
Butachlor	0.3365	0.4277	0.4148	0.4203
Bentazone	0.3374	0.3470	0.3715	0.3525
1983				
Weedy check	0.3344	0.3173	0.2509	0.3019
Butachlor	0.3506	0.3649	0.3923	0.4076
Bentazone + Propanil	0.3595	0.3807	0.3841	0.3917

	1982		1983	
	S.Em ±	CD (0.05)	S.Em ±	CD (0.05)
For comparing nitrogen means at the same level of weed control	0.0134	0.0384	0.0158	0.0456
For comparing weed control treatment means at the same level of nitrogen	0.0139	0.0410	0.0156	0.0456

Table 18. Nitrogen content (%) in shoot and crude protein content (%) in grain as affected by water regimes, weed control treatments and nitrogen levels

Treatments	Nitrogen content (%)								Crude protein content (%)	
	Tillering		Flowering		Maturity					
					Grain		Straw			
	1982	1983	1982	1983	1982	1983	1982	1983	1982	1983
Water regimes										
Continuous flooding	2.32	2.32	1.88	1.75	1.16	1.39	0.51	0.47	7.26	8.66
Alternate flooding and drying	2.41	2.35	1.85	1.82	1.17	1.38	0.50	0.47	7.32	8.62
'F' test	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S.Em ±	0.035	0.059	0.022	0.041	0.026	0.043	0.006	0.018	0.160	0.270
CD (0.05)	-	-	-	-	-	-	-	-	-	-
Weed control treatments										
Weedy check	2.13	2.23	1.80	1.56	1.09	1.41	0.48	0.39	6.79	8.84
Butachlor	2.59	2.38	1.97	1.90	1.27	1.40	0.52	0.53	7.91	8.76
Bentazone	2.36	-	1.82	-	1.15	-	0.50	-	7.17	-
Bentazone + Propanil	-	2.39	-	1.89	-	1.33	-	0.50	-	8.33
'F' test	**	NS	**	**	**	NS	**	**	**	NS
S.Em ±	0.043	0.072	0.027	0.050	0.031	0.053	0.007	0.022	0.196	0.331
CD (0.05)	0.134	-	0.084	0.159	0.099	-	0.021	0.070	0.619	-
Nitrogen (kg ha^{-1})										
0	2.05	2.04	1.64	1.67	0.95	0.16	0.44	0.42	5.92	7.27
50	2.29	2.37	1.90	1.76	1.05	1.34	0.48	0.46	6.53	8.41
100	2.47	2.40	2.00	1.85	1.26	1.42	0.53	0.48	7.87	8.87
150	2.64	2.54	1.90	1.87	1.41	1.60	0.56	0.53	8.83	10.00
F' test	**	**	**	**	**	**	**	**	**	**
.Em ±	0.040	0.086	0.039	0.040	0.027	0.043	0.011	0.008	0.168	0.270
D (0.05)	0.116	0.248	0.111	0.114	0.076	0.124	0.031	0.022	0.483	0.775

At tillering, the weed control treatments substantially influenced the nitrogen content of rice plants. Butachlor treated plants had a significantly higher nitrogen content (2.59 per cent) in the year 1982. In the subsequent year, however , no such difference was discernible among the weed control treatments. Additional increments of nitrogen resulted in a steady increase in the concentration of this nutrient in the plant tissues in both the years (2.64 and 2.54 per cent at 150 kg N ha^{-1} as against 2.05 and 2.04 per cent in no nitrogen control respectively in 1982 and 1983).

The interaction between weed control treatments and water regimes on the nitrogen content of rice at tillering was significant (Table 19) in the year 1982. The plants in butachlor plots had a significantly higher nitrogen content in both levels of irrigation. Similarly, with every additional increment of nitrogen, its concentration in the tissues increased in the butachlor plots (Table 20).

The nitrogen concentration in the plant at flowering was significantly influenced by the weed control treatments in both the years. Butachlor registered the highest value in both the seasons. However, in the year 1983, this was at par with the bentazone plus propanil combination. Nitrogen levels also had a prominent effect on the concentratic

Table 19. Nitrogen content (%) in rice at tillering as affected by the interaction between water regimes and weed control treatments (1982)

Water regimes	Weed control treatments		
	Weedy check	Butachlor	Bentazone
Continuous flooding	1.98	2.60	2.36
Alternate flooding and drying	2.28	2.58	2.36
S.Em ±	0.05		
CD (0.05)	0.16		

Table 20. Nitrogen content (%) in the rice plants at tillering as affected by the interaction between weed control treatments and nitrogen levels (1982)

Weed control treatments	Nitrogen (kg ha^{-1})			
	0	50	100	150
Weedy check	1.80	2.10	2.35	2.27
Butachlor	2.17	2.49	2.59	3.12
Bentazone	2.17	2.28	2.46	2.54

	S.Em ±	CD (0.05)
For comparing nitrogen means at the same level of weed control	0.070	0.201
For comparing weed control treatment means at the same level of nitrogen	0.074	0.220

of this element in the tissues. There was a consistent increase in nitrogen content with every additional increment of fertilizer nitrogen added. Regarding the interaction between nitrogen levels and weed control treatments (Table 21), the combinations of nitrogen with butachlor were distinctly superior to other treatments. Nevertheless, in the year 1983, they were bracketed with the combinations of nitrogen with bentazone plus propanil.

Butachlor recorded the highest value for grain nitrogen content in the year 1982 (1.27 per cent). Similarly the nitrogen concentration in the straw also varied tremendously as a function of the weed control treatments. The weedy check had the lowest nitrogen content in both the years. Nitrogen application favourably influenced the nitrogen content in the rice grain and straw. Concentration in the tissues increased with every additional increment of the nutrient. The nitrogen levels x weed control interaction was significant on the straw nitrogen content in 1983 (Table 22). At each level of nitrogen, the nitrogen percentage of straw increased in the butachlor and bentazone plus propanil plots. The highest straw nitrogen content (0.63 per cent) was recorded at the 150 kg N ha^{-1} level with butachlor which was significantly superior to all other nitrogen combinations with weedy check, although at par with bentazone plus propanil.

Table 21. Nitrogen content (%) in rice plants at flowering as affected by the interaction between weed control treatments and nitrogen levels

Weed control treatments	Nitrogen (kg ha^{-1})			
	0	50	100	150
1982				
Weedy check	1.58	1.93	1.96	1.72
Butachlor	1.72	1.87	2.05	2.26
Bentazone	1.63	1.92	1.99	1.73
1983				
Weedy check	1.54	1.59	1.65	1.46
Butachlor	1.72	1.86	1.99	2.05
Bentazone + Propanil	1.75	1.82	1.90	2.10
	S.Em ±		CD (0.05)	
	1982	1983	1982	1983
For comparing nitrogen means at the same level of weed control	0.067	0.069	0.192	0.197
For comparing weed control treatment means at the same level of nitrogen	0.064	0.078	0.186	0.233

Table 22. Nitrogen concentration (%) in rice straw as affected by the interaction between weed control treatments and nitrogen levels (1983)

Weed control treatments	Nitrogen (kg ha^{-1})			
	0	50	100	150
Weedy check	0.358	0.382	0.395	0.427
Butachlor	0.452	0.503	0.533	0.630
Bentazone + Propanil	0.462	0.485	0.510	0.523
			S.Em ±	CD (0.05)
For comparing nitrogen means at the same level of nitrogen			0.0132	0.0378
For comparing weed control treatment means at the same level of nitrogen			0.0251	0.0776

4.1.6. Crude protein content (%)

The data on crude protein content of grains, presented in Table 18 reveal that the weed control treatments displayed significant difference among them only in the year 1982. Butachlor treated plots had the distinction of having the highest protein content (7.91 per cent). There was a favourable effect of nitrogen too on protein content. A consistent increase in grain protein percentage with every additional increments of nitrogen was noted. Raising the level of nitrogen from 0 to 150 kg ha^{-1} raised the protein content from 5.92 to 8.83 and 7.27 to 10.00 per cent respectively in the two crop seasons.

4.1.7. Phosphorus concentration (%) in rice plant at various stages of growth

The data on phosphorus content in rice at tillering flowering and grain and straw are summarised in Table 23. Phosphorus content decreased with the age of the crop. It was, however, at any of the stages affected neither by water regimes nor weed control treatments.

Regarding nitrogen, the effect was evident in the year 1982. But in the subsequent year there was no discrimination among the nitrogen levels except at the flowering stage. Either in 1982, no clear trend was

Table 23. Phosphorus concentration (%) in rice as affected by water regimes, weed control treatments and nitrogen levels

Treatments	Tillering		Flowering		Maturity			
					Grain		Straw	
	1982	1983	1982	1983	1982	1983	1982	1983
Water regimes								
Continuous flooding	0.294	0.267	0.212	0.252	0.220	0.274	0.087	0.088
Alternate flooding and drying	0.287	0.279	0.216	0.243	0.218	0.276	0.083	0.083
'F' test	NS	NS	NS	NS	NS	NS	NS	NS
S.Em ±	0.0060	0.0085	0.0019	0.0085	0.0027	0.0027	0.0054	0.0043
CD (0.05)	–	–	–	–	–	–	–	–
Weed control treatments								
Weedy check	0.287	0.281	0.214	0.229	0.220	0.274	0.087	0.092
Butachlor	0.297	0.270	0.220	0.268	0.221	0.277	0.085	0.082
Bentazone	0.287	–	0.214	–	0.217	–	0.084	–
Bentazone + Propanil	–	0.268	–	0.247	–	0.273	–	0.083
'F' test	NS	NS	NS	NS	NS	NS	NS	NS
S.Em ±	0.0075	0.0134	0.0024	0.0104	0.0034	0.0033	0.0067	0.0053
CD (0.05)	–	–	–	–	–	–	–	–
Nitrogen (kg ha^{-1})								
0	0.309	0.267	0.189	0.228	0.213	0.273	0.067	0.088
50	0.289	0.272	0.238	0.242	0.212	0.281	0.082	0.085
100	0.291	0.267	0.230	0.260	0.219	0.273	0.094	0.087
150	0.272	0.286	0.206	0.262	0.232	0.273	0.098	0.083
'F' test	**	NS	**	**	*	NS	**	NS
S.Em ±	0.0055	0.0063	0.033	0.0058	0.0052	0.0084	0.0052	0.0031
CD (0.05)	0.1600	–	0.0095	0.0165	0.0150	–	0.0150	–

discernible with regard to the effect of nitrogen on phosphorus content of plant tissues. The no nitrogen and 50 kg N ha^{-1} treatments respectively resulted in the highest concentration of phosphorus at the tillering and flowering stages. The phosphorus content of grain, however, was greatest in the 150 kg N ha^{-1} level, while other treatments were statistically not different. Regarding the phosphorus content in straw, there was a steady and significant increase with increasing levels of nitrogen.

4.1.8. Potassium concentration (%) in rice plant at various stages of growth

The data presented in Table 24 make it clear that water regimes and weed control treatments failed to evoke any significant impact on the potassium content of tissues at any of the stages except straw in the year 1983. As regards nitrogen, in general, there was an increasing trend with increasing levels of nitrogen. However, the differences were significant only at the flowering and grain stages in 1982 and straw in both the years. In general, nitrogen application resulted in increased potassium content of the tissues.

The interaction between weed control treatments and nitrogen levels was significant in 1982 crop season at tillering and flowering stages (Tables 25 and 26). At each weed control treatment additional increments of nitrogen resulted in a higher potassium content.

Table 24. Potassium concentration (%) in rice as affected by water regimes, weed control treatments and nitrogen levels

Treatments	Tillering		Flowering		Maturity			
					Grain		Straw	
	1982	1983	1982	1983	1982	1983	1982	1983
Water regimes								
Continuous flooding	2.09	1.83	1.55	1.58	0.281	0.274	1.71	1.46
Alternate flooding and drying	2.03	1.74	1.56	1.50	0.290	0.290	1.71	1.52
'F' test	NS	NS	NS	NS	NS	NS	NS	NS
S.Em ±	0.046	0.045	0.032	0.044	0.0062	0.0075	0.039	0.024
CD (0.05)	-	-	-	-	-	-	-	-
Weed control treatments								
Weedy check	2.03	1.86	1.54	1.49	0.280	0.284	1.73	1.29
Butachlor	2.09	1.73	1.59	1.63	0.303	0.285	1.76	1.61
Bentazone	2.07	-	1.55	-	0.274	-	1.65	-
Bentazone + Propanil	-	1.77	-	1.50	-	0.277	-	1.57
'F' test	NS	NS	NS	NS	NS	NS	NS	**
S.Em ±	0.056	0.055	0.04	0.054	0.0076	0.0092	0.048	0.029
CD (0.05)	-	-	-	-	-	-	-	0.093
Nitrogen ($kg\ ha^{-1}$)								
0	1.97	1.76	1.42	1.56	0.246	0.286	1.54	1.41
50	2.10	1.81	1.56	1.54	0.284	0.290	1.70	1.47
100	2.06	1.71	1.63	1.52	0.300	0.250	1.78	1.52
150	2.12	1.87	1.62	1.54	0.312	0.278	1.82	1.57
'F' test	NS	NS	**	NS	**	NS	**	**
S.Em ±	0.043	0.041	0.023	0.051	0.0062	0.0092	0.055	0.013
CD (0.05)	-	-	0.066	-	0.0179	-	0.157	0.038

Table 25. Potassium content (%) in rice plants at tillering as affected by the interaction between weed control treatments and nitrogen levels (1982)

Weed control treatments	Nitrogen (kg ha^{-1})			
	0	50	100	150
Weedy check	1.71	2.17	2.11	2.13
Butachlor	2.11	2.12	1.96	2.15
Bentazone	2.09	2.00	2.10	2.07

	S.Em ±	CD(0.05)
For comparing nitrogen means at the same level of weed control	0.07	0.21
For comparing weed control treatment means at the same level of nitrogen	0.09	0.26

Table 26. Potassium content (%) in rice at flowering as affected by the interaction between weed control treatments and nitrogen levels (1982)

Weed control treatments	Nitrogen (kg ha^{-1})			
	0	50	100	150
Weedy check	1.41	1.60	1.56	1.57
Butachlor	1.37	1.57	1.66	1.76
Bentazone	1.49	1.51	1.67	1.53

	S.Em ±	CD (0.05)
For comparing nitrogen means at the same level of weed control	0.04	0.12
For comparing weed control treatment means at the same level of nitrogen	0.05	0.16

4.1.9. Nitrogen uptake by rice crop at harvest (kg ha^{-1})

The data pertaining to nitrogen removal by the crop are presented in Table 27 and Fig. 11. It reveals that water regimes failed to exert any significant effect on the nitrogen uptake (grain and straw) by rice crop. Among the weed control treatments butachlor was the most outstanding in terms of nitrogen uptake both in grain and straw. Total uptake in grain + straw reached 86.74 and 83.45 kg N ha^{-1} in 1982 and 1983 respectively. However, in the year 1983, butachlor was found to be at par with bentazone plus propanil combination (72.54 kg N ha^{-1}).

Application of nitrogen consistently increased its uptake by the plant. The highest values for uptake in both grain and straw were obtained in the 150 kg N ha^{-1} treatment in both seasons. There was 141 and 178 per cent higher nitrogen uptake in grain and 71 and 123 per cent higher in straw in 1982 and 1983 respectively over no nitrogen control.

The interaction effect of weed control treatments and nitrogen levels on grain and straw nitrogen removal was significant in both the years (Tables 28 and 29). The trend was similar in either cases. At each level of nitrogen, butachlor was significantly superior to the remaining weed control treatments in the year 1982. In the subsequent year,

Table 27. Nitrogen uptake (kg ha^{-1}) by rice as influenced by water regimes, weed control treatments and nitrogen levels

Treatments	Nitrogen uptake			
	Grain		Straw	
	1982	1983	1982	1983
Water regimes				
Continuous flooding	36.97	37.05	25.65	22.15
Alternate flooding and drying	32.66	37.38	23.12	23.03
'F' test	NS	NS	NS	NS
S.Em ±	1.75	2.02	1.05	1.01
CD (0.05)	-	-	-	-
Weed control treatments				
Weedy check	24.17	15.41	19.87	9.46
Butachlor	54.42	52.07	32.32	31.38
Bentazone	25.81	-	20.96	-
Bentazone + Propanil	-	45.63	-	26.91
'F' test	**	**	**	**
S.Em ±	2.14	2.47	1.29	1.24
CD (0.05)	6.75	7.79	4.07	3.91
Nitrogen (kg ha^{-1})				
0	19.32	19.86	17.27	13.65
50	30.71	31.37	22.63	19.53
100	42.65	44.50	28.11	26.71
150	46.59	55.13	29.52	30.44
'F' test	**	**	**	**
S.Em ±	2.25	2.57	1.36	1.41
CD (0.05)	6.46	7.39	3.90	4.05

Table 28. Nitrogen uptake (kg ha^{-1}) by grain as affected by the interaction between weed control treatments and nitrogen levels

Weed control treatments	Nitrogen (kg ha^{-1})			
	0	50	100	150
1982				
Weedy check	18.26	24.17	27.55	26.71
Butachlor	23.25	45.95	64.97	83.69
Bentazone	16.45	22.02	35.42	29.37
1983				
Weedy check	12.22	12.76	19.20	17.27
Butachlor	25.72	42.87	59.31	80.54
Bentazone + Propanil	21.66	38.26	54.99	67.60
	S.Em ±		CD(0.05)	
	1982	1983	1982	1983
For comparing nitrogen means at the same level of weed control	3.90	4.46	11.20	12.80
For comparing weed control treatment means at the same level of nitrogen	4.00	4.59	11.80	13.54

Table 29. Nitrogen uptake (kg ha^{-1}) by rice straw as affected by the interaction between weed control treatments and nitrogen levels

Weed control treatments	Nitrogen (kg ha^{-1})			
	0	50	100	150
1982				
Weedy check	17.97	20.80	20.34	20.36
Butachlor	19.19	29.88	35.56	44.65
Bentazone	14.66	17.22	28.44	23.54
1983				
Weedy check	7.99	8.36	12.03	9.48
Butachlor	18.12	27.29	34.30	45.83
Bentazone + Propanil	14.84	22.96	33.82	36.02
	S.Em ±		CD (0.05)	
	1982	1983	1982	1983
For comparing nitrogen means at the same level of weed control	2.36	2.44	6.76	7.02
For comparing weed control treatments means at the same level of nitrogen	2.41	2.45	7.12	7.22

at each level of nitrogen, both butachlor and bentazone plus propanil responded similarly, but both were significantly superior to weedy check. With increasing levels of nitrogen, its uptake also went up progressively in these treatments whereas in the weedy check and bentazone alone plots, it was nearly static.

4.1.10. Apparent nitrogen recovery (%)

The apparent nitrogen recovery obtained by the difference method is given in Table 30. The apparent recovery did not vary considerably due to the irrigation treatments (32 and 34 per cent, respectively in the continuously and alternately flooded plots). The weed control treatments butachlor and bentazone plus propanil recovered the highest amount of applied nitrogen (57 and 49 per cent respectively over weedy check). The data also indicate that nitrogen recovery first increased with increasing levels of applied nitrogen, reached a peak at around 100 kg N ha^{-1} and then started declining. This increasing-diminishing trend was true for both seasons.

4.1.11. Phosphorus uptake (kg P ha^{-1}) by rice crop at harvest

The data on phosphorus removal by rice crop as affected by various treatments are depicted in Table 31 and Fig. 11. It shows that phosphorus uptake by both grain and straw did not vary due to water regimes. Of the weed

Table 30. Apparent recovery of nitrogen as affected by soil moisture regimes, weed control treatments and nitrogen levels

Treatments	Apparent N recovery (%)		
	1982	1983	Mean
<u>Water regimes</u>			
Continuous flooding	33.28	31.59	32.44
Alternate flooding and drying	28.95	39.86	34.41
<u>Weed control treatments</u>			
Weedy check	12.12	5.87	9.00
Butachlor	60.71	52.47	56.59
Bentazone	21.19	-	21.19
Bentazone + Propanil	-	48.83	48.63
<u>Nitrogen (kg ha^{-1})</u>			
0	-	-	-
50	33.50	33.78	33.64
100	34.17	37.70	35.94
150	26.35	34.71	30.53

Table 31. Phosphorus uptake (P kg ha^{-1}) by rice as influenced by water regimes, weed control treatments and nitrogen levels

Treatments	Phosphorus uptake			
	Grain		Straw	
	1982	1983	1982	1983
Water regimes				
Continuous flooding	6.91	7.34	4.30	3.81
Alternate flooding and drying	5.90	7.44	3.99	3.84
'F' test	NS	NS	NS	NS
S.Em ±	0.34	0.30	0.26	0.31
CD (0.05)	-	-	-	-
Weed control treatments				
Weedy check	4.99	2.98	3.42	2.28
Butachlor	9.36	10.04	5.53	4.77
Bentazone	4.86	-	3.47	-
Bentazone + Propanil	-	9.15	-	4.42
'F' test	**	**	**	**
S.Em ±	0.42	0.36	0.31	0.38
CD (0.05)	1.32	1.14	0.98	1.19
Nitrogen (kg ha^{-1})				
0	4.35	4.64	2.69	2.85
50	6.55	6.56	3.74	3.40
100	7.31	8.78	5.03	4.55
150	7.40	9.59	5.10	4.50
'F' test	**	**	**	**
S.Em ±	0.44	0.54	0.35	0.27
CD (0.05)	1.26	1.54	1.01	0.78

control treatments, butachlor in 1982 and 1983 and bentazone plus propanil in the latter year showed a distinct superiority in terms of phosphorus uptake both by grain as well as straw. The total phosphorus uptake in the butachlor treated plots worked out to be 14.89 and 14.81 kg P ha^{-1} respectively in 1982 and 1983 and 13.57 kg P ha^{-1} in the bentazone plus propanil combination.

The data presented in Table 31 also make it amply clear that phosphorus uptake by grain and straw in both years were steadily increased by additional increments of nitrogen. However, at higher levels the differences were not significant.

The interaction between weed control treatments and nitrogen levels on phosphorus uptake of rice grain was significant in both years (Table 32). The highest amount of phosphorus removal was registered in the combination of butachlor with 150 kg N ha^{-1} in both seasons. Phosphorus uptake did not increase considerably either in the weedy check or bentazone alone plots over the entire range of 0 to 150 kg N ha^{-1}. Similarly, the interaction effect of weed control treatments and nitrogen levels was significant in respect of phosphorus uptake by straw in the year 1982 (Table 33). With increasing levels of nitrogen (barring 150 kg ha^{-1}), there was a steady increase in phosphorus uptake at each weed control treatment. But the magnitude of increase

Table 32. Phosphorus uptake (P kg ha^{-1}) by grain as influenced by the interaction between weed control treatments and nitrogen levels

Weed control treatments	Nitrogen (kg ha^{-1})			
	0	50	100	150
1982				
Weedy check	4.99	5.67	5.18	4.13
Butachlor	4.33	9.81	10.32	12.98
Bentazone	3.75	4.16	6.43	5.10
1983				
Weedy check	3.39	2.63	3.09	2.81
Butachlor	5.79	8.91	11.72	13.74
Bentazone + Propanil	4.73	8.13	11.53	12.22

	S.Em ±		CD (0.05)	
	1982	1983	1982	1983
For comparing nitrogen means at the same level of weed control	0.76	0.93	2.19	2.67
For comparing weed control treatment means at the same level of nitrogen	0.78	0.88	2.31	2.58

Table 33. Phosphorus uptake (P kg ha^{-1}) by rice straw as affected by the interaction between weed control treatments and nitrogen levels (1982)

Weed control treatments	Nitrogen (kg ha^{-1})			
	0	50	100	150
Weedy check	2.69	3.68	3.92	3.40
Butachlor	3.49	4.52	6.23	7.87
Bentazone	1.90	3.02	4.95	4.02

	S.Em ±	CD (0.05)
For comparing nitrogen means at the same level of weed control	0.608	1.745
For comparing weed control treatment means at the same level of nitrogen	0.612	1.802

was more in the butachlor treated plots and it continue upto the highest dose of nitrogen (150 kg N ha^{-1}).

4.1.12. Potassium uptake (kg K ha^{-1}) by rice crop at harvest

Potassium uptake was marked influenced by the weed control treatments (Table 34 and Fig. 11). The trend was similar to that of nitrogen and phosphorus uptake.

Potassium uptake by grain and straw increased with increasing levels of nitrogen in both years. There was 60 and 96 per cent increase in total potassium uptake at 150 kg N ha^{-1} plots over the no nitrogen control in 1982 and 1983, respectively. There was considerable variation in the potassium uptake by grain and straw at each of the weed control treatments with increasing levels of applied nitrogen (Tables 35 and 36). The trend was apparently the same for grain as well as straw uptake of potassium in both the years. Butachlor tremendously boosted the favourable effect of increasing nitrogen levels on potassium uptake. However, in the year 1983, it was at par with the combinations involving nitrogen and bentazone plus propanil.

4.2. Weeds

4.2.1. Weed population at various stages

The observations on population count of weeds are

Table 34. Potassium uptake (K kg ha^{-1}) by rice as affected by water regimes, weed control treatments and nitrogen levels

Treatments	Potassium uptake			
	Grain		Straw	
	1982	1983	1982	1983
Water regimes				
Continuous flooding	9.18	7.39	83.99	67.32
Alternate flooding and drying	7.95	7.61	78.33	73.46
'F' test	NS	NS	NS	NS
S.Em ±	0.49	0.39	3.72	2.76
CD (0.05)	-	-	-	-
Weed control treatments				
Weedy check	6.39	3.10	69.52	31.52
Butachlor	13.03	10.27	106.90	94.24
Bentazone	6.27	-	67.06	-
Bentazone + Propanil	-	9.14	-	85.39
'F' test	**	**	**	**
S.Em ±	0.60	0.47	4.55	3.38
CD (0.05)	1.68	1.49	14.34	10.66
Nitrogen (kg ha^{-1})				
0	5.15	4.95	59.75	45.54
50	8.55	6.79	78.61	62.51
100	10.29	8.79	92.69	83.80
150	10.26	9.48	93.60	89.69
'F' test	**	**	**	**
S.Em ±	0.69	0.49	4.34	3.99
CD (0.05)	1.98	1.41	12.44	11.45

Table 35. Potassium uptake (K kg ha^{-1}) by grain as affected by the interaction between weed control treatments and nitrogen levels

Weed control treatments	Nitrogen (kg ha^{-1})			
	0	50	100	150
1982				
Weedy check	5.50	7.09	6.96	5.99
Butachlor	5.74	12.67	15.55	18.18
Bentazone	4.21	5.89	8.37	6.62
1983				
Weedy check	3.55	2.71	3.18	2.95
Butachlor	6.22	9.63	11.38	13.85
Bentazone + Propanil	5.10	8.02	11.83	11.62
	S.Em ±		CD(0.05)	
	1982	1983	1982	1983
For comparing nitrogen means at the same level of weed control	0.85	0.85	2.44	2.45
For comparing weed control treatment means at the same level of nitrogen	0.95	0.88	2.83	2.59

Table 36. Potassium uptake (K kg ha^{-1}) by rice straw as affected by the interaction between weed control treatments and nitrogen levels

Weed control treatments	Nitrogen (kg ha^{-1})			
	0	50	100	150
1982				
Weedy check	63.36	69.20	69.96	75.59
Butachlor	65.78	105.35	120.75	135.73
Bentazone	50.10	61.29	87.36	69.49
1983				
Weedy check	29.67	29.04	38.37	29.02
Butachlor	60.13	85.99	104.72	126.12
Bentazone + Propanil	46.84	72.48	108.32	113.94
	S.Em ±		CD(0.05)	
	1982	1983	1982	1983
For comparing nitrogen means at the same level of weed control	7.50	9.72	21.55	19.82
For comparing weed control treatment means at the same level of nitrogen	7.94	6.87	23.51	20.19

reproduced in Table 37. In general, in 1983, the weed population was considerably higher than the previous year. The data reveal that water regimes failed to exert any considerable influence on this parameter. However, large variations in the weed population was observed in the weed control treatments. The lowest value was always obtained in the butachlor plots which was significantly superior to other treatments at all stages except at 100 days after sowing in the year 1982, when the differences were not significant. The weedy check invariably possessed the largest number of weeds and was at par with bentazone in 1982. But when bentazone was supplemented with propanil in the subsequent year, there was a marked reduction in the number of weeds. However, it was statistically inferior to butachlor.

The nitrogen levels did not display a significant effect on the weed count at any stage except the 70th day after sowing in 1982, when an increase in weed population was noticed with increasing levels of nitrogen (33 in the 150 kg ha^{-1} as against 19 in the no nitrogen control).

The interaction between water regimes and nitrogen levels touched the level of significance in the year 1982 (Table 38). The two irrigation treatments responded to nitrogen application differently in terms of weed population.

Table 37. Mean number of weeds m^{-2} as affected by water regimes, weed control treatments and nitrogen levels (transformed values)

Treatments	Days after sowing					
	35		70		100	
	1982	1983	1982	1983	1982	1983
Water regimes						
Continuous flooding	4.27(17.77)	6.59(43.41)	5.02(24.69)	6.34(40.17)	5.00(24.50)	7.25(52.57)
Alternate flooding and drying	4.74(21.97)	6.79(46.05)	5.27(27.22)	6.67(44.48)	4.81(22.64)	7.27(52.84)
'F' test	NS	NS	NS	NS	NS	NS
S.Em ±	0.34	0.33	0.25	0.32	0.28	0.16
CD (0.05)	-	-	-	-	-	-
Weed control treatments						
Weedy check	5.65(31.42)	10.24(104.89)	6.42(40.72)	10.88(118.47)	5.37(28.34)	10.97(120.25)
Butachlor	3.01(8.56)	4.07(16.59)	3.28(10.24)	3.30(10.88)	4.32(18.16)	3.93(15.45)
Bentazone	4.83(22.82)	-	5.69(31.91)	-	5.01(24.60)	-
Bentazone + Propanil	-	5.75(33.04)	-	5.33(28.39)	-	6.88(47.38)
'F' test	**	**	**	**	NS	**
S.Em ±	0.41	0.40	0.31	0.40	0.34	0.19
CD (0.05)	1.29	1.26	0.97	1.25	-	0.61
Nitrogen ($kg\ ha^{-1}$)						
0	3.68(13.04)	6.30(39.72)	4.42(19.03)	6.04(36.52)	5.03(24.80)	6.99(48.95)
50	4.87(23.22)	6.56(43.08)	5.08(25.35)	6.66(44.41)	4.50(19.75)	7.38(54.33)
100	4.88(23.31)	6.92(47.84)	5.31(27.65)	6.66(44.41)	4.99(24.40)	7.16(51.27)
150	4.60(20.66)	6.97(48.55)	5.75(32.57)	6.65(44.17)	5.08(25.31)	7.49(56.23)
'F' test	NS	NS	**	NS	NS	NS
S.Em ±	0.33	0.23	0.21	0.37	0.17	0.26
CD (0.05)	-	-	0.61	-	-	-

Figures in parenthesis indicate original values

Table 38. Number of weeds m^{-2} at harvest (transformed values) as affected by the interaction between water regimes and nitrogen levels (1983)

Nitrogen (kg ha^{-1})	Water regimes	
	Continuous flooding	Alternate flooding and drying
0	6.63(43.96)	7.36(54.22)
50	6.96(48.40)	7.81(61.03)
100	7.75(60.06)	6.57(43.18)
150	7.67(58.78)	7.33(53.73)

	S.Em ±	CD (0.05)
For comparing nitrogen means at the same level of irrigation	0.37	1.07
For comparing irrigation means at the same level of nitrogen	0.36	1.05

Figures in parenthesis indicate original values

In continuous submergence, there was a quadratic increase while in the alternate flooding and drying treatment, there was a curvilinear response with additional increments of nitrogen.

4.2.2. Dry weight of weeds at various stages

The data on dry matter production of weeds are presented in Table 39. Just as in the case of weed population, their dry matter yield also was higher in the year 1983. Of the weed control treatments, butachlor consistently had the lowest dry weight of weeds. This was significantly superior to all other treatments albeit at par with bentazon plus propanil at 35 days after sowing in the year 1983. At the subsequent stages also, the magnitude of difference between butachlor and bentazone plus propanil treatment was negligible compared to that of butachlor and weedy check (47 and 201 g m^{-2} respectively at 100 days after sowing).

Regarding nitrogen application, increasing levels of this element, resulted in progressively higher dry weight of weeds. However, the difference between two consecutive levels was not always significant. The interaction between weed control treatments and nitrogen levels was significant in the year 1983 at 35 and 100 days after sowing (Tables 40 and 41). Although, there was an increasing trend with increasing levels of nitrogen in

Table 39. Dry weight of weeds (g m^{-2}) as affected by water regimes, weed control treatments and nitrogen levels

Treatments	Days after sowing					
	35		70		100	
	1982(trans-formed values	1983	1982(trans-formed values)	1983	1982	1983
Water regimes						
Continuous flooding	4.59(20.57)	42.63	10.78(115.7)	128.3	109.8	147.2
Alternate flooding and drying	4.79(22.35)	40.74	12.42(153.8)	126.7	128.8	151.3
'F' test	NS	NS	NS	NS	NS	NS
S.Em ±	0.54	3.31	0.68	16.9	10.4	8.8
CD (0.05)	-	-	-	-	-	-
Weed control treatments						
Weedy check	5.69(35.02)	97.80	14.83(219.4)	238.2	145.9	267.6
Butachlor	2.91(7.97)	8.25	6.86(46.5)	33.8	72.1	66.4
Bentazone	5.15(26.02)	-	13.08(170.6)	-	138.9	-
Bentazone + Propanil	-	19.00	-	110.6	-	113.7
'F' test	*	**	**	**	**	**
S.Em ±	0.66	4.06	0.84	20.7	12.7	10.8
CD (0.05)	2.08	12.78	2.64	65.4	40.1	33.9
Nitrogen (kg ha^{-1})						
0	3.34(10.66)	20.29	9.15(83.2)	92.8	88.3	102.4
50	4.50(19.75)	41.66	10.60(111.8)	128.2	109.3	141.5
100	5.74(32.45)	47.73	12.98(167.9)	127.6	126.7	158.7
150	5.15(26.02)	57.05	13.66(186.1)	161.4	153.0	194.3
'F' test	*	**	**	**	**	**
S.Em ±	0.50	7.07	0.62	7.9	7.30	10.6
CD (0.05)	1.42	20.30	1.77	22.6	20.9	30.6

Figures in parenthesis indicate original values

Table 40. Dry weight of weeds (g m^{-2}) at 35 days after sowing as affected by the interaction between weed control treatments and nitrogen levels (1983)

Weed control treatments	Nitrogen (kg ha^{-1})			
	0	50	100	150
Weedy check	43.17	98.27	110.30	139.4
Butachlor	9.23	4.98	8.98	9.8
Bentazone + Propanil	8.47	21.73	23.92	21.8

	S.Em ±	CD(0.05)
For comparing nitrogen means at the same level of weed control	12.25	35.16
For comparing weed control treatment means at the same level of nitrogen	11.36	33.01

Table 41. Dry weight of weeds (g m^{-2}) at 100 days after sowin as affected by the interaction between weed control treatments and nitrogen levels (1983)

Weed control treatments	Nitrogen (kg ha^{-1})			
	0	50	100	150
Weedy check	190.1	234.6	291.4	353.6
Butachlor	41.1	70.8	56.1	97.4
Bentazone + Propanil	75.1	119.1	128.6	131.9

	S.Em ±	CD (0.05)
For comparing nitrogen means at the same level of weed control	18.4	52.9
For comparing weed control treatment means at the same level of nitrogen	19.2	56.9

all weed control treatments, the magnitude of increase was considerably higher in the weedy check. At 100 days after sowing, the weed dry weight increased from 41.1 to 97.4 g m^{-2} in the butachlor plots by raising the nitrogen levels from 0 to 150 kg ha^{-1}. The corresponding figures for the weedy check were 190.1 and 353.6 g m^{-2}.

4.2.3. Elemental composition of weeds (NPK %) at different stages

The data pertaining to the concentration of nitrogen, phosphorus and potassium in the weeds at 35 and 100 days after sowing are presented in Tables 42 and 43.

4.2.3.1. Nitrogen

The weed control treatments affected this parameter in the first year of experimentation at 100 days after sowing. Butachlor had a significantly lower tissue nitrogen content (1.11 per cent) compared to weedy check (1.31 per cent) and bentazone (1.33 per cent).

Nitrogen application resulted in a higher nitrogen content of tissues over no nitrogen control at all stages except at 100 days after sowing in the year 1983. The interaction between weed control treatments and nitrogen levels at 100 days after sowing was significant in the year 1982 (Table 44). At each weed control treatment, increasing doses of nitrogen raised nitrogen concentration in the weeds.

Table 42. Elemental composition (NPK %) of weeds as affected by water regimes, weed control treatments and nitrogen levels (1982)

Treatments	Nitrogen		Phosphorus		Potassium	
	30 DAS (trans-formed value)	100DAS	35 DAS (trans-formed value)	100 DAS	35 DAS (trans-formed value)	100 DAS
Water regimes						
Continuous flooding	1.49(1.72)	1.24	0.94(0.39)	0.282	1.42(1.51)	1.39
Alternate flooding and drying	1.48(1.71)	1.25	0.93(0.37)	0.284	1.37(1.39)	1.43
'F' test	NS	NS	NS	NS	NS	NS
S.Em ±	0.041	0.048	0.026	0.0057	0.0596	0.057
CD (0.05)						
Weed control treatments						
Weedy check	1.58(1.99)	1.31	0.98(0.46)	0.293	1.58(1.98)	1.50
Butachlor	1.35(1.32)	1.11	0.88(0.27)	0.280	1.16(0.85)	1.27
Bentazone	1.54(1.87)	1.33	0.95(0.40)	0.275	1.45(1.60)	1.46
'F' test	NS	*	NS	NS	**	NS
S.Em ±	0.050	0.059	0.032	0.0070	0.0730	0.069
CD (0.05)	-	0.186	-	-	0.2300	-
Nitrogen (kg ha^{-1})						
0	1.33(1.26)	1.07	0.88(0.29)	0.317	1.12(0.76)	1.14
50	1.47(1.66)	1.13	0.94(0.39)	0.279	1.38(1.40)	1.42
100	1.59(2.02)	1.32	0.95(0.40)	0.272	1.51(1.77)	1.57
150	1.57(1.97)	1.48	0.97(0.44)	0.263	1.57(1.98)	1.49
'F' test	*	**	*	NS	**	**
S.Em ±	0.061	0.049	0.016	0.0148	0.0508	0.062
CD (0.05)	0.174	0.140	0.047	-	0.1458	0.179

DAS : days after sowing. Figures in parenthesis indicate original values

Table 43. Elemental composition (NPK - %) of weeds as affected by water regimes, weed control treatments and nitrogen levels (1983)

Treatments	Nitrogen		Phosphorus		Potassium	
	30 DAS	100 DAS	35 DAS	100 DAS	35 DAS	100 DAS
Water regimes						
Continuous flooding	2.02	1.24	0.274	0.182	2.08	1.40
Alternate flooding and drying	2.08	1.25	0.282	0.174	2.18	1.35
'F' test	NS	NS	NS	NS	NS	NS
S.Em ±	0.11	0.03	0.009	0.006	0.071	0.056
CD (0.05)	-	-	-	-	-	-
Weed control treatments						
Weedy check	2.15	1.22	0.285	0.173	2.38	1.27
Butachlor	1.86	1.27	0.274	0.189	1.95	1.43
Bentazone + Propanil	2.15	1.25	0.274	0.172	2.07	1.43
'F' test	NS	NS	NS	NS	*	NS
S.Em ±	0.14	0.04	0.001	0.007	0.086	0.068
CD (0.05)	-	-	-	-	0.272	-
Nitrogen (kg ha^{-1})						
0	1.92	1.17	0.273	0.178	2.05	1.35
50	1.91	1.18	0.276	0.177	2.13	1.31
100	2.17	1.25	0.287	0.178	2.17	1.42
150	2.21	1.38	0.286	0.180	2.18	1.42
'F' test	**	NS	NS	NS	NS	NS
S.Em ±	0.07	0.08	0.008	0.006	0.041	0.080
CD (0.05)	0.20	-	-	-	-	-

DAS : Days after sowing

Table 44. Nitrogen content in weeds (%) at 100 days after sowing as affected by interaction between weed control treatments and nitrogen levels (1982)

Weed control treatments	Nitrogen (kg ha^{-1})			
	0	50	100	150
Weedy check	1.08	1.28	1.47	1.42
Butachlor	1.05	1.05	1.04	1.29
Bentazone	1.08	1.06	1.45	1.73

	S.Em ±	CD(0.05)
For comparing nitrogen means at the same level of weed control	0.0847	0.2430
For comparing weed control treatment means at the same level of nitrogen	0.0941	0.2805

Table 45. Potassium content (%) in weeds at 35 days after sowing (transformed values) as affected by interaction between weed control treatments and nitrogen levels (1982)

Weed control treatments	Nitrogen (kg ha^{-1})			
	0	50	100	150
Weedy check	1.48 (1.70)	1.57 (1.95)	1.60 (2.06)	1.65 (2.22)
Butachlor	0.85 (0.22)	0.99 (0.48)	1.34 (1.29)	1.45 (1.61)
Bentazone	1.04 (0.57)	1.57 (1.95)	1.58 (2.01)	1.62 (2.12)

	S.Em ±	CD (0.05)
For comparing nitrogen means at the same level of weed control	0.0879	0.2525
For comparing weed control treatment means at the same level of nitrogen	0.1055	0.3170

Figures in parenthesis indicate original values

The weedy check and bentazone had a markedly higher nitrogen content than butachlor.

4.2.3.2. Phosphorus

None of the treatments was found to play a dominan role in deciding the phosphorus concentration in weeds except the nitrogen levels at 35 days after sowing in the first year. It was observed that at this stage, additional increments of nitrogen favourably influenced this component. However, the differences were not significant over the entire range of 50 to 150 kg N ha^{-1}.

4.2.3.3. Potassium

The data presented in Tables 42 and 43 make it clear that there was marked difference among the weed control treatments at 35 days after sowing in both years. Butachlor and bentazone plus propanil treatments were found to have a lower concentration of potassium in the weeds.

Nitrogen application significantly increased the potassium content of weeds both at 35 and 100 days after sowing in the year 1982. As nitrogen levels increased, the accumulation of potassium was positively influenced. In the subsequent year no detectable difference among the nitrogen levels was noticed.

The interaction between weed control treatments and nitrogen levels turned out to be significant at 35 and 100 days after sowing in the year 1982 (Tables 45 and 46). So also, the interaction between water regimes and nitrogen levels at the latter stage in the same year (Table 47). At each level of irrigation and weed control treatment nitrogen application enhanced the tissue potassium concentration. The potassium content of weeds in the butachlor plots increased from 0.70 to 1.55 per cent over the range 0 to 150 kg N ha^{-1} at 100 days after sowing in 1982. The corresponding figures for weedy check were 1.32 and 1.61 per cent. The increase was more evident in the butachlor treated plots. In other words, the potassium concentration was more than double in the 150 kg N ha^{-1} treatment with butachlor compared to its no nitrogen treatment.

4.2.4. Nutrient depletion by weeds (kg NPK ha^{-1})

The data pertaining to the nutrient removal by weeds at harvest are summarised in Table 48 and Fig. 11. The irrigation treatments failed to have any noticeable influence on the NPK depletion by weeds. The weed control treatments resulted in a marked variation in this parameter. Butachlor registered the lowest value in both the seasons for all the three elements (19.17 and 19.39 kg NPK ha^{-1} in 1982 and 1983, respectively). However, in the year 1983,

Table 46. Potassium content in weeds (%) at 100 days after sowing as affected by interaction between weed control treatments and nitrogen levels (1982)

Weed control treatments	Nitrogen (kg ha^{-1})			
	0	50	100	150
Weedy check	1.32	1.45	1.62	1.61
Butachlor	0.70	1.26	1.57	1.55
Bentazone	1.41	1.56	1.55	1.32

	S.Em ±	CD(0.05)
For comparing nitrogen means at the same level of weed control	0.1079	0.3099
For comparing weed control treatment means at the same level of nitrogen	0.1164	0.3457

Table 47. Potassium content in weeds (%) at 100 days after sowing as affected by interaction between water regimes and nitrogen levels (1982)

Water regimes	Nitrogen (kg ha^{-1})			
	0	50	100	150
Continuous flooding	1.15	1.30	1.47	1.63
Alternate flooding and drying	1.14	1.54	1.69	1.35

	S.Em ±	CD (0.05)
For comparing nitrogen means at the same level of irrigation	0.0881	0.2530
For comparing irrigation means at the same level of nitrogen	0.0950	0.2822

Table 48. Depletion of N, P and K by weeds (kg ha^{-1}) at harvest as affected by water regimes, weed control treatments and nitrogen levels

Treatments	N		P		K	
	1982	1983	1982	1983	1982	1983
<u>Water regimes</u>						
Continuous flooding	14.23	18.14	3.03	2.62	15.26	20.45
Alternate flooding and drying	16.88	18.94	3.69	2.49	18.43	18.85
'F' test	NS	NS	NS	NS	NS	NS
S.Em ±	1.95	1.33	0.32	0.27	2.30	1.68
CD (0.05)	-	-	-	-	-	-
<u>Weed control treatments</u>						
Weedy check	19.87	32.50	4.26	4.54	22.04	32.48
Butachlor	7.99	8.59	2.03	1.23	9.15	9.57
Bentazone	18.80	-	3.78	-	20.29	-
Bentazone + Propanil	-	14.53	-	1.90	-	16.92
'F' test	*	**	**	**	**	**
S.Em ±	2.40	1.63	0.32	0.33	2.82	2.05
CD (0.05)	7.56	5.13	1.23	1.03	8.89	6.47
<u>Nitrogen (kg ha^{-1})</u>						
0	9.42	12.03	2.83	1.76	10.06	13.70
50	12.88	15.99	2.99	2.30	15.53	18.43
100	17.68	19.96	3.55	2.76	19.84	22.06
150	22.24	26.19	4.05	3.41	22.80	24.44
'F' test	**	**	*	**	**	*
S.Em ±	1.31	1.92	0.29	0.20	1.93	2.47
CD (0.05)	3.76	5.51	0.83	0.58	5.53	7.10

this was found to be at par with bentazone plus propanil combination which lost 33.35 kg NPK ha^{-1} through weed removal.

Nitrogen application always resulted in increased depletion of fertilizer nutrients. As the rates were increased, the losses also grew in magnitude. The interaction between weed control treatments and nitrogen levels was significant with respect to nitrogen and phosphorus depletion in 1982 and 1983 respectively (Tables 49 and 50). Nitrogen loss was accelerated by additional doses of nitrogen in the weedy check and bentazone plots. But it was almost unchanged in the butachlor plots over the entire range of 0 to 150 kg N ha^{-1}. The increase was from 5 to 9 kg N ha^{-1} in the butachlor, whereas it grew from 11 to 28 kg N ha^{-1} in the weedy check. As regards to the interaction between weed control treatments and nitrogen levels on phosphorus depletion by weeds, there was no marked difference amongst the nitrogen levels either in butachlor or bentazone plus propanil plots. However, there was a greater and greater loss of phosphorus in the weedy check with each additional increments of nitrogen.

4.3. Effect of Moisture Regimes on Croo Water Use

Rate of soil moisture depletion as depicted by the changes in daily mean soil moisture tension values (MPa)

Table 49. Nitrogen depletion by weeds (kg ha^{-1}) as affected by interaction between weed control treatments and nitrogen levels (1982)

Weed control treatments	Nitrogen (kg ha^{-1})			
	0	50	100	150
Weedy check	10.88	17.13	23.21	28.25
Butachlor	5.14	7.54	10.46	8.83
Bentazone	12.22	13.97	19.37	29.65

	S.Em ±	CD (0.05)
For comparing nitrogen means at the same level of weed control	2.244	7.071
For comparing weed control treatment means at the same level of nitrogen	3.084	9.457

Table 50. Phosphorus depletion by weeds (kg ha^{-1}) as affected by the interaction between weed control treatments and nitrogen levels (1983)

Weed control treatments	Nitrogen (kg ha^{-1})			
	0	50	100	150
Weedy check	3.13	3.61	5.12	6.30
Butachlor	0.77	1.27	1.10	1.78
Bentazone + Propanil	1.37	2.02	2.07	2.15

	S.Em ±	CD(0.05)
For comparing nitrogen means at the same level of weed control	0.35	1.01
For comparing weed control treatment means at the same level of nitrogen	0.45	1.35

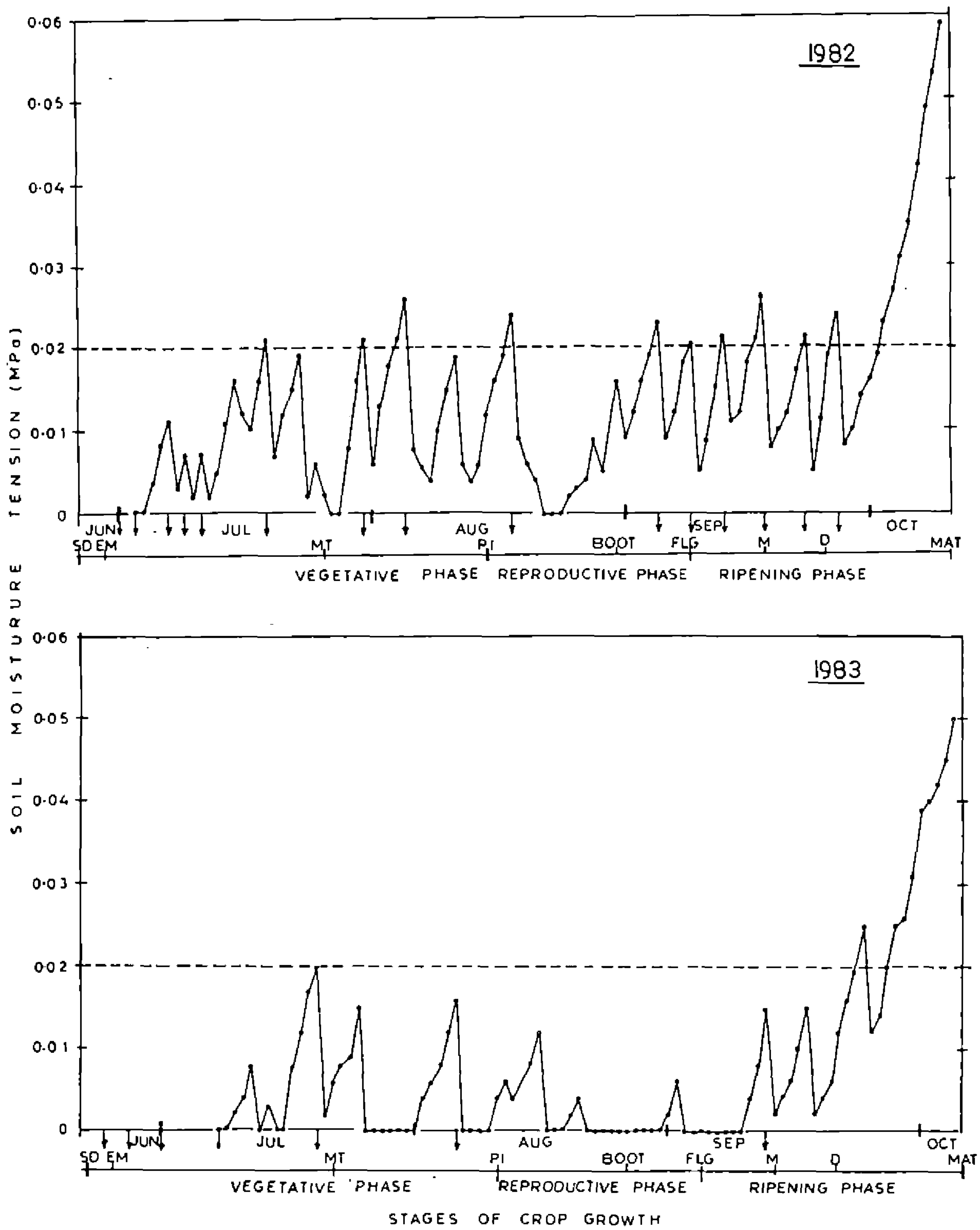
at 15 cm depth for the alternate flooding and drying treatment are presented graphically in Fig. 7. The crests depict the extent of maximum tension reached, while the troughs denote the tension reached just after the irrigation or rainfall. Dates of irrigation have been indicated by arrows on the abscissa.

A critical observation of the Fig. 7 reveals that in the year 1983 because of well distributed precipitation, the soil moisture tension seldom reached the critical value of 0.02 MPa. Therefore, the number of irrigations given during that season was considerably less than the previous year.

4.4. Irrigation Requirement and Water Use Efficiency (WUE)

The average account of water addition (by irrigation and effective rainfall) in mm and the water use efficiency (kg $ha^{-1} cm^{-1}$) as affected by water regimes are presented in Table 31. The figures for water use under the continuously and alternately submerged water regimes were 2358.16 mm and 1208.16 mm in 1982 and 1289.6 mm and 889.6 mm in 1983 respectively. Because of the climatic factors the figures were considerably low in 1983. The water use efficiency was greater in the second year under both the water regimes. The figures under continuously flooded and alternately flooded treatments were 1.32 and

FIG.7 PROGRESSIVE CHANGES IN SOIL MOISTURE TENSION IN THE ALTERNATE FLOODING AND DRYING PLOTS.



(↓ - Irrigation , SD - Seeding , EM - Emergence , MT - Maximum tillering , PI - Panicle initiation, BOOT - Booting stage , M - Milk stage, D - Dough grain stage, MAT - Maturity)

Table 51. Water use and water use efficiency as affected by moisture regimes

Treatments	Irrigation requirement (mm)	Effective rainfall (mm)	Water use (mm)	Grain yield (kg ha^{-1})	Water use efficiency (kg $ha^{-1} mm^{-1}$)
1982					
Continuous submergence	1900	458.16	2358.16	3108	1.32
Alternate flooding and drying	750	458.16	1208.16	2563	2.12
1983					
Continuous submergence	750	539.60	1289.6	2697	2.09
Alternate flooding and drying	350	539.60	889.6	2656	2.99

Table 52. Mean water use efficiency as affected by weed control treatments and nitrogen levels

Treatments	Water use efficiency (kg $ha^{-1} cm^{-1}$) 1982	1983
Weed control treatments		
Weedy check	1.35	1.04
Butachlor	2.53	3.44
Bentazone	1.41	-
Bentazone + Propanil	-	3.14
Nitrogen (kg ha^{-1})		
0	1.25	1.62
50	1.80	2.23
100	2.06	3.02
150	1.94	3.28

2.12 kg $ha^{-1}cm^{-1}$ in 1982 and 2.09 and 2.99 kg $ha^{-1}cm^{-1}$ in 1983 respectively. In both years the latter treatment turned out to be more efficient.

It is clear from Table 52, that WUE is extremely low in the weedy check and bentazone plots. Butachlor and bentazone plus propanil treatments recorded considerably higher water use efficiencies (2.53 and 3.44 kg $ha^{-1}cm^{-1}$ in 1982 and 1983 respectively in the butachlor plots as against 1.35 and 1.04 kg $ha^{-1}cm^{-1}$ in the weedy check). The favourable effect of nitrogen application on enhancing the WUE is well documented. There was 55 and 102 per cent increase in WUE in 1982 and 1983 respectively over the range 0 to 150 kg N ha^{-1}.

4.5. Economics of Direct-seeded Upland Rice Cultivation

Details of cost of inputs and produce are given in Appendices IV and V. A perusal of the data summarised in Table 53, makes it distinctly evident that net profit as well as return per rupee invested were high in the alternately flooded and dried treatment. As far as the weed control treatments are concerned, the highest net profit (Rs. 3714.0 and Rs. 3530.0 ha^{-1} in 1982 and 1983, respectivel and the maximum return per rupee invested (Rs. 1.13 and Rs. 1.32 in 1982 and 1983 respectively) were obtained in

Table 53. Net profit and net return per rupee invested as affected by soil moisture regimes weed control treatments and nitrogen levels

Treatments	Net profit (Rs ha^{-1})			Returns (Rs Re invested^{-1})		
	1982	1983	Mean	1982	1983	Mean
<u>Water regimes</u>						
Continuous flooding	1686	1860	1773	0.46	0.61	0.54
Alternate flooding and drying	1935	2177	2056	0.71	0.83	0.77
<u>Weed control treatments</u>						
Weedy check	1006	-238	384	0.38	-0.08	0.15
Butachlor	3714	3530	3622	1.13	1.32	1.23
Bentazone	713	-	713	0.24	-	0.24
Bentazone + Propanil	-	2764	2764	-	0.92	0.92
<u>Nitrogen (kg ha^{-1})</u>						
0	901	844	872	0.37	0.39	0.38
50	2050	1579	1814	0.68	0.61	0.65
100	2407	2734	2570	0.75	0.96	0.86
150	1887	2918	2402	0.54	0.93	0.74

the butachlor treated plots. The weedy check resulted in a net loss of Rs. 238.0 ha^{-1} in the year 1983. Application of bentazone provided only a meagre profit of Rs. 713.0 ha^{-1}. However, where it was supplemented with propanil the profit margin was substantially improved (Rs. 2764.0 ha^{-1}).

Increasing levels of nitrogen consistently increased the net profit and return per rupee invested. The highest net profit was recorded in the 100 kg N ha^{-1} plot in 1982 (167.17 per cent greater than no nitrogen control) and in the 150 kg N ha^{-1} plot in the subsequent year (245.75 per cent higher than no nitrogen control). However, the return per rupee invested was highest in the 100 kg N ha^{-1} treatment in both years (Rs. 0.75 and Rs. 0.96 in 1982 and 1983 respectively). Addition of nitrogen in the weedy plots progressively increased the losses (Table 54).

4.6. Pot Culture Studies

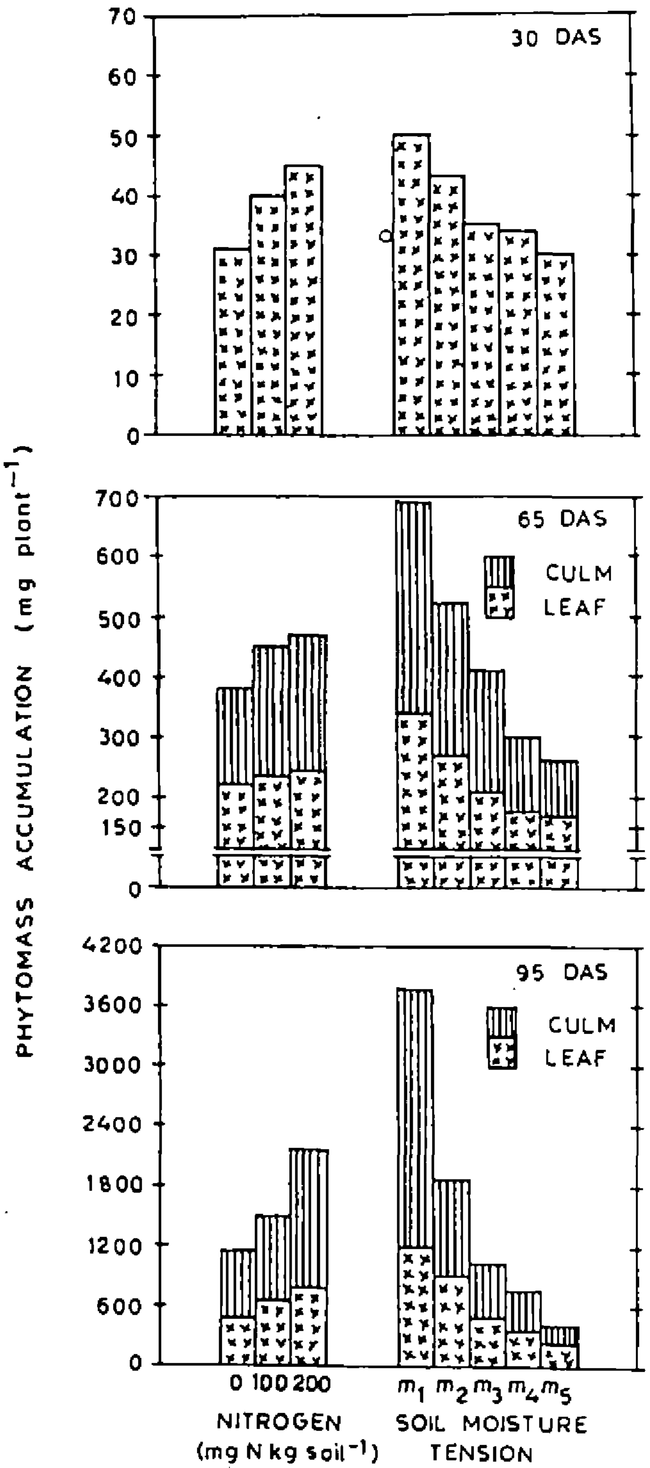
4.6.1. Phytomass accumulation (mg $plant^{-1}$) at various stages of growth

The observations on phytomass yield are presented in Table 55 and Fig. 8. It clearly points out that there is no significant difference between the two genotypes in this respect at any of the stages except that at 65 days

Table 54. Net profit (Rs. ha^{-1}) as affected by the interaction between weed control treatments and nitrogen levels

Weed control treatments	Nitrogen (kg ha^{-1})			
	0	50	100	150
<u>1982</u>				
Weedy check	1352	1512	952	211
Butachlor	1080	4237	4450	5088
Bentazone	271	402	1818	361
<u>1983</u>				
Weedy check	268	-358	-90	-773
Butachlor	1574	2948	4278	5322
Bentazone + Propanil	690	2145	4013	4205

FIG. 8 PHYTOMASS ACCUMULATION (mg plant⁻¹) IN THE SHOOT AS AFFECTED BY NITROGEN LEVELS AND SOIL MOISTURE TENSION



(m_1 –submergence to saturation and m_2–m_5, 0–0·025, 0–0·050, 0–0·075 and 0–0·10 MPa soil moisture tension respectively. DAS – Days after sowing)

Table 55. Phytomass accumulation (mg plant^{-1}) as affected by genotypes, nitrogen levels and moisture regimes

Treatments	Days after sowing					
	30	65		95		
	Shoot	Leaf	Culm	Leaf	Culm	Total
Genotypes						
Pusa 33 (v_1)	[illegible]9.00	219.44	185.78	624.44	968.89	1593.33
Pusa 312 (v_2)	[illegible]3.22	246.44	217.22	625.55	929.78	1523.11
'F' test	NS	*	NS	NS	NS	NS
S.Em ±	.864	10.22	13.80	41.97	142.40	176.90
CD (0.05)	-	29.98	-	-	-	-
Nitrogen (mg kg soil^{-1})						
0 (n_0)	30.83	222.50	155.83	476.67	618.33	1095.00
100 (n_1)	40.00	232.50	219.00	640.00	854.67	1494.66
200 (n_2)	45.00	245.83	229.67	758.33	1375.00	2133.33
'F' test	**	NS	*	**	*	**
S.Em ±	2.283	12.52	16.98	151.41	174.40	216.70
CD (0.05)	6.696	-	49.82	150.78	511.54	635.65
Moisture regimes						
Submergence to saturation (control) (m_1)	49.72	341.67	350.00	1197.22	2586.11	3783.33
0-0.025 MPa (m_2)	43.33	269.44	250.00	883.33	997.22	1880.55
0-0.05 MPa (m_3)	35.00	209.72	197.22	463.89	555.56	1019.44
0-0.075 MPa (m_4)	34.44	176.39	117.78	355.56	402.22	757.77
0-0.10 MPa (m_5)	30.56	167.50	92.50	225.00	205.56	430.55
'F' test	**	**	**	**	**	**
S.Em ±	2.947	16.16	21.90	66.37	225.15	280.10
CD (0.05)	8.644	47.41	64.30	194.66	660.40	821.58

after sowing when the drought tolerant cultivar, Pusa 312, has accumulated more phytomass in the leaves.

The phytomass accumulation increased considerably in response to the increasing levels of nitrogen albeit difference between the 100 and 200 mg N kg soil^{-1} was not significant in the initial phase of crop growth. But at 95 days after sowing, considerable variation was visible in the total as well as culm masses between these two treatments. The higher level was evidently more efficient (43 per cent higher) in total phytomass accumulation than the 100 mg N kg soil^{-1} treatment.

The data also make it clear that there exists a parallel relationship between soil matric potential and dry weight. The total dry weight decreased linearly as the soil matric potential decreased. The same trend was reflected on the leaf and culm phytomasses at all stages. The submergence to saturation (m_1) treatment was always superior (3783.33 mg plant^{-1} at 95 days after sowing) to the remaining water regimes except at 30 days after sowing. At this stage it was at par with the 0-0.025 MPa tension (m_2) treatment.

4.6.2. <u>In vivo nitrate reductase activity (NO_2^- formed nM g fr.wt.$^{-1}$h^{-1})</u>

The two genotypes did not differ statistically

(Table 56) even though the drought tolerant Pusa 312 invariably registered a higher nitrate reductase activity (NRA). Increments of nitrogen had a stimulatory effect on NRA. The lowest activity was recorded in the no nitrogen treatment at all stages of observation. NRA increased consistently as the amount of applied nitrogen increased. The 200 mg N kg soil^{-1} treatment had 78, 40 and 72 per cent higher NRA over no nitrogen control respectively at 30, 50 and 70 days after sowing. However, beyond 100 mg N kg soil^{-1}, the increase in activity was at a diminishing rate. Consequently, the 100 and 200 mg N kg soil^{-1} were at par initially upto the 50 day stage.

The enzyme activity was drastically affected by moisture stress at all stages of growth (Fig. 9a and Table 56). The reduction in NRA was characterized by an initial faster rate upto 0.05 MPa tension and a subsequent slower rate of decline. At 70 days after sowing, NRA was only 47 per cent of the control (m_1), in the m_3 treatment which further declined to 37 and 24 per cent respectively in the m_4 and m_5 moisture regimes. The highest activity recorded were 1652.13, 2678.58 and 1112.47 nM NO_2^- formed g fr. wt.$^{-1}$h^{-1} respectively at 30, 50 and 70 days after sowing in the m_1 treatment whereas the lowest values were obtained in driest treatment (m_5) viz. 379.06, 385.11 and 259.06 nM NO_2^- formed g fr. wt^{-1}h^{-1} respectively at 30, 50 and 70 days after sowing.

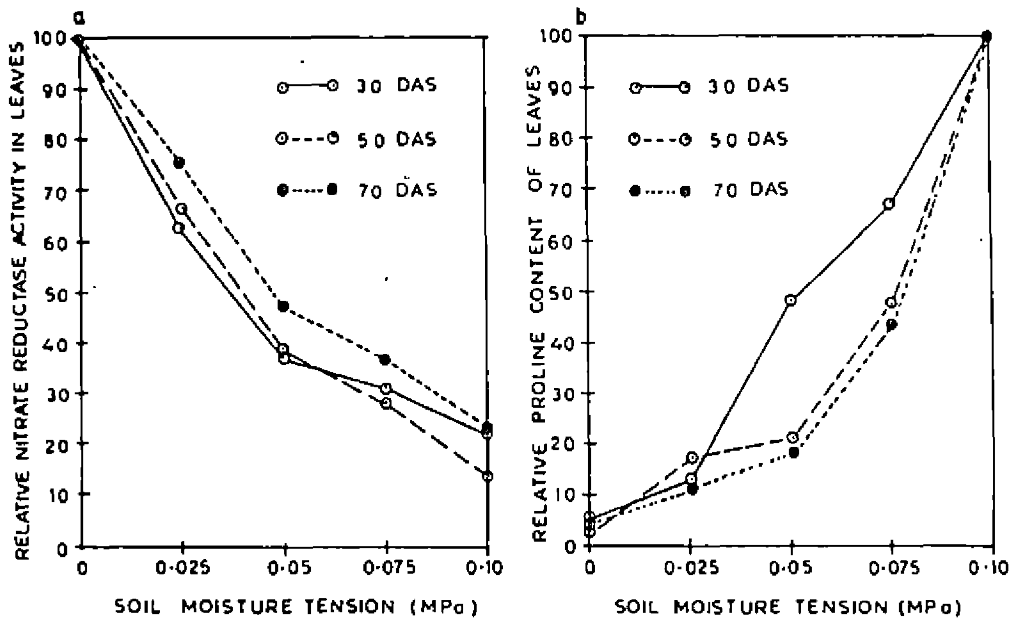


FIG.9. RELATIONSHIP BETWEEN SOIL MOISTURE TENSION AND NITRATE REDUCTASE ACTIVITY (a) AND PROLINE ACCUMULATION (b) IN RICE LEAVES.

(Relative values with submergence to saturation and 0–0·10 MPa soil moisture tension taken as 100 in (a) and (b) respectively. Points on the abscissa correspond to the tension at which irrigations were scheduled DAS–Days after sowing).

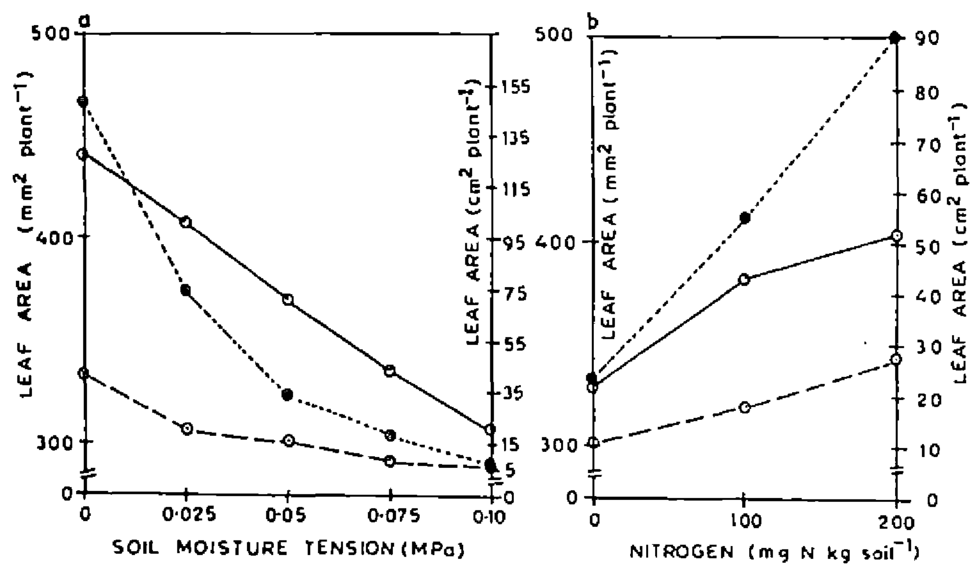


FIG.10. LEAF AREA AT 30 DAS (mm^2 plant^{-1} o——o) 65 DAS (cm^2 plant^{-1}, o– –o) AND 95 DAS (cm^2 plant^{-1} •·····•) AS AFFECTED BY SOIL MOISTURE TENSION (a) AND NITROGEN LEVELS (b).

(Points on the abscissa of FIG. 10. a correspond to the tension at which irrigations were scheduled, DAS –Days after sowing).

Table 56. Nitrate Reductase Activity (NO_2^- formed, nM g leaf fwt^{-1}h^{-1}) and free proline content (uM proline g leaf fwt^{-1}) as affected by genotypes, nitrogen levels and moisture regimes

Treatments	Nitrate Reductase Activity			Proline content		
	Days after sowing			Days after sowing		
	30	50	70	30	50	70
Genotypes						
Pusa 33 (v_1)	813.24	1278.64	612.39	0.2767	0.5816	0.8160
Pusa 312 (v_2)	861.37	1367.22	646.36	0.2829	0.5527	0.7979
'F' test	NS	NS	NS	NS	NS	NS
S.Em ±	84.96	86.75	35.36	0.0159	0.0255	0.0382
CD (0.05)	-	-	-	-	-	-
Nitrogen (mg kg soil^{-1})						
0 (n_0)	593.23	1059.93	453.13	0.2311	0.5079	0.6908
100 (n_1)	864.04	1423.40	652.25	0.2676	0.5249	0.8266
200 (n_2)	1054.65	1485.47	783.27	0.3407	0.6687	0.9033
'F' test	*	*	**	**	**	**
S.Em ±	104.05	106.24	43.31	0.0195	0.0312	0.0467
CD (0.05)	305.19	311.62	127.02	0.0572	0.0915	0.1370
Moisture regimes						
Submergence to saturation (control) (m_1)	1652.13	2678.58	1112.47	0.0319	0.0658	0.1259
0-0.025 MPa (m_2)	1035.40	1769.50	837.92	0.0747	0.2739	0.2730
0-0.05 MPa (m_3)	609.99	1016.95	527.33	0.2900	0.3223	0.4225
0-0.075 MPa (m_4)	509.93	764.51	410.97	0.4023	0.6014	0.9734
0-0.10 MPa (m_5)	379.06	385.11	259.06	0.6002	1.5725	2.2400
'F' test	**	**	**	**	**	**
S.Em ±	134.33	137.16	55.91	0.0252	0.0403	0.0603
CD (0.05)	393.10	402.30	163.99	0.0739	0.1182	0.1769

N application 15 and 45 days after sowing

It could also be seen that NRA increased with the age of the plant, reached a peak at around 50 days after sowing and then started declining.

4.6.3. Free proline content of rice leaves (μM proline g leaf fr. wt^{-1})

The free proline content of rice leaves as affected by genotypes, nitrogen levels and water stress are presented in Table 56. With respect to the accumulation of proline, the two cultivars behaved in a similar fashion. Nitrogen levels had a stimulatory effect on the accumulation of this iminoacid. However, the magnitude of increase was very small. Proline accumulation increased almost linearly with increasing water stress (Fig. 9b). The highest proline content was always obtained in the driest treatment (m_5). The m_1 possessed 5.6 per cent; m_2 - 12 per cent; m_3 - 19 per cent and m_4 - 43 per cent of this value, at 70 days after sowing. A similar trend was obtained at other stages also.

4.6.4. Leaf area (cm^2 plant^{-1})

The data are presented in Table 57 and Fig. 10. Regarding the genotypes, the difference was statistically not significant. The data also reveal that higher levels of nitrogen application consistently increased the leaf are at all the phenological stages studied.

Table 57. Leaf area (cm^2 $plant^{-1}$) and plant height (cm) as affected by genotypes, nitrogen levels and moisture regimes

Treatments	Leaf area			Plant height
	days after sowing			
	30	65	95	
<u>Genotypes</u>				
Pusa 33 (v_1)	3.662	15.16	53.48	38.90
Pusa 312 (v_2)	3.778	21.23	58.18	38.56
'F' test	NS	NS	NS	NS
S.Em ±	0.094	3.87	11.66	0.811
CD (0.05)	-	-	-	-
<u>Nitrogen (mg kg soil^{-1})</u>				
0 (n_0)	3.314	10.12	23.31	34.93
100 (n_1)	3.823	17.22	54.42	39.21
200 (n_2)	4.023	27.23	89.76	41.98
'F' test	**	NS	*	**
S.Em ±	0.115	4.74	14.28	0.99
CD (0.05)	0.338	-	41.89	2.91
<u>Moisture regimes</u>				
Submergence to saturation (control - m_1)	4.39	42.18	146.69	66.31
0-0.025 MPa - m_2	4.07	19.87	73.77	42.14
0-0.05 MPa - m_3	3.70	15.08	34.54	31.56
0-0.075 MPa - m_4	3.35	8.16	16.65	27.89
0-0.10 MPa - m_5	3.07	5.66	7.50	25.64
'F' test	**	*	**	**
S.Em ±	0.149	6.11	18.44	1.28
CD (0.05)	0.436	17.93	54.09	3.76

Depletion of soil moisture and decreased soil matric potential caused a decline in the leaf area expansion of water stressed plants. As the growth stages advanced the difference also grew in magnitude between the stressed and the control plants. The total leaf area per plant was 147 cm^2 after 95 days from sowing in the control, whereas it was only 7.5 cm^2 in the m_5. The data undoubtedly underscore the superiority of the control plants over the stressed plants for leaf area enlargement.

4.6.5. <u>Plant height (cm)</u>

The dominant role of nitrogen in increasing the plant height can be easily made out from the data given in Table 57. When the plants were nitrogen starved, just as leaf area, plant height also was significantly retarded. Plant height was found to decrease substantially as the soil matric potential decreased. The control plants were significantly taller than all other water regimes. So also m_2 was markedly superior to m_3, m_4 and m_5 in respect of plant height.

4.6.6. <u>Concentration (%) and uptake (mg $plant^{-1}$) of fertilizer elements</u>

The data pertaining to NPK concentration and uptake are presented in Table 58. There was no perceptible variation in the concentration of nitrogen and phosphorus in the two cultivars tried. Similarly, nitrogen levels were also

Table 58. NPK concentration and uptake as affected by the genotypes, nitrogen levels and moisture regimes at 95 days after sowing

Treatments	Concentration(%)			Uptake(mg plant^{-1})		
	N	P	K	N	P	K
Genotypes						
Pusa 33 (v_1)	2.80	0.187	1.280	37.47	3.01	20.66
Pusa 312 (v_2)	2.85	0.194	1.350	36.89	2.96	21.32
'F' test	NS	NS	**	NS	NS	NS
S.Em ±	0.038	0.004	0.005	2.78	0.32	2.37
CD (0.05)	-	-	0.015	-	-	-
Nitrogen (mg kg soil^{-1})						
0 - n_0	2.79	0.197	1.331	26.68	2.20	14.96
100 - n_1	2.88	0.193	1.291	36.84	2.82	19.70
200 - n_2	2.81	0.183	1.317	48.02	3.93	28.32
'F' test	NS	NS	NS	**	*	*
S.Em ±	0.046	0.005	0.006	3.41	0.39	2.91
CD (0.05)	-	-	-	10.01	1.14	8.53
Moisture regimes						
Submergence to saturation (control)-(m_1)	1.54	0.190	1.327	59.99	7.06	49.85
0-0.025 MPa (m_2)	3.00	0.193	1.427	56.45	3.62	26.82
0-0.05 MPa (m_3)	3.05	0.201	1.353	31.06	2.05	13.80
0-0.075 MPa (m_4)	3.14	0.187	1.187	23.86	1.40	9.00
0-0.10 MPa (m_5)	3.36	0.183	1.272	14.54	0.79	5.49
'F' test	**	NS	**	**	**	**
S.Em ±	0.060	0.007	0.008	4.41	0.50	3.75
CD (0.05)	0.176	-	0.023	12.92	1.47	11.01

at par in this regard. However, moisture regimes exerted a profound influence on nutrient concentration in the tissues. There was a distinct increase in nitrogen content of the plant tissues as the soil water availability decreased (3.36 per cent in the 0-0.1 MPa soil moisture tension as against 1.54 per cent in the control). Interestingly, phosphorus and potassium do not conform to this pattern. Regarding phosphorus concentration, first it increased from 0.19 per cent in the control to 0.201 per cent in the m_3 treatment. Finally it decreased again as the tension reached 0.10 MPa. However, the differences were not statistically significant. Potassium concentration was highest in m_2 which was significantly superior to all other treatments. After attaining this peak, the potassium content in the tissues decreased as the soil moisture tension further increased.

It appears from the data given in Table 58 that ....rogen, phosphorus and potassium uptake per plant did not differ in the two genotypes tried. At the same time, increasing levels of nitrogen resulted in a considerable effect on the uptake of all the three nutrients. The magnitude of increase in the 200 mg N kg soil^{-1} was to the tune of 79, 79 and 89 per cent respectively for nitrogen, phosphorus and potassium, over no nitrogen.

Nutrient uptake steadily declined as the soil water availability decreased. The lowest value was always obtained in the driest treatment : m_5 treatment contained 14.54, 0.79 and 5.49 mg N, P and K $plant^{-1}$ respectively as against 59.99, 7.06 and 49.85 mg N, P and K $plant^{-1}$ in the control.

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CHAPTER V

DISCUSSION

A field investigation to study the interaction of nitrogen with weed control treatments under two water regimes and a green house experiment to investigate the nitrogen assimilation as affected by water stress were undertaken. The salient findings are discussed in the ensuing section.

Climatic factors were comparatively more favourable in 1983 than during the previous year. A higher amount of well distributed rainfall was the hallmark of that season as against the first year, in which the rainfall distribution was positively skewed. During the critical phases of crop growth such as panicle initiation and flowering, there was very little rainfall in 1982. However, it is observed that growth and yield of rice in general were better in 1982. It is paradoxical that despite favourable climatic parameters, yield was low in 1983. Higher yields are highly correlated with a high net photosynthesis (photosynthesis - respiration). Mutual shading and inadequate nitrogen supply are known to upset the net photosynthesis. It is clear from the Tables 37 and 39, that the total number of weeds and their dry matter production were much higher in the second year. Competition for light between rice and weeds has been well documented (Okafor and De

Datta, 1974; 1976; Mercado et al., 1978). The intense weed growth and consequent increased mutual shading and decreased light transmission into the canopy might have upset the photosynthesis - respiration balance resulting in greater reduction in growth and yield of rice. Murata (1969) described that under low solar radiation nitrogen application reduced the dry weight of plants.

The difference in yield due to water regimes was significant in the year 1982 (Table 14). The results underscore the superiority of a continuously flooded cultural system for rice over intermittent flooding. The magnitude of yield increase was, however, very small compared to the huge difference in the volume of water consumed. The higher yield can be due to the innate advantages of a submerged soil system viz., nutrient availability, root activity, regulation of temperature and pH and algal fixation of atmospheric nitrogen (Yoshida, 1981). Similar high yields under shallow submergence were obtained for direct-seeded rice by Bhan and Padwal (1976); Reddy and Hukkeri (1979) and Hukkeri and Sharma (1980). According to Murata (1969) yield capacity of rice plant can be divided into three components : no. of panicles m^{-2}, no. of spikelets panicle^{-1} and size of hull. The yield components such as panicle length and thousand grain weight showed a remarkable increase in the standing water treatment (Table 12). The various growth parameters such as dry weight and number of tillers m^{-2} also showed a slight increase. The yield increase obtained in the submerged treatment, therefore, is the cumulative effect of all these increases.

The lack of any marked difference between the continuously flooded and intermittently flooded system in the second year is due to the well distributed and higher amount of precipitation received during that year. As shown in Fig. 7, the soil moisture tension seldom reached the critical value of 0.02 MPa. The various yield and growth parameters also reflected this lack of difference in yield.

Pre-emergence application of butachlor significantly increased the grain yield and so was post-emergence application of bentazone and propanil. Butachlor when applied 4 days after sowing, blocked some regulatory or biosynthetic steps needed for the normal cell division to occur and thereby inhibited the germination of weed seeds (Fedtke, 1982). This is evident from the remarkably lower number of weeds per unit area (Table 37). Phyto-toxic symptoms to rice such as stunted growth and seedling mortality were also observed. However, this was not serious and the seedlings recovered subsequently. Such toxicity symptoms were also reported by Mohamed Ali et al.

(1977); Ahmed and Hoque (1981) and Noriel (1981). After 25 to 30 days of application, the butachlor treated plots lost most of the herbicidal effect. In the soil, butachlo is dissipated through different mechanisms : physical removal through adsorption, volatilization and uptake by plants; and degradation through chemical, photochemical and microbial decomposition (Chen, 1981). The higher atmospheric temperature (ca 35°C, Fig. 1) prevailing during the crop seasons and the consequent higher soil temperature might have accelerated the processes of dissipation. Chen and Chen (1979) observed that soil temperature is a cardinal factor in deciding the extent of volatilization and adsorption of butachlor in the soil. To corroborate this, weeds started appearing in the butachlor plots at this stage (Tables 37 and 39). To check them, one hand weeding was given at around 40 days after sowing.

Thus, the butachlor application and hand weeding together reduced the competition for light and nutrients to a considerable degree. Competition for water is not relevant in this case since under both the irrigation treatments, water was not a limiting factor. Thus the higher yield obtained in the butachlor treated plots is mainly due to the reduction in weed competition for light and nutrients. Corroboratory results have also been obtained by Singh and Chauhan (1978), Mukhopadhyay and

De (1979), Mukhopadhyay and Mondal (1981) and IRRI (1982).

Post-emergence application of bentazone did not yield any favourable response on grain yield. This is due to the fact that this herbicide is primarily intended for broad-leaf weeds (Silk et al., 1980) and majority of the weeds present in the experimental field were grasses, mainly *Echinochloa crus-galli* and *E. colona*. Nevertheless, when bentazone was supplemented with propanil in the succeeding year, there was a remarkable increase in rice yield. This can be interpreted in terms of the effective control of the grassy weed flora, particularly *Echinochloa* spp. However, after 15-20 days of application, weeds started regrowing which necessitated one hand weeding. Upadhyay and Choudhary (1979), Borgochain and Upadhyay (1980), Kannaiyan et al. (1981) and Singh and Sharma (1981) also obtained higher grain yields with propanil.

No phytotoxic symptoms on rice were produced by bentazone. When propanil was applied with bentazone, leaf scortching was noticed on rice plants. However, the plants recovered subsequently. This is evident from the data on chlorophyll content of leaves presented in Table 11. There was only a minor decrease (4 per cent) in total chlorophyll content of the rice leaves at panicle initiation stage in the bentazone plus propanil treatment, compared to the no herbicide treatment.

The reduction in yield due to weed competition was as high as 47 and 69.5 per cent in 1982 and 1983, respectively. Thus, it is evident that weed competition is extremely severe in a direct seeded rice crop. Under this system of rice culture, crop and weed seeds germinate simultaneously and the latter being more competitive, suppresses crop growth.

There was a spectacular increase in grain yield with increasing levels of nitrogen (Table 14). The response was quadratic in 1982 while it tended to be linear in the subsequent season (Fig. 6). Nitrogen raises grain production since it is a substrate for synthesis of organic nitrogen compounds which constitute protoplasm and chloroplasts (Yoshida and Oritani, 1974). In the present study also it was seen that chlorophyll 'a', chlorophyll 'b' and total chlorophyll increased with increasing levels of nitrogen. Studies have shown that nitrogen and chlorophyll content of rice leaves are so closely related that a deficiency of nitrogen may bring about a sharp decline in the chlorophyll content of the leaves (Natr, 1972; Barker, 1979). The amount of leaf nitrogen, that is to say, the amount of photosynthetic enzymes including RuBP carboxylase often becomes a limiting factor for the photosynthetic process to proceed (Tsunoda, 1979). Under higher levels of nitrogen, this limiting factor was eliminated. From the foregoing discussion, it is clear that nitrogen supply resulted in increased net photosynthesis which produced a favourable effect on various growth and yield parameters culminating in higher grain yield (Tables, 3, 6, 12 and 14). Corroboratory results were also obtained by Singh et al. (1979), Vlek et al. (1979), Wilson and Mengel (1980), Ghobrial (1980), Kumar and Sharma (1980), Ghobrial (1982) and Singh et al. (1982a).

Weed infestation affects nitrogen response very conspicuously. There was absolutely no beneficial effect of applied nitrogen in the weedy check and bentazone plots (Table 15). While rice yields increased from 21.83 q ha^{-1} with no nitrogen to 53.13 q ha^{-1} at 150 kg N ha^{-1} in the butachlor plots, the yield remained at 19.53 q ha^{-1} even with 150 kg N ha^{-1} in the weedy plots in 1982. The corresponding figures for 1983 were 21.36 and 50.04 q ha^{-1} with no nitrogen and 150 kg N ha^{-1} respectively in the butachlor plots. The yield obtained in the weedy check during that season was barely 10.31 q ha^{-1} with 150 kg N ha^{-1}. Reduction in yield and dry matter was found to be associated with decrease in tiller number, phytomass yield, panicle number and panicle length (Tables 4, 5, 7, 8 and 13). Similar observations were also reported by Guh et al. (1980), Iwata and Takayanagi (1980b) and Ghobrial (1981). The data summarised in Tables 40 and 41 highlight that application of nitrogenous fertilizers resulted in enhanced growth of weeds in the weedy check and bentazone plots. Noguchi and Nakayama (1978) reported that fertilizers had a stimulatory effect on the growth and reproduction of weeds. It can be concluded that addition of nitrogen to weedy plots not only failed to compensate the losses due to weed competition, but it enhanced the yield losses due to intensified weed competition. Butachlor and bentazone plus propanil combination were able to check weed growth. Consequently in these treatments the weed dry matter production was considerably reduced at all levels of nitrogen (Tables 40 and 41). However, there was a near linear increase in the weed dry matter production in the weedy check upto 150 kg N ha^{-1} whereas in other treatments the response was quadratic. Narayanaswamy and Sankaran (1977) and Bhan (1983) also reported similar observations.

The harvest index was higher in the standing water treatment as compared to intermittent flooding in both years. A perusal of the yield data indicate a similar trend in grain yield also.

The weed control treatments, butachlor and bentazone plus propanil had a favourable effect on harvest index. It may be recalled that the herbicidal treatments had also registered a higher grain and biological yield as compared to weedy check. Thus it can be argued that because of the favourable effect of herbicides on harvest index the grain yield increased as grain yield is a function of harvest index and biological yield.

Application of nitrogen resulted in a higher harvest index. Donald and Hamblin (1976) also observed that application of nitrogen to cereals resulted in an increase in biological yield and harvest index. With additional increments of nitrogen (Table 17) application of butachlor and bentazone plus propanil produced a considerable increase in this parameter. However, nitrogen levels were promiscuous in their behaviour in the weedy check in both the years. This may be due to the deleterious effect of nitrogen fertilization in weedy plots on grain yield of rice (Table 15).

Though it is generally expected that significant amount of nitrogen will be lost from an alternately flooded and dried soil through nitrification - denitrification and consequently a low nitrogen uptake, but no such accelerated loss was observed in the present study (Table 27). In fact, there was a higher apparent recovery of nitrogen (34.41 per cent) in the intermittently flooded soil as against 32.44 per cent in the continuously flooded water regime (Table 30). Results obtained by Craswell and Vlek (1979a) indicated that intermittent flooding did not promote nitrogen losses in soil-plant systems. Sehrawat (1981), Fillery and Vlek (1982) and De Datta et al. (1983) also reported that intermittent flooding did not increase the losses of nitrogen. From these studies, it is clear that denitrification losses may be true for fallow soils undergoing intermittent flooding and not for a soil-plant system where the plant roots act as an active competitor for the denitrifiers for any NO_3^- formed in the soil. In terms of potential for nitrogen loss, the continuously flooded system is likely to lose more nitrogen. Because in such a system considerable amount of nitrogen can be lost through NH_3 volatilization. NH_3 volatilization is a pH dependent process and very high pH conditions can develop during bright sunshine hours as a result of the imbalance between photosynthesis and respiration of algae and aquatic macrophytes (Reddy, 1982; De Datta, et al., 1983).

In addition, denitrification losses can occur under submerged conditions. Recent studies by Zhou and Chen (1983) indicated that there is a facultatively anaerobic ecotype of nitrite bacterium that is active both in the oxidized and reduced layers of paddy soils. The explanation given earlier for denitrification in a soil-plant system a fortiori applies here also. But still denitrification may take place when higher levels of nitrogen are applied under both situations. Therefore, the higher apparent recovery obtained in the intermittently flooded treatment might be due to the greater losses in a submerged soil. Or alternatively, it can be due to the lower uptake value obtained in the no nitrogen control in the alternately flooded water regime compared to the continuously submerged one (31.78 kg N ha^{-1} in the intermittently flooded no nitrogen and 35.25 kg N ha^{-1} in the continuously submerged no nitrogen treatments) and ultimately getting a higher recovery percentage.. This is possible because of blue green algae fixing atmospheric nitrogen in a submerged system. Since the algal fixation of atmospheric nitrogen will be less in presence of combined nitrogen, the 'no nitrogen control' in the continuously flooded treatment can logically have a higher uptake and then a lower recovery of applied nitrogen.

In the year 1982, however, recovery as well as N uptake, were little lower in the intermittently flooded water regime as compared to continuously submerged one. This may be due to the poor root growth because of the frequent drying cycles as evident from Fig. 7 and consequently a lesser uptake. Therefore, it can be concluded that if the drying cycles in an alternate wetting and drying water regime is not very frequent, nitrogen uptake and recovery can be as good or even better than a continuously flooded system.

The nitrogen uptake and apparent recovery were stimulated by the herbicidal treatments, butachlor and bentazone plus propanil (Tables 27 and 30). This remarkably high uptake and nitrogen recovery in these treatments can be interpreted in terms of high biological yield and nitrogen content in the tissues (Tables 6 and 18) Similar results were obtained also by Moorthy and Dubey, 1979; Kaushik and Mani, 1980).

Nitrogen application increased its uptake (Fig. 11, Tables 27, 58). However, the apparent recovery decreased at higher levels of nitrogen (Table 30). The increase in nitrogen uptake with increasing levels of applied nutrient is in consonance with the high grain and biological yields. However, the decrease in apparent recovery is due to the fact that, with increasing doses, the denominator goes on increasing, whereas the numerator does not increase proportionately, with the result that the recovery percentage at higher nitrogen levels are invariably low. The less than proportionate increase in uptake might be due to the higher losses associated with the larger doses of nitrogen application. The apparent recovery was highest with 50 kg N ha^{-1} (34 per cent) and decreased as the nitrogen level has increased to 150 kg N ha^{-1} (31 per cent). In general, the recovery was very low, mainly because of the coarse textured soil allowing considerable amount of leaching loss and the weed competition. Similar observations were also reported by Vlek *et al.* (1979), Clark (1981), Thomas (1981), Wang *et al.* (1981).

Just as in the case of grain yield and phytomass production, the nutrient uptake also increased consistently in the butachlor and bentazone plus propanil plots with increasing levels of nitrogen, whereas it was almost stationary in the weedy check and bentazone plots (Tables 28 and 29). Corroboratory results were obtained by Kakati (1976) and Kaushik and Mani (1980).

Data from the green house studies indicate that not only nitrogen uptake, but nitrate reduction was also stimulated by nitrogen levels. It is important in the sense that nitrogen assimilation consists of uptake, translocation and reduction. There was roughly 73 per cent higher nitrate reductase activity (NRA) in the 200 mg N kg soil^{-1} pots over no nitrogen (Table 56). This can be interpreted in terms of the fact that nitrate reductase (NR), the first in the series of enzymes that reduces NO_3^- to NH_3 is a substrate inducible enzyme and its induction is closely related to the supply of nitrate (Beevers and Hageman, 1972; Hewitt, 1975; Guerrero *et al.*, 1981; Naik *et al.*, 1982).

Water stress is found to drastically affect the process of NO_3^- reduction. In the severely stressed m_5 treatment (Fig. 9a) at 75 days after sowing, NRA was only 23 per cent of the control. A reduction in NRA under stress was also observed by Ackerson et al. (1977), Mali and Metha (1977) and Morilla et al. (1973). The inhibition of NRA may be due to a direct effect of water potential on enzyme activity (Morilla et al., 1973) or a possible inactivation of the enzyme under water stress (Sinha and Nicholas, 1981). Shaner and Boyer (1976a,b), however, suggested that decreased NO_3^- flux into the induction site of the enzyme from the storage pool is the cause of the loss of NRA under water stress.

The nitrogen content of the plant increased under water stress (Table 58). The drastic difference in nitrogen concentration is due to the dilution effect associated with the higher phytomass production observed in the control plants. This is evident from the fact that the total nitrogen uptake followed the pattern of dry matter production rather than the concentration in the tissues. Similar observations were reported also by O'Toole and Baldia (1982).

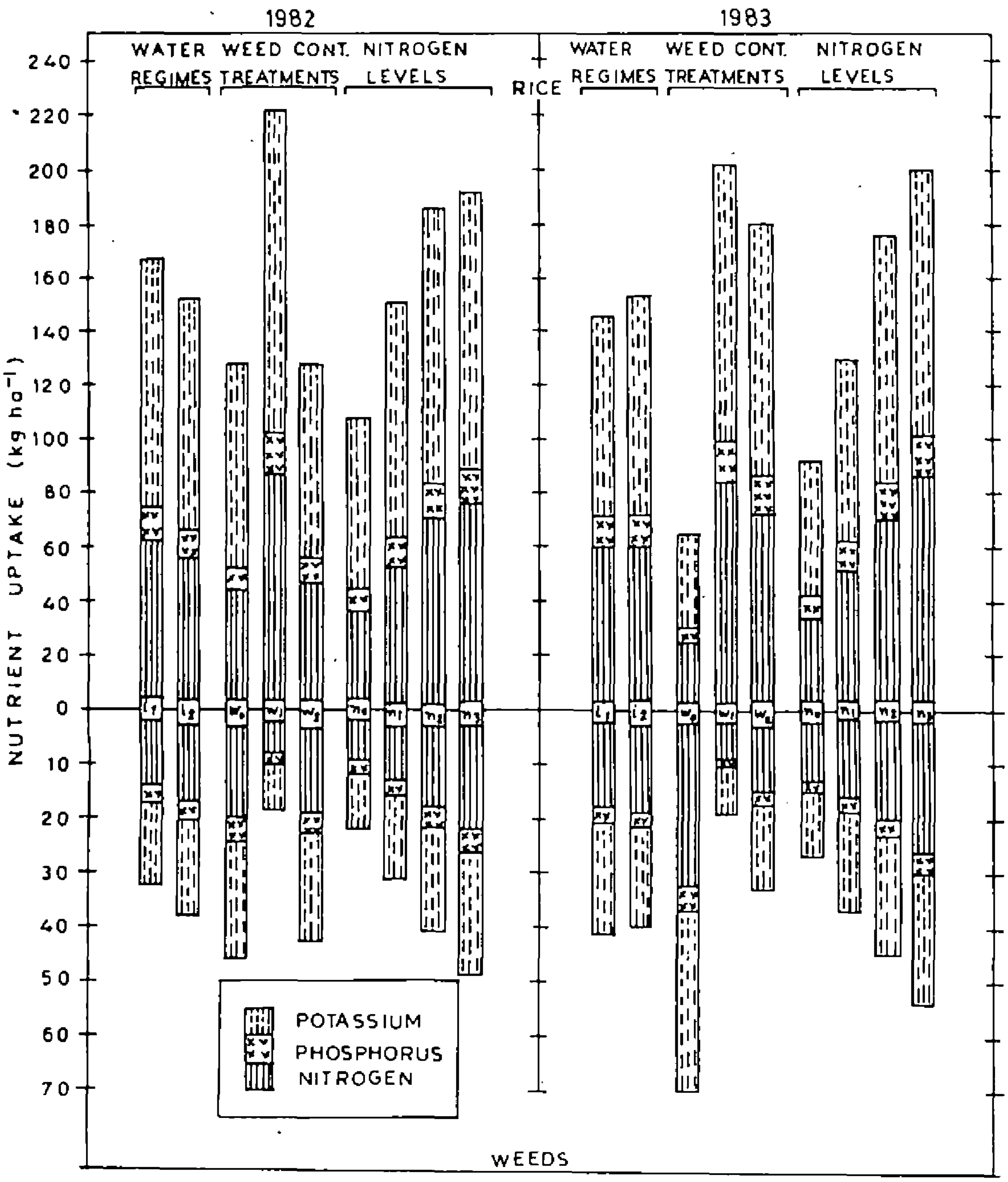
There was large accumulation of proline under water stress. There was a 17 fold increase in the 0-0.10 MPa treatment over the control (Table 56). Higher proline accumulation has also been reported by Singh et al. (1972, 1973a,b), Sirkar (1975); Mali and Metha (1977), Li and Chu

(1979) and Chu and Li (1979). No perceptible variation in proline content was, however, observed between the drought tolerant and drought susceptible rice cultivars included in the study. This is in contrast with the findings of Mali and Metha (1977) and Chu and Li (1979). Mali and Metha (1977) observed that a drought tolerant rice cultivar TKM-1 had a 5.4 fold increase in free proline content over its drought susceptible counterpart. Increase in proline occurs either due to fresh synthesis or from breakdown of proline rich proteins during stress. The various functions attributed to such an accumulation are osmoregulation, conservation of energy and amino groups, and as a sink for soluble nitrogen (Aspinall and Paleg, 1981; Huber and Eder, 1981). However, the adaptive significance of such an accumulation is questionable. Even though there was a tremendous increase in the accumulation of proline under water stress, no favourable effect was associated with phytomass yield, leaf area expansion and NPK uptake (Tables 55, 57 and 58). Wang <u>et al.</u> (1982) observed considerable increase in the free proline content of senescing leaves. There are also many reports which say that proline accumulation can be induced by abscissic acid (Aspinall <u>et al.</u>, 1973; Stewart and Hanson, 1980; Aspinall and Paleg, 1981). Therefore, proline accumulation in response to water stress may be a response of the accumulated abscissic acid and it may not impart much adaptive significance to the cultivars.

There was no marked variation in the phosphorus and potassium uptake by rice in the continuously and alternately flooded water regimes (Tables 31 and 34). This is understandable in the context of a lack of difference in the phytomass yield and the nutrient concentration in the tissues (Tables 6, 23 and 24). Phosphorus and potassium uptake by rice was, however, significantly influenced by weed control treatments. There was 77 and 181 per cent increase in phosphorus uptake in the butachlor plots in 1982 and 1983 respectively (Table 31 and Fig. 11). Since the nutrient uptake is a function of both dry matter and the nutrient concentration, the high dry matter production and phosphorus concentration in the butachlor and bentazone plus propanil treated plots (Tables 6 and 23) led to the increased phosphorus uptake. Potassium uptake in butachlor treatment was higher over weedy check by 58 and 200 per cent in 1982 and 1983 respectively. The explanation offered in the case of phosphorus a fortiori applies to potassium uptake also.

Nitrogen application resulted in greater uptake of both phosphorus and potassium. As discussed earlier, application of nitrogen stimulates vegetative growth. The resultant increased foraging capacity of the roots (Grunes, 1959) might have led to increased uptake of these nutrients. The data presented in Tables 3 and 6 indicate that there is a parallel relationship between the dry matter production and nutrient uptake. Similar observations were reported

FIG. 11 NUTRIENT REMOVAL BY RICE AND WEEDS.



(i_1 – Continuous submergence, i_2 – Alternate flooding and drying, W_0 – Weedy Check, W_1 – Butachlor, W_2 – Bentazone (1982) and Bentazone + Propanil, n_0 – no N, n_1 – 50 kg N ha^{-1}, n_2 – 100 kg N ha^{-1} and n_3 – 150 kg N ha^{-1})

by Murthy and Murthy (1978), Wilson and Mengel (1980), Hoque and Khan (1981).

Water stress was found to retard the uptake of phosphorus. This can be explained based on the slow rate of growth and lesser dry matter production. There was no perceptible difference in the phosphorus concentration of the tissues as evidenced from Table 58. Potassium uptake and concentration also decreased with increase in water stress. This can be explained based on the limited root growth in the pots under stress. As a result, rice plants experienced decreased transpiration, which is highly correlated with nutrient uptake (O'Toole and Baldia, 1982). Barber (1962) distinguished mass flow, diffusion and root interception as the three mechanisms of ion movement to the root surface. It can be safely assumed that all the three processes were deleteriously affected under an episode of water stress. Dunham and Nye (1974) illustrated marked change in the absorbing power of roots in soil solution when matric potential at the root surface became more negative. They interpreted the effect of root absorbing power as a water stress induced root physiological change. Decreased dry matter itself would result in decreased uptake of mineral nutrients regardless of water status in the system. These changes may also be expected to affect the rate of transpiration from shoot and hence mass flow dependent flux of nutrients.

There was no marked variation either in the NPK concentration of weeds or the depletion of nutrients as a function of water regimes (Tables 42, 43, 47, 48 and Fig. 11). This in fact followed the same trend as that of weed dry matter production (Tables 37, 38). Though it is generally expected that under continuously submerged conditions, weed growth should be suppressed (Bhan, 1983), no such favourable effects were noticed in the present study. This might be due to the fact that the water depth used (7-0 cm) that too on a light textured soil, is insufficient to bring about such marked effects on weed growth. This is in conformity with the studies at IRRI (IRRI, 1977). In fact, the nutrient depletion is a function of dry weight as well as the tissue concentration of nutrients. But these parameters did not show any noticeable variation in this respect.

Weed control treatments resulted in a conspicuous variation in nutrient (NPK) removal by weeds (Fig. 11). It is interesting to note that the nutrient removal by weeds and crops together was considerably higher in the butachlor plots (240.8 and 222.16 kg NPK ha^{-1} in 1982 and 1983, respectively)compared to weedy check (174.53 and 134.27 kg NPK ha^{-1}, in 1982 and 1983, respectively). Findings of Kakati (1976) support this view.

Nutrient depletion by weeds increased with increasing levels of nitrogen. This is due to the higher competitive ability of weeds. It may be noted that when fertilizers were applied to the weedy plots, the crop nutrient removal did not show any notable increase (Tables 27, 28, 29, 32) whereas when the weeds were checked, there was considerable improvement in the situation. Nitrogen and phosphorus depletion by weeds was found to increase linearly upto 150 kg N ha^{-1} in the weedy plots (Tables 49 and 50). In other words, in presence of weeds, application of heavy doses of fertilizers is not advantageous to the crop. In butachlor and bentazone plus propanil treatments, there was considerably higher crop uptake with increasing levels of nitrogen. This observation clearly indicate that the crop was able to make the best use of applied nitrogen in the absence of weed growth and not in their presence. Saefuddin et al. (1978), Ahmed and Moody (1981) and Pillai (1981) also observed that fertilizer application in heavily weed infested fields will have the adverse effect and stimulates weed growth to such an extent that the crop plants will consequently suffer severe damage.

Irrigation requirement and water use were found to be high in the standing water treatment (Table 51). The net amount of water the crop received, worked out to be 2358.16 and 1208.16 mm in 1982 and 1289.6 and 889.6 mm in 1983 for the continuously and intermittently flooded water regimes, respectively. These figures indicate the enormous quantities of water that have to be applied to maintain a layer of standing water. Irrigation requirement for the standing water treatment was 2.5 and 2.14 times higher than intermittently flooded water regime respectively in 1982 and 1983. Consequent to the high water requirement, the water use efficiency (WUE) was low in the standing water treatment. It may also be remembered that the continuously flooded water regime has also got a higher potential for nitrogen loss through ammonia volatilization. This is to say that continuously flooded water regime is characterised by not only low WUE but also low nitrogen use efficiency. Tanaka (1976), Biswas and Mahapatra (1979) and Reddy and Hukkeri (1979) also obtained similar low WUE under standing water treatment. The high WUE obtained in the herbicidal treatments (butachlor and bentazone plus propanil) can be traced to the high grain yield obtained in these treatments (Tables 14 and 52).

The huge irrigation requirement for continuous flooding resulted in a considerably lower net profit and returns per rupee invested (Table 53). This is because of the high cost involved therein. Though grain yields were higher in the continuously flooded treatment, the net returns were lower than the intermittently flooded treatment.

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CHAPTER VI

SUMMARY AND CONCLUSIONS

Field and green house experiments were conducted in the Division of Agronomy, Indian Agricultural Research Institute, New Delhi, during 1982 and 1983 to study the interaction of nitrogen x weed control x water regimes, on the growth, productivity and nutrient use pattern of direct seeded rice. The treatments in the field trials consisted of 4 levels of nitrogen (0, 50, 100 and 150 kg N ha^{-1}), 3 weed control treatments (weedy check, butachlor, bentazone in 1982 and bentazone plus propanil in 1983) and 2 water regimes (continuously and intermittently flooded). The experiment was laid out in a split plot design, replicated thrice. The variables in the green house experiment were 2 rice cultivars (Pusa 33, drought susceptible and Pusa 312, drought tolerant), 3 nitrogen levels (0, 100 and 200 mg N kg $soil^{-1}$) and 5 soil moisture regimes (submergence to saturation, 0-0.025 MPa, 0-0.05 MPa, 0-0.075 MPa and 0-0.10 MPa soil moisture tension). The important findings are summarised below:

1. The growth (plant height, number of tillers, chlorophyll content) and yield attributes (panicle length, number of spikelets per panicle, thousand grain weight), grain yield, biological yield and harvest index were almost similar under the two water regimes. However, in the year 1982 significantly higher yields were obtained in

the continuously submerged treatment as compared to alternate flooding and drying. Concomittant increases in panicle length and thousand grain weight were also noted during that season.

2. The herbicides, butachlor and bentazone plus propanil coupled with one hand weeding had a remarkable effect on grain yield, biological yield and various growth and yield parameters.

3. Nitrogen played a key role in increasing the grain yield. Simultaneous increase in growth and yield attributes was also noticed at higher levels of nitrogen. However, when heavy doses of nitrogen are applied to weedy plots (weedy check as well as bentazone) there was greater reduction in grain yield due to enhanced competition.

4. The optimum doses of nitrogen worked out to be 119.06, 81.34, 30.78 and 90.94 kg N ha^{-1} respectively for the butachlor, bentazone, weedy check and overall effects in 1982. The response was linear in the subsequent year.

5. All the three factors viz., water regimes, weed control treatments and nitrogen levels had a beneficial effect on harvest index.

6. There was no noticeable effect of water regimes on either the concentration of nitrogen, phosphorus and potassium in rice at any of the stages or the crude protein content of grains.

7. Herbicides, butachlor and bentazone plus propanil with one weeding, favoured an accumulation of nitrogen in the rice plant. A similar favourable effect was observed on the protein content of grains also. However, phosphorus and potassium contents were less affected by the herbicidal treatments.

8. Application of nitrogen, in general, resulted in increased accumulation of nitrogen, phosphorus and potassium in plant tissues. Crude protein content also increased with increasing levels of this nutrient.

9. Neither uptake of nitrogen nor that of phosphorus and potassium had a significant bearing on the continuously and intermittently flooded water regimes. The apparent recovery of applied nitrogen was higher in the latter.

10. Application of either nitrogen or the herbicides (butachlor and bentazone plus propanil with one hand weeding) stimulated the uptake of nitrogen, phosphorus and potassium. However, with heavy dressings of nitrogen to weedy plots, there was absolutely no beneficial effect.

11. Neither the number of weeds nor the weed dry matter production were influenced by the water regimes.

12. Weed control treatments butachlor and bentazone plus propanil together with one hand weeding markedly suppressed the weed growth.

13. Nitrogen had a stimulatory effect on the dry weight

of weeds. When large quantities were given to weedy plots, the increase in weed dry matter production assumed linear proportions.

14. Depletion of nutrients (NPK) was maximum in the weedy check. A similar high loss of nutrients through weed competition was also observed in the bentazone alone plots. Butachlor and bentazone plus propanil allowed only a markedly low amount of nutrient loss through weed competition.

15. Higher the amount of nitrogen applied, greater was the loss of nutrients. When large quantities of nitrogen were applied to weedy plots, proportionately greater loss of nutrients resulted.

16. Due to the heavy water requirement for maintaining a layer of standing water, irrigation requirement was very high and water use efficiency was low in the continuously flooded water regime.

17. Butachlor and bentazone plus propanil as well as nitrogen application increased the water use efficiency, obviously due to the higher grain yield obtained in these treatments.

18. There was a marked increase in the nitrate reductase activity in rice leaves due to the application of nitrogen.

19. Water stress was found to decrease growth, nitrate reductase activity and nutrient uptake drastically. However, free proline content and nitrogen concentration in the rice

plant was found to increase with increasing soil moisture stress.

20. Because of the heavy water requirement and the high cost involved therein, net profit and return per rupee invested were low in the standing water treatment.

21. Nitrogen, butachlor and bentazone plus propanil increased the net profit and return per rupee invested. Among the nitrogen levels, the most profitable was 100 kg N ha^{-1}.

It can be concluded from these investigations that under weedy conditions, application of nitrogen not only failed to compensate the losses, but also resulted in increased losses due to competition for other growth factors. Herbicides such as butachlor or bentazone with propanil accompanied by one hand weeding can keep the weed infestation below the economic threshold. The recovery of applied nitrogen, though not an end in itself, was high under these circumstances. Maintenance of continuous submergence favours growth and yield of rice. However, the yield increase obtained would not commensurate with the large volume of water used. Water stress was found to seriously retard the processes of nitrate reduction, leaf area expansion and eventually growth itself in rice. The results suggest that under conditions of uncertain moisture supply, nitrogen application rate should be reduced from that normally used for assured water supply situations.

Future lines of work

1. Basic studies on nitrogen turnover in soil-plant systems under different water regimes, particularly the magnitude and mechanisms of nitrogen losses such as ammonia volatilization, nitrification, denitrification and leaching are to be undertaken.

2. Investigations are also necessary to identify newer herbicides that selectively kill the weeds in a direct-sown rice field. Further, the effect of these herbicides, particularly the soil applied ones, on the variou soil biochemical processes such as nitrogen transformations, biological nitrogen fixation in the rhizosphere etc. need to be studied.

3. Efforts may be made to develop/screen suitable rice cultivars which possess relatively faster initial growth to compete with the weeds to extract maximum of the applied nutrients.

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BIBLIOGRAPHY

Ackerson, R.C., Krieg, D.R.; Haring, C.L. and Chang, N. 1977. Effects of plant water status on stomatal activity, photosynthesis and NRA of field grown cotton. Crop Sci. 17:81-84.

Ahmed, N.U. and Hoque, Z.M. 1981. Weed control in dry-seeded rainfed bunded rice and its residual effect on weed growth of the subsequent transplanted rice. Int. Rice Res. Newsl. 6(2):13-14.

Ahmed, N.U. and Islam, A. (1983). Farmers' weed control technology for direct-seeded rice. Pages 203-212. in International Rice Research Institute and International Weed Science Society. Proc. Conf. Weed Control in Rice. Los Banos, Philippines.

Ahmed, N.U. and Moody, K. 1979. Tolerance of crops to butachlor and pendimethalin at different growth stages. Philippine J. Weed Sci. 6:10-22.

Ahmed, N.U. and Moody, K. 1981. Effect of time of N application on weed growth and yield of dry-seeded rice. Int. Rice Res. Newsl. 6(2):12-13.

Akobundu, J.O. 1981. Weed control in direct-seeded lowland rice under poor water control conditions. Weed Res. 21(6):272-278.

*Alkamper, J. 1976. Influence of weed infestation on effect of fertilizer dressings. Pflanzenchutz Nachr. Bayer. 29: 191-235.

*Alkamper, J. and Do van Long. 1978. Interaction between fertilizer use and weed population. Pages 188-193. in. Troiseme Symp. sur le desherbage des cultures tropicales Dakar. 17-21 Sept. 1978.

*Amarlal, A. and Dos, S. 1980. The effect of water management and herbicides on the yield of rice. Pages 151-153. in Instituto Rice Grandense. Annois 10^{a} reunio da cultura do arroz irrigado. Porto Alegre, Brazil.

Arnon, D.I. 1949. Copper enzymes in isolated chloroplasts. Polyphenol oxidase in *Beta vulgaris*. Plant Physiol. 24:1-15.

Aspinall, D. and Paleg, L.G. 1981. Proline accumulation. Physiological aspects. Pages 205-242. in L.G. Paleg and D. Aspinall (eds.). Physiology and Biochemistry of Drought Resistance in Plants. Academic Press, Sydney.

Aspinall, D., Singh, T.N. and Paleg, L.G. 1973. Stress metabolism V. ABA and N metabolism in barley and Lolium temulentum. Aust. J. biol. Sci. 26:319-327.

Assemat, L. and Oka, H.I. 1980. Neighbor effects between ric and Echinochloa crus-galli strains. I. Performance in mixture and aggressiveness as influenced by planting density. Acta Oecologica/Oecologia Plantarum 15(4):371-393.

Bangladesh Rice Research Institute (BRRI) 1977. Annual Report for 1974-75. Dacca, Bangladesh 99 p.

Barber, S.A. 1962. A diffusion and mass-flow concept of soil nutrient availability. Soil Sci. 93:39-49.

Barbiker, A.G.T. 1982. Chemical weed control in irrigated direct-seeded rice in the Sudan Gezira. Weed Res. 22:117-12

Barker, A.V. 1979. Nutritional factors in photosynthesis of higher plants. J. Pl. Nutrition 1:309-42.

Barrett, S.C.H. 1981. Crop mimicry as an adaptive strategy in weeds. page 122. in International Botanical Congress. Abstracts XIII. Sydney, Australia.

Bates, L.S. 1973. Rapid determination of free proline for water stress studies. Plant and Soil. 39:205-207.

Beevers, L. and Hageman, R.H. 1969. Nitrate reduction in higher plants. Ann. Rev. Plant Physiol. 20:495-522.

Beevers, L. and Hageman, R.H. 1972. The role of light in nitrate metabolism in higher plants. Pages 85-113. in A.C. Giese (ed.) Photo-physiology 7. Academic Press, New York

Begg, J.E. and Turner, N.C. 1976. Crop-water deficits. Adv. Agron. 28:161-217.

Beringer, H. 1980. Nutritional and environmental effects on yield formation. Pages 155-174. in International Potash Institute. Physiological Aspects of Crop Productivity. Berne, Switzerland.

Besold, B.W. 1978. Aerial application of bentazone to rice. Pages 19-29. in Proceedings of the Mediterranean Herbicide Symposium Vol. 2. Madrid.

Bhan, S. and Padwal, V.D. 1976. Effect of soil and water management practices on the yield and water use of direct-seeded rice under light textured alluvium of U.P. Indian J. agric. Sci. 46(11):503-506.

Bhan, V.M. 1983. Effects of hydrology, soil moisture regime and fertility management on weed populations and their control in rice. Pages 47-56 in International Rice Research Institute and International Weed Science Society. Proc. Conf. Weed Control in Rice. Los Banos, Philippines.

Bilal, I.M., Henderson, D.W. and Tauji, K.K. 1979. N losses in irrigation return flows from flooded rice plots fertilized with ammonium sulphate. Agron. J. 71(2):279-284.

Biswas, B.C. and Mahapatra, I.C. 1979. Effect of moisture regimes, phosphatic fertilizers and weather on growth and yield of direct-seeded rice. Oryza 16(2):99-106.

Biswas, B.C. and Mahapatra, I.C. 1980. Uptake of plant nutrients by direct-seeded rice under well drained and water-logged conditions. Indian J. Agron. 25(3):471-478.

Bodman, G.B. 1942. Nomograms for rapid calculation of soil density, water content and total porosity relationships. J. Amer. Soc. Agron. 34:883-893.

Bodman, G.B. and Rubin, J. 1948. Soil Puddling. Soil Sci. Soc. Am. Proc. 13:27-36.

Borgochain, M. and Upadhyay, L.P. 1980. Efficiency of butachlor, propanil and 2,4-D in controlling weeds in upland rice. Indian J. Weed Sci. 12(2):145-150.

Borner, H. 1979. Causes of selective action of the photosynthetic inhibitors and bentazone. Zeitschrift fur Naturforschung 34 C (11):926-930.

Bouyoucos, G.J. 1962. Hydrometer method for particle size analysis of soils. Agron. J. 54:464-465.

Boyer, J.S. 1976. Photosynthesis at low water potentials. Phil. Trans. R. Soc. London B. 273:501-512.

Buschmann, C., Grumbach, K.H. and Bach, T.J. 1980. Herbicides which inhibit photosystem II or produce chlorosis and their effect on production and transformation of pigments in etiolated radish seedlings. Physiol. Plant. 49(4):455-466.

*Cabello, R. 1979. Investigations of effect of weed competition on rice crops. Cultivos Tropicales 1(3):75-85.

Carson, A.G. 1975. Weed competition and some promising combinations for its control in upland rice. Ghana J. agric. Sci. 8(3):223-230.

Centre for Science and Environment (CSE) 1982. The stage of India's Environment: A citizen's report. New Delhi. 192 p.

Chandler, J.M. 1981. Estimated losses of crops to weeds. Pages 95-109. in D. Pimentel (ed.) CRC Handbook of Pest Management in Agriculture Vol. I. CRC Press Boca Raton, Florida.

Chantarotwong, W., Huffakar, R.C., Miller, B.L. and Granstedt, R.C. 1976. In vivo NO_2 reduction in relation to NO_3 uptake, nitrate content and invivo NRA in intact barley seedlings. Plant Physiol. 57:519-522.

Chen, Y.L. 1981. Degradation of butachlor in paddy fields. Food and Fertilizer Technology Center Technical Bulletin No. 57. 22 p.

Chen, Y.L. and Chen, J.S. 1979. Degradation and dissipation of herbicide butachlor in paddy fields. J. Pesticide Sci. 4(4):431-438.

Chisaka, H. and Noda, K. 1983. Farmer's weed control technology in mechanized rice systems in East Asia. Pages 153-165. in: International Rice Research Institute and International Weed Science Society. Proc. Conf. Weed Control in Rice. Los Banos, Philippines.

Chow, H.T. 1980. Comparative studies on ecological characteristics of rice. Efforts on the growth and yield of rice. J. Science and Engg. 17:191-201.

Chowdhury, S.L. and Singh, M. 1968. The problem of water management in rice crop. Indian Chemical Manufacturer 6(2):32-36.

Chu, T.M. and Li, C.C. 1979. Studies on drought resistance in rice. 1. Proline accumulation and its inheritance. Natl. Sci. Council Monthly 7(2):167-179.

Clarete, C.L. and Mabbayad, B.B. 1978. Effects of fertilization, row spacing and weed control on the yield of upland rice. Philippine J. Crop Sci. 3(3):200-202.

Clark, R.B. 1981. Plant response to mineral element toxicity and deficiency. Pages 71-142. in M.N. Christiansen and C.F. Lewis (eds.) Breeding Plants for Less Favourable Environments. John Wiley and Sons, Inc. New York.

Cochran, W.G. and Cox, G.M. 1957. Experimental designs. John Wiley and Sons, Inc., New York.

Colman, E.A. 1944. The dependence of field capacity upon the depth of wetting of soils. Soil Sci. 58:43-50.

Corsini, P.C., Politano, W., Santos, A.S. and Paya, L.C. 1979. Effect of soil moisture tension on emergence and initial vegetative growth of seedlings of rice. Cientifica 7(2):165-171.

Craswell, E.T. and De Datta, S.K. 1980. Recent developments in research on N fertilizers for rice. IRRI Res. Pap. Ser. 49:11 p.

Craswell, E.T. and Vlek, P.L.G. 1979a. Fate of fertilizer N applied to wetland rice. Pages 175-192. in International Rice Research Institute. Nitrogen and Rice. Los Banos, Philippines.

Craswell, E.T. and Vlek, P.L.G. 1979b. Green-house evaluation of N fertilizers for rice. Soil Sci. Soc. Am. J. 43:1184-1188.

Cutler, J.M., Shahan, K.W. and Steponkus, P.L. 1980a. Dynamics of osmotic adjustment in rice. Crop Sci. 20(3): 310-314.

Cutler, J.M., Shahan, K.W. and Steponkus, P.L. 1980b. Alteration of the internal water relations of rice in response to drought hardening. Crop Sci. 20:307-310.

Cutler, J.M.; Shahan, K.W. and Steponkus, P.L. 1980c. Influence of water deficits and osmotic adjustment on leaf elongation in rice. Crop Sci. 20(3):314-318.

Cutler, J.M., Shaner, K.W. and Steponkus, P.L. 1980d. Influence of water deficits and osmotic adjustment on leaf elongation in rice. Crop Sci. 20(3):14-17.

Daniell, H., Sarojini, G., Kumarachinnayan, P. and Kulandaivelu, G. 1981. Action of propanil on in vivo chlorophyll 'a' fluorescence in Echinochloa crus-galli and rice. Weed Res. 21(3/4):171-177.

Dastane, N.G. 1974. Effective rainfall in irrigated agriculture. FAO Irrigation and drainage paper No. 25 FAO, Rome 62 p.

Dayanand and Singh, A.K. 1980. Puddled rice proves better. Seeds and Farms 6(5):35.

De Datta, S.K. 1978. Land preparation for rice soils. Pages 623-648. in International Rice Research Institute. Soils and Rice: Los Banos, Philippines.

De Datta, S.K. 1979. Weed problems and methods of control in tropical rice. Pages 9-44. in Weed Science Society of the Philippines, Inc. and Philippine Council for Agriculture and Resources Research, Symposium "Weed Control in Tropical Crops" Los Banos, Philippines.

De Datta, S.K. 1981. Principles and Practices of Rice Production. John Wiley and Sons, Inc. New York. 618 p.

De Datta, S.K. and Barker, R. 1978. Land preparation for rice soils. Pages 623-648. in International Rice Research Institute. Soils and Rice. Los Banos, Philippines.

De Datta, S.K. and Craswell, E.T. 1982. N fertility and fertilizer management in wetland soils. Pages 283-316. in International Rice Research Institute. Rice Research Strategies for the Future. Los Banos, Philippines.

De Datta, S.K., Fillery, I.R.P. and Craswell, E.T. 1983. Results from recent studies on N fertilizer efficiency in wetland rice. Outlook on Agriculture 12(3):125-134.

De Datta, S.K. and Herdt, R.W. 1983. Weed control technology in irrigated rice. Pages 89-108. in International Rice Research Institute and International Weed Science Society. Proc. Conf. Weed Control in Rice. Los Banos. Philippines.

Donald, C.M. and Hamblin, J. 1976. The biological yield and harvest index of cereals as agronomic and plant breeding criteria. Adv. Agron. 28:361-405.

Dubey, A.N., Manna, G.B. and Rao, M.V. 1977. Studies on weed competition, weed control and varietal interaction with propanil and parathion in direct-seeded rice. Indian J. Weed Sci. 9(2):75-81.

Dunham, R.J. and Nye, P.H. 1974. The influence of soil water content on the uptake of ions by roots. Part II. Chloride uptake and concentration gradients in soil. J. Appl. Ecol. 11:581-596.

Evans, H.J. and Nason, A. 1953. Pyridine nucleotide nitrate reductase from extracts of higher plants. Plant Physiol. 28:233-244.

Fagi, A.M. and De Datta, S.K. 1981. Environmental factors affecting N efficiency in flooded tropical rice. Fert. Res. 2:53-67.

Fedtke, C. 1982. Biochemistry and Physiology of Herbicide Action. Springer Verlag Berlin 202 p.

Fillery, I.R.P. and Vlek, P.L.G. 1982. The significance of denitrification of applied N in fallow and cropped soils under different flooding regimes. Plant and Soil 65:153-169.

Franco, A.A. and Munns, D.N. 1982. Plant assimilation and nitrogen cycling. Plant and Soil 67:1-13.

Garrett, R.H. and Amy, N.K. 1978. Nitrate assimilation in fungi. Adv. Microb. Physiol. 18:1-65.

Ghildayal, B.P. 1983. Water management practices for rice production. Paper presented at the National Seminar on Integrated Approach to Water Management in the Command Areas. Indian Agricultural Research Institute, New Delhi.

Ghildyal, B.P. and Tomar, V.S. 1976. Soil-plant-atmosphere-water relations in rice culture. Pantnagar J. Res. 1(1):16-20.

Ghobrial, G.L. 1980. Effects of level, time and splitting of urea on the yield of irrigated direct-seeded rice. Plant and Soil 56(2):209-215.

Ghobrial, G.I. 1981. Weed control in irrigated dry-seeded rice. Weed Res. 21(5):201-204.

Ghobrial, G.I. 1982. Response of irrigated dry-seeded rice to N and P in a semiarid environment. Plant and Soil. 65: 429-432.

Ghosh, A.K. 1976. Efficacy of herbicides for upland rice applied either alone or as tank mixtures. Pages 176-186. in Proc. 6th East African Weed Sci. Conf.

Ghosh, A.K. 1977. Efficiency of recommended herbicides for upland rice applied either alone or as a tank mixture. Tropical Pesticides Research Institute. Miscellaneous Report No. 949. 11p.

Ghosh, B.C., Sharma, H.C. and Singh, M. 1977. Method and time of weed control in upland rice. Indian J. Weed Sci. 9(1):43-48.

Ghosh, T., Sharma, K.C. and Sharma, G.L. 1982. Ground water and vegetative growth, yield, yield components and evapotranspiration demand of dryland rice. Int. Rice Res. Newsl. 7(2):18-19.

Gooding, T.H. and Mc Calla, T.M. 1945. Loss of CO_2 and NH_3 from crop residues during decomposition. Soil Sci. Soc. Am. Proc. 10:185-190.

Greenwood, D.J. 1982. Nitrogen supply and crop yield: The global scene. Plant and Soil. 67:45-59.

Greenwood, E.A.N. 1976. Nitrogen stress in plants. Adv. Agron. 28:1-36.

Grunes, D.L. 1959. Effect of N on P availability. Adv. Agron. 11:369-393.

Guerrero, M.G., Vega, J.M. and Losada, M. 1981. The assimilatory nitrate reducing system and its regulation. Ann. Rev. Plant Physiol. 32:169-204.

Gueye, M. and Renard, C. 1982. Comparison of 2 rice cvs. subjected to drought in early flowering. Agronomie Tropicale 37(1):81-88.

Guh, J.O., Chung, S.T. and Chung, B.H. 1980. Studies on we competition. 1. Interpretation of weed competition in paddy rice under various cultural patterns. J. Korean Soc. Crop Sci. 25(1):77-86.

Guh, J.O. and Kwon, Y.W. 1975. On the response of paddy rice cultivars to herbicides 1. varietal response of growth components to several herbicide treatments. Seoul Universit J.B. 25:321-336.

*Gulidov, A.M. and Volkotrub, Z.N. 1981. The influence of herbicides on the vegetative organs of clubrush. Khimiya v. Sel'skom Khozyaistve 19(5):50-51.

Gunasena, H.P.M. and Arceo, L.M. 1981. Weed control studie with butachlor in direct-seeded rice in Sri Lanka. Pages 27-33 in Proc. 8th Asian-Pacific Weed Sci. Soc. Conf.

Hageman, R.H. and Hucklesby, D.P. 1971. Nitrate reductase from higher plants. Pages 491-503 in A. San Pietro (ed.) Methods of Enzymology Vol. 23.

Hanson, A.D. and Hitz, W.D. 1982. Metabolic response of mesophyles to plant water deficits. Ann. Rev. Plant Physiol 33:163-203.

Hanson, A.D. and Nelsen, C.E. 1980. Water : Adaptations of crops to drought prone environments. Pages 78-154. in P.S. Carlson (ed.). The Biology of Crop Productivity. Academic Press, Inc. New York.

Hauck, R.D. 1979. Methods for studying in N transformations in paddy soils : review and comments. Pages 73-94 in International Rice Research Institute. Nitrogen and Rice. Los Banos, Philippines.

Heenan, D.P. and Lewin, L.G. 1982. Response of Inga rice t N fertilizer rate and timing in New South Wales. Aust. J. Expl. Agric. and Anim. Husb. 22(114/115):62-66.

*Henrich, J. 1981. Interaction between weed control and fertilizer use in rice in Sierra Leone. Giessener Beitrage Zur Entwicklungsfor-schung 1 (Symposien) 7:139-149.

Hewitt, E.J. 1975. Assimilatory nitrate-nitrite reduction. Ann. Rev. Plant Physiol. 26:73-100.

Hewitt, E.J., Hucklesby, D.P. and Notton, B.A. 1976. Nitrate metabolism. Pages 633-681. in J. Bonner and J.E. Varner (eds.) Plant Biochemistry. Academic Press, New York.

Hirasawa, T. and Ishihara, K. 1979. The relationship between environmental factors and water status in the rice plant. 2. on leaf water potential and xylem water potential. Jap. J. Crop Sci. 48(4):557-568.

Hoque, Z.M. and Akanda, R. 1979. Fertilizer and Weed Management of aus rice in Bangladesh. Int. Rice Res. Newsl. 4(6):21.

Hoque, Z.M.; Hobbs, P.R. and Ahmed, A. 1978. Weed management studies on direct-seeded and transplanted rice in 1976 in Bangladesh. Int. Rice Res. New-sl. 3(4):19-20.

Hoque, Z.M. and Khan, M.A.H. 1981. Role of N rate, S and Zn application in bridging the gap of farmers boro rice in Bangladesh. Int. Rice Res. Newsl. 6(4):20.

Huber, W. and Eder, A. 1982. Proline and glycine betaine accumulation in leaves and shoots of Euphoria trigona and their role during water deficiency. Biochem Physiol. Pflanz. (BPP) 177(2):184-191.

Hukkeri, S.B. and Sharma, A.K. 1980. Water use efficiency of transplanted rice under different water management practices. Indian J. agric. Sci. 50(3):240-243.

International Rice Research Institute (IRRI) 1977. Annual Report for 1976. Los Banos, Philippines. 418 p.

International Rice Research Institute (IRRI) 1980. Annual Report for 1979. Los Banos, Philippines 538 p.

International Rice Research Institute (IRRI) 1982. Research highlights. Los Banos, Philippines.

Iruthayaraj, M.R. 1981. Study on effect of water management practices and nitrogen levels on weed growth in 2 swamp rice varieties. Agric. Sci. Digest, 1(1):39-42.

Iruthayaraj, M.R. and Morachan, Y.B. 1980a. Effect of water management practices and N application on losses of N in lowland rice. Madras agric. J. 67(8):502-505-

Iruthayaraj, M.R. and Morachan, Y.B. 1980b. Effect of season, water management and nitrogen levels on the uptake of N by 2 rice varieties. Madras agric. J. 67(9):606-607.

Iwata, I and Takayanagi, S. 1980a. Studies on the damage to upland crops caused by weeds. 1. Competition between upland crops and weeds. Weed Res. Japan 25(3):194-199.

Iwata, I. and Takayanagi, S. 1980b. Studies on the damage to upland crops caused by weeds. 2. The effects of weed competition on the growth and yield of crops. Weed Res. Japan 25(3):200-206.

Jackson, M.L. 1967. Soil Chemical Analysis 2nd ed. Prentice Hall of India Pvt. Ltd., New Delhi. p. 498.

Jha, K.P., Chandra, D. and Challaiah, 1981. Irrigation requirement of high yielding rice varieties grown on soils having shallow water table. Indian J. agric. Sci. 51(10): 732-737.

Jones, U.S., Katyal, J.C., Mamaril, C.P. and Park, C.S. 1982. Wetland rice-nutrient deficiencies other than N. Pages 327-380. in International Rice Research Institute. Rice Research Strategies for the Future. Los Banos, Philippines.

Kakati, N.N. 1976. Chemical weed control in rice in relation to fertilizer use. Ph.D. Dissertation. Indian Agricultural Research Institute, New Delhi. 144 p.

Kakati, N.N. and Mani, V.S. 1977. Chemical weed control in rice in relation to fertilizer use. Pages 7-8. in Indian Society of Weed Science Proc. Weed Sci. Conf. Hyderabad, A.P. India.

Kannaiyan, S., Govindarajan, K. and Levin, H.D. 1981. Studies on the chemical control of weeds in dry-seeded wetland rice. Int. Rice Res. Newsl. 6(2):14.

Kao, C.H. 1981. Senescence of rice leaves. VI. Comparative study of the metabolic changes of senescing turgid and water stressed excised leaves. Plant Cell Physiol. 22(4): 683-688.

Kaushik, S.K. and Mani, V.S. 1978. Weed control in direct-seeded and transplanted rice. Indian J. Weed Sci. 10(1/2): 73-78.

Kaushik, S.K. and Mani, V.S. 1980. Effect of chemical weed control on the nutrition and seed yield of direct-sown rice. Indian J. agric. Sci. 50(1):41-44.

Kemmler, G. 1980. Advances in fertilizer use to rice in South-east Asia 1958-1978. Fert. News 25(2):17-24.

Khind, C.S. and Ponnamperuma, F.N. 1981. Effects of water regimes on growth, yield and N uptake of rice. Plant and Soil 59(2):287-298.

*Kim, J.K., Kim, D.S., Lee, J.H. and Kang, B.H. 1979. Competition between weeds and rice in machine transplanted paddy. The effect of time of weed removal Research Reports of the office of Rural Development Suweon, Korea. 21(Crop):131-144.

*Kim, J.K., Kim, S.C., Lee, S.K. and Park, R.K. 1981. Effect of herbicides on weed species diversity in transplanted lowland rice. Research Reports of the Office of Rural Development, Suweon, Korea, 23(Crop):111-119.

Kim, S.C. and Moody, K. 1980. Effect of a mixture of 2 rice cultivars on the competitive ability of rice against weeds and on rice grain yield. Philippine J. Weed Sci. 7:17-25.

Klepper, L., Flesher, D. and Hageman, R.H. 1971. Generation of reduced nicotinamide adenine dinucleotide for nitrate reduction in green leaves. Plant Physiol. 48:580-590.

Kolhe, S.S. and Mittra, B.N. 1981. Weed control in direct-seeded upland rice. Pages 67-72. in Proc. 8th Asian-Pacific Weed Sci. Soc. Conf.

Kramer, P.J. 1980. Drought, stress and the origin of adaptations. Pages 7-20. in N.C. Turner and P.J. Kramer (eds.) Adaptations of Plants to water and High Temperature Stress. John Wiley Sons, Inc., New York.

Krishnamurthy, M. 1978. Studies on water management of irrigated rice. Thesis Abstracts 4(4):268-269.

Kumar, P. and Gill, H.S. 1982. Weed control in direct-seeded rice under puddled conditions. Oryza. 19:162-166.

Kumar, S.D. and Sharma, H.C. 1980. Response of direct-sown rice to levels of N under rainfed conditions. Indian J. Agron. 25(4):717-718.

Lahiri, A.N. 1980. Interaction of water stress and mineral nutrition on growth and yield. Pages 341 to 352 in N.C. Turner and P.J. Kramer (eds.) Adaptation of Plants to water and high temperature stress. John Wiley Sons, Inc., New York.

Li, C.C. and Chu, T.M. 1979. Studies on drought resistance in rice. 2. Utilization of proline accumulation in measuring drought resistance. Nat. Sci. Council Monthly 7(4):383-393.

Lion, S. 1980. Rice yield response to N and relevant soil fertility factors. Pages 15-36. in Food and Fertilizer Technology Center. Increasing N Efficiency for Rice Cultivation. Taipei, Taiwan.

Lichtenthaler, H.K., Burkard, G., Grumbach, K.H. and Meier, D. 1980. Physiological effects of Photosystem II herbicides on the development of photosynthetic apparatus. Photosynthesis Research 1(1):29-43.

*Long, D., Vang and Alkamper, J. 1978. Influence of various weeds on crop yields under increased fertilization. Mededalingen van de Fakulteit Landbouwwetenschappen. Gent. 43(2):1085-1076.

Losada, M. and Guerrero, M.G. 1979. The photosynthetic reduction of nitrate and its regulation. Pages 365-408. in J. Barber (ed.) Photosynthesis in Relation to Model Systems. Elsevier, Amsterdam.

Luis, M. and Weerd, J.C. van De. 1974. New Results with bentazone combinations in rice. Pages 151-156. in Proc. 12th British Weed Control Conf. British Crop Protection Council, London, U.K.

Luis, M. and Weerd, J.C. van De. 1976. New results with bentazone in the rice growing areas of Europe and the Americas (sown rice). Pages 256-259. in Proc. 5th Asian-Pacific Weed Sci. Soc. Conf. Tokyo, Japan.

Lyster, S., Morgan, M.A. and O'Toole, J.C. 1980. Ammonia volatilization from soils fertilized with urea and ammonium nitrate. J. Life Sci. Royal Dublin Soc. 1:167-176.

Mabbayad, B.B. and Obordo, R.A. 1970. Methods of planting rice. Pages 84-88. in University of the Philippines College of Agriculture in cooperation with the International Rice Research Institute. Rice Production Manual. Los Banos, Philippines.

Mahapatra, I.C. 1969. Recent advances in rice agronomy. Indian Fmg. 19:9-11.

Mali, P.C. and Metha, S.L. 1977. Effect of drought on enzymes and free proline in rice varieties. Phytochem. 16(9):1355-1357.

Mali, C.V. and Varade, S.B. 1981. Response of rice to varying soil moisture conditions in vertisols. 1. Studies on soil pH and nutrient availability. Zeitschrift fur Acker und Pflanzenbau 150(2):129-139.

Mallick, S.N. and Das, K.C. 1966. A preliminary study on water requirement of crops in Hirakud irrigated areas. Pages 25-31. in Proc. Symp. Water Management. Udaipur. Indian Society of Agronomy and Indian Council of Agrl. Research, New Delhi.

Malvolta, S. 1954. Studies on nitrogenous nutrition of rice. Plant Physiol. 29:98-99.

Mann, R.K. and Rick, C.E. 1979. Effect of soil moisture on herbicidal action of foliar applied herbicides. Page 31. in Proc. 32nd Annual Meeting Southern Weed Science Society.

Matsunaka, S. 1983. Evolution of rice weed control practices and research : World perspective. Pages 5-18. in International Rice Research Institute and International Weed Science Society. Proc. Conf. Weed Control in Rice. Los Banos, Philippines.

Matsunaka, S. and Aoyama, Y. 1981. Distribution of propanil hydrolyzing enzyme (rice aryl acyl amidase 1) in Oryza genus. Pages 353-355. in Proc. 8th Asian-Pacific Weed Sci. Soc. Conf.

Meier, D. and Lichtenthaler, H.K. 1980. Induction of a degenerative stage in chloroplast ultrastructure by the herbicide bentazone. Electron Microscopy 2:244-245.

Meier, D. and Lichtenthaler, H.K. 1981. Ultrastructural development of chloroplasts in radish seedlings grown at high and low light conditions and in the presence of the herbicide bentazone. Protoplasma 107:195-207.

Meier, D., Lichtenthaler, H.K. and Burkard, G. 1980. Change of chloroplast ultrastructure in radish seedlings under the influence of the photosystem II herbicide bentazone. Zeitschrift fur Naturforschung 35(7/8):656-664.

Menck, B.H. 1983. Bentazone alone or in combination with other herbicides for rice weed control. Page 279. in International Rice Research Institute and International Weed Science Society. Proc. Conf. Weed Control in Rice. Los Banos, Philippines.

Mercado, B.L., Mercado, L.R. and Manimtim, M.B. 1978. Weed control in direct-seeded lowland rice. Pages 34-36. in College of Agriculture University of Philippines. Weed Science Report 1976-1977. Los Banos, Philippines.

Mercado, B.L. and Razon, J.L. 1977-78. Evaluation of herbicides for weed control in rice. Pages 11-25. in University of the Philippines, College of Agriculture. Weed Science Report, Los Banos, Philippines.

Mercado, B.L. and Talatala, R.L. 1977. Competitive ability of Echinochloa colonum L. against direct-seeded lowland rice. Pages 161-165. in Proc. 6th Asian-Pacific Weed Sci. Soc. Conf. Indonesia. Volume 1.

Mikkelsen, D.S. and De Datta, S.K. 1979. Ammonia volatilization from wetland rice soils. Pages 135-156. in International Rice Research Institute. Nitrogen and Rice. Los Banos, Philippines.

Misra, B.B., Behera, P.K. and Tripathy, P.C. 1980. Comparative studies on NO_3 uptake and NR in root and shoot of rice seedlings induced by NO_3. Indian J. Plant Physiol. 23(2): 97-102.

Mohamed Ali, A., Arokia Raj, A. and Sankaran, S. 1977. Weed control in direct-seeded rice. Page 11. in Program and Abstracts of Papers. Weed Sci. Conf. and Workshop in India, Paper No. 17.

Moody, K. 1981a. Weed control in dry-seeded rice. Pages 30-35. in International Rice Research Institute. Report of a Workshop on Cropping Systems research in Asia. Los Banos, Philippines.

Moody, K. 1981b. Weed-fertilizer interactions in rice. IRRI Res. Pap. Ser. 68:35.

Moody, K. and Mukhopadhyay, S.K. 1982. Weed control in dry-seeded rice - problems, present status, future research directions. Pages 147-158. in International Rice Research Institute. Rice Research Strategies for the future. Los Banos, Philippines.

Moore, P.A. Jr., Gilmour, J.T. and Wells, B.R. 1981. Seasonal patterns of growth and soil N by rice. Soil Sci. Soc. Am. J. 45(5):875-879.

Moorthy, B.T.S. and Dubey, A.N. 1979. Uptake of N by puddle seeded rice and the associated weeds under different pre-emergence herbicides. Oryza. 16(1):60-61.

Moorthy, B.T.S. and Dubey, A.N. 1981. Relative efficacy of different herbicides for control of weeds in upland rainfed rice. Indian J. Weed Sci. 13(1):56-62.

Morilla, C.A., Boyer, J.S. and Hageman, R.H. 1973. Nitrate reductase activity and polyribosomal content of corn having low water potentials. Plant Physiol. 51:817-824.

Morison, J.T.L. and Gifford, R.M. 1983. Stomatal sensitivity to CO_2 and humidity. Plant Physiol. 71:789-796.

Mukhopadhyay, S.K. and De, G.C. 1979. Efficiency of granular herbicides and cultural methods in rice weed control. Int. Rice Res. Newsl. 4(4):11-12.

Mukhopadhyay, S.K. and Mondal, A. 1981. Efficiency of fluchloralin, butachlor, nitrofen and hand weeding for rice weed control. Int. Rice Res. Newsl. 6(4):16-17.

Murakami, M., Nakanishi, H., Moris, S. and Tominaga, T. 1978. Influence of barnyard grass on the productivity of paddy rice. Pages 1-8. in Scientific Reports of the Kyoto Prefactural University (Agriculture) No.30.

Murata, Y. 1969. Physiological responses to nitrogen in plants. Pages 235-263 in Am. Soc. Agron. and Crop Sci. Soc. Am. Physiological Aspects of Crop Yield.

Murayama, N. 1979. The importance of nitrogen for rice production. Pages 5-25. in International Rice Research Institute. Nitrogen and Rice, Los Banos, Philippines.

Murthy, P.S. and Murthy, M.S. 1978. Productive efficiency and N response of high yielding rice cultures of A.P. Oryza 15(1):83-85.

Naidu, G.N. and Bhan, V.M. 1980. Effect of different groups of weeds and periods of weed free maintenance on the grain yields of drilled rice. Indian J. Weed Sci. 12(1):151-157.

Naik, M.S., Abrol, Y.P., Nair, T.V.R. and Ramarao, C.S. 1982. NO_3 assimilation - its regulation and relationship to reduced N in higher plants. Phytochem. 21(3):495-504.

Nair, R.R., Pillai, G.R., Pisharody, P.N. and Gopalakrishnan, R. 1976. Investigations on the competing ability of rice with weeds in the rainfed uplands. Agric. Res. J. Kerala 13(2): 146-151.

Nair, T.V.R. and Abrol, Y.P. 1977. Studies on nitrate reducing system in developing wheat ears. Crop Sci. 17:438-442.

Nanjappa, H.V. and Krishnamurthy, K. 1980. Nutrient losses due to weed competition in tall and dwarf varieties of rice. Indian J. Agron. 25:273-278.

Narayanaswamy, V. and Sankaran, S. 1977. Relative efficiency of granular and emulsifiable concentrate herbicides under graded levels of N in rice. Page 8 in Prog. and Abstr. Papers Weed Sci. Conf. and Workshop in India, 1977, Pap.12.

Natr, L. (1972). Influence of Mineral nutrients on photosynthesis of higher plants. Photosynthetica 6:80-99.

Nayak, R.L. 1970. Effect of soil drought at different physiological growth stages on yield and water requirement of upland rice. M.Sc. Dissertation, Indian Agrl. Res. Institute, New Delhi.

Nayek, B., Biswas, A.K. and Choudhuri, M.A. 1982. Water stress induced changes in enzymic activities with age and development of field grown rice. Phyton, Argentina 42(1): 103-108.

Noda, K. 1980. Main weeds in rice culture and their control. Pages 150-159 in Association of Agricultural Relations. Plant Protection in Japan 1980, Tokyo, Japan.

Noguchi, K. and Nakayama, K. 1978. Studies on competition between upland crops and weeds. 2. Comparison of early growth of crops and weeds. Jap. J. Crop Sci. 47(1):48-55.

Noriel, L.M. 1981. Effect of butachlor on the protein content of C-168 and IR-36 in rice cvs at different growth stages. Ann. Trop. Res. 3(2):111-116.

Oaks, A. 1979. Nitrate reductase in roots and its regulation. Pages 227-244 in E.J. Hewitt and C.V. Cutting (eds.). Nitrogen Assimilation in Plants. Academic Press, London.

Okafor, L.I. 1980. Chemical weed control in transplanted rice under two levels of flooding. Pages 326-330. in Weeds and Their Control in the Humid and Sub-humid Tropics. Proc. Conf. Int. Inst. Trop. Agric. 1978.

Okafor, L.I. and De Datta, S.K. 1974. Competition between weeds and upland rice in monsoon rice. Philippine Weed Sci. Bull. 1(1):39-45.

Okafor, L.I. and De Datta, S.K. 1976. Competition between upland rice and purple nutsedge for N, moisture and light. Weed Sci. 24(1):43-46.

*Olofintoye, J.A. 1980. The effects of different tillage techniques, seeding rates, time and methods of N application on the growth and yield of upland rice. MS Dissertation. University of Philippines. Los Banos, Laguna, Philippines 158 p.

Olsen, S.R. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. U.S.D.A. (Washington) Circ. No. 939.

O'Toole, J.C., Aquino, R.S. and Alluri, K. 1978. Seedling stage drought response in rice. Agron. J. 70:1101-1103.

O'Toole, J.C. and Baldia, E.P. 1982. Water deficits and mineral uptake in rice. Crop Sci. 22:1144-1150.

O'Toole, J.C. and Moya, T.B. 1979. Genotypic variations in maintenance of leaf water potential in rice. Crop Sci. 18(5):873-876.

O'Toole, J.C. and Moya, T.B. 1981. Water deficits and yield in upland rice. Field Crops Res. 4:247-259.

Panda, S.C., Sahu, S.K. and Misra, B. 1979. Leaching loss of NO_3^--N under different water table depths and water management practices in rice fields. Oryza 16(2):107-112.

Pande, H.N. 1963. A study of the effect of light irrigation on the grain and straw yield of late aman paddy. Paper presented in the 36th Ann. Meeting Central Bd. Irri. and Power, India.

Parker, C. and Fryer, J.D. 1975. Weed control problems causing major reductions in world food supplies. F.A.O. Plant Protection Bull. 23(3/4):83-95.

Parsons, L.R. 1982. Plant Responses to Water Stress. Pages 175-192 in M.N. Christansen and F.C. Lewis (eds.) Breeding Plants for less favourable environments. John. Wiley and Sons, Inc. New York.

Passioura, J.B. 1982. Water in the soil-plant-Atmosphere continuum. Pages 1-33. in A. Pirson and M.H. Zimmerman. Encyclopedia of Plant Physiology 12 B. Springer Verlang, Berlin.

Paul, A.K. and Jacob, P. 1977. Effectiveness of post-emergence application of herbicide butachlor at different rates and at different time in controlling weeds in upland rice. Allahabad Farmer 48(4):437-438.

*Pereiro, G.A. 1975. Effect of the duration of weed control and of weed competition on rice yields. Centro Agricola. 2(1):27-31.

Pesticides Association of India (PAI). 1975. Rice Revolution through Pest Control. Pesticides 9(6):13.

Pillai, G.R. 1980. Studids on the influence of fertilizer N and blue-green algae on growth and yield of rice under different soil moisture regimes. Ph.D. Dissertation. Indian Agrl. Research Institute, New Delhi. 234 p.

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

Pillai, K.G. and De, R. 1979. Mineral N status of soil, leaf N content and grain yield of rice var. Jaya as affected by water and nitrogen fertilizer management. Field Crops Res. 2(2):125-133.

Pillai, K.G., Vamadevan, V.K. and Subbaiah, S.V. 1977. Weed problems in rice and possibilities of chemical weed control. Page 1 in Programme and Abstracts. Weed Science Conference and Workshop in India. Paper no.1.

Pillai, S. 1958. Rice cultural trials and practices in India. Monograph No. 27. Indian Council of Agricultural Research, New Delhi.

Piper, C.S. 1950. Soil and Plant Analysis. The University of Adelaide, Australia. 286p.

Podkin, O.V., Chanukvadze, O.V., Frolova, V.S. 1983. Farmers' weed control technology for water seeded rice in Eastern Europe. Pages 179-182 in International Rice Research Institute and International Weed Science Society. Proc. Conf. Weed control in rice. Loss Banos, Philippines.

*Polthanee, A. 1980. The effect of N fertilizer application method and depth of planting on dry-seeded rice. MS Dissertation University of Philippines, Los Banos, Laguna, Philippines. 118 p.

Pons, T.L. 1980. Growth rates and competitiveness to rice of some annual weed species. Page 65-70 in Proc. 7th Conf. Asian-Pacific Weed Sci. Soc. Sydney, Suppl. Vol.

Pons, T.L. and Utomo, I.H. 1979. The competition of 4 selected weed species with rice. The effect of the time of weed removal and the rate of fertilizer application. Page 331 in Ecophysiological Studies on Weeds of Lowland Rice Doc. No. Brotrop /TP/79.

Prasad, M. and Prasad, R. 1980. Yield and nitrogen uptake by rice as affected by variety, method of planting and new nitrogen fertilizers. Fert. News 1(4):207-214.

Prasad, M. and Prasad, R. 1983. Removal of N, P and K by rice-wheat double cropping system as affected by duration of rice variety, methods of planting rice and levels and sources of N. Plant and Soil. 70(2):287-295.

Prasad, R. 1982. A practical manual for students in soil fertility, Division of Agronomy, IARI, New Delhi (Mimeographed).

Prasad, R. and De Datta, S.K. 1979. Increasing fertilizer nitrogen efficiency in wetland rice. Pages 465-484 in International Rice Research Institute, Nitrogen and Rice. Los Banos, Philippines.

Radin, J.W., Parker, L.L. and Guin, G. 1982. Water relations in cotton plants under N deficiency. 5. Environmental control of ABA accumulation and stomatal sensitivity to ABA. Plant Physiol. 70:1066-1070.

Rai, R.S.V. and Murthy, K.S. 1979. Path analysis of grain yield in rice under different N rates. Oryza 16(1): 62-63.

Rajale, G.B. and Prasad, R. 1974. Relative efficiency of urea, nitrification inhibitor treated urea and slow release N fertilizers for rice. J. agric. Sci., Camb. 83:303-307.

Rajan, M.S.S. and Mahapatra, I.C. 1980. Influence of N management and weed control methods in direct-seeded rice on the available ammoniacal and NO_3-N of upland soils. Indian J. Agron. 25(4):666-672.

Rajput, R.K. 1979. Progress Report on Integrated Project for Research on Water Management and Soil Salinity. Indian Council of Agrl. Research, New Delhi.

Rao, E.V.S.P., Prasad, R. and Abrol, Y.P. 1979. NO_3 assimilation in rice grown under lowland conditions. Physiol. Plant. 47:139-143.

Ray, T.B. and Still, C.C. 1975. Propanil metabolism in rice, a comparison of propanil amidase activities in rice plants and callus cultures. Pesticide Biochem. Physiol. 5:171-177.

Reddy, K.R. 1982. Nitrogen cycling in a flooded soil-ecosystem planted to rice. Plant and Soil 67:209-220.

Reddy, K.R. and Patrick, W.H. Jr. 1975. Effect of alternate aerobic and anaerobic conditions on redox potential, organic matter decomposition and nitrogen loss in a flooded soil. Soil Biol. Biochem. 7:87-94.

Reddy, K.R. and Patrick, W.H. Jr. 1976. Yield and N utilization by rice as affected by method and time of application of labelled N. Agron. J. 68:965-969.

Reddy, K.R. and Patrick, W.H. Jr. 1978. Residual fertilizer N in a flooded rice soil. Soil Sci. Soc. Am. J. 42:316-318.

Reddy, K.R. and Patrick, W.H. Jr. 1980a. Losses of applied ammonium N^{15}, urea N^{15} and organic N^{15} in flooded soils. Soil Sci. 130:326-330.

Reddy, K.R. and Patrick, W.H. Jr. 1980b. Uptake of fertilizer N and soil N by using N15 labelled N fertilizer. Plant and Soil 57(2/3):375-381.

Reddy, S.R. and Hukkeri, S.B. 1979. Soil, water and weed management for direct-seeded rice grown on irrigated soils in NW India. Indian J. agric. Sci. 49(6):427-433.

Renard, C. and Alluri, K. 1981. Leaf water potential, stomatal conductances and leaf characteristics of cultivars of rice in their response to water stress. Acta Oecol. Oecol. Plant 2(4):339-350.

*Retzlaff, G. and Hamm, R. 1977. Current knowledge on the mode of action of 3-isopropyl-2,1,3-thiadiazin-4-one-2,2-dioxide (bentazone). Mitteilungen aus der Biologischen Bundesanstalt fur Land-und Forstwirtschaft, Berlin-Dahlem No.178:220-221.

*Retzlaff, G., Hilton, J.L. and St. John, J.B. 1979. Inhibitio of photosynthesis by bentazone in intact plants and isolated cells in relation to the pH. Zeitschrift fur Naturforschung 34 C(11):944-947.

Rice, E.L. 1979. Allelopathy - an update Bot. Rev. 45: 15-109.

Richards, L.A. and Weaver, L.R. 1943. Fifteen atmosphere percentage as related to the permanent wilting percentage. Soil Sci. 56:331-339.

Rosswall, T. 1982. Microbiological regulation of the bio-geo-chemical N cycle. Plant and Soil. 67:15-34.

*Ryang, W.S. 1974. Studies on varietal reaction of some herbicides incorporated into soils and applied on the surface before transplanting of rice. 3. Sandy loam soil conditions. Research Reports of the Office of Rural Development (Crop) 16:79-88.

Sabio, E.A., Fisher, H.H. and Pastores, R.M. 1980. Preliminary results of herbicide selectivity and labor/capital substitutio experiments. Weed Sci. Soc. Philippines Newsl. 7(2):7-8.

Saefuddin, S.W.A., Tajudin, S., Hidayut, A. and Effendi, S. 1978. Methods of N application and weed control in gogo-ranch rice culture. Int. Rice Res. Newsl. 3(1):15.

Sahrawat, K.L. 1981. Influence of water regime on growth, yield and nitrogen uptake of rice. Commun. in Soil Sci. Plant Anal. 12(9); 919-932.

Sahu, B.N. and Rao, B.J.M. 1974. Water regime in rice soils. 1. Effect of soil moisture stress at different phases of growth of 3 rice plant species. Oryza 11(2):59-65.

Saif, M.S. and Rana, A.J. 1980. Nutritional studies for dry matter yield and mineral concentration of crops. Part 1. Effect of nutrients on rice. Pakistan J. Scientific Ind. R 23(6):271-274.

Samui, R.C., Maiti, B.K. and Jana, P.K. 1979. Effect of N on pre-*kharif* direct-seeded rice. Indian J. Agron. 24(1): 77-80.

Sandhu, B.S., Khera, K.L., Prihar, S.S. and Singh, B. 1980. Irrigation needs and yield of rice on a sandy loam soil as affected by continuous and intermittent submergence. Indian J. agric. Sci. 50(6):492-496.

Santos, C.A.L. Dos and Cruz, L.S.P. 1979. Effect of bentaz and bentazone + dichlorprop on irrigated rice and on weeds. Planta Daninha 2(1):18-21.

Sarkar, P.A. and Ghosh, A.K. 1980. Influence of variety, spacing and N levels on weed flora in transplanted rice. Pages 1-2 in Proc. All India Weed Sci. Conf., Coimbatore.

Sarkar, P.A. and Moody, K. 1981. An estimate of yield loss in rice due to weeds in the Philippines. 12th Annual Conference of the Pest Control Council of the Philippines. WSSP Newsl. 9(1):5.

Sasakawa, H. and Yamamoto, Y. 1977. Nitrate assimilation in rice seedlings as affected by mineral nutrition. Plant Cell Physiol. 18(1):215-224.

Sasakawa, H. and Yamamoto, Y. 1978. Comparison of uptake of NO_3 and NH_4 by rice seedlings. Influences of light, tem O_2 concentration, exogenous sucrose and metabolic inhibitors. Plant Physiol. 62(4):665-669.

Savant, N.K. and De Datta, S.K. 1982. N transformations in wetland rice soils. Adv. Agron. 35:241-302.

Schiller, J.M. and Indhaphun, P. 1979. Weed control studies in direct-seeded upland rice. Pages 271-276 in Proc. 7th Asian-Pacific Weed Sci. Conf., Sydney, Australia.

Shahi, H.N., Gill, P.S. and Khind, C.S. 1979. Comparative effect of different herbicides on weed control and nutrient removal in transplanted rice. Int. Pest Control 21(3):55-58

Shaner, D.L. and Boyer, J.S. 1976a. NRA in maize leaves. 1. Regulation of NO_3 flux. Plant Physiol. 58:499-504.

Shaner, D.N. and Boyer, J.S. 1976b. NRA in maize leaves II. Regulation of NO_3 flux at low leaf water potential. Plant Physiol. 58:505-509.

Shankar, V. 1971. Ecological studies on crop area weeds in India - a review. Indian J. Weed Sci. 3(2):120-129.

*Sierra, J.N. and Mercado, B.L. 1975. Competitive ability of Cyperus rotundus with some associated crops. Paper presented at the Third Indonesian Weed Science Conference, Bandung.

Silk, J.A., Dean, M.L., Richardson, G. and Taylor, W.A. 1980. Properties of herbicides. Pages 85-154 in J.D. Fryer and R.J. Makepeace (eds.). Weed Control Handbook Vol. 1. Blackwell Scientific Publications, Oxford.

Silva, P.R.F. Da. 1980. N volatilization from rice leaves as affected by genotype temperature, rate and source of N applied. Dissert. Abstr. Int. B 41(5):1586-1587.

*Silva, P.R.F. Da and Stutte, C.A. 1980. Nitrogen volatilization by rice leaves through transpiration. Lavoura Arrozeira 33(325):10-18.

Singh, B.K. and Modgal, S.C. 1978. Effect of levels and methods of N application on the performance of rice varieties on rainfed uplands. Indian J. agric. Sci. 48(6): 337-341.

Singh, B.K., and Modgal, S.C. 1979a. Pattern of dry matter accumulation and nitrogen concentration and uptake as influenced by levels and methods of N application in rainfed upland rice. Plant and Soil. 52(1):9-17.

Singh, B.K. and Modgal, S.C. 1979b. Dry matter and nitrogen accumulation in 2 semi-dwarf rices in rainfed-upland conditions. Int. Rice Res. Newsl. 4(1):8-9.

Singh, G. and Chauhan, R.S. 1978. Weed management in upland paddy. Indian J. Weed Sci. 10(1&2):83-86.

Singh, M.K. and Sahrawat, T. 1981. Photosynthesis and transpiration in rice as influenced by soil moisture and air humidity. Ann. Bot. 48(4):513-517.

Singh, M.T., Patel, M.S., Singh, R. and Vig, A.C. 1980. Effect of soil compaction on yield and WUE of rice in a highly permeable soil. Agron. J. 72:499-502.

Singh, R.A., Sharma, H.C., Singh, U.N. and Singh, M. 1979. Response of direct-seeded rice to N under dryland conditions. Indian J. Agron. 24(2):161-165.

Singh, R.K., Rafey, A. and Rao, M.S.S. 1982a. Effect of split application of N on the performance of upland rice. Indian J. Agron. 27(3):199-201.

Singh, R.P. and Sharma, G.L. 1981. Effect of methods of planting and herbicides on rice/weed competition. Pages 75-78 in Proc. 6th Australian Weeds Conf. Vol. 1.

Singh, R.P. and Singh M. 1976-77. Effect of herbicides on weed control and yield of direct-seeded rice under puddled conditions. J. Scientific Res. BHU. 27(1-2):51-54.

Singh, T.N., Aspinall, D. and Paleg, L.G. 1972. Proline accumulation and varietal adaptation to drought in barley. A potential metabolic measure for drought tolerance. Nature New Biol. 236:188-190.

Singh, T.N., Paleg, L.G. and Aspinall, D. 1973a. Stress metabolism III. Variations in response to water deficit in the barley plant. Aust. J. biol. Sci. 26:65-76.

Singh, T.N., Aspinall, D. and Paleg, L.G. 1973b. Stress metabolism IV. The influence of CCC and GA on the growth and proline accumulation of wheat plants during water stress. Aust. J. biol. Sci. 26:77-86.

Singh, T.N., Singh, G. and Singh, H.P. 1982b. Chemical weed control in dryland rice. Int. Rice Res. Newsl. 7(5):21-22.

Singh, Y.P., Siwach, M.S. and Rathi, S.S. 1973c. Comparative study of methods of paddy planting in Tarai region of U.P. Indian J. Agron. 18:269-272.

Sinha, S.K. and Nicholas, D.J.D. 1981. Nitrate reductase. Pages 145-169 in L.G. Paleg and D. Aspinall (eds.). Physiology and Biochemistry of drought resistance in plants. Academic Press, Sydney.

Sircar, S.P. 1975. Screening techniques and selection criteria for drought tolerance in upland rice. Ph.D. Dissertation. Indian Agricultural Research Institute, New Delhi.

Smith, R.J. Jr. 1979. How to control hard to kill weeds in rice. Weeds Today 10(1):12-14.

Smith, R.J. Jr. 1983. Weeds of major economic importance in rice and yield losses due to weed competition. Pages 19-36 in International Rice Research Institute and International Weed Science Society. Proc. Conf. Weed Control in Rice. Los Banos, Philippines.

Snitwongse, P. and Jirathana, P. 1981. The study on the effect of water managements and N fertilizer practices on the efficiency of fertilizer utilization. Thai J. Agric. Sci. 14(2):107-121.

*Socorro, M., Sanzo, R. and Sedeno, R. 1978. Influence of nitrogen on the growth and yield of 2 high yielding rice cultivars. Centro Agricola, Revista Cientifica dela Facultad de Ciencias Agricolas 5(2):15-25.

Sonar, K.R. and Ghugare, R.V. 1982. Release of Fe, Mn and P in a calcareous vertisol and yield of upland rice as influenced by pre-sowing soil-water treatments. Plant and Soil 68(1):11-18.

Srivastava, H.S. 1980. Regulation of nitrate reductase activity in higher plants. Phytochem. 19:725-733.

Srivastava, H.S. and Metha, P. 1983. Regulation of NRA by NH_4 in higher plants. Trop. Plant Sci. Res. 1(1):75-79.

Stanford, G. and Epstein, E. 1974. N mineralization-water relations in soil. Soil Sci. Soc. Am. Proc. 38:103-107.

Stanford, G. and Smith, S.J. 1972. N mineralization potentials of soils. Soil Sci. Soc. Am. Proc. 36:465-472.

Steer, B.T. 1981. N. and NO_3 accumulation in species having different relationships between NO_3 uptake and reduction. Ann. Bot. 49:191-198.

Stewart, C.R. and Hanson, A.D. 1980. Proline accumulation as a metabolic response. Pages 173-190 in P.J. Kramer and N.C. Turner (eds.) Adaptations of plants to water and high temperature stress. John Wiley Sons, Inc. New York.

*Stone, L.F. and Steinmetz, S. 1979. N fertilization and the LAI of 2 rice cultivars under upland conditions. Pesquisa Agropecuaria Brasileira 14(1):25-28.

Subramanian, S. and Rajagopalan, K. 1979. Water management for lowland rice. Madras agric. J. 66(6):370-375.

Subramanian, S., Sundara Singh, S.D. and Ramaswami, K.P. 1978. Crop sequence studies under different irrigation regimes and manuring for Valgai Periyar Command Area. Madras agric. J. 65(9):567-571.

Suwanketnikom, R., Penner, D. and Good, N.E. 1978. Site of bentazone electron transport inhibition in isolated spinach chloroplasts. Pages 115-116 in Proc. North Central Weed Control Conf. Vol. 33: Michigan State University, East Lansing, USA.

Suzuki, K., Uda, M., Samoto, K. and Yamakawa, I. 1975. Weed injury and its control on dryland direct-sowing under different conditions of water management. Bull. Tokai Kinki Nat. Agrl. Expl. Sta. 28:39-49.

Tanaka, I. 1976. Agroecological note of irrigation in rice culture. Symposium on water management in rice field. Proc. Symp. Trop. Agrl. Res. 161-172.

Tang, P.S. and Wu, H.Y. 1957. Adaptive formation of NR in rice seedlings. Nature 179:1650-1655.

Tasic, R.C., Sabordo, M.P. and Balairos, J.B. 1980. The effect of various weed control practices in the yield of upland rice. Philippine J. Weed Sci. 7:76-79.

Tomar, V.S. and O'Toole, J.C. 1979. Evapotranspiration from rice fields. IRRI Res. Pap. Ser. No.34. 15p.

Tomar, V.S. and O'Toole, J.C. 1980. Water use in lowland rice cultivation in Asia-A review of evapotranspiration. Agricultural Water Management 3:83-106.

Thomas, J. 1981. Studies on the nitrogen management of direct-seeded rice. Ph.D. dissertation, Indian Agricultural Research Institute, New Delhi, 203 p.

Trewavas, A.J. 1981. How do plant growth substances work. Plant Cell Environ. 4:203-228.

Tsunoda, S. 1979. Characteristic of photosynthesis and environmental adaptation of rice. Pages 3-8 in Institute of Botany, Academia Sinica. Proc. Roc-Japan Symp. Rice Productivity. Taipei, Republic of China.

Ulug, E. 1978. Field trial for chemical weed control in rice in the Aegean region. Page 155 in Genel Mudurlugu, Arastirina Dairesi Baskanligi Sam. Plant Protection Research Annual Report, Bey Caddesi Ankara, Turkey.

Upadhyay, U.C. and Choudhary, 1979. Effect of different weed control methods on growth and yield of rice under upland conditions. Pages 289-291 in Proc. 7th Asian-Pacific Weed Sci. Soc. Conf. Sydney, Australia.

Upadhyay, R.M. and Pathak, A.N. 1981. Influence of N, P and Mn on dry matter and harvest of economic products in Ratna rice. Indian J. agric. Res. 15(1):11-16.

Utomo, I.H. and Mercado, B.L. 1980. Response of different rice varieties to herbicide applications. Pages 13-17 in Proc. 7th Asian-Pacific Weed Sci. Soc. Conf. Sydney, Australia, 1979, Suppl. Vol.

Vamadevan, V.K. and Dastane, N.G. 1973. Effect of withholding water at different growth stages on NP 130 and TN-1. Il Riso 22:295-297.

Varughese, A. and Nair, K.P.M. 1980. Critical periods of weed competition in short duration variety 'Triveni'. Agric. Res. J. Kerala. 18(1):1-7.

Villegas, V.G.A. 1980. Introduction of puddling, an Asian technique in rice production in Columbia. Int. Rice Res. Newsl. 5(3):22.

Vlek, P.L.G. and Craswell, E.T. 1979. Effect of N source and management on NH_3 volatilization losses from flooded rice soil systems. Soil Sci. Soc. Am. J. 43:352-358.

Vlek, P.L.G., Hong, C.W. and Youngdahl, L.J. 1979. An analysis of N nutrition and yield components for the improvement of rice fertilization in Korea. Agron. J. 71(5): 829-833.

Wang, C.Y., Cheng, S.H. and Kao, C.H. 1982. Senescence of rice leaves. VII. Proline accumulation in senescing leaves. Plant Physiol. 69:1348-1349.

Wang, F.J., Peng, G.Y., Zhang, Q.G., Deng, H.M., Wang, B.Z., Wen, X.F. and Mai, H.K. 1981. Studies on fertilizer N uptake in rice using the N^{15} isotope and on the effect of application of fertilizer-N. Scientia Agricultura Sinica 4: 66-71.

Wann, S.S. 1976. Water management of soils for growing rice. ASPAC Food and Fertilizer Technology Center Technical Bulletin No. 40, 12p.

Weerd, J.C. van de. 1977. Cyperus difformis - worldwide rice enemy. Agrl. News BASF 2:7-10.

Wells, G.J. and Cabradilla, N. 1981. Weed competition in upland rice. Pages 143-144 in Proc. 8th Asian-Pacific Weed Sci. Soc. Conf.

Wickham, T.H. and Singh, V.P. 1978. Water movement through wet soils. Pages 337-358 in. International Rice Research Institute. Soils and Rice. Los Banos, Philippines.

Wilson, F.E. and Mengel, D.B. 1980. Timing of N for rice in relation to initial flood. Page 45 in American Society of Agronomy. Agronomy Abstracts, Madison, Wisconsin, USA.

Xiang, M. 1982. A study of correlation between photosynthesis rates of different leaves on a rice plant with GA and DCPA treatment. Plant Physiol.Commns. 2:15-17.

Yadav, J.S.P. 1972. Water management and irrigation scheduling in relation to rice production. Oryza. 9(2): 77-96.

Yadav, J.S.P. 1974. Water management practices in rice production. Oryza 11(2):17-25.

Yamagishi, H., Morishima, H. and Oka, H.I. 1978. An experiment on the interaction between cultivated rice and barnyard grass at different planting densities. Agro-Ecosystems 4(4):449-458.

Yoshida, R. and Oritani, T. 1974. Studies on N metabolisms in crop plants. I. Effects of N topdressing on cytokinin content in the root exudate of rice plants. Proc. Crop Sci. Soc. (Japan) 43:47-51.

Yoshida, S. 1981. Fundamentals of Rice Crop Science. International Rice Research Institute, Los Banos, Philippines 269 p.

Yoshida, S., Satake, T. and Mackill, D.S. 1981. High temperature stress in rice. IRRI Res. Pap. Ser. 67 15p.

Zhou, Qi and Chen Hua-Kuei. 1983. The activity of nitrifying and denitrifying bacteria in paddy soil. Soil Sci. 135(1):31-34.

Zimdahl, R.L. 1980. Weed crop competition - a review. International Plant Protection Center. Oregon State University, Corvallis, Oregon 197 p.

* Original not seen

Appendix 1. Meteorological data during the crop seasons

Weeks	Mean temp. (°C)		Mean R.H. (%)		Total rain-fall (mm)	Mean pan evapora-tion (mm)	Mean sol radiatio (Cal. cm^{-2}
	Max.	Min.	Max.	Min.			
June 1982							
20-26	38.86	28.86	61.75	41.75	0.0	6.37	434.16
27-3	36.93	29.43	55.17	37.67	25.2	10.48	519.97
July 1982							
4-10	41.36	30.07	46.00	33.80	0.4	12.01	524.68
11-17	34.71	27.29	75.33	62.00	23.6	7.41	425.86
18-24	35.53	26.63	79.50	72.67	79.3	6.48	512.51
25-31	32.75	25.53	71.83	62.20	171.8	5.37	568.08
Aug. 1982							
1-7	32.39	25.61	94.71	76.00	58.7	3.59	395.44
8-14	33.13	25.36	91.29	82.00	76.8	4.39	371.48
15-21	34.51	26.17	96.14	58.67	85.6	5.03	364.78
22-28	33.36	24.21	97.43	66.00	34.3	3.90	353.96
29-4	34.73	24.65	96.57	44.57	14.4	5.61	453.52
Sept. 1982							
5-11	36.63	23.73	96.43	38.57	0.0	7.81	425.86
12-18	36.29	23.29	81.71	35.14	0.0	8.36	494.08
19-25	35.16	21.27	90.00	36.29	0.0	7.73	445.65
26-2	35.21	18.54	97.00	26.00	0.0	6.59	431.39
Oct. 1982							
3-9	35.47	19.89	97.14	33.14	2.6	5.27	364.10
March 1983							
6-12	27.87	15.82	94.67	48.33	0.2	4.63	368.72

Appendix I (contd.....)

Weeks	Mean temp. (°C)		Mean R.H. (%)		Total rain-fall(mm)	Mean pan evapora-tion (mm)	Mean solar radiation (Ca cm^{-2})
	Max.	Min	Max.	Min			
13-19	29.47	14.66	92.57	27.71	3.2	5.96	449.83
20-26	27.76	13.75	92.29	29.71	0.4	6.39	440.62
27-2	30.08	13.76	88.00	36.86	6.0	6.43	530.94
April 1983							
3-9	33.33	18.47	86.14	31.29	0.0	7.54	470.15
10-16	25.63	14.60	97.71	52.00	139.6	4.15	368.71
17-23	29.69	15.94	97.57	41.43	11.4	5.24	559.61
24-30	38.76	22.46	75.14	31.43	0.0	7.69	573.40
May 1983							
1-7	39.47	24.83	49.14	22.33	0.0	10.06	594.70
8-14	36.71	24.57	66.40	36.75	20.4	7.91	524.32
15-21	35.43	25.83	66.67	44.17	15.6	6.93	440.61
22-28	36.43	24.57	65.60	37.80	1.2	7.23	469.19
June 1983							
29-4	40.64	26.86	56.67	30.50	0.0	11.89	558.60
5-11	41.50	28.57	49.85	34.80	2.2	11.94	511.59
12-18	35.67	26.75	65.50	45.60	32.0	7.93	471.03
19-25	40.29	27.64	56.83	42.83	0.0	9.59	488.69
26-2	33.86	28.07	78.50	70.00	4.6	7.10	353.96
July 1983							
3-9	34.93	26.64	73.80	60.80	73.2	6.21	455.35
10-16	35.21	27.57	81.40	67.50	27.0	6.46	396.37
17-23	37.26	29.50	76.00	56.00	0.0	7.23	489.47
24-30	31.70	27.50	89.25	80.25	202.2	3.55	264.55
Aug. 1983							
31-6	33.14	28.33	84.17	71.80	97.0	5.83	378.85
7-13	34.43	28.07	79.40	68.20	4.2	5.14	419.41
14-20	33.00	29.00	86.60	79.50	56.0	3.20	296.81
21-27	32.60	27.00	91.00	79.50	66.1	3.53	301.11

Contd.....

Appendix I (contd.....)

Weeks	Mean Temp. (°C)		Mean R.H. (%)		Total rain-fall (mm)	Mean pan evapora-tion (mm)	Mean solar radiation (Ca cm⁻2)
	Max.	Min.	Max.	Min.			
Sept. 1983							
28-3	32.50	8.43	78.25	77.50	70.6	3.87	249.06
4-10	32.60	7.00	7.75	77.00	68.0	4.37	330.92
11-17	34.64	9.00	5.33	64.83	2.8	5.33	392.69
18-24	35.24	5.07	5.57	52.57	2.8	5.40	330.78
25-1	35.87	4.87	9.71	42.00	0.0	4.53	372.40
Oct. 1983							
2-8	37.19	23.27	99.00	36.86	0.0	3.71	398.21

Appendix II. Depth to ground water table during the crop seasons

Date 1982	Depth to water table from local ground level (cm)	Date 1983	Depth to water table from local ground level (cm)
3.7.1982	223	2.7.1983	220
10.7.1982	210	9.7.1983	190
17.7.1982	169	16.7.1983	160
24.7.1982	102	23.7.1983	170
31.7.1982	82	30.7.1983	56
7.8.1982	66	6.8.1983	52
14.8.1982	60	13.8.1983	66
21.8.1982	40	20.8.1983	45
28.8.1982	49	27.8.1983	36
4.9.1982	58	3.9.1983	38
11.9.1982	75	10.9.1983	42
18.9.1982	102	17.9.1983	66
25.9.1982	118	24.9.1983	72
2.10.1982	139	1.10.1983	96
9.10.1982	152	8.10.1983	122

Appendix III. Detailed schedule of irrigations*

Month	1982		1983	
	i_1	i_2	i_1	i_2
June	30	30	24,27	24,27
July	2,6,7,8,9, 10,11,12,13, 17,19,21, 24,29,31	2,7,8, 10,18, 30	1,7,9, 13,16, 19,22	7,19
August	2,4,9,14, 17,25,28, 31	4,17	2,5,13	5
Sept.	2,4,6,8,11, 13,15,17, 20,23,26, 29	4,8,12, 17,22, 26	12,17,20	12,17
Oct.	1,4			
Total number of irrigations excluding pre-sowing irrigations	38	15	15	7
Depth of irrigation water applied (mm)	1900	750	750	350
Amount of rainfall received mm	572.7	572.7	674.5	674.5
Total water use (mm)	2358.16	1208.16	1289.60	889.60

* excludes pre-sowing irrigations

Appendix IV. Fixed cost of cultivation of rice

S.No.	Particulars	Inputs	Rate	Total cost (Rs. ha^{-1})
1.	Land preparation			
	i) Discing with offset disc and levelling twice	1 tractor for 4 h	Rs. 20 h^{-1}	80.00
	ii) Presowing irrigation	One irrigation		
		Water cost	Rs. 22 $irrigation^{-1}$ ha^{-1}	22.00
		application 2 man days	Rs. 9.25 day^{-1}	$8.50
	iii) Puddling and planking twice	with bullock pair	Rs. 75.00 each	150.00
2.	Seeds and sowing			
	i) Cost of seed	80 kg	Rs. 2.35 kg^{-1}	188.00
	ii) Drilling with seed drill/broadcasting and bird scaring	9 mandays	Rs. 9.25 day^{-1}	83.25
	iii) Gap sowing	1 manday	Rs. 9.25 day^{-1}	9.25
3.	Fertilizers and fertilizer application	50 kg P_2O_5 ha^{-1}	Rs. 6.70 kg^{-1}	335.00
		50 kg K_2O ha^{-1}	Rs. 2.62 kg^{-1}	131.00
	application	1 manday	Rs. 9.25 day^{-1}	9.25
4.	Harvesting, threshing and transportation	30 mandays	Rs. 9.25 day^{-1}	277.50
5.	Land rent	For 4 months	Rs. 400 $ha^{-1}yr^{-1}$	133.30
			Total	1437.05

Appendix V. Details of calculation of economics of rice cultivation (1982)

Treatment	Inputs*	Total cost** (Rs ha^{-1})	Yield (q ha^{-1}) Grain	Straw	Gross income (Rs ha^{-1})*** Grain	Straw	Total	Net profit/loss Rs ha^{-1}	Rs Re^{-1} invested@
1	2	3	4	5	6	7	8	9	10
$i_1w_0n_0$	38 irrigations	2976	22	40	2844	1004	3849	873	0.29
$i_1w_0n_1$	38 irrigations, 109 kg urea 3 mandays	3260	32	53	4130	1313	5443	2182	0.67
$i_1w_0n_2$	38 irrigations, 217 kg urea, 3 mandays	3517	25	43	3216	1064	4280	763	0.22
$i_1w_0n_3$	38 irrigations, 326 kg urea, 3 mandays	3773	22	45	2809	1120	3929	156	0.04
$i_1w_1n_0$	38 irrigations, 20 kg machete, 12 mandays	3302	21	43	2776	1083	3859	556	0.17
$i_1w_1n_1$	38 irrigations, 20 kg machete, 109 kg urea, 15 mandays	3587	47	60	6127	1505	7632	4045	1.13
$i_1w_1n_2$	38 irrigations, 20 kg machete, 217 kg urea, 15 mandays	3843	55	76	7177	1904	9082	5238	1.36
$i_1w_1n_3$	38 irrigations, 20 kg machete, 326 kg urea, 15 mandays	4100	61	80	7888	1992	9880	5780	1.41

Contd...

Appendix V (contd......)

1	2	3	4	5	6	7	8	9	10
$i_1w_2n_0$	38 irrigations, 2 l basagran, 15 mandays	3275	21	39	2776	967	3742	467	0.14
$i_1w_2n_1$	38 irrigations, 2 l basagran, 109 kg urea, 18 mandays	3559	23	42	2945	1051	3995	436	0.12
$i_1w_2n_2$	38 irrigations, 2 l basagran, 217 kg urea, 18 mandays	3816	25	40	3216	999	4215	400	0.10
$i_1w_2n_3$	38 irrigations, 2 l basagran, 326 kg urea, 18 mandays	4072	20	34	2573	840	3413	-659	-0.16
$i_2w_0n_0$	15 irrigations	2045	22	41	2844	1031	3876	1831	0.90
$i_2w_0n_1$	15 irrigations, 109 kg urea, 3 mandays	2329	18	32	2370	800	3170	841	0.36
$i_2w_0n_2$	15 irrigations, 217 kg urea, 3 mandays	2585	21	39	2742	984	3726	1141	0.44
$i_2w_0n_3$	15 irrigations, 326 kg urea, 3 mandays	2842	17	34	2269	839	3107	265	0.09
$i_2w_1n_0$	15 irrigations, 20 kg machete, 12 mandays	2371	22	43	2912	1063	3975	1604	0.68
$i_2w_1n_1$	15 irrigations, 20 kg machete, 109 kg urea, 15 mandays	2655	43	60	5586	1497	7083	4428	1.67

Appendix V (contd.....

1	2	3	4	5	6	7	8	9	10
$i_2w_1n_2$	15 irrigations, 20 kg machete, 217 kg urea, 15 mandays	2912	40	57	5147	1427	6574	3662	1.26
$i_2w_1n_3$	15 irrigations, 20 kg machete, 326 kg urea, 15 mandays	3168	46	66	5925	1639	7564	4396	1.39
$i_2w_2n_0$	15 irrigations, 2 l basagran, 15 mandays	2343	13	28	1726	691	2417	74	0.03
$i_2w_2n_1$	15 irrigations, 2 l basagran, 109 kg urea, 18 mandays	2628	17	33	2167	827	2994	367	0.14
$i_2w_2n_2$	15 irrigations, 2 l basagran, 217 kg urea, 18 mandays	2884	35	62	4571	1549	6120	3236	1.12
$i_2w_2n_3$	15 irrigations, 2 l basagran, 326 kg urea, 18 mandays	3141	25	50	3284	1239	4522	1382	0.44

Contd.....

Appendix V (contd.....)

1983

1	2	3	4	5	6	7	8	9	10
$i_1w_0n_0$	15 irrigations	2045	11	23	1430	573	2003	-42	-0.02
$i_1w_0n_1$	15 irrigations, 109 kg urea, 3 mandays	2329	7	13	880	327	1207	-1121	-0.49
$i_1w_0n_2$	15 irrigations, 217 kg urea 3 mandays	2585	16	34	2075	853	2928	343	0.13
$i_1w_0n_3$	15 irrigations, 326 kg urea, 3 mandays	2842	12	25	1598	613	2210	-632	-0.22
$i_1w_1n_0$	15 irrigations, 20 kg machete, 12 mandays	2371	23	41	2961	1036	3997	1626	0.69
$i_1w_1n_1$	15 irrigations, 20 kg machete, 109 kg urea, 15 mandays	2655	28	48	3682	1208	4889	2234	0.84
$i_1w_1n_2$	15 irrigations, 20 kg machete, 217 kg urea, 15 mandays	2912	41	62	5353	1545	6899	3987	1.37
$i_1w_1n_3$	15 irrigations, 20 kg machete, 326 kg urea, 15 mandays	3168	51	69	6565	1736	8301	5133	1.62
$i_1w_2n_0$	15 irrigations, 5.7 l stam F-34, 2 l basagran, 15 mandays	2640	19	33	2465	823	3288	648	0.25

Contd....

Appendix V (contd.......)

1	2	3	4	5	6	7	8	9	10
$i_1w_2n_1$	15 irrigations, 5.7 l Stam F-34, 2 l basagran, 109 kg urea, 18 mandays	2924	31	51	3982	1283	5265	2341	0.80
$i_1w_2n_2$	15 irrigations, 5.7 l Stam F-34, 2 l basagran, 217 kg urea, 18 mandays	3180	38	62	4911	1549	6460	3280	1.03
$i_1w_2n_3$	15 irrigations, 5.7 l Stam F-34, 2 l basagran, 326 kg urea, 18 mandays	3437	48	72	6175	1788	7963	4526	1.32
$i_2w_0n_0$	7 irrigations	1721	13	25	1671	627	2297	577	0.34
$i_2w_0n_1$	7 irrigations, 109 kg urea, 3 mandays	2005	13	31	1625	786	2411	406	0.20
$i_2w_0n_2$	7 irrigations, 217 kg urea, 3 mandays	2261	9	25	1122	617	1738	-523	-0.23
$i_2w_0n_3$	7 irrigations, 326 kg urea, 3 mandays	2518	8	21	1083	520	1603	-915	-0.36
$i_2w_1n_0$	7 irrigations, 20 kg machete, 12 mandays	2047	20	39	2591	978	3568	1521	0.74
$i_2w_1n_1$	7 irrigations, 20 kg machete, 109 kg urea, 15 mandays	2331	34	61	4477	1516	5993	3662	1.57

Appendix V (contd.....)

1	2	3	4	5	6	7	8	9	10
$i_2w_1n_2$	7 irrigations, 20 kg machete, 217 kg urea, 15 mandays	2588	42	67	5489	1669	7157	4569	1.77
$i_2w_1n_3$	7 irrigations, 20 kg machete, 326 kg urea, 15 mandays	2845	50	76	6445	1910	8355	5511	1.94
$i_2w_2n_0$	7 irrigations, 5.7 l Stam F-34 2 l basagran, 15 mandays	2316	17	32	2257	792	3049	733	0.32
$i_2w_2n_1$	7 irrigations, 5.7 l Stam F-34, 2 l basagran, 109 kg urea, 18 mandays	2600	27	43	3476	1073	4549	1950	0.75
$i_2w_2n_2$	7 irrigations, 5.7 l Stam F-34, 2 l basagran, 217 kg urea, 18 mandays	2856	45	70	5841	1762	7603	4747	1.66
$i_2w_2n_3$	7 irrigations, 5.7 l Stam F-34, 2 l basagran, 326 kg urea, 18 mandays	3113	41	66	5355	1643	6997	3885	1.25

* Prices of inputs - Irrigation - Rs. 40.50 $irrigation^{-1}$; Urea - Rs. 2.36 kg^{-1}; Machete - Rs. 10.77 kg^{-1}; Basagran - Rs. 80 l^{-1}; Stam F-34; Rs. 52 l^{-1}; Labour charges - Rs. 9.25 $manday^{-1}$.

** Total cost = Fixed cost + cost of inputs.

*** Price of produce - grain - Rs. 130 q^{-1}; straw - Rs. 25 q^{-1}

@ Net returns per rupee invested - (Gross income - total cost) / Total cost

Appendix VI. List of weeds quoted in the text

Botanical name	Common name	Family
Amaranthus viridis L.	Pigweed	Amaranthaceae
Ammannia baccifera L.	-	Lythraceae
Cynodon dactylon (L.) Pers.	Bermuda grass	Graminae
Cyperus esculentus L.	-	Cyperaceae
C. rotundus L	Purple nutsedge	Cyperaceae
Echinochloa colona (L.)Link	Jungle grass	Graminae
E. crus-galli (L.) Beauv.	Barnyard grass	Graminae
E. crus-galli (L.) Beauv. var. crus-galli	Barnyard grass	Graminae
E. crus-galli (L.) Beauv. var. oryzicola	Barnyard grass	Graminae
Eleocharis acicularis (L.) Roem & Schult	Slender spikerush	Cyperaceae
Eclipta erecta L.	-	Compositae
Fimbristylis miliacea syn. F. littoralis Gaud.	Hooragrass	Cyperaceae
Oryza punctata L.	-	Graminae
Panicum spp.		Graminae
Paspalum spp.	-	Graminae
Phyllanthus niruri L.	-	Euphorbiaceae
Portulaca oleracea L.	Common purslane	Portulacaceae
Rottboellia exaltata L.f.	Itchgrass	Poaceae
Scirpus compactus L.	Bulrush	Cyperaceae

Appendix VII. Chemical terminology of the herbicides quoted in the text

Common name	Chemical name
Bentazone	3-isopropyl-(1 H) - benzo-2,1,3-thiadiazin-4-one 2,2-dioxide
Butachlor	N-butoxymethyl- α - chloro-2',6'-diethylacetanilide
Propanil	3',4'-dichloropropionanilide