

**STUDIES ON INTEGRATED WEED MANAGEMENT UNDER
SPLIT APPLICATION OF NITROGEN IN
WET SEEDED LOWLAND RICE**

Thesis submitted in part fulfilment of the requirements for the degree of
DOCTOR OF PHILOSOPHY (Agriculture) in Agronomy to the
Tamil Nadu Agricultural University, Coimbatore – 3.

BY

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2000

CERTIFICATE

This is to certify that the thesis entitled “**STUDIES ON INTEGRATED WEED MANAGEMENT UNDER SPLIT APPLICATION OF NITROGEN IN WET SEEDED LOWLAND RICE**” submitted in part fulfilment of the requirements for the degree of **DOCTOR OF PHILOSOPHY** (Agriculture) in Agronomy to the Tamil Nadu Agricultural University, Coimbatore is a record of bonafide research work carried out by Sri **HARIHAR CHANDRA BAYAN**, under my supervision and guidance and that no part of this thesis has been submitted for the award of any other degree, diploma, fellowship or other similar titles, prizes and that the work has not been published in part or full in any scientific or popular journal or magazine.

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ABSTRACT

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STUDIES ON INTEGRATED WEED MANAGEMENT UNDER SPLIT APPLICATION OF NITROGEN IN WET SEEDED LOWLAND RICE

By

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Field experiments were conducted at Tamil Nadu Agricultural University, Coimbatore, during *kharif* and *rabi* seasons of 1998-99 and 1999-2000, to study the effect of integrated methods of weed control (manual, mechanical, cultural and chemical) and split application of N on growth, productivity and nutrient uptake of wet seeded lowland rice. The experiments were laid out in a split-plot design with two N management practices (four splits of N - 10 days after sowing (DAS), active tillering (AT), panicle initiation (PI) and heading stage and five splits of N - basal, 10 DAS, AT, PI and heading stage) in the main plots and seven weed control methods (manual, mechanical + manual, cultural + manual, cultural + mechanical, cultural + chemical + mechanical, chemical + manual and unweeded control) in the sub plots, replicated thrice. The varieties used were ADT 36 during *kharif* and ADT 39 in *rabi* seasons.

The results of the experiments averaged across the seasons and crops revealed that, the smother intercrop of *Sesbania rostrata* used as cultural weed control method produced a fresh biomass of 11.58 t ha⁻¹ and was estimated to contribute 72.7 kg N ha⁻¹ at the time of incorporation (35 DAS).

The weed flora of the experimental fields consisted of fifteen species including five grasses, four sedges and six broad leaved weeds. The grass weeds dominated in *rabi* seasons and broad leaved weeds during the *kharif* seasons. The major species were *Echinochloa crus-galli* (L) P. Beauv in grass, *Cyperus difformis* (L.) in sedges and *Eclipta alba* (L.) Hassk in broad leaved weeds.

The result of the experiments revealed that application of N in four splits (without basal dose) enhanced the growth and yield of rice through reduced weed population and its growth, restricted nutrient depletion by weeds and increased nutrient uptake by crop compared to application of same dose of N in five equal splits including basal.

Uncontrolled weed growth resulted in the yield loss of 37.8 to 40.1 per cent compared with the best weed control treatment of cultural + manual method which markedly suppressed the weed population and growth, thus reducing the nutrient removal by weeds. The *Sesbania* as smother intercrop incorporation in this treatment also added additional nutrient especially N to the crop. These effects provided favourable environment for crop growth and development, resulting in increased grain yield to the tune of 8.5 to 15.0 and 58 to 66 per cent over recommended practice of manual method and unweeded control, respectively. Compared to cultural + manual method of weed control, cultural + chemical + mechanical method also gave effective control of weeds.

and increased the yield substantially. However, cultural + mechanical method was not found to be efficient in suppressing the weed growth. Weeds under unweeded control depleted 4 to 6 times more N, 3 to 4 times more P and 4 to 5 times more K compared to the nutrient uptake values with efficient weed control method (cultural + manual).

Correlation studies between grain yield with total weed population, weed DMP and N removal by weeds showed significant negative correlations. Among the different crop characters studied for correlation, LAI at flowering, SPAD values at active tillering and panicle initiation stages, total tillers, crop DMP, panicles m^{-2} , filled grains panicle⁻¹ and 1000 grain weight showed significant positive association with grain yield.

Maximum energy use efficiency (EUE) and net income with higher B: C ratio and the lowest energy requirement for per kg grain output was realised by integration of cultural + manual method of weed control with four splits of N, the best treatment over rest of the combinations studied.

From the two years study it is clearly evident that integration of four splits of N (no basal) along with weed management by cultural + manual method is the efficient and economic N management and weed control method in wet seeded lowland rice production.

ACKNOWLEDGEMENT

ACKNOWLEDGEMENT

I wish to place on record my deep sense of gratitude to Dr. O.S. Kandasamy, Professor, Department of Agronomy and Chairman of the Advisory Committee, for his expert guidance, constructive criticism and untiring help rendered during the course of study.

My grateful thanks are due to Dr. G. James Martin, Professor of Agronomy, Dr. T.M. Thiyagarajan, Director, Centre for Soil and Crop Management Studies TNAU and Dr. R. Chandra Babu, Associate Professor, Centre for Plant Molecular Biology, members of the advisory committee, for the ideas and information they have provided during the period of investigation.

I am grateful to Dr. J. Krishnarajan, former Head and Dr. N. Sankaran the present Head, Department of Agronomy and Dr. P. Rajendran, Professor and Head, Agricultural Research Station, Bhavanisagar for their various help during this study.

I must express my sincere thanks to Dr. A.L. Christopher and Mr. C.N. Chandrasekhar, Assistant Professors for their continued help during the study.

I also express my sincere thanks to all the staff members of the Department of Agronomy, TNAU.

I owe my loving thanks to Dr. A. Anderson, whose help made my task lighter in completing this dissertation.

Thanks are also due to Assam Agricultural University, Jorhat, Assam for granting study leave to carry out the doctoral programme on deputation.

I wish to express my deep sense of gratitude and ever indebtedness to my beloved parents, sisters N relatives for their love, affection, encouragement and sacrifices.

I extend my thanks to Miss Sowmiya for her elegant and neat typing and Mr. Eswaran for his execution.

My thanks and appreciation are due to all those friends and well wishers who extended their immense help and encouragement at various stages in the preparation of this dissertation.



(H.C. BAYAN)

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LIST OF ABBREVIATIONS USED

AT	active tillering
B:C ratio	benefit cost ratio
BLW	broad leaved weed
cm	centimeter
CD	critical difference
CGR	crop growth rate
DAS	days after sowing
DAE	days after emergence
DAT	days after transplanting
DMP	dry matter production
dS	deci Simen
evap.	evaporation
EC	electrical conductivity
F	flowering
g	gram
ha	hectare
hr	hour
HI	harvest index
kg	kilogram
L	litre
m	metre
OC	organic carbon
ppm	parts per million
PI	panicle initiation
pre em.	pre emergence
post em.	post emergence
r	coefficient of correlation
t	Tonne

INTRODUCTION

CHAPTER I

INTRODUCTION

Rice (*Oryza sativa* L) has been the companion of humankind for more than 8000 years providing staple food to 2.5 billion people which will escalate to 4.6 billion by the year 2050. To feed the increasing global population, the world's annual rice production should increase from the present 528 million tonnes to 760 million tonnes by the year 2050 (Paroda, 1998). In India, rice is the most important cereal crop and tops the list in terms of area constituting 28 per cent of world's rice. During 1998-99, the country produced 84.48 million tonnes of rice from an area of 43.28 million hectares. By the year 2007, India would need 103.5 million tonnes of rice to balance the food budget (Siddiq, 1997; Singhal, 1999).

Expansion in the irrigated area, introduction of early maturing rice cultivars, availability of selective herbicides for weed management and improved fertilizer management together with increasing transplanting cost and declining profitability of transplanted rice production system have encouraged rice farmers to shift from transplanting to direct seeding (Govindarasu, 1998; Subbaiah *et al.*, 1999).

Rice crop management is very complex, involving several elements ranging from soil to the social conditions of the farmer. Among the mineral nutrients, response of rice to N is almost universal. However, fertilizer N loss can be as high as 60 per cent under field conditions due to volatilization, denitrification, leaching and runoff etc. (De Datta *et al.*, 1989; Frency *et al.*, 1990). With increasing cost of N, it is imperative that efficient N management strategy for wet seeded rice is to be developed. Split application of N,

perhaps, is the simplest agronomic management for improving the N use efficiency. For deriving maximum benefit from fertilizer N, it is important to apply the right amount at right time as the need of the plant for nutrient is not the same throughout their growth period (Manjappa *et al.*, 1994).

The recent transformation in crop establishment technique from transplanted to wet seeded rice cultivation has resulted in dramatic changes in the types and intensity of weed infestation. Weed competition is greater in wet seeded rice than transplanted rice. Yield losses due to uncontrolled weed growth are on an average 9 per cent higher in wet seeded rice than in transplanted rice in trials conducted at IRRI over the past 20 years (Ho, 1996). Weeds cause severe damage to direct seeded rice and yield may be reduced to the extent of 50 to 60 per cent, sometimes complete crop failure due to weed infestation (Govindarasu, 1998). Hence, weed control is the major problem that has to be solved before this method of growing rice can be recommended as a general practice.

Weed control is carried out through the implementation of various control methods. Hand weeding is most common method with better weed control efficiency in wet seeded rice (Singh *et al.*, 1999). However, it is laborious, time consuming and expensive and it is quite difficult in wet seeded rice due to high density rice population in this system (Hassan and Rao, 1996). Mechanical weeding in wet seeded rice has been emphasised by many workers as this practice can be done by unskilled labour and generally is economical, non-polluting without residual problems and relatively safe to the operator (Bhan and Sushilkumar, 1996), but technical aspects such as limited workability of existing mechanical devices in rice fields restrict wider adoption of this

method (Hassan *et al.*, 1994; Pandey and Pingali, 1996). Therefore, manual and mechanical weeding in wet seeded rice should be used only in conjunction with other cultural and chemical methods to minimise labour requirement, wherever appropriate (Ho, 1996).

Cultural method such as growing smother intercrop also provides greater scope to control weeds. Intercropping not only suppresses weeds, but also reduces weeding cost and the intercrop yield provides bonus yield (Bhan and Sushilkumar, 1996). Intercropping green manure crop in wet seeded rice for a brief spell of period would encash the least detrimental effect of early shading to crop and smothering effect to weeds besides ensuring organic manure addition. Such a measure if succeeds, would reduce the labour cost for weeding as well as reduction in nitrogenous fertilizer input. Intercropping with *Crotalaria juncea*, *Vigna sinensis*, *Glycine max* or *Sesbania rostrata* may be suitable for sustainable weed management in rainfed lowland rice (Angadi and Umapathy, 1997).

In an intensive cropping system, use of herbicide forms an integral part of crop production technology. The effective and possible method would be controlling weeds in the early stages with pre emergence application of selective herbicides. Herbicide selectivity in wet seeded rice can be improved by adjusting the time of application and by applying crop safeners (Mabbayad and Moody, 1985). Effective weed control by application of pre emergence herbicide pretilachlor + safener (SOFIT) in wet seeded rice was reported by Ramesh and Veerabadran (1997) and Jayadeva *et al.* (1998).

The over dependence and over use of herbicide for weed management in some developed countries has created undesirable results like development of herbicide resistance, environmental pollution etc. This results in greater pressure on farmers to reduce herbicide use and the need to reorient our efforts towards non-chemical and non-hazardous means of weed management. Complete control of weeds can not be achieved by using any one method alone. Integrated approach involving manual, mechanical, cultural and chemical methods would be economically viable and an effective weed management method with less environmental impact. A judicious combination of viable weed management practices in an integrated way, may therefore, prove effective and economically feasible.

Research work on the interaction of integrated weed control methods and nitrogen management is limited in wet seeded lowland rice seeded by drum seeder. Hence, the present investigation was undertaken with the following objectives:

- * To evolve an integrated and economic weed control method for wet seeded lowland rice
- * To assess the interaction effect of time and number of split application of N and weed control methods on weeds
- * To evaluate the effect of intercropping (*Sesbania rostrata*) and herbicide application on weed suppression and growth and yield of rice
- * To study the N uptake by rice and weeds under different weed control methods

REVIEW OF LITERATURE

CHAPTER – II

REVIEW OF LITERATURE

Rice a major cereal crop serves as staple food to one third of the world's population. Rice was depended upon by nearly two third population as food, which is mainly produced by two principal methods viz., direct seeding and transplanting. It is mainly grown as a wetland crop by transplanting seedlings into puddled fields. However, in South East Asia over the past 10 - 15 years there has been a shift in the rice production system from transplanting to direct seeding (Moody, 1993) as it involved minimal use of labour force than the transplanting system (Jayadeva *et al.*, 1998). But major constraints in wet seeded rice are severe weed competition and low nitrogen use efficiency. Poor utilization of chemical N fertilizers by rice is thought to be largely due to N losses from the soil - plant system (De Datta *et al.*, 1990) and uncontrolled weed growth (Chandrakar and Chandrakar, 1992). Therefore, it emphasizes the need to develop a viable, effective and economical weed control technology and a suitable fertilizer management technique especially N for wet seeded rice. The available literature on the nature of weed spectrum and their competitive effect on rice, methods of weed control and N management on wet seeded rice are briefly reviewed in this chapter. However, in certain cases where the findings are relevant, literature on other systems of rice culture is also reviewed.

2.1. Direct seeded and transplanted rice

Rice, a semi-aquatic plant has high degree of adaptability to changing conditions.. The systems of rice cultivation vary largely depends upon the soil and climatic

conditions prevalent in the rice growing regions. The principal systems of rice cultures are dry, semi dry and wet and principal methods are direct seeding and transplanting (De Datta, 1981).

In direct seeded system, seeds are directly sown in the field for grain production completely eliminating the operations such as nursery raising and transplanting. This system involves sowing of dry seeds on pulverised soil (dry seeded) or sprouted seeds on puddled soil (wet seeded) (Govindarasu *et al.*, 1998).

Dry land preparation is required for dry seeded rice culture and is the most common method of cultivation in upland regions particularly in north eastern India under rainfed condition. For wet seeding, the field is puddled and properly levelled and the sprouted seeds are sown uniformly by broadcasting or in lines using seed drill. The depth of water in the field is regulated in the usual manner as the plants grow. This system is practiced in areas with assured supply of water (Govindarasu *et al.*, 1998). Irrigated rice culture as a percentage of total rice area is 100, 77, 44, 23, and 16 in Pakistan, Sri Lanka, India, Nepal and Bangladesh, respectively (Malik and Moorthy, 1996).

It is generally believed that the transplanting method gives more stable yield than the direct seeding (dry and wet) method. However, studies in rice growing countries showed that grain yields from direct seeding could be similar or even higher than the transplanting method. Wet seeded rice producing similar or higher yield than transplanted rice was well documented by several workers in Philippines (Khan, 1990; Moody, 1993), in Pakistan (Majid *et al.*, 1996) and in India (Ramasamy *et al.*, 1994; Rachel and Martin, 1995). Recent studies in India also showed that wet seeding either by

broadcast or drilling or drum seeding gave similar or higher yields compared to transplanted rice (Bharathi, 1996; Budhar *et al.*, 1996; Mehta *et al.*, 1997; Prabhakar and Reddy, 1997; Bhuvaneswari, 1998).

2.2. Wet seeded rice under puddled soil – problems and prospects

Although, transplanting is the most common method in Asia's irrigated rice growing areas (De Datta, 1986), this practice is increasingly being replaced by direct seeding as labour becomes a demand as well as a cost factor (De Datta, 1989; Rachel and Martin, 1995; Madhu and Nanjappa, 1995; Jayadeva *et al.*, 1998; Govindarasu *et al.*, 1998; Ito, 1998). The cost of labour required for transplanted rice cultivation is almost two times more than wet seeded rice (Coxhead, 1984; Sivaperumal, 1995). The practice of wet seeding was first adopted by Malaysian farmers in the late seventies because of labour shortage and high labour costs during peak demand (Wan and Daud, 1990).

Many researchers emphasized the multitude of prerequisites including level land, effective weed control, efficient water management and timely water supply in relation to crop-water demand, to ensure a successful wet seeded rice crop (Biswas and Sattar, 1992; Prasootsittisuang, 1994). However, Bhuiyan (1992) from Philippines opined that the water use efficiency was more in direct seeded rice as the water requirement for the land preparation is less compared to transplanted rice. Further, wet seeded rice yields were high in both water sufficient and water stress situations (Sattar, 1992) and was more drought tolerant than transplanted rice (Khan, 1990).

One of the main problems encountered under transplanting technique is delayed land preparation service, which may render transplanting of the aged seedlings. However, such problem could be overcome with wet seeding (Soo *et al.*, 1989) and it has

an edge over the former as wet seeded rice flowered earlier than semi dryseeded and transplanted rice, leading to a reduction in crop duration by one to two weeks (Peng *et al.*, 1996; Santhi *et al.*, 1998) and this period even though small, had great significance in economic intensive cropping system (Singh and Bhattacharya, 1989).

Crop growth dynamics of direct seeded flooded rice culture is profoundly different from those resulting from transplanted rice. Early accumulation of vegetative biomass, higher leaf area, enforced total and productive tillers per unit area with profuse root system are considered to be the favourable characteristic features of direct seeded flooded rice (Dingkuhn *et al.*, 1990a Schnier *et al.*, 1990; Wang and Sun, 1990; Sharma and Sharma 1994; Prabhakar and Narsa Reddy 1997), but number of filled grains per panicle are usually lower than transplanted rice (Schnier *et al.*, 1990; Sharma and Sharma, 1994; Prabhakar and Narsa Reddy, 1997).

Though direct seeded (wet seeded) rice is becoming popular and alternative to transplanted rice, heavy weed infestation and competition are serious among the several constraints for higher yield in puddled seeded rice (Moody, 1993; Madhu and Nanjappa, 1995; Kandasamy and Sivaperumal, 1997; Jayadeva *et al.*, 1998). Crop as well as weed seeds germinate simultaneously and weeds being more effective than the crop, the competition exerted by weeds during critical period of crop growth is more severe. Reddy *et al.* (1994) also observed that weed infestation was a major problem in wet seeded rice culture due to alternate wetting and drying practice during the initial seedling growth.

The vigorous growth of seedlings in direct seeded puddled rice favoured rapid uptake of N (Peng *et al.*, 1996) and reduced ammonium volatilization by 28 per cent and total N loss by 10 per cent (De Datta *et al.*, 1989). Ultimately, the recovery of inorganic N was greater for wet seeded rice (47%) as compared to transplanted rice (37%) (Diekmann, 1990). Under similar N management practices Obcemea *et al.* (1990) observed a net saving of 9 to 10 per cent of applied inorganic N in wet seeded rice.

2.3. Wet seeding methods (through drum seeder)

Wet seeding (pre-germinated seed broadcasted manually on puddled soil) has been the common practice of direct seeding adopted in many countries of South East Asia (Wan and Daud, 1990; Moody, 1993). But major constraints in broadcasting are severe weed competition and poor plant stand. Weed infestation is more critical in broadcast wet seeded rice because of exposure of more land during the initial growth stage till the rice seedlings established to provide canopy cover (Moorthy and Dubey, 1979). Absence of rows is another difficulty encountered for hand or rotary weeding in wet seeded rice (Moody and Cordova, 1985) and the only feasible alternative weed control method for this system is chemical control. Undulating field, improper levelling and heavy weed competition are the possible reasons to the poor plant germination and establishment of the broadcast seeded crop (Govindarasu *et al.*, 1998).

Successful adoption of direct seeding in lines under puddled rice fields using a seed drill (seeder) was discussed as early as 1969 (Pradhan, 1969). This practice could replace transplanting without any reduction in yield and in addition reducing the cost. The time taken for drilling seeds in a puddled soil using a manually operated planter was

only one third of that required for transplanting. Row sown rice showed the fastest establishment and greater vegetative growth due to the absence of transplanting shock. Tiller number per unit area and leaf area index (LAI) were more in row sown rice than in broadcasted and transplanted rice (Dingkuhn *et al.*, 1990b; Bharathi, 1996).

Ramamoorthy and Subbaiah (1999) observed that wet seeded rice culture by drum seeder could be a viable alternative to transplanted rice in irrigated areas of India. The drum seeder developed by IRRI and Phil Rice of the Philippines sows rice seeds (preferably pregerminated) in nearly straight rows which facilitates chemical free weeding method (both manual and mechanical) and thus minimising environmental pollution and hazardous chemical contamination for both human and animals. Studies conducted at Philippines showed that by the use seeder, the labour cost required for transplanting (1200 Peso ha⁻¹) can be avoided and also saved the cost of seed wasted by broadcasting (925 Peso ha⁻¹) thus increasing the farmers income by an average of 7.5 and 28 per cent respectively, compared with manual broadcasting and transplanting (Bautista and Gagelonia, 1994). Whereas, in Andhra Pradesh (India), drum seeder method recorded 16 per cent more profit over transplanting and 55 per cent over broadcasting method (Subbaiah *et al.*, 1999).

Okazaki *et al.* (1990) achieved 63 to 73 per cent seedling establishment when seeds were sown by using a machine comprising of furrow openers and seed drills and was 10 per cent higher than the values obtained by broadcasting on puddled soil. Direct seeding using drum seeder enhanced early crop establishment and reduced the crop duration by 2 –14 days (Bharathi, 1996; Subbaiah *et al.*, 1999) and gave higher yield as

compared to manual broadcasting and traditional transplanting methods (Rachel and Martin, 1995; Bharathi, 1996; Subbaiah *et al.*, 1999). In Nizamabad, India, Subbaiah *et al.* (1999) observed that direct seeding through drum seeder recorded higher grain yield (5.11 t ha^{-1}) (mean of *kharif* and rabi seasons) followed by transplanting (4.93 t ha^{-1}) and broadcasting (4.93 t ha^{-1}). This technique also facilitates effective and efficient manual weeding either by hand pulling or with mechanical push type weeder (Jaffer *et al.*, 1994).

2.4. Weed flora in wet seeded rice

Information on the weed flora of direct seeded rice describing the ecology and habitat of weeds is very much needed for planning effective weed control measures. Even though the weed flora is similar in transplanted and wet-seeded rice, the spectrum of weeds has a bearing on the efficacy of the control measures adopted (Janiya and Moody, 1989). The weed vegetation of a particular area is determined by many interrelated factors such as climatic, edaphic and biotic factors. In a given environment, however, the weed vegetation is most strongly affected by the biotic factor and cultural practices such as fertilizer management, irrigation, cultivar grown, tillage, weed management and crop rotation (Kim and Moody, 1980).

The kind and number of weed species associated with rice (*Oryza sativa* L.) have been reported by many researchers from different regions. Wide variation from country to country and among the different types of rice cultures has been reported. They ranged from 30 species in Eastern Europe (Podkin *et al.*, 1983) to about 1800 species in South and South East Asia (Moody, 1989). In a survey of South and South East Asia, Moody (1989) listed 65 species in deep water rice, 559 species in transplanted rice, 558

species in upland rice, 194 species in dry seeded rice and 180 species in wet seeded rice. In spite of the wide variation, the number of species that constitute the major portion of the weed flora causing economic concern to the grower is usually less than 10 (Baltazar and De Datta, 1992) which include *Echinochloa crus-galli* (L) P. Beauv., *Cynodon dactylon* (L) Pers., *Digitaria* sp., *Cyperus* sp., *Fimbristylis miliacea* (L) Vahl., *Eclipta alba* (L) Hassk., *Sagittaria* sp., *Scirpus* sp., *Monochoria vaginalis* (Burm.f.) Presl and *Marsilea quadrifolia* L. (Moody, 1989; Malik *et al.*, 1992; Singh *et al.*, 1992; Malik and Moorthy, 1996).

The frequency and abundance of the 10 species vary according to particular geographical location and growing conditions. Among these, rarely more than three or four species are really important (Baltazar and De Datta, 1992). Diversity further decreases in proportion to kind and degree of weed control. Most of these are annuals, but a few perennials are on the increase in importance (De Datta, 1981; Fajardo and Moody, 1990).

The recent transformation from transplanting to direct seeding in rice in South East Asia have resulted in dramatic alteration in the abundance and distribution of weeds (Mortimer, 1996). Direct seeding techniques cause weed communities to change in composition with the less competitive dicotyledonous weeds and sedges being replaced by competitive grasses which had previously occurred at lower abundance along the edges of direct seeded field (Moody, 1993; Ho, 1996).

Relatively rapid shifts in weed flora have been recorded for different instances. In Korea, the introduction of machine transplanting of rice increased both the density of rice weeds and a change in the composition of weed flora (Kim *et al.*, 1984). In India,

Singh *et al.* (1998) reported that *Echinochloa crus-galli*, *E. colona*, *Cyperus iria*, *Ipomea sp.*, *Sphenochlea zeylanica*, *Ludwigia parviflora* and *Panicum repens* were the major weed flora found in wet seeded rice fields. Ramakrishnan *et al.* (1992) recorded more than 45 weed species in wet seeded rice in Tamil Nadu. Srinivasan and Palaniappan (1994) found that *Echinochloa sp.*, *Cyperus difformis*, *Marsilea minuta* and *Eclipta alba* were predominant weed flora in wet seeded rice in South India. In Assam, lowland transplanted rice field comprised of 29 per cent grasses, 50 per cent sedges and 21 per cent broadleaved weeds (Gogoi, 1995) and as a whole, only five weed species viz., *Echinochloa crus-galli* (16.85%), *Commelina benghalensis* (11.27%), *Paspalum distichum* (10.54%), *Eclipta alba* (10.06%) and *Cyperus iria* (9.65%) accounted for 58.27 per cent of the total weed intensity.

A wide spectrum of weeds infesting wet seeded rice fields in India were also reported from Uttar Pradesh (Tripathy and Vaishya, 1993), Karnataka (Madhu and Nanjappa, 1995; Mutanal *et al.*, 1997) New Delhi (Subhash Chandra and Pandey, 1996), and Tamil Nadu (Thirumurugan *et al.*, 1998).

Most of the weeds possess the C₄ photosynthetic pathway and provide severe competition to the C₃ rice plant. Cyperaceae and Gramineae are the two predominant weed families in wetland rice fields. Dicot weeds are comparatively less in number and many of them belong to the families of Sorophulariaceae, Compositae/Asteraceae, Lythraceae, Onagraceae and Marsiliaceae (Ampong-Nyarko and De Datta, 1989; Kandasamy and Palaniappan, 1990).

All researchers agree that because of its close morphological similarity to rice, the most dominant weed of rice worldwide is *Echinochloa crus-galli*, except in Latin America and Africa where *E.colona* is considered more important. The taxonomy and distribution of this weed was studied by Mitch (1990) and its biology and characteristics by Yabuno (1983) and Kwon *et al.* (1989).

Another important factor is reproductive characteristics of weeds. Reproduction in weeds is often remarked upon as prodigious (Norris, 1992) and whilst this is undoubtedly real for *Echinochloa crus-galli* (Produces > 10,000 seeds plant⁻¹), more significance is the plasticity of weed species that are present in rice ecosystem (Mortimer, 1996). *Monochoria vaginalis*, *Cyperus difformis*, *Fimbristylis miliacea* and *Echinochloa sp.* have been reported to begin flowering even when plants have achieved less than 10 per cent of their maximum dry weight and seed production continuing for more than four months (Kim and Moody, 1989). *Cyperus iria* and *C. dehiscent* found to flower extremely rapid (take as little as 28 days to flower from seedling establishment) while *Echinochloa colona* achieved production of mature seeds within 30 – 40 days under short day periods. Similarly, weedy rices (wild rice) often can be distinguished or identified in rice cropping by their earliness to flower (Mortimer, 1996).

2.5. Crop – weed competition

The degree of rice-weed competition mostly depends on rainfall, variety, soil type, nutrient resources, nature of weeds, stage and duration of weed competition with the crop (De Datta and Ampong- Nyarko, 1988; Madhu and Nanjappa, 1995). Cultural practices greatly alter the competitive relationship between rice and weeds.

Weed competition is complicated because various factors affect the extent to which it occurs. The total effect of the competition as reflected in the crop growth and yield results from competition for light, nutrient and moisture (Rao, 1983; Singh and Bhattacharya, 1989; Ampong-Nyarko and De Datta, 1991; Srinivasan and Palaniappan, 1994; Kempuchetty, 1997). In addition to competition for the resources (nutrients, water and light), weeds release certain compounds which may affect growth, nutrient uptake, photosynthesis, respiration and conductance of xylem tissues (Rice, 1979).

Grasses are usually the most dominant competitor during early season while sedges and broad leaved weeds dominate later in the season (Jiang, 1989). Direct seeded rice is less competitive than transplanted rice because of closer similarities in size and morphology of rice and grassy weeds (Hill et al., 1990; De Datta and Baltazar, 1996). Tall cultivars compete better for sunlight than short cultivars (Smith, 1989; Ampong – Nyarko and De Datta, 1991). Most reports also agree that weeds, being more vigorous competitors, end up using a greater portion of the fertilizer applied to the rice crop (Lee and Moody, 1989; Madhu and Nanajappa, 1996; Thirumurugan *et al.*, 1998).

Losses due to weeds have been estimated in several rice producing countries. Due to uncontrolled weed growth, yield of lowland rice reduced by 15 - 73 per cent in India (Choudhury and Thakuria, 1998; Singh and Mehta, 1998), 60 per cent in Philippines (Moody, 1990b); 30-65 per cent in Turkey and 30-100 per cent in Morocco (Hassan and Rao, 1996).

Direct yield losses due to competition have been estimated to range from 16 to 86 per cent or even upto 100 per cent depending on type of rice culture, rice cultivar, weed species and density, cropping seasons etc. (Zimdahl, 1980; Ali and Sankaran, 1984; Moody, 1990b). Weeds in dry, wet seeded and transplanted rice caused 70-100 per cent, 46-84 per cent and 33-75 per cent reduction in grain yield, respectively (Ravichandran, 1991; Choudhury and Thakuria, 1998; Ramamoorthy, 1999). Studies at Bangalore, India (sandy clay soils with neutral pH) showed that in the absence of weed control, yield losses were estimated 47 per cent for the wet (*kharif*) season and 94 per cent for the dry (summer) season in direct seeded puddled rice (Madhu and Nanjappa, 1995).

Many workers reported the effects of weed competition on rice growth and yield components. Severe infestation of weeds suppressed the plant height (Bhargavi and Yellamanda Reddy, 1994; Kalita and Gogoi, 1994) increased tiller mortality, decreased shoot and grain production (Srinivasan and Palaniappan, 1994; Caton *et al.*, 1997).

Reduction in grain yield was associated with decrease in tiller number (Srinivasan and Palaniappan, 1994; Choudhury and Thakuria, 1998), panicle number (Madhu and Nanjappa, 1995; Choudhury and Thakuria, 1998 and Angiras and Rana, 1998), crop growth rate (Kalita and Gogoi, 1994), leaf area index, leaf area duration, boot leaf and flag leaf area (Srinivasan and Palaniappan, 1994; Kalita and Gogoi, 1994), filled grains per panicle (Choudhury and Thakuria, 1998; Angiras and Rana, 1998); panicle weight (Madhu and Nanjappa, 1995); 1000 grain weight (Bhanumurthy, 1987, Choudhury and Thakuria, 1998, Angiras and Rana, 1998) and light transmission ratio (Srinivasan and Palaniappan, 1994; Caton *et al.*, 1997). The reduction in panicle number due to weed

competition was 24-38 per cent, spikelets panicle⁻¹ by 12-22 per cent, spikelet fertility by 6-8 per cent and 1000 grain weight by 6-11 per cent in direct seeded puddled rice in silty clay loam soils at Palampur during rainy (*khari*) season as reported by Angiras and Rana (1998).

The overall effect of crop weed competition is the reduction in the economic as well as biological yield of rice. Worldwide loss in yield of rice due to weeds has been estimated to be around 10 per cent of total production (Moody, 1991). Taking 1993 rice production of 520 million tons, this accounts to a loss of \$14 billion due to weeds (Pandey and Pingali, 1996).

2.6. Critical period of crop weed competition

In the crop growth period, there exists a critical period during which the crop is very sensitive to weed competition. The presence of weeds beyond a certain density at that time will cause significant yield reduction. Zimdahl (1980) stated that the full impact of weed competition occurred as early in the growing season to as long as 80 days (Smith, 1989). The critical density that reduced yields ranged from only 1 to 3 weeds m⁻² in highly competitive species like *E. crus-galli* or red rice (Smith, 1974) to about 100 weeds m⁻² in less competitive species like *Monochoria vaginalis* (Lubigan and Vega, 1971). Short weeds and those that germinate late in the cropping season tend to compete less than tall weeds or those that germinate early in the cropping season. The most critical period for competition between rice and weeds is when rice is in vegetative phase and yield components of the rice plants are being differentiated (Kim and Moody, 1989; Bayer, 1991).

In direct seeded rice, weed emergence is almost at the same time as the rice plants emerge and therefore, the competition is severe at early stages of the rice crop (Balyan, 1982; Reddy *et al.*, 1994). Most of the research findings showed that

competition period from 15 to 45 DAS had the most impact on yield of wet seeded rice (Ampong – Nyarko and De Datta, 1991; Moody, 1993; Madhu and Nanjappa, 1995; Govindarasu *et al.*, 1998; Sathyamoorthy and Kandasamy, 1998). However, a study conducted at Hyderabad in wet seeded rice using drum seeder revealed that weeds did not affect the crop productivity upto 45 DAS, but beyond 45 days considerable yield reduction was observed due to severe crop – weed competition (Ramamoorthy, 1999). Radosevich *et al.* (1997) also reported that weeds should be controlled during the critical period to prevent yield losses.

2.7. Nutrient drain by weeds

Weeds have a large requirement of nutrients and have higher mineral content than crop plants (Pons and Utomo, 1979; Singh *et al.*, 1986). Weeds usually grow faster than crop plants and absorb added nutrients more rapidly and in larger quantities than by crops (De Datta and Baltazar, 1996) and thus deprive the supply of nutrients to the crop plants. Kim and Moody (1989) observed that some weed species (*E. crus-galli*) started independent growth on the 6th day compared to 10th day in rice seedlings. Uptake of nutrients by weeds in unweeded plot was nearly nine times more than the chemical or manual weeded treatments (Sankaran *et al.*, 1974). Ampong - Nyarko and De Datta (1989) also reported higher resource efficiency of many weeds than rice. In wet seeded rice, weeds depleted considerable amount of applied costly fertilizer nutrients and resulted in poor crop growth and lower grain yield (Estorninos and Moody, 1994; Subash chandra and Pandey, 1996; Cavero *et al.*, 1997; Pandey *et al.*, 1997).

Nutrient removal by weeds in rice eco-system vary very much depending on the nature of weed flora, soil management practices etc. Weeds growing in association with

wet seeded rice removed approximately 27.0, 6.6 and 44.8 kg ha⁻¹ of N, P and K, respectively in Philippines (Moody, 1980), whereas Madhu and Nanjappa (1996) observed a nutrient drain of 57.7 kg N, 50.9 kg P₂O₅ and 72.8 kg K₂O ha⁻¹ by weeds in wet seeded rice in India. Similar observation was also made by Balasubramanian *et al.* (1996) in lowland rice at Tamil Nadu. Most reports also agree that weeds, being more vigorous competitors, end up using a greater portion of the fertilizer applied to the rice crop (Lee and Moody, 1989; Baltazar and De Datta, 1992; Karuppiyah, 1995; Bhuvaneswari, 1998).

2.8. Approaches in weed control

A much wider range and intensity of weed problems occur in direct seeded rice. Weeds vary in their growth habit and life cycles. Therefore, no single method used in isolation could give effective and continuous control of all weed species. The effective methods are those that provide favourable stand establishment and growth for rice which are simultaneously unfavourable to weeds and best results are obtained when direct (therapeutic) methods are combined with indirect (prophylactic) methods (De Datta, 1989; Smith and Hill, 1990; Moody 1990a, 1991).

Weeds can be controlled ecologically by flooding, manually by hand pulling, mechanically, culturally, chemically by applying herbicides and by few biological methods. Each method has its own advantages and disadvantages and a single method is rarely adequate for effective and economical control (Ampong-Nyarko and De Datta, 1991; Moody, 1993; De Datta and Baltazar, 1996). A weed control method, that could be accepted by farmers must be agronomically feasible, economically viable and within the farmers managerial capability.

2.8.1. Manual method of weed control

Manual method includes removal of weeds by hand, with weeding tools (hoe, scythe, and spade) or with manually drawn mechanical implements.

Pulling weeds by hand is the reliable way to control weeds and in older times it was the only direct method of controlling weeds in rice (De Datta and Baltazar, 1996). Though hand weeding is very effective, it is labourious, time consuming and expensive due to high cost of labour particularly during peak period of labour requirement (Moody, 1993; Kandasamy and Raja, 1999). In an effort to reduce the hours spent in hand weeding, research has shown that, if done at the right time, the number of hand weeding that provide season-long weed control can be reduced to only one in transplanted rice, two in wet seeded rice and three in dry seeded lowland or upland rice (De Datta and Baltazar, 1996).

Choudhury and Thakuria (1998) and Singh *et al.* (1999) reported that hand weeding was more effective compared to chemical weeding in wet seeded puddled rice. Number of weedings may vary from one to three during the rice growing season depending on weed infestation but two hand weedings are generally found adequate (Samantaray *et al.*, 1992; Hassan and Rao, 1996; Choudhury and Thakuria, 1998; Singh *et al.*, 1999) in reducing weed count and weed dry weight and increasing grain yield of direct seeded puddled rice. In broadcast seeded rice, hand weeding is difficult as it may cause physical damage, while weeders fail to remove some of the grassy weeds (Moody and Cordova, 1985; Moody, 1993).

Mechanical weeding is done with human or engine-powered inter-row cultivators or rotary weeders. Single row rotary weeders take about 80 to 90 man hr. ha⁻¹ which is twice to several fold efficient than hand weeding. It is practical only in row-seeded rice but does not remove weeds within rows and close to the rice hills which can still cause marked reduction in yield or rice plant may be destroyed in the process (De Datta, 1981; De Datta and Baltazar, 1996).

At IRRI, Philippines, single and double row conoweeders were effectively used to uproot and incorporate weeds into the soil, to increase the weed control efficiency and yield of wet seeded line sown rice (De Datta and Flinn, 1986). But Moody (1991) reported that push-type rotary weeders are difficult to use because they must be moved back and forth and do not work well if soil is too dry and weeds are large sized, or if flood water is too deep.

Singh and Mehta (1998) reported that use of paddy weeder at 15 days after transplanting (DAT) produced significantly higher yield than three tine wheel hoe and sweep hoe and was at par with two hand weeding (20 and 40 DAT) in lowland transplanted rice in Uttar Pradesh, India. Srivastava and Solanki (1993) also observed higher grain yield and N uptake in lowland rice at Jabalpur with rotary weeding + manual weeding. Manual and mechanical weeding in direct seeded rice could be used in conjunction with other cultural and chemical methods to minimize labour requirements (Ho, 1996). Mechanical weed control can be done by unskilled labour and generally economical, non-polluting without residual problems and relatively safe to the operators (Bhan and Sushilkumar, 1996).

2.8.2. Cultural method of weed control

Cultural weed control practices in direct seeded rice are all designed to reduce weed growth and improve crop stand and establishment (Baltazar and De Datta, 1992; Kandasamy *et al.*, 1999). Weed managers face increasingly strong economic, social and biological pressures to limit the use of herbicide and tillage. Presently, these methods are the mainstays of most weed management systems which have significant economic and environmental costs (Pereira and Hostettler, 1993; Seta *et al.*, 1993) and neither is indefinitely effective in controlling weeds (Altieri and Liebman, 1988). Alternative weed management systems have potential to reduce herbicide and tillage use on a wide scale through increased use of other cultural methods of weed control (Wyse, 1994) such as N management, growing of smother/dual crops etc.

2.8.2.1. Weed control by nitrogen management

Application of N stimulates weed germination and increases density and growth of weeds (Everaarts, 1992; Ho, 1996). Singh *et al.* (1986) observed significant increase in the population of monocot and dicot weeds with increasing rate of N application. Addition of fertilizer without control of weeds aggravated weed problems under high weed infestation (De Datta, 1981; Hassan and Rao, 1996), whereas increased level of N application with weed control considerably reduced the weed damage and increased grain yield (Ho, 1996, Patro *et al.*, 1999). In Philippines, Estorninos and Moody (1994) reported that grain yield of wet seeded rice in both dry and wet seasons increased with higher N levels along with herbicide application. However, Das and Saharay (1996) and Pandey *et al.* (1997) observed that N levels and split application did not influence weed population though weed biomass was reduced when N was applied less at the time of

sowing. In California, Cavero *et al.* (1997) observed increased grain yield of direct seeded rice independent of weed density at moderate rate of N and increased yield losses with higher N rates due to weed competition.

2.8.2.2. Weed control by Intercropping / dual cropping

Growing of green manure crop as intercrop has the ability to suppress weeds because of its quick ground cover. Intercropping not only suppressed weeds, but also reduced weeding cost and gave additional yield (Bhan and Sushilkumar 1996). Intercrop/ live mulch suppressed weeds more effectively and for longer time than killed mulches (Brandsaeter, 1996; Masiunas, 1998).

In dry sown rice, maximum yield was observed when cowpea and sunhemp were dual cultured and incorporated on 30 DAS by light hoeing (Abraham Varughese and Sushama Kumari, 1993). Many researchers in Philippines and India, observed that *Azolla* as a dual crop in rice effectively suppressed *Monochoria vaginalis*, *Echinochloa glaberescens*, *Cyperus difformis*, *Paspalum sp.* (Moody, 1984), *Marsilea sp* (Srinivasan and Pothiraj, 1988) suggesting the possibility of inoculating *Azolla* for weed management in lowland rice (Satapathy, 1995).

Mathew and Alexander (1995) reported that concurrent cropping of green manure crops with semi-dry rice significantly reduced the weed growth. They also found that *Sesbania* intercropped and manual incorporation at 35 DAS recorded 37.7g m⁻² of weed dry matter compared to 161.7 g m⁻² in sole paddy crops with a WCE of 77 per cent in the former. The weed control effect appears to be the smothering effect of the green manure crops (Gupta and Lamba, 1978). Angadi and Umapathy (1997) observed that intercrop

Crotolaria juncea, *Vigna sinensis*, *Glycine max* and *Sesbania aculeata* when combined with intercultivation at 15 DAE and HW at 40 DAE suppressed weed effectively in rainfed lowland rice at Mugad, Karnataka. They also found that *V. sinensis* had better weed smothering ability and rice yields were comparable with those using butachlor with one HW at 30 DAE, even when combined with one HW at 30 DAE.

Possibility of growing green manure (*Sesbania rostrata*, Brem and Oberm) as intercrop with direct seeded (semi-dry and wet seeded) and transplanted crop and with its incorporation increased the yield attributes and enhanced rice yield (Jayachandran and Veerabadran, 1996a & b; Somasundaram *et al.*, 1996; Islam *et al.*, 1999). Green manure as an intercrop partially shifted the rice weed flora from the common rice weeds to leguminous N-fixing species enhancing the level of crop competition with weeds (Torres *et al.*, 1995). Thus, *Sesbania* as inter crop has become a viable option for sustainable rice production because of contribution to soil fertility, improved crop performance and suppression of weed growth.

2.9. Chemical method of weed control

Non-chemical methods of weed control for rice although are beneficial, seldom they control weeds adequately (Smith and Moody, 1979). The success of direct seeded rice is fundamentally dependent on weed control with herbicides (Moody and Cordova, 1985). Herbicide usage is one of the most labour saving innovations that has been introduced in rice farming for weed control which minimised the seasonal peak of farm labour demand (Ampong – Nyarko and De Datta 1991; Moody, 1993) and also under adverse soil and climatic conditions herbicidal weed control comes handy (Sankaran and Subbiah Mudaliar, 1991). However, herbicides should not be regarded as replacements

for other weed control practices but should be used in conjunction with them. It is unreasonable to expect that herbicide used singly or in combination will give complete weed control (Moody, 1993).

Moody and Cordova (1985) indicated that herbicides are the only practical and logical alternative for weed control in wet seeded rice. Supplementing post emergence herbicide to pre emergence herbicide application widened the weed management and was more effective in wet seeded rice (Lubigan and Moody, 1982; Kandasamy, 1996). Pre emergence treatments controlled mostly annual grasses, had short residual activity, and were most effective only from germination to no-later than the one leaf stage of weeds (De Datta and Baltazar, 1996).

2.9.1. Pretilachlor plus safener

Pretilachlor, a chloroacetamide group rice herbicide is selective to transplanted rice, but only marginally selective in direct seeded rice without an antidote (safener). Rufener and Quadranti (1983) prescribed that the new safening agent fenclorim (CGA 123407) protected wet seeded rice from pretilachlor injury and pre-mix formulation of pretilachlor + safener (Sofit) was safe on wet as well as dry sown paddy (Christ, 1984). The fenclorim mediated reduction in the root uptake of pretilachlor and an enhancement of the metabolism of pretilachlor via enzymatic or non-enzymatic conjugation with glutathione offered protection to rice (Han and Hatzios, 1991; Deng *et al.*, 1997; Nagao *et al.*, 1998 and Usui *et al.*, 1999).

Pre emergence application of pretilachlor + safener (hereafter mentioned as pretilachlor) gave effective control of annual grasses, sedges and certain broad leaved weeds in direct seeded (dry and wet) rice. Many workers have reported on the spectrum

of activity of pretilachlor on the predominant rice weeds viz. *Echinochloa spp* (Ooi and Chung, 1988; Hare *et al.*, 1989; Zhang, 1991; Dhiman *et al.*, 1998; Jayadeva *et al.*, 1998), *Cyperus difformis* (Ooi and Chung, 1988; Ramesh and Veerabadran, 1997; Dhiman *et al.*, 1998), *Fimbristylis miliacea*, *Leptochloa chinensis*, *Sphenoclea zeylanica*, *Sagittaria pigmea*, *Monochoria vaginalis* (Ooi and Chung, 1988; Hare *et al.*, 1989), *Cyperus iria* (Dhiman *et al.*, 1998) and *Marsilea quadrifolia*, *Ludwigia sp.* and *Eclipta alba* (Ramesh and Veerabadran, 1997; Jayadeva *et al.*, 1998).

Pretilachlor was found to be safe in wet seeded rice with excellent weed control and had positive effect on grain yield (Allard and Andreas, 1990). Pretilachlor 0.4 to 0.6 kg ha⁻¹ applied 3 to 6 DAS gave excellent control of many grasses, sedges and broad leaved weeds in wet seeded puddled rice and was an economical alternative to hand weeding (Mabbayad and Moody, 1992; Bharathi, 1996; Ramesh and Veerabadran, 1997; Choudhury and Thakuria, 1998). However, some researchers recommended a higher dose of 0.75 to 1.0 kg ha⁻¹ applied 3-6 DAS for satisfactory control of most of the weed species in direct sown puddled rice (Angiras and Rana, 1998; Jayadeva *et al.*, 1998; Dhiman *et al.*, 1998). Uthaykumar *et al.* (1996) from Tamil Nadu observed that application of pretilachlor 0.3 kg ha⁻¹ on 3 days before or after sowing recorded significantly higher grain yield in wet seeded rice. However, Kandasamy and Chandrababu (1995) found application of pretilachlor 0.45 kg ha⁻¹ at 8 DAS was more effective and economical at Coimbatore.

Integrated weed management approach of pre emergence application of pretilachlor applied 0.45 to 0.75 kg ha⁻¹ followed by one hand weeding at 25 to 30 DAS effectively controlled grasses, sedges and broad leaved weeds and thus minimised the

nutrient removal by weeds due to improved weed control efficiency and contributed to higher grain yield and benefit – cost ratio (Ramesh and Veerabadran, 1997; Thirumurugan *et al.*, 1998) in Tamil Nadu.

2.10. Integrated weed management

In wet seeded rice, there is considerable (and sometimes complete) reliance on herbicides for weed control (Moody, 1993). However, problems with herbicides including groundwater and surface water contamination, other offsite movement, herbicide residues in food and resistance developed by weeds against continuous use of single herbicides has sparked public awareness and restriction of herbicide use (Clay and Oberle, 1996). There arises a need to find ways to reduce this dependency on herbicides. Weeds are most efficiently controlled by the simultaneous application of a variety of practices, the total effect of which is usually greater than the effects of individual measures employed separately (Day, 1972). Integrated weed management is the rational use of direct and indirect control methods to provide cost effective weed control and should be consistent and compatible with other rice production practices (Ampong – Nyarko and De Datta, 1991).

Weed – rice ecological relationship is never static and the continuous adoption of any particular practice caused shift in dominance and distribution of weeds in rice (Ho *et al.*, 1992; Kandasamy, 1995). This has happened in rice fields in American continent (Labrada, 1996), Egypt (Hassan *et al.*, 1991) and India (Kandasamy, 1995). Moody (1993) reported that integrated weed management combining all feasible methods viz. tillage, cultivar, seeding rate, N management and herbicide application provided good weed control in wet seeded rice.

Many workers reported effective weed control when herbicide was used in combination with other control methods, especially water management (Moussavi, 1985; Hassan *et al.*, 1991; Allard *et al.*, 1996) during the early stages of weed growth and / or hand weeding (Kandasamy and Sankaran, 1994). In direct seeded puddled rice, application of pre emergence herbicide (butachlor or pretilachlor each at 1.0 kg ha⁻¹) followed by one hand weeding at 35 DAS gave better weed control and was comparable to hand weeding alone (Reddy *et al.*, 1995; Nandal and Hari Om, 1998). In another study, Singh *et al.* (1994) reported that application of butachlor followed by two mechanical weedings might be a potential substitute for conventional manual weeding.

In India, mixed crops of *Sesbania* sp., sunhemp, cowpea and soybean with rainfed direct seeded rice combined with one hand weeding (30 DAE of rice) or inter-cultivation (15 DAE of rice) + hand weeding (30 DAE) showed significant reduction of weed dry weight and the grain yield were equal to those obtained by farmers using herbicide + hand weeding or hand weeding twice during the first month of the crop cycle (Angadi *et al.*, 1993; Angadi and Umapathy, 1997). Gogoi (1996) also reported that intercropping (with fodder cowpea, soybean, groundnut, *Vigna radiata*) in upland rice suppressed weeds and were more profitable.

2.11. Nitrogen management in wet seeded rice

With any rice establishment method, N fertilization is one of the important factors that affect rice production (Mikkelsen, 1987). The yield increase obtained by N fertilizer is mostly interpreted as N being a substrate for the synthesis of proteins, which are constituents of protoplasm and chloroplasts. In addition, the nutritional status of N can

also be visualized from hormonal view so far as N stimulates meristematic growth and cytokinin biosynthesis (Yoshida and Oritani, 1974; Beringer, 1980). Nitrogen accounts for 67 per cent of the total amount of fertilizers applied to rice (Prasad and De Datta, 1979) and a balanced, rational use of green manure / bio-fertilizers with chemical fertilizers may increase the efficiency and supplement fertilizer nitrogen. Crop yield is influenced, often decisively by the extent to which the plant requirement for N can be met. This varies greatly from crop to crop, soil to soil and from one climate to another (Greenwood, 1976 & 1982). The response of direct seeded rice to N was found linear upto 180 kg N ha^{-1} at Indian Agricultural Research Institute, New Delhi (Sudhakar *et al.*, 1987). A fertilizer dose of $150 \text{ kg N} + 75 \text{ kg K}_2\text{O ha}^{-1}$ during the winter period (*rabi*) and $100 \text{ kg N} + 50 \text{ kg K}_2\text{O ha}^{-1}$ during the South West Monsoon period (*kharif*) was found to be optimum to increase the grain yield in Tamil Nadu (Kandasamy and Palaniappan, 1990). For Coimbatore, optimum dose of N for *kharif* and *rabi* seasons in direct seeded rice are 120 and 150 kg ha^{-1} respectively (CPG, 1994).

2.11.1. Split application of nitrogen

Nitrogenous fertilizer is one of the costliest and perhaps the most crucial primary nutrient which can limit the rice yield. Though modern rice varieties respond well to N fertilization, the recovery of applied N is very low. It is between 25 and 40 per cent in many situations and even under the best cultural conditions, the applied N recovery does not exceed 49 per cent (De Datta *et al.*, 1990). The low recovery of applied N is attributed to ammonia volatilization, denitrification, leaching, runoff, immobilization and ammonium fixation (Savant and De Datta, 1982). Among the various ways for increasing the

applied nitrogen use efficiency, proper time of application offers considerable prospects for reducing N losses and on the other hand, matching the N availability as per the plant requirement at critical growth stages (De Datta and Buresh, 1989).

Many workers recommended application of first dose of N from a week after germination till maximum tillering stage which favourably influenced yield components and the yield of direct seeded rice (Ahmed and Moody, 1981; Songmuang *et al.*, 1983; Choubey *et al.*, 1985 Veno *et al.*, 1990). Delayed application of N rather than basal application reduced the losses of fertilizer N (Uppal and Sarkar, 1992; Kandasamy, 1997) and minimised uptake of N by weeds (De Datta *et al.*, 1991). When N supply to rice crop was delayed upto 16 DAT, higher grain yields were obtained due to increased tiller production and leaf N content (Thiyagarajan *et al.*, 1993). Application of N at reproductive stage also increased yield contributing characters and yield of rice (Tanaka, 1976; Penyan *et al.*, 1993; Channabasavanna and Setty, 1994). Dingkuhn *et al.* (1992) reported that early and mid season N fertilisation increased dry matter, leaf area and tiller number, while late season application increased foliar N concentration, delayed flag leaf senescence and increased photosynthetic rate thereby resulting in higher grain yield. Similarly, Norman *et al.* (1992) found that the accumulation and distribution of N in vegetative and reproductive parts also determined the yield of rice.

Application of recommended dose of nitrogen in three to four splits at sowing, active tillering, late tillering and panicle initiation stage to semi-dwarf varieties proved beneficial (Moorthy and Mitra, 1992). Plant height, tiller and panicle production did not differ significantly in four splits compared to three splits (Bhattacharya and Singh, 1992).

Similarly, Pandey *et al.* (1997) observed that grain yield did not vary significantly due to three and four split application of N in drill seeded rice at Jabalpur. Similar result was also observed by Murali and Reddy (1995) in *khariif* lowland rice.

However, study of Sanbagavalli and Kandasamy (1998) revealed that four splits of recommended N was superior than three splits in wet season rice at Coimbatore. Vijayalakshmi *et al.* (1992) also from Coimbatore recommended four equal splits of N on 21, 35, 50 and 65 DAS for increased panicle number, spikelet number, filled grain percentage and grain yield. Similarly, Bhattacharya and Singh (1992) also found that application of N in four equal splits (basal or at seedling stage, tillering, panicle initiation and heading stage) gave higher panicle weight and grain yield.

In contrast, Pandey *et al.* (1989) found that application of N in five equal splits at basal, active tillering, one week before panicle initiation, booting stage and panicle emergence produced highest grain yield. Similarly, Sanbagavalli and Kandasamy (1998) found that five split application of recommended dose of nitrogen was superior to four splits in dry season lowland rice at Coimbatore.

2.11.2. Nitrogen uptake and crop response

The role of N in plant production was reviewed by Novoa and Loomis (1986). Nitrogen has greater effect on plant growth and metabolism and therefore, it largely influenced the yield attributes of rice (Morris *et al.*, 1990), yield (Singh *et al.*, 1990) and quality by increasing the protein content (Biswas *et al.*, 1992). Many workers emphasised the need for N application before panicle initiation (PI) to ensure sufficient biomass production and increased yield (Greenwood *et al.*, 1991; Thiyagarajan *et al.*, 1994).

Samantary *et al.* (1990) reported that the N uptake was high between vegetative and reproductive stages. Kitada *et al.* (1991) recorded 80 per cent recovery when N was applied between PI and heading stages, 60 per cent from heading to maturity and 70 per cent at 17 days before heading. Rao *et al.* (1994) and Dash *et al.* (1994) reported that the total amount of leaf, stem and root N continued to increase until flowering after which it decreased. However, Johnkutty (1996) observed continued uptake of soil N by the crop even after heading and an enhancement of N uptake after heading by late N supply. In another study, Kandasamy (1997) observed that N application caused a general increase in the yield of rice, however the response was at decreasing rate. The economic dose of N was reported 95.8, 122.5 and 123.3 kg ha⁻¹ to get a grain yield of 51.8, 34.5 and 52.5 q ha⁻¹ in *kuruvai*, *thaladi* and *samba* seasons respectively in direct seeded lowland rice at Aduthurai. Budhar *et al.* (1994) observed highest N uptake at lower level of fertilizer (100 kg N ha⁻¹), but at higher N levels (200 – 218 kg ha⁻¹), application of N in the form of green manure or in combination with urea only succeeded in achieving this benefit. Nagarajah *et al.* (1989) reported 29 to 45 per cent apparent recovery of applied N (ANR) from *Sesbania* green manure. Similar efficiency range of 15 to 25 kg grains per Kg N from both green manure and chemical fertilizer has been reported by Yoshida (1981) and Morris *et al.* (1989). Increased N recovery of fertilizer N when combined with green manure was reported by Haroon *et al.* (1992); Diekman *et al.* (1993); Vaiyapuri *et al.* (1995).

De Datta *et al.* (1989) evaluated broadcast seeded and transplanted rice under similar N management practices. With applied urea, ¹⁵N recovery was greater for

broadcast seeded rice (47%) than for transplanted rice (37%). However, Schnier *et al.* (1990) observed that row-sown rice had a higher N demand and had an inferior ability to convert high biomass production into grain yield as compared to transplanted rice.

2.11.3. Green manuring

The growing concern about the sustainability of tropical agricultural systems necessitate the use of soil improving organic manures. Organic manures are valued and stressed to be included in integrated nutrient management in rice. Saravana Pandian and Rani Perumal (1994) had observed higher response in rice for green manures than other organics such as farm yard manure and bio-fertilizer *Azospirillum*. The physiological efficiency (kg of grain per kg of absorbed N) in rice was the highest with green manuring alone and it was better than fertilizer and integrated N sources (Budhar and Palaniappan, 1996). In addition to provision of N and other mineral nutrients for the immediate need of the growing rice crop, there is rapid and abundant evolution of CO₂ which might benefit the rice crop under intercropping system, influencing its photosynthetic activity (Bhardwaj and Dev, 1985). Matiwade and Sheelavantar (1994a) reported that 100 per cent of N requirement to the rice crop could be substituted by green manuring with *Sesbania rostrata*.

Several research workers reported that *Sesbania rostrata* was superior to other green manure species (*Sesbania aculeata*, *S. speciosa*, *Azolla sp.* and *Cyamopsis tetragonoloba*) in terms of biomass production and N contribution in a wide range of soil and climatic conditions (Medhi and Medhi, 1996; Hussain *et al.*, 1995; Jayachandran and Veerabadran, 1996 a & b; Rangasamy *et al.*, 1997).

Sesbania rostrata is characterised by profused stem nodules, fast growth and more active N fixation than most root nodulating legumes. Root nodulation and biological N fixation of *S. rostrata* were reported to be either inhibited or unaffected drastically by soil flooding (N'doye and Dreyfus, 1998), but stem nodules were unaffected (Kalidurai and Kannaiyan, 1992) probably due to their position on above ground plant parts (Ladha *et al.*, 1992; Kwon and Beevers, 1993). It also showed high sensitivity to climatic variations, particularly temperature and photoperiod (Derives *et al.*, 1985; Becker *et al.*, 1991) and exhibited dwarf canopy and early flowering during cooler months and rapid vegetative growth with late flowering in the summer (Gopalaswamy *et al.*, 1997). It was also found to grow well in saline and alkaline soils (Palaniappan *et al.*, 1990).

Rao and Gill (1993) reported that *S. rostrata* exhibited excellent nodulation (300 nodules plant⁻¹) with an average concentration of N, P, K, S, Ca and Mg of 3.2, 0.28, 1.5, 0.28, 1.5 and 0.4 per cent, respectively in the shoots, thus reflecting the usefulness of the green manure as an integrated bio-fertilizer source. However, Joshua *et al.* (1992) observed that stem nodule number and weight decreased with increased fertilizer N levels, while N content in stem and leaf increased, but application of N suppressed root nodulation completely.

In India, growing of *S. rostrata* (var. Col) during May – June produced 21, 34 and 52 t ha⁻¹ green matter contributing 68, 167 and 213 kg N ha⁻¹ respectively in 30, 45 and 60 days growth period (Rangasamy *et al.*, 1997). A 56 day old *S. rostrata* gave an average dry matter yield of 6.18 t ha⁻¹ with a N accumulation of 159 kg ha⁻¹ in Philippines. Halepyati and Sheelavantar (1991) also observed higher dry matter

production (2.36 t ha^{-1}) in *S. rostrata* compared to *S. aculeata* (1.49 t ha^{-1}) and *S. grandiflora* (1.29 t) at 35 DAS and *S. rostrata* contributed 143 kg ha^{-1} of N with a N content of 6.23 per cent. Dry matter and N accumulation increased and percentage of N content decreased with plant age. Further, it improved the soil sodicity faster than FYM and wheat straw (Kumar and Yadav, 1995).

2.11.4. Effect of *Sesbania rostrata* on growth and yield of rice

The major effect of green manure is undoubtedly due to its N contribution, but the favourable effects of organic matter addition and availability of plant nutrients can not be overlooked as it improves the soil fertility that reflects on crop growth and yield. Many workers reported that incorporation of *Sesbania rostrata* significantly increased the plant height, dry matter, productive tillers per unit area, filled spikelet per panicle, 1000 grain weight and grain yield of direct seeded (semi-dry and wet seeded) and transplanted rice (Ladha *et al.*, 1989; Becker *et al.*, 1991; Matiwade and Sheelavantar, 1994b).

In Bangladesh, number of panicles per unit area, grains per panicle, grain and straw yields of transplanted rice were unaffected due to *S. rostrata* intercropping (Islam *et al.*, 1999). However, Biswas *et al.* (1992) observed that prolific growth of *S. rostrata* suppressed the growth as well as yield of transplanted rice. In contrast, wet seeded rice benefited from intercropping of 20 days old *S. rostrata* seedlings at $1.5 \text{ m} \times 0.15 \text{ m}$ inter- and intra-row spacing respectively (Jayapaul *et al.*, 1995).

Kalidurai and Kannaiyan (1992) observed an increase of 127 per cent over control in rice yield, when a biomass of 20 t ha^{-1} of *S. rostrata* was applied. Similar results of higher grain yield were also reported by Becker *et al.* (1991), Sahu and Sahu (1992),

Pillai and Nair (1995) and Somasundaram *et al.* (1996). Incorporation of *S. rostrata* alone gave similar yield as that of fertilizer N applied at 100 kg ha⁻¹. Increasing fertilizer N with *S. rostrata* further increased rice grain yield (Halepyati and Sheelavantar, 1990; Diekmann *et al.*, 1993). However, Bhandari *et al.* (1992) found that grain yield by substitution with *S. aculeata* at 25 to 50 per cent N levels was inferior to 100 per cent inorganic fertilizers.

2.11.5. Integrated nitrogen management

Most of the arable soils suffer degradation and decline in productivity due to erosion, nutrient loss and decrease in organic matter (Parr *et al.*, 1986) and modern intensive farming systems increased the risk of soil fertility losses and environmental contamination (Lee *et al.*, 1992). Therefore, it is necessary that soil organic matter be maintained or wherever possible increased, if better crop yields are aimed (Rovira, 1993). The concern on the ecological sustainability and increasing prices of N fertilizer in relation to price of rice has clearly resulted in a tremendous renewal of interest in the practice of green manuring. Green manures in integrated N management along with inorganic nitrogenous fertilizer received a great deal of attention for efficient and economic management of N in rice. In Panagasinan, Philippines both 50/50 and 75/25 of inorganic N and organic N combination in research farm and farmers fields produced yields comparable to those obtained with complete inorganic forms of N (Dascalsota *et al.*, 1986). In Karnataka, green manuring of *Sesbania rostrata* along with 100 per cent recommended N fertilizer gave highest rice yield and found to be better than 100 per cent of inorganic N alone in red silty clay loam soil under irrigated condition during *kharif* and *rabi* seasons (Matiwade and Sheelavantar, 1994b). Similar results regardless of seasons were also

reported by Kalidurai and Kannaiyan (1991) and Setty and Channabasavanna (1991). However some workers observed that recommended N dose had to be applied through green manure and inorganic N fertilizers in equal proportions to produce higher grain yield than 100 per cent of recommended dose of inorganic N (Pillai and Nair, 1995; Budhar and Palaniappan, 1996; Somasundaram *et al.*, 1996). Rao *et al.* (1994) noted that the grain yield decline was, in general, greater in the conventional three way split application of prilled urea than in the integrated N application schedules and also with the organic and inorganic fertilizer application in equal proportions.

2.11.6. Effect on chlorophyll content

It is well known fact that chlorophyll is responsible for green colour of the leaf. Chlorophyll and accessory pigments are required for absorbing the radiant energy for photosynthesis. However, chlorophyll was generally considered as a non-limiting compound unless the plant was subjected to severe nutritional deficiencies (Leidi *et al.*, 1991). Chlorophyll and carotenoid content were found to be higher in dark coloured (higher N) than in light coloured leaves (Tao *et al.*, 1991). Nitrogen deficiency reduced chlorophyll content per unit area (Litchenthaler, 1973) and chlorophyll as well as carotenoid formation in higher plants (Sundquisit *et al.*, 1980). Devi (1990) studied the effect of N on chlorophyll content of four improved rice varieties at Orissa (India) and reported that leaf chlorophyll content increased from 0.387 to 1.25 mg g⁻¹ fresh weight with application of 40 kg N ha⁻¹. The N application significantly increased chlorophyll (a, b and total) content in rice leaves. Similar findings for direct seeded semi-lowland rice were also reported by Sudhakar *et al.* (1987) and Laza *et al.* (1993).

Investigation of Lin *et al.* (1990) on LAI and chlorophyll content of rice plants revealed that sum of LAI and chlorophyll content at PI, heading and 29 days after heading positively correlated with applied N rates. According to Singh and Ram (1991), the effect of herbicide, mechanical and manual weed control methods on the chlorophyll content of rice was comparable. The highest rice leaf chlorophyll content at 50 DAS (2.71 mg g^{-1}) was recorded in weeded plot as compared to 1.21 mg g^{-1} in rice from weedy plots.

2.11.7. Use of chlorophyll meter (SPAD-502)

Leaf photosynthetic rate and leaf N concentration are closely related in rice (Greenwood *et al.*, 1991), since N is an essential constituent of chlorophyll. A minimum concentration of N in the leaves is needed to attain a higher yield level (Johnkutty and Palaniappan, 1996). The chlorophyll meter (SPAD) has been recently used to estimate the need of N concentration of plant leaves. In rice, it has been widely used by Takebe *et al.* (1990), Peng and Cassman (1995), Johnkutty and Palaniappan (1996). The relationship between SPAD meter readings and N concentration in rice leaves was found to differ markedly depending on growth stage, genotype and environment (Peng *et al.*, 1995). Since photosynthetic rate is highly correlated to leaf area and SPAD (Peng and Cassaman, 1995), SPAD can be used directly to estimate leaf N status and forecast for N top dressing. The relationship between SPAD meter readings and crop yield in rice had been studied by many workers (Peng *et al.*, 1995; Johnkutty and Palaniappan, 1996, Muralidharan, 1996; Liangthuan and QinNan, 1999). Muralidharan (1996) fixed the critical SPAD value of 37 for the rice cultivar IR 50 and 38 for ADT36 and ASD18. In general, in India, the critical SPAD values for transplanted rice have been found to be 37 for wet (*kharif*) season and 35-37 for dry and winter (*rabi*) seasons to obtain higher

yields (IRRI-CREMNET, 1998). Janaki and Thiagarajan (1999) showed that when same SPAD threshold was used for various plant densities (33 to 100 m⁻²) in transplanted rice, more N was needed to produce similar grain yields in Coimbatore, India. Based on using single SPAD threshold value for different grain type varieties (coarse, medium and fine), Thiagarajan and Aruna Geetha (1999) observed that, finer the grain type, larger was the amount of N required and higher was the number of split application, especially after panicle initiation. Liangttuan and QinNan (1999) observed significant positive correlation between chlorophyll meter readings and leaf chlorophyll of Indica and Japonica rice genotypes at mid tillering as well as panicle differentiation stages and also established the relationship between grain yield and chlorophyll meter readings. Johnkutty and Palaniappan (1996) obtained a high positive correlation coefficient between SPAD and grain yield (0.75 to 0.90) in lowland rice in Tamil Nadu.

2.12. Economics and energetics

Wet seeding onto puddled field with its reduced crop establishment costs, is a low cost but viable alternative to transplanting (Ogihara, 1993). Coxhead (1984) found that number of man days per hectare per harvest for wet seeded rice is only 32 compared to 63 for transplanting rice. Similar result was also reported by Sivaperumal (1995). Additional profit of 15 per cent due to wet seeding over transplanting was reported by Bhuiyan (1993). In another study at Tamil Nadu, maximum net return and energy use efficiency were recorded in direct seeding using drum seeder over broadcasting of seeds and random transplanting and line transplanting of seedlings (Bhuvaneswari, 1998). On many occasions, direct seeded rice performed better than other planting methods (Purohit *et al.*, 1990; Thabonithy *et al.*, 1994; Bhuiyan *et al.*, 1995).

Higher cost of hand weeding due to labour input gave lower return per rupee invested compared to herbicide application in direct sown rice (Ramakrishnan *et al.*, 1992; Ramamoorthy, 1994). However, Suresh Chandra and Tiwari (1998) observed highest grain yield and returns with two hand weedings (25 and 40 DAS) as compared to pre emergence application of herbicide alone in direct seeded puddled rice at Kanpur. In another study at Jorhat, Dutta and Gogoi (1994) reported that growing of intercrop (harvested 45 DAS) with direct seeded rice showed superiority in earning the maximum net return over other weed control (hand weeding and chemical) measures.

Ruthenberg (1977) stated that the marginal benefit – cost ratio (B:C) should be at least 2:1 before adopting an innovation. Thus, chemical weed control is clearly a profitable production technique in wet seeded rice. Marginal B:C ratios of greater than 2:1 for herbicide use in wet seeded rice have been reported by Heinrichs *et al.* (1987) and Diop and Moody (1989) from the Philippines. Many researchers also observed higher economic returns by application of pre emergence herbicide followed by one hand weeding in wet seeded rice (Kandasamy and Chandrababu, 1995; Udaykumar *et al.*, 1997; Singh and Mehta, 1998; Thirumurugan *et al.*, 1998). In a study under Arkansas Rice Research Verification trials (Slaton *et al.*, 1992), weed control costs varied between \$62 ha⁻¹ and \$180 ha⁻¹, representing an average of 15 per cent of the total specified operating costs. It clearly indicated that weed management decisions affect the profitability of rice production.

Worldwide efforts are being made to make effective and economic utilization of available energy sources. In India, more than 60 per cent of total energy is utilized for agricultural sector alone. Therefore, energy conservation in agricultural sector is the most important factor.

Use of seed drill saved about 45 per cent bullock energy and 54 per cent human energy in sowing, 50 per cent energy in weeding with an increase of 30 per cent benefit : cost ratio as compared to broadcast seeding (Patel *et al.*, 1994).

In Coimbatore, Bhuvaneswari (1998) observed higher energy use efficiency under direct seeding using drum seeder (8.17 and 8.48 MJ ha⁻¹ during *summer* and *kharif* seasons, respectively) over broadcasting and transplanting methods. She also observed highest energy use efficiency with pre emergence application of herbicide + one hand weeding which was closely followed by hand weeding twice in both *summer* and *kharif* seasons.

From the foregoing review, it is clear that the integrated weed management approach is an urgent requirement for improvement of rice production as the production factors *viz.*, N and weed control do not act independently, rather they strongly interact with each other. Limited literature is available on these aspects, particularly in wet seeded rice system and *Sesbania* intercropping. Therefore, it is necessary to generate an ecofriendly, agronomically effective, economically viable and practicable weed and N management package to sustain the productivity of drum seeded lowland rice.

MATERIALS AND METHODS

CHAPTER – III

MATERIALS AND METHODS

Field experiments were conducted during *Kharif* and *Rabi* seasons of 1998-1999 and 1999-2000 in Wetland Farm of Tamil Nadu Agricultural University, Coimbatore to evaluate the interactive effects of split application of N and weed control methods in drum seeded lowland rice (*Oryza sativa* L.). The experimental details, materials used and the methods employed during the course of investigations are presented in this chapter.

3.1. MATERIALS

3.1.1. Field location

The field experiments were carried out in G,N and E blocks of the wetland farm of Tamil Nadu Agricultural University, Coimbatore (11° N latitude, 77° E longitude and 426.7 m altitude).

3.1.2. Climate and Weather Conditions

The mean annual rainfall of Coimbatore is 674.2 mm received in 46 rainy days (mean of past 50 years). The mean maximum and minimum temperatures ranged from 29.2 to 35.2 °C and 17.9 to 23.8 °C, respectively. Relative humidity ranged from 61 to 91 per cent during forenoon and 14 to 68 per cent in the afternoon. The bright sunshine hours per day was 7.3 with a mean solar radiation of 429.2 Cal cm⁻² day⁻¹. The mean weekly weather parameters recorded at the meteorological observatory of the University during the cropping period are presented in Fig 1 and 2 and Appendix I.

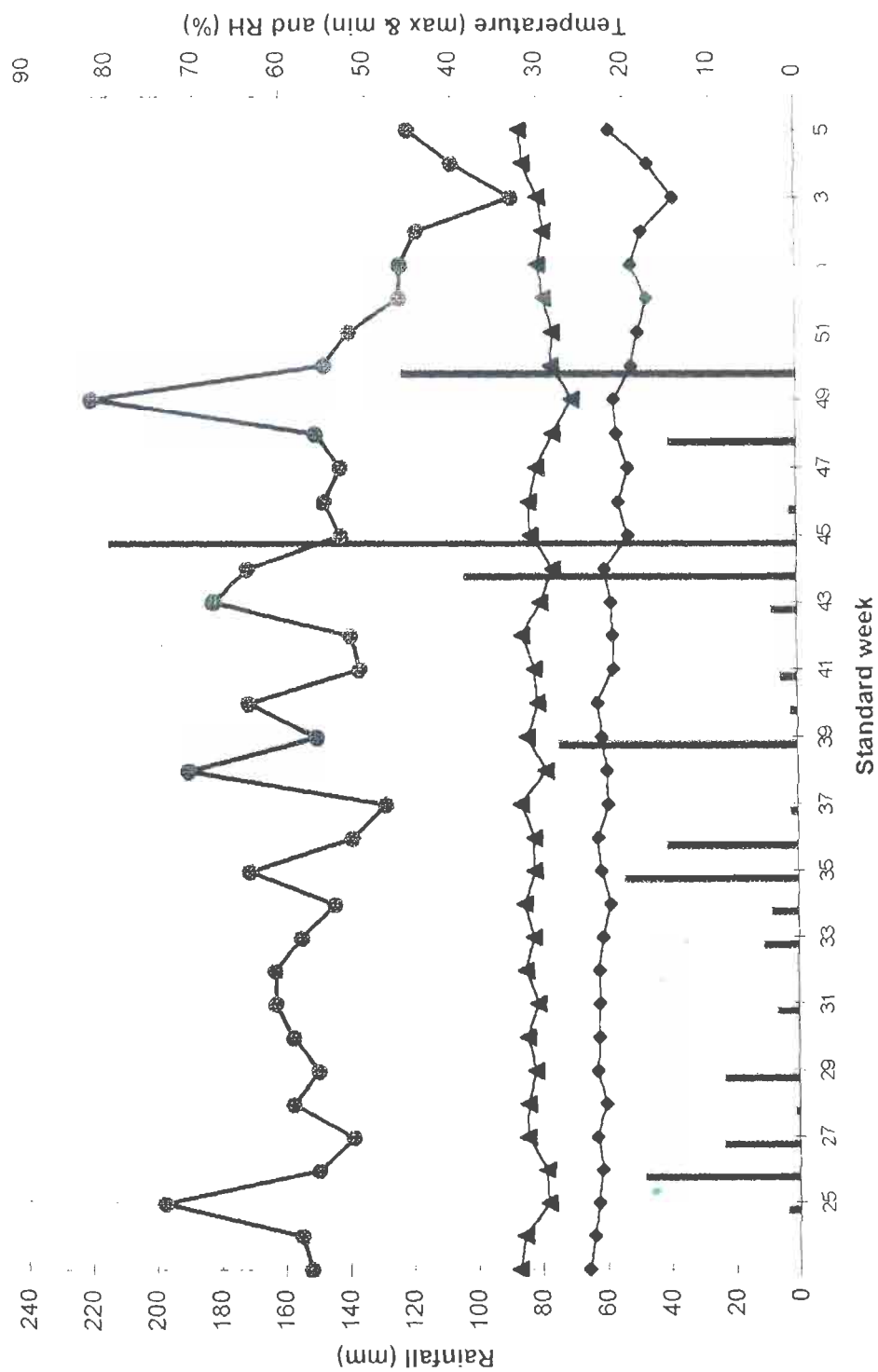


Fig 1. Weather parameters during the cropping period (1998-99)

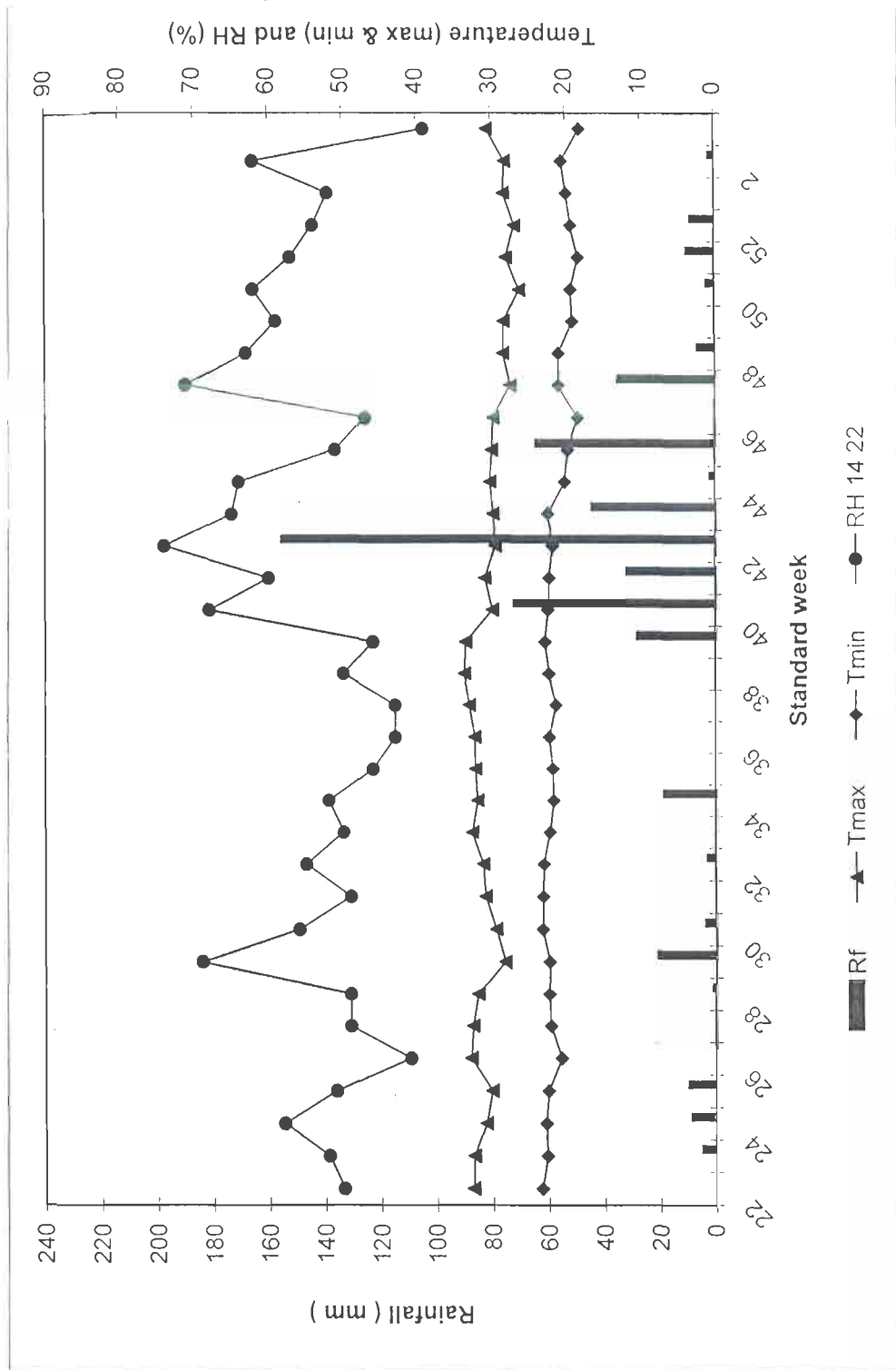


Fig 2. Weather parameters during the cropping period (1999 - 2000)

3.13. Physico – Chemical Characteristics of the soil

The soils of experimental fields (G₆, N₄ and E₄) were clay loam or clayey in texture and taxonomically classified as *Typic haplustalf*. The soil was low in available nitrogen, medium in available phosphorus and high in available potassium contents. The details on physico-chemical properties of the soil are given in Table 1.

3.1.4. Crop variety and seasons

Short duration (ADT36) and medium duration (ADT39) rice cultivars were grown during June-October (*khariif*) and September to January (*rabi*) seasons, respectively, in both the years (1998-99 and 1999-2000). The details of cultivars used are given below:

ADT36: The variety ADT36 (Triveni X IR 20) is a short duration (105-110 days), erect type having long compact panicle. The grains are medium and white in colour. The variety released by Tamil Nadu Rice Research Institute, Aduthurai, Tamil Nadu Agricultural University in 1980 is a high yielding variety suitable for direct seeding.

ADT39: ADT39 is a medium duration (120-125 days) rice variety with the parentage of IR8 and IR20. The grains are medium slender and white in colour. This non-lodging variety having high yield potential was released by Tamil Nadu Rice Research Institute, Aduthurai, Tamil Nadu Agricultural University during 1988.

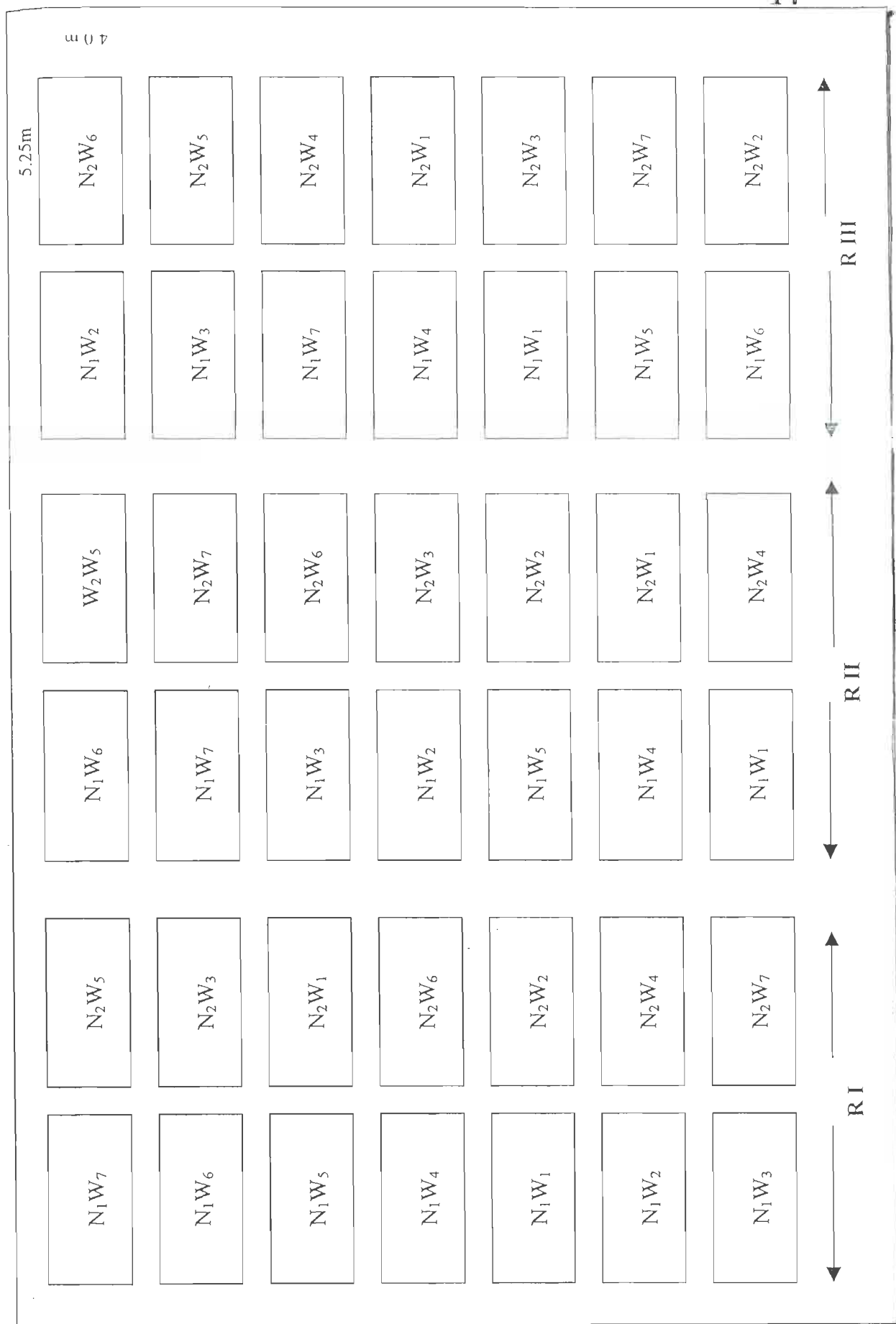
3.1.5. *Sesbania* (intercrop in rice)

Sesbania rostrata, a leguminous green manure crop (variety Co1, developed at Paddy Breeding Station, Tamil Nadu Agricultural University, Coimbatore) was grown as intercrop as per treatment. *S. rostrata* is indigenous to Senegal, West Africa. It produces

Table 1. Initial Physico - Chemical properties of soil of the experimental field

Soil properties	Methodology and author (s)	Average value			
		Kharif'98	Rabi'98-99	Kharif'99	Rabi'99-2000
A. Particle size analysis	International pipette method (Piper, 1966)				
Clay (%)		38.9	36.4	36.4	41.4
Silt (%)		33.3	32.3	32.3	29.8
Fine sand (%)		18.8	19.9	19.9	19.7
Coarse sand (%)		9.0	11.4	11.4	9.1
Textural class		clay loam	clay loam	clay loam	clay
B. Chemical composition					
Organic carbon (%)	Chromic acid wet digestion method (Walkley and Black, 1934)	0.51	0.48	0.48	0.59
Available N (kg ha ⁻¹)	Alkaline permanganate method (Subbiah and Asija, 1956)	198.7	186.3	183.0	223.0
Available P (kg ha ⁻¹)	0.5 M sodium -bi-carbonate extraction using colorimetry (Olsen <i>et al.</i> , 1954)	21.2	18.3	19.1	19.4
Available K (kg ha ⁻¹)	Flame photometric method (neutral normal ammonium acetate extraction) (Stanford and English, 1949).	523.6	485.5	495.0	571.0
pH	Glass electrode, 1:2 soil water suspension (Jackson, 1973)	8.1	8.3	8.4	7.9
Electrical conductivity (dS m ⁻¹)	Solubridge, 1:2 soil water suspension (Jackson, 1973)	0.41	0.38	0.39	0.45

Fig 3. Layout plan of the experimental field (same layout was followed for all experiments)



effective aerial rhizobial nodules throughout the stem besides the roots. It is quick growing succulent green manure capable of producing 30 to 35 tonnes of biomass per hectare accumulating 120-140 kg N ha⁻¹ within 55-60 days. It is tolerant to flooding and water logging and is quickly decomposable upon incorporation.

3.2. Methods

3.2.1. Layout

The experiments conducted during *kharif* and *rabi* seasons 1998-99 and 1999-2000 were laid out in a split plot design with three replications and the details are presented below:

Main plot treatments : 2 (split application of N)

Sub – plot treatments : 7 (weed control methods)

Number of replication : 3

Gross plot size : 5.25 x 4.0 m

Net plot size : 3 x 3 m

The layout plan of field experiment is shown in Fig. 3

3.2.1. Details of treatments

A. Main plot treatments: (split application of N)

N₁ – Four splits (1/6 at 10 days after sowing (DAS) + 1/3 at active tillering + 1/3 at panicle initiation + 1/6 at heading stage)

N₂ – Five equal splits (1/5 each at sowing, 10 DAS, active tillering, panicle initiation and heading stage).

B. Sub-plot treatments: (weed control methods)

- W₁ Manual weeding twice at 20 and 35 DAS (manual method)
- W₂ Rotary weeding at 20 DAS + manual weeding at 35 DAS (mechanical + manual method)
- W₃ *Sesbania* intercrop and manual incorporation cum weeding once at 35 DAS (cultural + manual method)
- W₄ *Sesbania* intercrop and rotary incorporation alone at 35 DAS (cultural + mechanical method)
- W₅ Herbicide + *Sesbania* intercrop and rotary incorporation alone at 35 DAS (cultural + chemical + mechanical method)
- W₆ Herbicide + manual weeding at 35 DAS (chemical + manual method)
- W₇ Unweeded control.

* Herbicide was applied as pre emergence. The chemical terminology and formulation of herbicide used are presented in Appendix II.

3.3. Crop husbandry

All the cultural practices and plant protection measures for rice other than the treatments (split application of N and weed control methods) were followed as per recommendations of the Crop Production Guide of Tamil Nadu Agricultural University (CPG, 1994).

3.3.1. Field preparation

The selected experimental field was initially dry ploughed with tractor drawn disc harrow and then puddled with tractor drawn cage wheel. The field was levelled with

wooden plank before layout. The main and sub-plots were laid out with irrigation and drainage channels all around the experimental field.

3.3.2. Wet seeding using drum seeder

The manually drawn “Two wheel, rice-cum-green manure seeder” developed at Tamil Nadu Agricultural University, Coimbatore was used in the study. The seeder has two wheels and designed to sow rice and green manure (*Sesbania*) in alternate rows of 12.5 cm apart, sowing 6 rows at a time. The seeder width is 0.75m and the walking speed is around 1.5 km hr⁻¹. Two men can cover 0.54 ha day⁻¹ taking into account the time loss for unhooking and hooking the handle after each pass.

Pre-germinated rice seeds (seeds soaked in water over night and incubated for 24 hours) were drum seeded at the rate of 75-80 kg ha⁻¹. For the intercrop, *Sesbania rostrata* seeds treated with concentrated sulphuric acid for 15 minutes, washed repeatedly with clean water 4 times, were shade dried and drum seeded at a rate of 22-25 kg ha⁻¹.

Rice and *Sesbania* seeds were sown in alternate rows of 12.5 cm apart in W₃, W₄ and W₅ treatments, while rice was sown at a row spacing of 25 cm in other treatments.

3.3.3. Weed control methods

As per the treatment schedule, manual weeding was carried out twice at 20 and 35 DAS in W₁ treatment whereas in the W₂, W₃ and W₆ treatments manual weeding was done only once at 35 DAS. In W₄ and W₅ treatments, Push type conoweeder was used (at 35 DAS) for weeding as well as *Sesbania* incorporation as per treatment. In W₃ treatment, both cultural and manual methods were used where *Sesbania* trampling and weeding was done simultaneously by manual method at 35 DAS. Chemical weed control was done in W₅ and W₆ treatments where pre emergence herbicide pretilachlor + safener



Plate 1. Rice cum green manure crop drum seeding



Plate 2. Combined operation of green manure incorporation and mechanical weeding using conoweeder

@ 0.45 kg ha⁻¹ was applied on 7 DAS. Calculated quantity of herbicide for each plot was diluted with water at the rate of 800 l ha⁻¹ and sprayed with a knapsack sprayer having a fan type nozzle. A thin film of water was maintained at the time of herbicide application.

3.3.4. Fertilizer application

A recommended dose of 120:38:38 kg ha⁻¹ (*kharif*) and 150:50:50 kg ha⁻¹ (*rabi*) of nitrogen, phosphorus and potassium in the form of urea (46% N), single super phosphate (16% P₂O₅) and muriate of potash (60% K₂O) was applied to the rice in the experiment. Split application of N was done as per the treatment and an entire dose of phosphorus and potassium were applied basally before sowing. At active tillering stage, nitrogen split was applied after completion of weeding operation (as per the treatments).

3.3.5. Water management

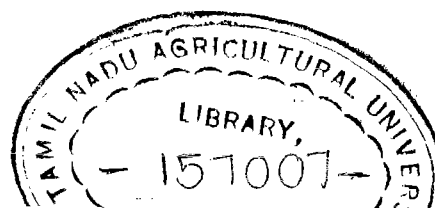
A thin film of water was maintained at the time of drum seeding. Subsequently for the next 8-10 days, irrigation and drainage of water were alternated to facilitate aeration and adequate moisture for germination of seeds and establishment of seedlings. Thereafter, the crop was irrigated to 5 cm depth at required interval when the water completely drained and the irrigation was withheld 10 days prior to harvest.

3.4. Calendar of operations

The details of cropping are as follows:

S.No.	Particulars	1998-1999		1999-2000	
		<i>Kharif</i>	<i>Rabi</i>	<i>Kharif</i>	<i>Rabi</i>
1	Date of sowing	22.06.1998	28.09.1998	07.06.1999	08.09.1999
2	Date of harvest	08.10.1998	29.01.1999	24.09.1999	04.01.2000
3	Field duration (days)	109	124	110	119

Some important cultural operations are given in Appendix III.



3.5. Sampling technique

Crop and weed samples were collected from the predesignated sample area on either side of the plot excluding two border rows. Periodically crop and weed samples were taken from an area of 0.5 m² (0.25 m² each at two locations) in each plot, randomly.

3.6. Studies on weeds

3.6.1. Weed density and dry weight

In each plot weeds were sampled at 20 DAS, tillering (35 DAS), flowering (75-85 DAS) and at physiological maturity stages of the crop from an area of 0.5 m², counted and dried to constant weights at 70°C in an oven and expressed as g m⁻².

3.6.2. Weed control efficiency

Weed control efficiency was worked out on the basis of weed dry matter recorded in each treatment at tillering, flowering and at maturity, using the formula suggested by Sankaran and Mani (1974).

$$WCE = \frac{DWC - DWT}{DWC} \times 100$$

where,
 WCE - weed control efficiency in percentage
 DWC - dry weight of weeds in unweeded control
 DWT - dry weight of weeds in weed control treatment.

3.6.3. Relative density

Relative density (RD) of grass, sedges and broad leaved weeds were calculated using the formula suggested by Kim and Moody (1983).

$$RD = \frac{\text{Absolute density of a given species}}{\text{Total absolute density of all species}} \times 100$$

3.6.4. Weed index

Weed index (WI) was worked out on the basis of the economic produce recorded in each treatment as outlined by Gill and Vijayakumar (1966).

$$WI = \frac{X - Y}{X} \times 100$$

where, WI - Weed index
 X - Yield from minimum weed competition plot
 Y - Yield from the treatment for which WI is to be worked out

3.7. Studies on rice

3.7.1. Growth parameters

3.7.1.1. Plant height

Plant height was measured from ground level to the tip of the longest leaf at tillering and flowering stages and upto tip of the panicle at maturity stage from five randomly selected plants and the average was worked out and expressed in cm.

3.7.1.2. Leaf area index (LAI)

Ten hills in sampling area were selected at random at flowering stages. The leaf area of all the leaves was measured using the leaf area meter (Licor-model 3100). Total number of tillers in 0.25 m² was counted and total leaf area of all the tillers in the above said area was computed. The LAI was worked out by dividing the total leaf area by the land area (0.25 m²).

3.7.1.3. Number of tillers

The number of tillers in 0.5 m² area counted at tillering, flowering and at maturity stages and expressed as number m⁻².

3.7.1.4. Dry matter production

Plant samples drawn at tillering, flowering and maturity stages from the sampling zone at two locations (0.25 m² each) in each plot were sun dried and then oven dried to a constant weight at 70°C and computed to kg ha⁻¹.

3.7.1.5. Crop growth rate (CGR)

Crop growth rates for the periods from 20DAS to tillering, tillering to flowering and flowering to physiological maturity were calculated using the mathematical formula given by Watson (1958) and expressed in g m⁻² day⁻¹.

$$\text{CGR} = \frac{W_2 - W_1}{G (t_2 - t_1)} \text{ g m}^{-2} \text{ day}^{-1}$$

where, W_1 and W_2 - Plant dry weight recorded at t_1 and t_2 days, respectively

$t_2 - t_1$ - time interval in days

G - ground area in which W_1 and W_2 were estimated

3.8. Chlorophyll meter's (SPAD 502) estimate of rice leaf N concentration

A chlorophyll meter [SPAD 502, Soil – Plant Analysis Division (SPAD) Minolta Camera Co Ltd., Osaka, Japan] was used to record SPAD values of intact leaves as described by Peng *et al.* (1993). The SPAD meter uses light sources and detectors to measure the light transmitted by a plant leaf at two different wave lengths, red (650 nm) and near infra-red (950 nm). The ratio of the light transmittance at these wave lengths, in

addition to the ratio determined with no sample is processed by the instrument to produce a reading shown on a digital display. This reading is in SPAD unit which are values defined by “Minolta” to indicate the relative amount of chlorophyll content in plant leaves (Minolta Camera Co. Ltd., 1989).

SPAD measurements were taken at active tillering and panicle initiation stages on the fully expanded third leaf from the top of the rice plant. Three SPAD meter readings were taken at points along the length of leaf lamina, one at the middle point and the other two about 3cm above and below. The fifteen such SPAD readings in a treatment were averaged to represent the mean SPAD value (Peng *et al.*, 1993).

3.9. Total chlorophyll estimation

The leaves used for SPAD readings were sampled for estimation of total chlorophyll. The total chlorophyll content of leaf was estimated following the procedure of Yoshida *et al.* (1971).

3.10. Yield and yield components

The paddy crop from predesignated area of 9 m² in each plot was harvested separately after cutting and removing the border and sample zone and yield and yield components were recorded.

3.10.1. Yield components

The number of panicles m⁻² were counted in the net plot area at maturity stage. Spikelet number, filled grains panicle⁻¹, 1000 grain weight of filled grains and per cent unfilled grains panicle⁻¹ were recorded from 10 randomly selected panicles. Filled grains and unfilled grains were separated by floatation technique using salt solution (Yoshida *et al.*, 1976).

3.10.2. Grain and straw yield

The grains from individual net plot were sun dried, cleaned and weighed. The results were expressed on 14 per cent moisture basis as suggested by Yoshida *et al.* (1976). Straw was sun dried for 4 days and weighed separately. Grain and straw yields were expressed in kg ha⁻¹.

3.10.3. Harvest index

From the estimated grain and straw yields, harvest index (HI) was calculated using the formula suggested by Donald and Humblin (1976).

$$\text{Harvest index} = \frac{\text{Grain yield (kg ha}^{-1}\text{)}}{\text{Grain yield} + \text{straw yield (kg ha}^{-1}\text{)}}$$

3.11. Observation on intercrop (*Sesbania rostrata*)

3.11.1. Population

The population stand was counted in the sample zone at two locations (0.25m² each) in each plot at the time of incorporation (35 DAS) and expressed as number of plants m⁻².

3.11.2. Plant height

Height of *Sesbania* was measured from ground level to growing point at 35 DAS (at the time of incorporation) in five randomly chosen plants and the mean height given in cm.

3.11.3. Nodules plant⁻¹

Root and shoot nodules plant⁻¹ were counted on 35 DAS in five plants chosen at random and the mean arrived at as total nodules plant⁻¹.

3.11.4. Biomass production

The total biomass of the plants chosen for population count in 0.5m² area in each plot were weighed to estimate fresh biomass and expressed in t ha⁻¹. The samples were air dried followed by oven drying at 70°C to attain constant weight and were used for estimation of N.

3.12. Chemical analysis

3.12.1. Crop and weed analysis

Crop and weed plant samples from individual plots sampled for dry matter estimation were ground into a fine powder in a Wiley mill. The ground sample was analysed for N by micro kjeldahl method (Humphries, 1956), P by triple acid digestion and colorimetric method (Jackson, 1973) and K by triple acid digestion and flame photometric method (Jackson, 1973). The nutrient content of the samples was assessed with the respective dry matter values and nutrient uptake was calculated and expressed in kg ha⁻¹. The N content of *Sesbania rostrata* was estimated at the time of incorporation and expressed in kg ha⁻¹.

3.12.2. Soil analysis

Composite pre-sowing soil samples were collected randomly from each experimental field and analysed for physico-chemical properties. Post – harvest soil samples drawn from each plot were air dried and gently beaten with a wooden mallet and sieved through 2 mm nylon sieve mesh. Then the soil samples were analysed for organic carbon and available N, P and K. The details of analytical methods employed for soil analysis are presented in Table 1.

3.13. Economic analysis

Cropwise economic evaluation was done by calculating the gross return, net return and cost of cultivation. The benefit: cost (B:C) ratio based on the present market rate was also worked out using the following formula:

$$B:C = \frac{\text{Gross income}}{\text{Cost of cultivation}}$$

3.14. Studies on energetics

Energy equivalent for direct and indirect inputs (like tillage, seeds, seeding, fertilizer, irrigation, pesticides, weeding, harvesting, cleaning and drying for rice production) were calculated for all the inputs used in the experimentation period and also for output obtained and thereby energy requirement for different treatments in wet seeded rice were calculated.

3.14.1. Energy use efficiency

Cultural energy (Mega Joules) used through various inputs in the cropping period was computed (Dazhong and Pimental, 1984) in different treatments and the energy use efficiency (energy ratio) was worked out as follows.

$$\text{Energy ratio} = \frac{\text{Energy output (MJ ha}^{-1}\text{)}}{\text{Energy input (MJ ha}^{-1}\text{)}}$$

3.14.2. Specific energy

Specific energy of the crop was calculated in terms of energy required to produce a kilogram of economic yield and expressed as MJ kg⁻¹.

The energy contents of various inputs are presented in Appendix VII (Mittal *et al.*, 1985).

3.15. Statistical analysis

All the data in the experiment were statistically analysed by Analysis of variance (F-test) as per the methods suggested by Gomez and Gomez (1984). Data on weed density showed high variation and hence they were subjected to log transformation $[\log (X+2)]$ as suggested by Bartlett (1947) and analysed statistically. Wherever statistical significance was observed, critical difference (CD) at 0.05 level of probability was worked out for comparison. Non significant comparison were indicated as NS.

Simple correlation and regression equation were worked out for various weed and crop parameters with the grain yield of rice to study the association between the variables.

EXPERIMENTAL RESULTS

CHAPTER IV

EXPERIMENTAL RESULTS

The results of the field experiments conducted at Tamil Nadu Agricultural University, Coimbatore during *kharif* and *rabi* seasons of 1998-99 and 1999-2000 to study the effect of integrated methods (manual, mechanical, cultural and chemical) of weed control and split application of N on growth and yield of drum seeder sown wet seeded (drum seeded) lowland rice are presented in this chapter. The relevant interaction effects of treatments are also presented.

In the presentation, the four crops of the study have been denoted by first, second, third and fourth crop for *kharif*'98, *rabi*'98-99, *kharif*'99 and *rabi*'99 – 2000, respectively.

4.1. Growth characters of intercrop (*Sesbania rostrata*) at the time of incorporation (35 DAS) (Table 2 and 3)

The three weed control treatments in the present investigation, where *S. rostrata* was included as intercrop (W_3 , W_4 and W_5) along with two N management practices (N_1 and N_2) were statistically analysed separately to study the growth characteristics of *S. rostrata*.

4.1.1. Plant (*S. rostrata*) population (m^{-2})

The population stand of *S. rostrata* either under split application of N or weed control methods did not vary significantly in all the seasons under study.

Table 2. Plant population m⁻², plant height (cm) and nodules plant⁻¹ of *Sesbania rostrata* as influenced by N management practices and weed control methods at the time of incorporation (35 DAS)

Treatments	Plant population m ⁻²				Plant height (cm)				Nodules plant ⁻¹			
	Kharif '98	Rabi' 98-99	Kharif 99	Rabi' 99-2000	Kharif 98	Rabi' 98-99	Kharif 98	Rabi' 99-2000	Kharif 98	Rabi' 98-99	Kharif 99	Rabi' 99-2000
N management												
N ₁ (four splits)	79.7	77.0	76.0	77.7	51.8	57.6	43.9	64.0	98.2	87.1	71.8	93.9
N ₂ (five splits)	79.4	78.1	74.3	79.0	54.3	56.8	49.2	66.6	90.5	83.4	63.1	91.2
SEd	2.29	0.75	1.35	0.55	0.38	1.91	0.52	0.77	2.28	1.28	1.36	1.17
CD (p=0.05)	NS	NS	NS	NS	0.86	NS	1.15	1.73	5.08	2.87	3.03	2.60
Weed control methods												
W ₃ (cultural + manual)	82.0	76.0	74.5	78.5	52.7	58.1	45.9	65.2	87.9	83.5	64.5	94.4
W ₄ (cultural + mechanical)	76.3	79.2	74.5	78.5	52.5	55.9	46.0	64.5	93.0	81.2	68.0	89.0
W ₅ (cultural + chemical + mechanical)	80.3	77.5	76.5	78.0	54.1	57.6	47.8	66.2	102.2	91.1	69.8	94.3
SEd	2.80	1.51	1.65	0.67	0.47	2.33	0.63	0.95	2.79	1.57	1.66	1.43
CD (p=0.05)	NS	NS	NS	NS	1.05	NS	1.41	NS	6.22	3.52	3.71	3.19

Table 3. Biomass ($t\ ha^{-1}$) and N uptake ($kg\ ha^{-1}$) of *Sesbania rostrata* as influenced by N management practices and weed control methods at the time of incorporation (35 DAS)

Treatment	Biomass $t\ ha^{-1}$ (wet basis)				N uptake ($kg\ ha^{-1}$)			
	Kharif'98	Rabi'98-99	Kharif'99	Rabi'99-2000	Kharif'98	Rabi'98-99	Kharif'99	Rabi'99-2000
N management								
N ₁ (four splits)	12.54	10.67	8.81	13.40	73.1	67.5	64.2	83.3
N ₂ (five splits)	13.01	11.21	9.10	13.96	72.8	72.2	65.5	82.9
SEd	0.23	0.08	0.16	0.14	1.68	2.16	1.19	0.76
CD ($p=0.05$)	NS	0.18	NS	NS	NS	NS	NS	NS
Weed control methods								
W ₃ (cultural + manual)	12.68	10.85	8.80	13.82	73.2	67.5	64.6	82.8
W ₄ (cultural + mechanical)	12.55	10.71	8.93	13.33	72.4	66.0	63.8	82.4
W ₅ (cultural + chemical + mechanical)	13.10	11.26	9.14	13.89	73.2	76.1	66.2	84.2
SEd	0.28	0.20	0.19	0.25	2.06	2.65	1.46	0.92
CD ($p=0.05$)	NS	0.45	NS	NS	NS	5.90	NS	NS

4.1.2. Plant height (cm)

Significantly taller plants were recorded with N_2 treatment compared to N_1 treatment in all the crops, except second crop, where both remained at par. With respect to weed control methods, significant differences in plant height of *S. rostrata* were observed only in the first and third cropping seasons where cultural + chemical + mechanical method (W_5) recorded maximum height and was significantly superior to other two treatments.

4.1.3. Nodules plant⁻¹

Higher number of nodules plant⁻¹ was observed in N_1 treatment (71.8 to 98.2) compared to N_2 (63.1 to 91.2) in all the cropping seasons.

The weed control treatment of cultural + chemical + mechanical methods (W_5) enhanced nodulation significantly as compared to the other two treatments in first, second and third crops with an exception in the fourth crop, where it remained at par with cultural + manual method (W_3).

4.1.4. Biomass

Significantly higher biomass of *Sesbania rostrata* was recorded with the N_2 treatment in the second crop. However, in the first, third and fourth crops, both the N management treatments did not show any significant variation in influencing this parameter of *S. rostrata*.

Among the weed control treatments, cultural + chemical + mechanical method (W_5) recorded maximum biomass (9.4 to 13.89 t ha⁻¹) and was on par with other two treatments in all the four crops except in second crop, where it was significantly superior over W_3 and W_4 treatments. Averaged across the seasons and crops, *S. rostrata* produced a biomass of 11.58 t ha⁻¹ on wet basis.

4.1.5. N contribution

The split application of N as well as weed control methods could not bring any significant influence in N contribution (N uptake) in all the crops except in the second crop, where the differences in N uptake was found to be significant with respect to weed control treatments. In the second crop, the highest N uptake was recorded in W_5 (76.1 kg ha⁻¹) and revealed significant superiority over W_3 and W_4 treatments. Numerically higher N contribution was also observed in W_5 treatment as compared to W_3 and W_4 in first, third and fourth crops.

4.2. Effect of treatments on weeds

4.2.1. Weed flora of the experimental field

The observations made on the common weeds of the experimental fields in the four seasons of study at flowering stage of the crop from unweeded control plot are presented in Table 4.

The major graminaceous weeds were *Echinochloa crus-galli* and *Echinochloa colona*. The common cyperaceae weeds observed were *Cyperus difformis*, *C. rotundus*, *C. iria* and *Fimbristylis miliaceae*. In the dicot weeds, *Eclipta alba* (Asteraceae),

Table 4. Weed flora of the experimental field

Botanical name	Common name	Life form	Family
Grasses			
<i>Agropyron repens</i> (L.) P. Beauv	Couch grass, twitch	P	Poaceae
<i>Echinochloa colona</i> (L.) Link	Jungle grass	A	Poaceae
<i>Echinochloa crus-galli</i> (L.) P. Beauv	Barn yard grass	A	Poaceae
<i>Paspalum distichum</i> (L.)	Knot grass	P	Poaceae
<i>Leptochloa chinensis</i> (L.) Ness	Red sprangletop	A	Poaceae
Sedges			
<i>Cyperus difformis</i> (L.)	Umbrella plant	A	Cyperaceae
<i>Cyperus rotundus</i> (L.)	Purple nut sedge	P	Cyperaceae
<i>Cyperus iria</i> (L.)	Rice flat sedge	A	Cyperaceae
<i>Fimbristylis miliacea</i> (L.) Vahl	Hoorah grass	A	Cyperaceae
Broad Leaves			
<i>Ammania baccifera</i> (L.)	Red stem	A	Lytharaceae
<i>Eclipta alba</i> (L.) Hassk.	False daisy	A	Asteraceae
<i>Ludwigia parviflora</i> Roxb.	Neer kirambu (Tamil)	A	Onagraceae
<i>Marsilea quadrifolia</i> (L.)	The water fern	P	Marsileaceae
<i>Monochoria vaginalis</i> (Burm.f.) Presl.	<i>Monochoria</i> Neer Tamarai (Tamil)	A	Pontederiaceae
<i>Phyllanthus niruri</i> (L.)	Niruri	A	Euphorbiaceae

A : Annual P : Perennial

Monochoria vaginalis (Pontederiaceae), *Ammania baccifera* (Lytharaceae) and *Ludwigia parviflora* (Onagraceae) were dominant.

The absolute density and relative density of individual weed species presented in Table 5 revealed that the total weed densities was considerably higher during *kharif* seasons (185.2 and 196.6 m⁻² in 1998 and 1999, respectively) than the *rabi* seasons of the respective years (163.4 and 145.5 m⁻²). In general, the broad leaved weeds were dominant in *kharif* season (38.5 to 40.1 per cent) over grasses (36.4 to 32.9 per cent) and sedges (25.1 to 27.0 per cent), while in the *rabi* season grasses dominated (36.2 to 38.2 per cent) sedges (34.0 to 34.6 per cent) and broad leaved weeds (27.8 to 29.2 per cent). Among the grasses, irrespective of the seasons *Echinochloa crus-galli* was the major weed species representing 21.1 to 23.8 per cent of the total weeds. Likewise, *C. difformis* (15.7 to 20.6 per cent) among sedges and *Eclipta alba* (11.0 to 16.4 per cent) among broad leaved weeds were the dominant species that infested the wet seeded rice field over the seasons.

4.2.2. Weed density and dry weight

4.2.2.1. Weeds at seedling stage of rice (20 DAS) (Table 6 to 9)

Application of N in four splits (N₁) characterized by no initial basal dose significantly reduced the density of monocot weeds compared to five splits (N₂) in all the cropping seasons, except *rabi*98-99 (Table 6).

Significant variations in the monocot weed density were observed for the weed control treatments. Pre emergence herbicide applied either alone (W₆) or along with cultural method (W₅) controlled monocot weeds effectively over all other treatments and

Table 5. Weed density (m⁻²) and relative density (per cent) of the experimental field

Weeds	Cropping seasons							
	Kharif' 98		Rabi '98'99		Kharif' 99		Rabi '99-2000	
	D	Rd	D	Rd	D	Rd	D	Rd
<i>Echinochloa crus-galli</i>	39.0	21.1	37.2	22.8	45.7	23.2	34.7	23.8
<i>Echinochloa colona</i>	15.0	8.1	12.5	7.6	15.6	7.9	13.1	9.0
Others	7.0	3.8	9.5	5.8	10.2	5.2	7.8	5.4
Total grasses	61.0	32.9	59.2	36.2	71.5	36.4	55.6	38.2
<i>Cyperus difformis</i>	29.0	15.7	33.6	20.6	35.7	18.2	25.4	17.5
<i>Cyperus rotundus</i>	10.0	5.4	6.0	3.7	7.5	3.8	8.0	5.5
<i>Cyperus iria</i>	5.0	2.8	11.5	7.0	4.2	2.1	13.0	8.9
Others	6.0	3.5	5.5	3.4	2.0	1.0	3.0	2.1
Total sedges	50.0	27.0	56.5	34.6	49.5	25.1	49.4	34.0
<i>Eclipta alba</i>	26.0	14.0	19.8	12.1	32.3	16.4	16.0	11.0
<i>Monochoria vaginalis</i>	18.0	9.7	8.8	5.4	16.7	8.5	7.0	4.8
<i>Ammania baccifera</i>	13.4	7.2	5.0	3.1	10.3	5.2	7.5	5.2
<i>Ludwigia parviflora</i>	7.3	3.9	6.1	3.7	3.4	1.7	2.0	1.4
<i>Marsilea quadrifolia</i>	5.3	2.9	4.0	2.4	6.0	3.1	5.0	3.4
Others	4.2	2.3	4.0	2.4	7.0	3.6	3.0	2.1
Total broad leaved	74.2	40.1	47.7	29.2	75.7	38.5	40.5	27.8
Total weeds	185.2	100.0	163.4	100.0	196.6	100.0	145.5	100.0

D : Density (m⁻²)

Rd : Relative density (per cent)

Table 6. Monocot weeds m^{-2} as influenced by N management practices and weed control methods at 20 DAS

Treatment	Monocot weeds m^{-2} at 20 DAS			
	<i>Kharif 98</i>	<i>Rabi 98-99</i>	<i>Kharif 99</i>	<i>Rabi 99-2000</i>
N management				
N_1 (four splits)	1.55 (38.4)	1.43 (29.0)	1.53 (37.4)	1.39 (25.7)
N_2 (five splits)	1.62 (46.1)	1.51 (34.6)	1.68 (50.1)	1.47 (31.8)
SEd	0.014	0.03	0.03	0.01
CD ($p=0.05$)	0.06	NS	0.13	0.04
Weed control methods				
W_1 (manual)	1.76 (56.5)	1.64 (42.7)	1.77 (57.5)	1.61 (39.2)
W_2 (mechanical + manual)	1.72 (52.0)	1.63 (41.9)	1.71 (50.8)	1.60 (38.5)
W_3 (cultural + manual)	1.72 (51.0)	1.57 (35.6)	1.72 (51.5)	1.51 (31.0)
W_4 (cultural + mechanical)	1.73 (53.5)	1.58 (36.6)	1.73 (53.5)	1.53 (32.4)
W_5 (cultural + chemical + mechanical)	1.21 (14.3)	1.11 (11.1)	1.23 (15.8)	1.10 (10.8)
W_6 (chemical + manual)	1.22 (15.0)	1.13 (11.8)	1.35 (22.0)	1.08 (10.4)
W_7 (unweeded control)	1.74 (53.7)	1.64 (43.2)	1.75 (55.3)	1.60 (39.0)
SEd	0.026	0.04	0.03	0.05
CD ($p=0.05$)	0.05	0.08	0.07	0.11

Figures in parenthesis indicate original values

both were statistically on par in all the seasons of the study. Though intercropping of *Sesbania* without application of herbicide (W_3 and W_4) recorded lower monocot weeds, the values of these treatments were comparable with unweeded control plots over seasons.

Substantially lower dicot weed population was recorded under four splits of N application (by skipping basal dose) in second and fourth crops over five equal splits of N (N_2). However, there was no significant variation between these two treatments with respect to dicot weed population in the *kharif* season crops (Table 7).

Larger variation of dicot weed density was observed for the weed control treatments. The lowest value ranging from 2.2 to 6.7 m^{-2} was recorded in cultural + chemical + mechanical weed control treatment (W_5) followed by chemical + manual (W_6) weed control treatment (2.3 to 8.2 m^{-2}) and both these two treatments were significantly superior to other treatments in restricting dicot weeds in both the years. Cultural + manual (W_3) and cultural + mechanical (W_4) methods controlled the dicot weeds significantly over unweeded control (W_7) as well as manual (W_1) and mechanical + manual (W_2) treatments and later these three treatments invariably registered the maximum number of dicot weeds in all the four crops.

Total weed density at 20 DAS was significantly lower under four splits of N over five splits in all the cropping seasons, except second crop (*rabi* 98-99). Four splits of N also caused substantial reduction of total weeds compared to five splits (N_2) in all the cropping seasons (Table 8).

Table 7. Dicot weeds m^{-2} as influenced by N management practices and weed control methods at 20 DAS

Treatment	Dicot weeds m^{-2} at 20 DAS			
	<i>Kharif 98</i>	<i>Rabi 98-99</i>	<i>Kharif 99</i>	<i>Rabi 99-2000</i>
N management				
N_1 (four splits)	1.10 (13.2)	1.08 (11.2)	1.09 (14.2)	1.06 (10.5)
N_2 (five splits)	1.22 (18.0)	1.25 (17.3)	1.16 (16.6)	1.19 (14.5)
SEd	0.03	0.02	0.02	0.02
CD ($p=0.05$)	NS	0.10	NS	0.10
Weed control methods				
W_1 (manual)	1.37 (22.2)	1.36 (21.3)	1.37 (22.2)	1.26 (16.5)
W_2 (mechanical + manual)	1.45 (27.0)	1.32 (19.8)	1.45 (26.4)	1.24 (15.6)
W_3 (cultural + manual)	1.07 (10.2)	1.15 (12.3)	1.24 (15.8)	1.13 (11.9)
W_4 (cultural + mechanical)	1.15 (12.9)	1.06 (10.3)	1.18 (13.3)	1.17 (13.1)
W_5 (cultural + chemical + mechanical)	0.73 (3.5)	0.93 (6.7)	0.60 (2.2)	0.81 (4.6)
W_6 (chemical + manual)	0.90 (6.1)	0.99 (8.2)	0.63 (2.3)	0.99 (7.8)
W_7 (unweeded control)	1.45 (27.4)	1.35 (20.8)	1.43 (25.7)	1.29 (18.2)
SEd	0.04	0.05	0.05	0.06
CD ($p=0.05$)	0.09	0.10	0.10	0.13

Figures in parenthesis indicate original values

Table 8. Total weeds m⁻² as influenced by interaction of N management practices and weed control methods at 20 DAS

Treatment	Total weeds m ⁻² at 20 DAS											
	Kharif'98			Rabi' 98 - 99			Kharif' 99			Rabi' 99 - 2000		
	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean
W ₁ (manual)	1.85 (70.0)	1.95 (87.3)	1.90 (78.7)	1.75 (54.4)	1.87 (73.5)	1.81 (64.0)	1.89 (75.9)	1.93 (83.5)	1.91 (79.7)	1.70 (49.0)	1.80 (62.3)	1.75 (55.7)
W ₂ (mechanical + manual)	1.86 (70.5)	1.95 (87.5)	1.91 (79.0)	1.74 (53.0)	1.85 (70.0)	1.79 (61.5)	1.90 (77.3)	1.94 (86.9)	1.92 (82.1)	1.69 (47.5)	1.79 (60.5)	1.74 (54.0)
W ₃ (cultural + manual)	1.75 (55.0)	1.84 (67.7)	1.79 (61.4)	1.65 (43.4)	1.73 (52.7)	1.69 (48.1)	1.84 (68.3)	1.89 (76.3)	1.86 (72.3)	1.59 (37.3)	1.70 (48.4)	1.64 (42.9)
W ₄ (cultural + mechanical)	1.78 (58.4)	1.88 (74.3)	1.83 (66.4)	1.66 (43.9)	1.70 (49.0)	1.68 (46.5)	1.80 (61.2)	1.87 (72.3)	1.83 (66.8)	1.62 (40.4)	1.72 (50.6)	1.67 (45.5)
W ₅ (cultural + chemical + mechanical)	1.25 (16.0)	1.33 (19.5)	1.29 (17.8)	1.24 (15.4)	1.34 (20.2)	1.29 (17.8)	1.15 (12.2)	1.41 (23.7)	1.28 (18.0)	1.20 (14.0)	1.27 (16.7)	1.23 (15.4)
W ₆ (chemical + manual)	1.32 (19.3)	1.39 (22.7)	1.35 (21.0)	1.23 (15.3)	1.42 (24.7)	1.32 (20.0)	1.27 (17.0)	1.52 (31.7)	1.39 (24.3)	1.23 (15.3)	1.36 (20.9)	1.29 (18.1)
W ₇ (unweeded control)	1.87 (72.3)	1.96 (89.8)	1.92 (81.1)	1.76 (55.7)	1.87 (72.7)	1.81 (64.2)	1.85 (69.7)	1.98 (93.3)	1.92 (81.5)	1.70 (49.1)	1.82 (65.2)	1.76 (57.2)
Mean	1.66 (51.6)	1.75 (64.1)		1.57 (40.2)	1.68 (51.8)		1.67 (54.5)	1.79 (66.8)		1.53 (36.1)	1.63 (46.4)	

	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)
N	0.01	0.04	0.03	NS	0.02	0.10	0.01	0.06
W	0.06	0.12	0.07	0.14	0.05	0.11	0.04	0.09
N at W	0.082	0.17	0.089	0.19	0.074	0.17	0.059	0.13
W at N	0.082	0.17	0.096	0.20	0.075	0.16	0.062	0.13

Figures in parenthesis indicate original values

Among the weed control treatments, cultural + chemical + mechanical (W_5) and chemical + manual (W_6) treatments recorded similar and lower density of total weeds compared to other treatments in all the four crops. Lowest total weed density was recorded under W_5 (15.4 to 18.0 m^{-2}) in both the years. Cultural + manual (W_3) and cultural + mechanical (W_4) methods adopted plots also recorded lower total weed density over control, and were statistically on par with W_5 in all the seasons.

The interaction between split application of N and weed control methods on total weed density was significant in both the years. Combination of either four or five splits of N with cultural + chemical + mechanical (W_5) and chemical + manual (W_6) methods of weed control had total weed density statistically on par and significantly superior to other combinations. The cultural + manual and cultural + mechanical methods under four splits of N were also effective in reducing the total weed population over the combination of five splits of N with unweeded control plot in all the crops, except in third crop, where cultural + manual under four splits of N was on par with unweeded control with five splits of N (Table 8).

The time of application of N had significant influence on dry weight of weeds at 20 DAS. Application of N in four splits significantly reduced the dry weight of weeds over five splits of N in all the four crops (Table 9).

Among the weed control methods, chemical + manual (W_6) and cultural + chemical + mechanical (W_5) treatments were statistically on par and significantly superior over rest of the treatments in reducing the weed dry weight in all the four crops except first crop where W_5 treatment recorded significantly lower weed dry weight over W_6 treatment.

Table 9. Total weed dry weight (g m^{-2}) as influenced by interaction of N management practices and weed control methods at 20 DAS

Treatment	Total weed dry weight g m^{-2} at 20 DAS											
	Kharif'98			Rabi' 98 - 99			Kharif' 99			Rabi' 99 - 2000		
	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean
W ₁ (manual)	5.52	6.40	5.96	2.92	3.11	3.02	6.03	6.80	6.42	2.53	3.37	2.95
W ₂ (mechanical + manual)	5.74	7.02	6.38	3.00	3.03	3.02	7.16	7.96	7.56	2.92	3.46	3.19
W ₃ (cultural + manual)	4.86	6.43	5.65	2.14	3.47	2.81	5.66	6.56	6.11	2.11	3.09	2.60
W ₄ (cultural + mechanical)	4.90	5.80	5.36	2.73	2.77	2.75	5.91	6.80	6.36	1.98	2.88	2.43
W ₅ (cultural + chemical + mechanical)	2.78	3.56	3.17	0.82	1.02	0.92	2.08	2.02	2.05	0.97	1.25	1.11
W ₆ (chemical + manual)	3.40	4.44	3.92	1.01	1.06	1.04	2.42	2.96	2.69	1.05	2.33	1.69
W ₇ (unweeded control)	5.81	6.55	6.18	2.65	3.70	3.18	5.80	8.40	7.10	2.91	3.75	3.33
Mean	4.72	5.74		2.18	2.59		5.01	5.93		2.07	2.87	
N W N at W W at N	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)
	0.02	0.09	0.04	0.19	0.14	0.59	0.11	0.47				
	0.10	0.20	0.14	0.29	0.36	0.75	0.29	0.60				
	0.13	0.27	0.187	0.41	0.50	1.11	0.40	0.89				
	0.14	0.28	0.197	0.41	0.52	1.07	0.41	0.85				

Significant interaction between split application of N and weed control methods on total weed dry weight at 20 DAS was observed in both the years. Integration of pre emergence herbicide application with *Sesbania* intercropping and the N applied in four splits (N_1W_5) recorded the lowest weed biomass in the first (2.78 g m^{-2}), second (0.82 g m^{-2}) and fourth (0.97 g m^{-2}) crops. In the third crop, five splits of N combined with cultural + chemical + mechanical (N_2W_5) method of weed control registered lowest weed dry weight (2.02 g m^{-2}).

4.2.2.2. Weeds at tillering stage of rice (Table 10 to 13)

The timing of N application at different stages of the crop had significant influence on weed density and their growth in all the four crops at tillering stage. The mean number of monocot weeds was significantly lower under four splits of N (33.5 to 55.7 m^{-2}) than five equal splits in all the seasons, except in the third crop, where the monocot weeds under both the N management practices were similar (Table 10).

The unweeded control plots invariably recorded the maximum monocot weed population in all the crops. Among the weed control treatments, both manual (W_1) and cultural + chemical + mechanical (W_5) treatments were equally effective in controlling monocot weeds in first, second and fourth crops, while in third crop W_5 treatment was most effective.

The different N management practices at tillering stage showed similar effect on dicot weed density as that of monocot weeds. Significantly more dicot weeds were recorded under four splits of N over five splits application in all the crops, except in *kharif*99.

Table 10. Monocot weeds m^{-2} as influenced by N management practices and weed control methods at tillering stage of the crop

Treatment	Monocot weeds m^{-2} at tillering stage			
	<i>Kharif 98</i>	<i>Rabi 98-99</i>	<i>Kharif 99</i>	<i>Rabi 99-2000</i>
N management				
N_1 (four splits)	1.62 (44.1)	1.55 (40.2)	1.73 (55.7)	1.49 (33.5)
N_2 (five splits)	1.67 (51.2)	1.63 (45.8)	1.78 (63.3)	1.58 (41.3)
SEd	0.001	0.006	0.03	0.002
CD ($p=0.05$)	0.01	0.03	NS	0.01
Weed control methods				
W_1 (manual)	1.40 (23.8)	1.35 (20.9)	1.67 (45.3)	1.30 (17.8)
W_2 (mechanical + manual)	1.63 (41.4)	1.50 (30.5)	1.75 (55.1)	1.49 (29.5)
W_3 (cultural + manual)	1.77 (58.4)	1.72 (51.9)	1.85 (70.5)	1.65 (44.3)
W_4 (cultural + mechanical)	1.81 (63.2)	1.78 (58.6)	1.87 (73.8)	1.65 (43.2)
W_5 (cultural + chemical + mechanical)	1.44 (26.0)	1.37 (22.0)	1.54 (33.0)	1.33 (19.8)
W_6 (chemical + manual)	1.52 (31.7)	1.44 (27.5)	1.62 (40.4)	1.43 (24.8)
W_7 (unweeded control)	1.95 (89.0)	1.95 (89.9)	2.00 (98.7)	1.92 (82.6)
SEd	0.026	0.026	0.024	0.031
CD ($p=0.05$)	0.06	0.06	0.05	0.07

Figures in parenthesis indicate original values

Among the weed control treatments, lowest dicot weed density was recorded under cultural + chemical + mechanical (W_5) (8.2 to 14.8 m^{-2}) method in all the four crops followed by manual (W_1) (first crop) and chemical + manual method (second, third and fourth crops). However, the influence of W_5 treatment on dicot weeds was comparable with W_1 in the first crop and W_6 in the second crop (Table 11).

Split application of N had significant influence on total weed population at tillering stage in all the four seasons. Four splits of N recorded significantly lower total weeds over application of N in five splits (Table 12).

Large variations in the total weed density was observed among weed control methods. Invariably, total weed density was highest in unweeded plots in all the four crops. The lowest values were obtained in all the crops in cultural + chemical + mechanical method (W_5) except in the first crop, where manual method (W_1) was the best. Cultural + manual (W_3) and cultural + mechanical (W_4) methods were comparatively less effective over other treatments, but significantly better than weedy check plot in reducing the monocot and dicot weeds as well as the total weed density. The interaction effect of treatments on weed density at this stage of the crop was not significant in all the four crops.

The data on dry weight of weeds at tillering stage presented in Table 13 clearly indicated that four splits of N did not favour weed growth compared to five splits in all the four crops. Manual method (W_1) of weed control recorded significantly lower dry weight of weeds followed by manual + mechanical (W_2) and cultural + chemical + mechanical (W_5) methods in all the seasons. Maximum dry weight of weeds was observed under unweeded plots (28.5 to 51.0 g m^{-2}) over seasons (Table 13).

Table 11. Dicot weeds m^{-2} as influenced by N management practices and weed control methods at tillering stage of the crop

Treatment	Dicot weeds m^{-2} at tillering stage			
	<i>Kharif 98</i>	<i>Rabi 98-99</i>	<i>Kharif 99</i>	<i>Rabi 99-2000</i>
N management				
N_1 (four splits)	1.32 (22.2)	1.20 (16.0)	1.28 (20.6)	1.21 (15.6)
N_2 (five splits)	1.41 (27.1)	1.31 (20.9)	1.30 (22.2)	1.30 (19.5)
SEd	0.004	0.006	0.01	0.002
CD ($p=0.05$)	0.02	0.03	NS	0.01
Weed control methods				
W_1 (manual)	1.24 (15.9)	1.20 (14.3)	1.32 (19.4)	1.22 (14.7)
W_2 (mechanical + manual)	1.32 (19.3)	1.31 (18.9)	1.30 (18.5)	1.27 (16.7)
W_3 (cultural + manual)	1.34 (20.2)	1.19 (14.2)	1.22 (14.9)	1.34 (20.2)
W_4 (cultural + mechanical)	1.31 (18.8)	1.24 (15.8)	1.24 (15.8)	1.32 (19.0)
W_5 (cultural + chemical + mechanical)	1.22 (14.8)	1.06 (9.6)	1.03 (8.8)	1.01 (8.2)
W_6 ((chemical + manual)	1.30 (18.5)	1.12 (11.4)	1.14 (12.2)	1.08 (10.5)
W_7 (unweeded control)	1.82 (65.2)	1.66 (45.1)	1.79 (60.5)	1.55 (33.9)
SEd	0.024	0.033	0.040	0.030
CD ($p=0.05$)	0.05	0.07	0.08	0.06

Figures in parenthesis indicate original values

Table 12. Total weeds m⁻² as influenced by interaction of N management practices and weed control methods at tillering stage of the crop

Treatment	Total weeds m ⁻² at tillering stage											
	Kharif 98			Rabi' 98 - 99			Kharif 99			Rabi' 99 - 2000		
	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean
W ₁ (manual)	1.58 (36.8)	1.64 (42.5)	1.61 (39.7)	1.52 (31.7)	1.60 (38.6)	1.56 (35.2)	1.80 (61.3)	1.84 (68.0)	1.82 (64.7)	1.51 (30.3)	1.56 (34.6)	1.54 (32.5)
W ₂ (mechanical + manual)	1.77 (57.4)	1.81 (63.9)	1.79 (60.7)	1.67 (44.7)	1.74 (54.0)	1.70 (49.4)	1.82 (64.0)	1.92 (82.7)	1.87 (73.4)	1.65 (43.3)	1.71 (49.3)	1.68 (46.3)
W ₃ (cultural + manual)	1.87 (72.5)	1.93 (84.6)	1.90 (78.6)	1.76 (56.7)	1.88 (75.3)	1.82 (66.0)	1.91 (80.7)	1.96 (90.1)	1.93 (85.4)	1.73 (52.4)	1.89 (76.6)	1.81 (64.5)
W ₄ (cultural + mechanical)	1.89 (76.1)	1.95 (87.9)	1.92 (82.0)	1.87 (73.0)	1.89 (75.7)	1.88 (74.4)	1.94 (85.6)	1.98 (93.5)	1.96 (89.6)	1.74 (54.0)	1.86 (70.4)	1.80 (62.2)
W ₅ (cultural + chemical + mechanical)	1.59 (37.2)	1.66 (44.3)	1.62 (40.8)	1.44 (26.7)	1.59 (37.3)	1.52 (31.7)	1.62 (40.0)	1.65 (43.5)	1.63 (41.8)	1.42 (24.4)	1.52 (31.5)	1.47 (28.0)
W ₆ (chemical + manual)	1.66 (44.5)	1.76 (55.8)	1.71 (50.2)	1.54 (33.3)	1.66 (44.5)	1.60 (38.9)	1.73 (52.4)	1.73 (52.7)	1.73 (52.3)	1.51 (31.0)	1.61 (39.5)	1.56 (35.3)
W ₇ (unweeded control)	2.15 (139.3)	2.23 (169.1)	2.19 (154.2)	2.11 (127.3)	2.16 (142.5)	2.13 (134.9)	2.18 (150.3)	2.23 (168.7)	2.21 (159.2)	2.04 (108.8)	2.10 (124.0)	2.07 (116.4)
Mean	1.78 (66.3)	1.85 (78.3)		1.70 (56.1)	1.79 (66.8)		1.85 (76.3)	1.90 (85.6)		1.66 (49.2)	1.75 (60.8)	

	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)
N	0.01	0.05	0.01	0.08	0.01	0.04	0.006	0.03
W	0.034	0.07	0.037	0.08	0.028	0.06	0.029	0.06
N at W	0.046	NS	0.052	NS	0.038	NS	0.039	NS
W at N	0.049	NS	0.053	NS	0.040	NS	0.042	NS

Figures in parenthesis indicate original values

Table 13. Total weed dry weight (g m^{-2}) as influenced by interaction of N management practices and weed control methods at tillering stage of the crop

Total weed dry weight (g m ⁻²) at tillering stage												
Treatment	Kharif'98			Rabi' 98 - 99			Kharif' 99			Rabi' 99 - 2000		
	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean
W ₁ (manual)	4.6	6.5	5.5	2.9	3.4	3.1	10.2	14.4	12.3	3.1	3.7	3.4
W ₂ (mechanical + manual)	9.8	13.8	11.8	9.6	8.7	9.2	16.6	19.5	18.0	7.4	10.1	8.7
W ₃ (cultural + manual)	17.1	21.1	19.1	18.5	20.2	19.3	28.1	33.9	31.0	14.8	16.2	16.1
W ₄ (cultural + mechanical)	19.3	21.3	20.3	16.3	19.1	17.7	30.4	27.0	28.7	15.1	17.1	17.8
W ₅ (cultural + chemical + mechanical)	13.5	18.8	16.1	15.1	13.3	14.2	19.3	21.3	20.3	12.5	13.4	13.0
W ₆ (chemical + manual)	19.4	18.0	18.7	15.2	19.0	17.2	26.7	30.1	28.4	15.7	19.9	15.5
W ₇ (unweeded control)	48.0	50.6	49.3	29.3	35.3	32.3	49.0	52.9	51.0	26.3	30.7	28.5
Mean	18.8	21.4		15.3	17.0		25.8	28.5		13.6	15.9	
	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)
N	0.32	1.40	0.22	0.95	0.51	2.20	0.42	1.81				
W	1.12	2.32	0.99	2.05	1.15	2.37	1.12	2.32				
N at W	1.50	3.25	1.32	2.80	1.59	3.64	1.55	3.42				
W at N	1.59	3.28	1.40	2.90	1.62	3.35	1.59	3.28				

The interaction effect between nitrogen timing and weed control treatments on total weed weight at tillering stage was significant in all the four crops (Table 13). In general, the lowest weed dry weight was recorded in the manually weeded crop with four splits of N. Significantly lower weed dry weight was observed in W₂, W₃ and W₅ (first crop), W₆ and W₇ in both second and fourth crops and W₁, W₃ and W₇ (third crop) under four splits of N as compared to five splits of N.

4.2.2.3. Weeds at flowering stage of rice (Table 14 to 17)

Number of split application of N did not exert any significant influence on monocot, dicot and total weed density at flowering stage during any cropping season.

Large variations in the monocot weed density was observed under different weed control methods (Table 14). The lowest values were obtained under cultural + manual (W₃) treatment over seasons and was on par with chemical + manual (W₆) (first crop) and manual method (W₁) (third and fourth crops). In general, pre emergence herbicide application followed by one hand weeding (W₆) controlled the monocot weeds comparable with hand weeding twice (W₁), but cultural + mechanical method (W₄) was not much effective to check the monocots. The unweeded control plot invariably had the maximum number of monocot weeds (105.0 to 120.9 m⁻²) in all the cropping seasons.

Similar to the effect on monocot weeds, adoption of cultural + manual method (W₃) was most effective in restricting the dicot weed population and recorded the lowest dicot weed density in all the four crops. However, manual (W₁), mechanical + manual (W₂), cultural + chemical + mechanical (W₅) and chemical + manual (W₆) methods were also comparable in controlling the dicot weeds in all the four crops (Table 15).

Table 14. Monocot weeds m^{-2} as influenced by N management practices and weed control methods at flowering stage of the crop

Treatment	Monocot weeds m^{-2} at flowering stage			
	<i>Kharif</i> 98	<i>Rabi</i> 98-99	<i>Kharif</i> 99	<i>Rabi</i> 99-2000
N management				
N_1 (four splits)	1.56 (42.0)	1.50 (38.6)	1.60 (45.3)	1.47 (35.6)
N_2 (five splits)	1.62 (47.4)	1.58 (45.6)	1.67 (52.3)	1.54 (40.8)
SEd	0.02	0.03	0.02	0.03
CD ($p=0.05$)	NS	NS	NS	NS
Weed control methods				
W_1 (manual)	1.48 (28.5)	1.34 (20.8)	1.47 (28.7)	1.29 (17.5)
W_2 (mechanical + manual)	1.55 (34.4)	1.48 (28.4)	1.53 (31.9)	1.41 (24.0)
W_3 (cultural + manual)	1.33 (19.7)	1.21 (14.5)	1.43 (25.3)	1.23 (15.2)
W_4 (cultural + mechanical)	1.80 (62.7)	1.76 (56.7)	1.79 (60.2)	1.72 (50.4)
W_5 (cultural + chemical + mechanical)	1.50 (30.5)	1.57 (35.7)	1.62 (40.6)	1.55 (33.8)
W_6 (chemical + manual)	1.44 (26.4)	1.39 (22.9)	1.55 (33.8)	1.37 (21.7)
W_7 (unweeded control)	2.04 (111.0)	2.06 (115.7)	2.08 (120.9)	2.02 (105.0)
SEd	0.06	0.06	0.054	0.07
CD ($p=0.05$)	0.12	0.12	0.11	0.15

Figures in parenthesis indicate original values

Table 15. Dicot weeds m^{-2} as influenced by N management practices and weed control methods at flowering stage of the crop

Treatment	Dicot weeds m^{-2} at flowering stage			
	<i>Kharif</i> 98	<i>Rabi</i> 98-99	<i>Kharif</i> 99	<i>Rabi</i> 99-2000
N management				
N_1 (four splits)	1.39 (26.4)	1.26 (19.1)	1.43 (29.4)	1.21 (16.2)
N_2 (five splits)	1.46 (31.6)	1.29 (20.9)	1.51 (34.8)	1.27 (18.6)
SEd	0.02	0.02	0.03	0.04
CD ($p=0.05$)	NS	NS	NS	NS
Weed control methods				
W_1 (manual)	1.31 (18.7)	1.21 (14.8)	1.37 (21.7)	1.22 (14.6)
W_2 (mechanical + manual)	1.32 (19.6)	1.21 (15.1)	1.45 (27.1)	1.14 (12.0)
W_3 (cultural + manual)	1.20 (14.0)	0.94 (6.9)	1.25 (16.4)	1.06 (9.4)
W_4 (cultural + mechanical)	1.52 (31.3)	1.33 (20.0)	1.61 (39.3)	1.33 (19.5)
W_5 (cultural + chemical + mechanical)	1.39 (22.8)	1.31 (18.7)	1.43 (25.8)	1.16 (12.6)
W_6 (chemical + manual)	1.37 (22.4)	1.27 (17.2)	1.31 (18.8)	1.19 (13.5)
W_7 (unweeded control)	1.88 (74.2)	1.69 (47.7)	1.89 (75.7)	1.63 (40.5)
SEd	0.04	0.07	0.07	0.05
CD ($p=0.05$)	0.09	0.14	0.14	0.10

Figures in parenthesis indicate original values

On an average the effect of weed control treatments on total weed density (Table 16) was similar to their effect on the monocot and dicot weeds control over seasons.

The interaction effect between split application of nitrogen and weed control methods was significant in all the crops. Irrespective of application of four or five splits of N, the cultural + manual method (W_3) of weed control recorded lowest weed density (Table 16). In first and second crops, under four splits of N, cultural + manual method was more effective followed by manual (W_1) and chemical + manual (W_6) methods over rest of the treatment combinations in reducing the total weed density. However, combinations of N_1W_3 and N_1W_1 were comparable (third crop) which in turn were also equally effective with N_1W_2 and N_1W_6 (fourth crop). Under five equal splits of nitrogen (N_2), manual, manual + mechanical, cultural + chemical + mechanical and chemical + manual methods were equally effective in reducing the total weed density and these combinations were significantly superior over cultural + mechanical and unweeded control in all the four crops.

At flowering stage also, the dry weight of weeds differed significantly with split application of N and weed control methods. Four splits of N significantly decreased the weed dry weight over five splits of N in all the four crops (Table 17).

Among the weed control treatments, cultural + manual method (W_3) controlled the weeds effectively as evident from the lowest dry weight of weeds recorded with this treatment and was on par with manual method which in turn was comparable with

Table 16. Total weeds m⁻² as influenced by interaction of N management practices and weed control methods at flowering stage of the crop

Total weeds m ⁻² at flowering stage												
Treatment	Kharif 98			Rabi 98 - 99			Kharif 99			Rabi 99 - 2000		
	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean
W ₁ (manual)	1.65 (43.4)	1.72 (50.9)	1.68 (47.2)	1.53 (32.0)	1.62 (40.0)	1.57 (36.1)	1.66 (44.4)	1.76 (56.4)	1.71 (50.4)	1.49 (28.9)	1.57 (35.3)	1.53 (32.1)
W ₂ (mechanical + manual)	1.72 (50.4)	1.77 (57.4)	1.74 (53.9)	1.60 (38.0)	1.71 (48.7)	1.65 (43.5)	1.76 (56.4)	1.80 (61.5)	1.78 (59.0)	1.55 (34.0)	1.60 (37.8)	1.57 (35.9)
W ₃ (cultural + manual)	1.51 (30.7)	1.58 (36.7)	1.54 (33.7)	1.36 (20.7)	1.38 (22.0)	1.36 (21.4)	1.57 (35.7)	1.69 (47.6)	1.63 (41.7)	1.37 (21.7)	1.46 (27.4)	1.41 (24.6)
W ₄ (cultural + mechanical)	1.97 (91.4)	1.99 (96.5)	1.98 (93.9)	1.89 (75.3)	1.90 (78.1)	1.89 (76.7)	1.97 (91.5)	2.04 (107.4)	2.00 (99.5)	1.83 (66.7)	1.87 (73.0)	1.85 (69.9)
W ₅ (cultural + chemical + mechanical)	1.70 (48.8)	1.77 (57.8)	1.73 (53.3)	1.72 (50.4)	1.78 (58.4)	1.74 (54.4)	1.78 (58.3)	1.88 (74.4)	1.83 (66.4)	1.64 (42.4)	1.71 (50.2)	1.67 (46.3)
W ₆ (chemical + manual)	1.65 (42.6)	1.75 (54.8)	1.70 (48.7)	1.59 (37.3)	1.65 (42.7)	1.62 (40.0)	1.70 (48.6)	1.76 (56.6)	1.73 (52.6)	1.54 (32.3)	1.60 (38.0)	1.56 (35.1)
W ₇ (unweeded control)	2.24 (171.5)	2.30 (198.9)	2.27 (185.2)	2.18 (150.7)	2.25 (176.0)	2.21 (163.4)	2.27 (187.8)	2.31 (205.4)	2.29 (196.6)	2.14 (136.8)	2.19 (154.2)	2.17 (145.5)
Mean	1.77 (68.4)	1.84 (79.0)		1.69 (57.9)	1.75 (66.6)		1.81 (74.7)	1.89 (87.0)		1.65 (51.11)	1.71 (59.7)	
	SEd	CD (p = 0.05)		SEd	CD (p = 0.05)		SEd	CD (p = 0.05)		SEd	CD (p = 0.05)	
	0.02	NS		0.03	NS		0.02	NS		0.02	NS	
N												
W	0.03	0.07		0.06	0.12		0.06	0.12		0.07	0.14	
N at W	0.049	0.12		0.083	0.20		0.08	0.18		0.091	0.20	
W at N	0.048	0.10		0.082	0.17		0.082	0.17		0.096	0.20	

Table 17. Total weed dry weight (g m^{-2}) as influenced by interaction of N management practices and weed control methods at flowering stage of the crop

Treatment	Total weed dry weight (gm ²) at flowering stage											
	Kharif 98			Rabi' 98 - 99			Kharif 99			Rabi' 99 - 2000		
	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean
W ₁ (manual)	33.3	36.7	35.0	18.2	20.5	19.4	38.6	43.0	40.8	15.7	22.2	18.9
W ₂ (mechanical + manual)	39.1	38.3	38.7	18.3	22.7	20.5	40.6	49.2	44.9	18.7	22.1	20.4
W ₃ (cultural + manual)	30.2	34.6	32.4	15.7	16.3	16.0	37.5	36.0	36.8	15.3	16.0	15.7
W ₄ (cultural + mechanical)	60.5	79.2	69.8	42.3	47.0	44.7	76.2	85.2	80.7	39.5	46.4	42.9
W ₅ (cultural + chemical + mechanical)	37.3	42.7	40.0	22.3	23.3	22.8	43.4	51.5	47.5	20.4	24.6	22.5
W ₆ (chemical + manual)	35.0	37.6	36.3	20.4	23.1	21.7	41.8	45.1	43.4	18.2	21.6	19.9
W ₇ (unweeded control)	124.0	146.0	135.0	96.0	101.0	98.5	138.2	151.4	144.8	83.5	103.7	93.6
Mean	51.3	59.3		33.3	36.3		59.5	65.9		30.2	36.7	
	SED	CD (p = 0.05)	SED	CD (p = 0.05)	SED	CD (p = 0.05)	SED	CD (p = 0.05)	SED	CD (p = 0.05)	SED	CD (p = 0.05)
N	0.65	2.78	0.34	1.46	0.35	1.52	0.50	2.15	0.50	2.15	0.50	2.15
W	2.47	5.09	1.93	3.98	1.60	3.30	1.79	3.69	1.79	3.69	1.79	3.69
N at W	3.29	7.08	2.57	5.41	2.12	4.51	2.39	4.83	2.39	4.83	2.39	4.83
W at N	3.49	7.20	2.73	5.68	2.26	4.67	2.53	5.22	2.53	5.22	2.53	5.22

mechanical + manual (W_2), cultural + chemical + mechanical (W_5) and chemical + manual (W_6) methods of weed control in all the crops, except in third crop (*kharif* 99). However, in the third crop W_3 was significantly superior over rest of the treatments in reducing weed dry weight. The dry weight of weeds recorded under unweeded control and cultural + mechanical (W_4) method was significantly more than the other weed control methods.

Split application of N and weed control methods interacted significantly in influencing the weed growth over seasons (Table 17). Across the seasons, the weed dry weight was more in weedy check plots irrespective of split application of N. Under four splits of N, manual (W_1), cultural + manual (W_3) and chemical + manual (W_6) treatments were equally effective to check the weed growth in all the four crops and were significantly superior to cultural + mechanical (W_4) and unweeded (W_7) plots. However, under five equal splits of N in combination with cultural + manual (N_2W_3) method proved to be more effective (third and fourth crops) and comparable with manual method (N_2W_1) (first and second crops) in restricting the weed biomass at flowering stage of the crop.

4.2.2.4. Weeds at maturity stage of the rice (Table 18 to 21)

Mean number of monocot weeds present at maturity stage (Table 18) under different nitrogen timing (split application) did not vary significantly in all four crops.

The effect of weed control methods on monocot weeds observed at flowering stage continued to exist until harvest in all the crops. Intercropping of *Sesbania* and its manual incorporation combined with weeding on 35 DAS (W_3) proved to be superior in controlling the monocot weeds and recorded the lowest population at maturity (10.8 to 18.7 m^{-2}) in first to fourth crops and was on par with manual method of two hand

Table 18. Monocot weeds m^{-2} as influenced by N management practices and weed control methods at maturity stage of the crop

Treatment	Monocot weeds m^{-2} at maturity stage			
	<i>Kharif 98</i>	<i>Rabi 98-99</i>	<i>Kharif 99</i>	<i>Rabi 99-2000</i>
N management				
N_1 (four splits)	1.46 (31.8)	1.43 (29.7)	1.50 (35.1)	1.37 (26.5)
N_2 (five splits)	1.52 (35.7)	1.49 (34.2)	1.56 (40.6)	1.47 (31.9)
SEd	0.02	0.02	0.03	0.03
CD ($p=0.05$)	NS	NS	NS	NS
Weed control methods				
W_1 (manual)	1.36 (21.5)	1.34 (20.5)	1.43 (25.7)	1.31 (18.8)
W_2 (mechanical + manual)	1.42 (24.5)	1.42 (24.7)	1.45 (26.7)	1.32 (19.5)
W_3 (cultural + manual)	1.29 (18.1)	1.24 (15.7)	1.30 (18.7)	1.10 (10.8)
W_4 (cultural + mechanical)	1.64 (42.3)	1.56 (35.2)	1.67 (46.3)	1.54 (33.3)
W_5 (cultural + chemical + mechanical)	1.42 (25.7)	1.43 (25.4)	1.47 (28.1)	1.44 (26.7)
W_6 (chemical + manual)	1.38 (22.5)	1.36 (21.7)	1.42 (24.4)	1.34 (20.7)
W_7 (unweeded control)	1.92 (82.5)	1.91 (80.7)	1.98 (95.3)	1.88 (74.9)
SEd	0.03	0.04	0.05	0.04
CD ($p=0.05$)	0.07	0.09	0.01	0.09

Figures in parenthesis indicate original values

weedings (first crop). Manual (W_1), manual + mechanical (W_2) and chemical + manual (W_6) methods were equally effective in suppressing the monocot weeds and significantly superior over cultural + mechanical (W_4) and unweeded control (W_7) treatments over seasons. Highest density of monocot weeds was recorded in unweeded plot in all the four crops.

The dicot weed density also did not vary significantly under different split application of N (Table 19) at maturity stage of all the four crops.

Among the weed control methods, though cultural + manual method (W_3) was most effective in checking dicot weeds, it was comparable with manual method (W_1) in all the seasons, except in third crop where, chemical + manual (W_6) method registered the lowest dicot weed density and was comparable with W_3 . Performance of cultural + chemical + mechanical (W_5) and mechanical + manual (W_2) treatments were also comparable with W_3 (first and third crops) at maturity stage of the crop.

Though split application of N did not influence the total weed density at maturity stage of the crops (Table 20), in general, the total weed density was comparatively lower with four splits than five splits of N application.

Among the weed control treatments, cultural + manual (W_3) method was the most effective by registering lowest total weed population (28.8, 25.8, 35.5 and 21.5, in first to fourth crops, respectively) and was comparable with mechanical + manual (W_2), cultural + chemical + mechanical (W_5) and chemical + manual (W_6) methods in third crop. Unweeded control treatment invariably recorded the highest total weed population (111.2 to 153.0 m^{-2}) over seasons.

Table 19. Dicot weeds m^{-2} as influenced by N management practices and weed control methods at maturity stage of the crop

Treatment	Dicot weeds m^{-2} at maturity stage			
	<i>Kharif 98</i>	<i>Rabi 98-99</i>	<i>Kharif 99</i>	<i>Rabi 99-2000</i>
N management				
N_1 (four splits)	1.27 (19.9)	1.28 (19.0)	1.37 (24.2)	1.24 (17.4)
N_2 (five splits)	1.32 (22.7)	1.33 (21.5)	1.46 (29.6)	1.31 (20.5)
SEd	0.01	0.02	0.05	0.03
CD ($p=0.05$)	NS	NS	NS	NS
Weed control methods				
W_1 (manual)	1.17 (13.2)	1.17 (13.2)	1.35 (20.7)	1.15 (12.5)
W_2 (mechanical + manual)	1.15 (12.4)	1.19 (13.8)	1.35 (20.6)	1.22 (14.9)
W_3 (cultural + manual)	1.10 (10.7)	1.08 (10.2)	1.27 (16.8)	1.09 (10.7)
W_4 (cultural + mechanical)	1.43 (25.6)	1.39 (22.7)	1.55 (34.3)	1.37 (22.3)
W_5 (cultural + chemical + mechanical)	1.21 (14.7)	1.38 (22.4)	1.38 (23.4)	1.21 (14.6)
W_6 (chemical + manual)	1.25 (16.1)	1.30 (18.5)	1.22 (15.1)	1.25 (16.6)
W_7 (unweeded control)	1.76 (56.8)	1.62 (41.2)	1.77 (57.8)	1.63 (41.3)
SEd	0.05	0.05	0.08	0.05
CD ($p=0.05$)	0.11	0.10	0.17	0.11

Figures in parenthesis indicate original values

Table 20. Total weeds m⁻² as influenced by interaction of N management practices and weed control methods at maturity stage of the crop

Treatment	Total weeds m ⁻² at maturity stage											
	Kharif'98			Rabi' 98 - 99			Kharif' 99			Rabi' 99 - 2000		
	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean
W ₁ (manual)	1.53 (32.3)	1.59 (37.0)	1.56 (34.7)	1.53 (32.0)	1.57 (35.4)	1.55 (33.7)	1.63 (41.2)	1.72 (51.5)	1.67 (46.4)	1.48 (28.6)	1.55 (34.0)	1.51 (31.3)
W ₂ (mechanical + manual)	1.56 (34.4)	1.61 (39.3)	1.58 (36.9)	1.57 (35.2)	1.64 (41.7)	1.60 (38.5)	1.65 (43.3)	1.72 (51.2)	1.68 (47.3)	1.52 (31.3)	1.59 (37.4)	1.55 (34.4)
W ₃ (cultural + manual)	1.44 (26.1)	1.52 (31.5)	1.48 (28.8)	1.43 (25.4)	1.45 (26.2)	1.44 (25.8)	1.52 (31.4)	1.61 (39.5)	1.56 (35.5)	1.33 (19.4)	1.40 (23.6)	1.36 (21.5)
W ₄ (cultural + mechanical)	1.81 (63.2)	1.87 (72.5)	1.84 (67.9)	1.74 (53.8)	1.80 (62.0)	1.77 (57.9)	1.88 (74.3)	1.94 (86.8)	1.91 (80.6)	1.72 (51.6)	1.78 (59.5)	1.75 (55.6)
W ₅ (cultural + chemical + mechanical)	1.57 (35.3)	1.66 (44.0)	1.61 (39.7)	1.66 (44.2)	1.72 (51.2)	1.69 (47.7)	1.58 (36.4)	1.76 (56.4)	1.67 (46.4)	1.54 (33.2)	1.71 (49.4)	1.62 (41.3)
W ₆ (chemical + manual)	1.57 (35.3)	1.62 (39.7)	1.59 (37.5)	1.55 (34.3)	1.68 (46.0)	1.61 (40.2)	1.56 (34.5)	1.66 (44.5)	1.61 (39.5)	1.50 (30.0)	1.66 (44.5)	1.58 (37.3)
W ₇ (unweeded control)	2.13 (133.6)	2.16 (144.8)	2.14 (139.2)	2.07 (116.0)	2.11 (127.7)	2.09 (121.9)	2.16 (144.5)	2.21 (161.5)	2.18 (153.0)	2.02 (103.6)	2.08 (118.8)	2.05 (111.2)
Mean	1.66 (51.5)	1.72 (58.4)		1.65 (48.7)	1.71 (55.7)		1.71 (57.9)	1.80 (70.7)		1.58 (42.5)	1.68 (52.4)	

SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)
N	0.02	NS	0.02	NS	0.03	NS	NS
W	0.03	0.06	0.033	0.07	0.06	0.13	0.12
N at W	0.045	0.12	0.048	0.12	0.09	0.22	0.19
W at N	0.041	0.09	0.048	0.10	0.09	0.18	0.17

Figures in parenthesis indicate original values

At harvest, interaction effect between split application of N and weed control methods was observed. Combination of four splits of N and cultural + manual method (N_1W_3) significantly reduced the total weeds to 19.4 to 31.4 m^{-2} (first to fourth crops) and was on par with manual method and four splits of N (N_1W_3) as well as cultural + manual method with five splits of N (N_2W_5).

Dry weight of weeds differed significantly with number of nitrogen split application and weed control methods. Nitrogen applied in four splits excluding basal application showed superiority by significantly lowering the weed growth at maturity over five equal splits with basal application in all the four crops (Table 21).

Among the weed control methods, cultural + manual method (W_3) recorded the lowest weed dry matter in all the four crops and was significantly superior over rest of the treatments in third crop. However, this treatment (W_3) was comparable with manual, mechanical + manual and chemical + manual (second and fourth crops) and manual and mechanical + manual (first crop) methods to reduce the weed growth at crop maturity stage.

Significant interaction effect between split application of N and weed control methods on total weed growth was observed in all the four crops. The weed growth and development was brought down to a lower level in cultural + manual method in combination with four splits of N. Significantly highest dry weight of weeds was recorded under five splits of N with unweeded control plot.

Table 21. Total weed dry weight (g m^{-2}) as influenced by interaction of N management practices and weed control methods at maturity stage of the crop

Total weed dry weight (gm ⁻²) at maturity stage															
Treatment	Kharif 98			Rabi 98 - 99			Kharif 99			Rabi 99 - 2000					
	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean			
W ₁ (manual)	42.2	45.7	44.0	33.8	39.8	36.8	48.1	56.6	52.4	31.6	34.3	32.9			
W ₂ (mechanical + manual)	43.5	49.1	46.3	37.9	39.3	38.6	55.4	64.7	60.1	33.3	37.4	35.4			
W ₃ (cultural + manual)	39.0	42.6	40.8	34.9	35.9	35.4	40.8	47.0	43.9	29.8	31.5	30.6			
W ₄ (cultural + mechanical)	124.1	141.7	132.9	75.0	82.9	78.9	133.6	151.8	142.7	72.2	82.9	77.5			
W ₅ (cultural + chemical + mechanical)	59.1	71.6	65.3	46.4	39.6	43.0	58.9	74.5	66.7	37.5	44.0	40.7			
W ₆ (chemical + manual)	47.5	56.9	52.2	35.5	41.0	38.2	51.4	57.5	54.5	31.5	38.8	35.2			
W ₇ (unweeded control)	193.0	216.7	204.9	119.5	133.8	126.6	214.0	231.3	222.7	109.5	124.4	117.0			
Mean	78.3	89.2		54.7	58.9		86.1	97.6		49.3	56.2				
	SEd	CD (p = 0.05)		SEd	CD (p = 0.05)		SEd	CD (p = 0.05)		SEd	CD (p = 0.05)				
N	0.40	1.71		0.51	2.20		0.86	3.68		0.71	3.05				
W	3.38	6.97		2.10	4.30		2.60	5.37		2.38	4.91				
N at W	4.44	9.24		2.77	5.94		3.51	7.71		3.19	6.94				
W at N	4.77	9.85		2.95	6.08		3.68	7.59		3.36	6.94				

4.2.3. Relative density of weeds at flowering stage of rice (Table 22)

The relative density of grasses, sedges and broad leaved weeds to total weed density at flowering stage of the crop was worked out and presented in Table 22.

Different time of N application did not show much influence on the relative density of all the three groups of weeds irrespective of the cropping season.

Among the weed control methods, wide variations were observed in the relative density values. In unweeded control plot, broad leaved weeds were more dominant over grasses and sedges in first and third crops (*kharif* seasons), while in second and fourth crops (*rabi* seasons) grasses were dominant over other two groups of weeds. Manual method (W_1) of weed control showed the lowest relative density of grasses in all the four crops. Sedges had the lowest relative density either in cultural + chemical + mechanical (first and third crops) method or chemical + manual (second and fourth crops) method of weed control. However, lower values of relative density of broad leaved weeds was observed in cultural + mechanical (first and second crops), chemical + manual (third crop) and cultural + chemical + mechanical (fourth crop) method at flowering stage of the crop.

4.2.4. Weed control efficiency (Table 23)

The efficiency of different weed control methods on weed control in relation to weed dry weight under control plot at tillering, flowering and maturity stages of crop was worked out and presented in Table 23. Manually weeded plots recorded the highest weed control efficiency (75.9 to 90.3 per cent) in all the crops at tillering stage of rice, when the weeds were sampled. However, at flowering and maturity stages, cultural + manual

Table 22. Relative density (per cent) of weeds as influenced by N management practices and weed control methods at flowering stage

Treatment	Relative density (per cent) at flowering stage											
	<i>Kharif</i> 98			<i>Rabi</i> 98 - 99			<i>Kharif</i> 99			<i>Rabi</i> 99 - 2000		
	G	S	BLW	G	S	BLW	G	S	BLW	G	S	BLW
N management												
N ₁ (four splits)	29.7	30.9	39.3	31.7	32.8	35.8	31.7	28.5	39.7	29.4	36.5	34.0
N ₂ (five splits)	31.5	28.1	40.4	32.7	33.9	33.1	32.6	27.3	40.4	32.5	33.4	34.1
Weed control methods												
W ₁ (manual)	22.1	38.6	39.6	23.2	35.2	41.5	24.1	32.7	43.4	21.8	32.8	45.4
W ₂ (mechanical + manual)	29.8	33.8	36.4	28.9	36.8	34.4	25.3	28.9	45.9	27.7	39.1	33.2
W ₃ (cultural + manual)	24.6	34.0	41.4	30.9	36.7	32.3	26.0	35.2	38.8	24.7	36.9	38.4
W ₄ (cultural + mechanical)	39.9	26.9	33.3	38.5	35.5	26.1	36.0	24.7	39.4	35.0	37.1	28.0
W ₅ (cultural + chemical + mechanical)	35.8	21.5	42.7	36.8	28.8	34.5	40.1	21.4	38.6	38.4	34.6	27.1
W ₆ (chemical + manual)	29.1	25.1	45.6	31.1	25.9	43.1	36.4	27.7	35.9	31.1	30.4	38.5
W ₇ (unweeded control)	32.9	27.0	40.1	36.2	34.6	29.2	36.4	25.1	38.5	38.2	34.0	27.8

Data not statistically analysed G : Grasses S : Sedges BLW : Broad leaved weeds.

Table 23. Weed control efficiency (per cent)

Treatment	Weed control efficiency (per cent)											
	Kharif'98			Rabi' 98 - 99			Kharif' 99			Rabi' 99 - 2000		
	T	F	M	T	F	M	T	F	M	T	F	M
W ₁ (manual)	88.8	74.1	78.5	90.3	80.3	71.0	75.9	71.8	76.5	88.0	79.8	71.8
W ₂ (mechanical + manual)	76.1	71.3	77.4	71.6	79.2	69.5	64.6	69.0	73.0	69.4	78.2	69.7
W ₃ (cultural + manual)	61.3	76.0	80.1	40.2	83.8	72.1	39.2	74.6	80.3	43.5	83.3	73.8
W ₄ (cultural + mechanical)	58.8	48.3	35.1	45.2	54.6	37.7	43.7	44.3	35.9	37.5	54.1	33.7
W ₅ (cultural + chemical + mechanical)	67.3	70.4	68.1	56.0	76.9	66.0	60.2	67.2	70.0	54.6	75.9	65.2
W ₆ (chemical + manual)	62.1	73.1	74.5	46.7	78.0	69.8	44.3	70.0	75.5	45.6	78.7	69.9
W ₇ (unweeded control)	-	-	-	-	-	-	-	-	-	-	-	-

Data not statistically analysed T : Tillering F : Flowering M : Maturity

method (W_3) recorded higher weed control efficiency of 72.1 to 83.8 per cent which was followed by manual method (71.0 to 80.3 per cent) of weed control in all the crops.

Apart from cultural + manual and manual methods of weed control, pre emergence application of pretilachlor with one hand weeding (chemical + manual) also had higher weed control efficiency over rest of the treatments at flowering and maturity stages in all the crops, except in first crop (maturity stage) and second crop (flowering stage), where mechanical + manual method (W_2) was better than chemical + manual method with respect to weed control efficiency.

4.2.5. Nutrient removal by weeds

4.2.5.1. Nitrogen removal by weeds at 20 DAS (Table 24)

Split application of N had significant influence on N removal by weeds at 20 DAS. Application of N in four splits significantly lowered the N removal by weeds (0.48 to 1.15 kg ha^{-1}) over five splits of N (0.59 to 1.40 kg ha^{-1}) in all the four crops.

Removal of N by weeds at 20 DAS under unweeded treatment was significantly higher and varied from 0.72 to 1.64 kg ha^{-1} in the four seasons under study. Among the weed control methods, use of pre emergence herbicide in W_5 and W_6 treatments significantly restricted the N removal over rest of the weed control treatments. In the first crop of rice, cultural + chemical + mechanical (W_5) weed control plot was significantly superior and recorded the lowest value of N removal followed by chemical + manual method (W_6) and both these two treatments (W_5 and W_6) were equally effective (second and third crops) and significantly superior to rest of the treatments in restricting N removal

Table 24. Nitrogen removal (kg ha^{-1}) by weeds as influenced by interaction of N management and weed control methods in rice at 20 DAS

Nitrogen removal (kg ha ⁻¹) at 20 DAS												
Treatment	Kharif'98			Rabi' 98 - 99			Kharif' 99			Rabi' 99 - 2000		
	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean
W ₁ (manual)	1.29	1.55	1.42	0.74	0.64	0.69	1.45	1.66	1.56	0.58	0.79	0.68
W ₂ (mechanical + manual)	1.34	1.67	1.51	0.70	0.71	0.71	1.62	1.79	1.71	0.68	0.82	0.75
W ₃ (cultural + manual)	1.15	1.57	1.36	0.64	0.65	0.65	1.29	1.49	1.39	0.49	0.73	0.61
W ₄ (cultural + mechanical)	1.14	1.53	1.34	0.47	0.79	0.63	1.36	1.54	1.45	0.46	0.67	0.56
W ₅ (cultural + chemical + mechanical)	0.66	0.81	0.74	0.18	0.23	0.21	0.46	0.45	0.46	0.24	0.28	0.26
W ₆ (chemical + manual)	0.78	0.97	0.88	0.24	0.25	0.25	0.54	0.66	0.60	0.25	0.55	0.40
W ₇ (unweeded control)	1.35	1.68	1.52	0.60	0.84	0.72	1.34	1.94	1.64	0.69	0.89	0.79
Mean	1.10	1.40		0.51	0.59		1.15	1.36		0.48	0.68	
	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)		
N	0.05	0.21	0.02	0.07	0.04	0.19	0.04	0.19	0.03	0.13		
W	0.05	0.10	0.02	0.04	0.08	0.16	0.08	0.16	0.06	0.12		
N at W	0.08	0.23	0.029	0.08	0.112	0.27	0.112	0.27	0.082	0.19		
W at N	0.069	0.14	0.026	0.05	0.110	0.23	0.110	0.23	0.080	0.17		

by weeds. In the fourth crop, cultural + chemical + mechanical method was significantly effective in minimizing N removal (0.26 kg ha^{-1}) by weeds.

The interaction between split application of N and weed control methods was significant in all the crops. Lowest nitrogen removal by weeds was observed in cultural + chemical + mechanical method of weed control under four split application of N (first, second and fourth crops) and under five splits of N application (third crop). The cultural + chemical + mechanical and chemical + manual methods of weed control irrespective of the number of nitrogen split were promising in minimizing the N removal by weeds. In unweeded control plot, highest uptake of N by weeds was observed in five splits of N.

4.2.5.2. Nitrogen removal by weeds at tillering stage of rice (Table 25)

Split application of nitrogen had noticeable influence on N removal by weeds in all the seasons. Delay in application of initial dose of N upto 10 DAS under N_1 treatment resulted in significantly lower N depletion by weeds compared to basal application in N_2 treatment in second, third and fourth crops. However, in first crop, N depletion by weeds under both the N management practices were comparable.

Among the weed control methods, N removal by weeds were significantly reduced under all weed control measures over unweeded control plot and the lowest values were obtained in manual method, where weeds depleted only 1.31, 0.73, 2.84 and 0.81 kg ha^{-1} of N in first to fourth crops respectively, in comparison to 11.39, 7.25, 12.44 and 6.67 kg ha^{-1} over seasons in unweeded plots.

Table 25. Nitrogen removal (kg ha^{-1}) by weeds as influenced by interaction of N management practices and weed control methods at tillering stage of the crop

Nitrogen removal (kg ha ⁻¹) at tillering stage												
Treatment	Kharif'98			Rabi' 98 - 99			Kharif' 99			Rabi' 99 - 2000		
	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean
W ₁ (manual)	1.08	1.53	1.31	0.66	0.79	0.73	2.35	3.33	2.84	0.74	0.88	0.81
W ₂ (mechanical + manual)	2.30	3.25	2.78	2.16	1.95	2.06	3.70	4.88	4.29	1.71	2.36	2.03
W ₃ (cultural + manual)	3.30	5.65	4.48	4.29	4.50	4.40	7.18	7.51	7.35	3.40	3.70	4.14
W ₄ (cultural + mechanical)	4.60	5.06	4.83	3.85	4.51	4.18	6.33	7.14	6.74	3.52	3.98	3.75
W ₅ (cultural + chemical + mechanical)	3.86	3.68	3.77	3.38	3.30	3.34	4.51	4.98	4.75	3.01	3.21	3.11
W ₆ (chemical + manual)	4.66	4.33	4.50	3.68	4.38	4.03	7.14	6.34	6.74	3.68	4.60	3.55
W ₇ (unweeded control)	11.08	11.69	11.39	6.54	7.95	7.25	11.70	13.18	12.44	6.18	7.15	6.67
Mean	4.41	5.03		3.51	3.91		6.13	6.77		3.18	3.70	
	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)
N	0.23	NS	0.04	0.16	0.08	0.35	0.08	0.35	0.05	0.21	0.05	0.21
W	0.27	0.57	0.12	0.25	0.16	0.33	0.16	0.33	0.19	0.40	0.19	0.40
N at W	0.08	0.23	0.03	0.08	0.11	0.27	0.11	0.27	0.08	0.19	0.08	0.19
W at N	0.07	0.14	0.03	0.05	0.11	0.23	0.11	0.23	0.08	0.17	0.08	0.17

The interaction effect between N management and weed control methods was significant in all crops. Combinations of manual method of weed control along with four splits of N was more effective in all the crops except fourth crop, where under both the N splits, this weed control method out scored the other combinations in checking the N removal by weeds.

4.2.5.3. Nitrogen removal by weeds at flowering stage of rice (Table 26)

Depletion of N by weeds at flowering stage also showed similar trend as that of 20 DAS and tillering stages. Restricting the N application to four splits effectively limited N removal by weeds over five splits.

Significantly higher amount of N removal of 17.98 to 29.11 kg ha⁻¹ (first to fourth crops) was evident in unweeded plots (Table 25). Cultural + manual (W₃) and manual (W₁) methods of weed control were comparable (first and second crops) and the former one was significantly superior over later treatment (third and fourth crops) in reducing the N removal by weeds at flowering stage of the rice.

The interaction between split application of N and weed control methods was significant in all the seasons. Application of N in four splits and control of weeds by cultural + manual (first crop) or manual method (second and fourth crops), and irrespective of N splits with cultural + manual method (third crop) were more effective in restricting N depletion by weeds.

Table 26. Nitrogen removal (kg ha^{-1}) by weeds as influenced by interaction of N management practices and weed control methods at flowering stage of the crop

Treatment	Nitrogen removal (kg ha^{-1}) at flowering stage											
	Kharif 98			Rabi' 98 - 99			Kharif 99			Rabi' 99 - 2000		
	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean
W ₁ (manual)	6.09	6.82	6.46	3.88	4.37	4.13	7.38	8.21	7.79	3.07	4.64	3.86
W ₂ (mechanical + manual)	6.26	7.81	7.04	4.10	5.03	4.57	7.58	9.20	8.40	3.91	4.63	4.27
W ₃ (cultural + manual)	5.41	6.68	6.05	3.98	4.12	4.05	6.67	6.41	6.54	3.10	3.30	3.20
W ₄ (cultural + mechanical)	10.57	14.54	12.56	8.62	9.61	9.12	14.78	16.53	15.65	8.26	9.69	8.98
W ₅ (cultural + chemical + mechanical)	7.47	7.30	7.39	4.48	5.06	4.77	8.38	9.94	9.16	4.26	5.15	4.71
W ₆ (chemical + manual)	5.99	7.14	6.57	4.54	4.77	4.66	7.56	8.16	7.86	3.80	4.72	4.26
W ₇ (unweeded control)	24.91	29.69	27.30	17.45	18.51	17.98	27.78	30.44	29.11	17.45	22.67	20.06
Mean	9.53	11.43		6.72	7.35		11.45	12.70		6.26	7.83	

N W N at W W at N	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)
	0.15	0.65	0.09	0.40	0.08	0.35	0.12	0.52
	0.42	0.87	0.16	0.32	0.30	0.63	0.22	0.45
	0.57	1.27	0.223	0.55	0.41	0.88	0.31	0.75
	0.60	1.23	0.219	0.45	0.43	0.89	0.31	0.64

4.2.5.4. Nitrogen removal by weeds at maturity of rice (Table 27)

Nitrogen management profoundly influenced the N uptake by weeds at maturity stage of the crop. Four splits of N significantly minimized the N removal by weeds (second, third and fourth crops) over five splits. However, both the methods were on par in the first crop in respect of N depletion by weeds.

When weed growth was unchecked until harvest of rice crop, weeds removed as much as 25.36 to 48.99 kg N ha⁻¹ during the four cropping seasons. All the weed control methods checked the N removal by weeds significantly over unweeded control in both the years. Nitrogen depletion by weeds was minimum in cultural + manual method (W₃) in all the crops and manual method (W₁) in the first and second crops was equally effective with W₃. The cultural + mechanical method (W₄) recorded significantly more N removal by weeds compared to other weed control methods but significantly lower values of unweeded treatment in all the four crops.

The interaction effect of N management and weed control methods was significant at maturity stage of rice in both the years. Four splits of N along with cultural + manual method (first, third and fourth crops) or manual method (second crop) effectively minimized the N removal by weeds over rest of the treatment combinations.

4.2.5.5. Phosphorus removal by weeds at maturity stage of rice (Table 28)

Under unweeded condition, weeds removed 4.82 to 8.02 kg ha⁻¹ of P at maturity of rice over seasons. Four splits of N was more effective in restricting the P removal by weeds and was significantly superior over five splits of N in all the four crops.

Table 27. Nitrogen removal (kg ha^{-1}) by weeds as influenced by interaction of N management practices and weed control methods at maturity stage of the crop

Treatment	Nitrogen removal (kg ha ⁻¹) at maturity stage											
	Kharif 98			Rabi' 98 - 99			Kharif 99			Rabi' 99 - 2000		
	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean
W ₁ (manual)	8.81	9.18	9.00	6.99	8.25	7.62	10.10	11.89	11.0	7.17	7.84	7.46
W ₂ (mechanical + manual)	9.14	9.72	9.43	8.02	8.31	8.17	11.78	13.79	12.78	7.33	8.43	7.88
W ₃ (cultural + manual)	8.24	8.62	8.43	7.49	7.63	7.56	7.75	8.92	8.34	6.35	6.93	6.64
W ₄ (cultural + mechanical)	23.07	24.90	23.99	15.26	16.92	16.09	29.40	33.40	31.40	15.90	18.43	17.16
W ₅ (cultural + chemical + mechanical)	12.50	13.82	13.16	9.72	8.30	9.01	11.79	14.90	13.34	8.15	9.57	8.86
W ₆ (chemical + manual)	9.97	10.96	10.47	7.46	8.62	8.04	10.80	12.07	11.44	6.93	8.54	7.74
W ₇ (unweeded control)	39.53	42.02	40.78	23.84	26.89	25.36	47.09	50.89	48.99	24.19	27.87	26.03
Mean	15.89	17.03		11.25	12.13		18.39	20.84		10.86	12.52	

	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)
N	0.29	NS	0.18	0.77	0.50	2.16	0.35	1.50
W	0.40	0.83	0.19	0.40	0.56	1.15	0.35	0.72
N at W	0.61	1.57	0.31	0.87	0.89	2.46	0.58	1.66
W at N	0.57	1.18	0.27	0.57	0.79	1.63	0.49	1.02

Table 28. Phosphorus removal (kg ha^{-1}) by weeds as influenced by interaction of N management practices and weed control methods at maturity stage of the crop

Treatment	Phosphorus removal (kg ha^{-1}) at maturity stage											
	<i>Kharif 98</i>			<i>Rabi 98 - 99</i>			<i>Kharif 99</i>			<i>Rabi 99 - 2000</i>		
	N_1	N_2	Mean	N_1	N_2	Mean	N_1	N_2	Mean	N_1	N_2	Mean
W_1 (manual)	1.89	2.00	1.95	1.58	1.77	1.68	1.95	2.21	2.08	1.44	1.49	1.47
W_2 (mechanical + manual)	2.03	2.21	2.12	1.66	1.86	1.76	2.22	2.40	2.31	1.50	1.66	1.58
W_3 (cultural + manual)	1.79	1.91	1.85	1.65	1.65	1.65	1.88	2.06	1.97	1.30	1.42	1.36
W_4 (cultural + mechanical)	4.41	5.06	4.74	1.99	3.22	2.61	4.71	5.03	4.87	2.24	2.79	2.52
W_5 (cultural + chemical + mechanical)	2.14	2.56	2.35	2.01	1.80	1.91	2.32	2.44	2.38	1.62	1.82	1.72
W_6 (chemical + manual)	2.08	2.39	2.24	1.70	1.76	1.73	2.20	2.36	2.28	1.42	1.58	1.50
W_7 (unweeded control)	7.55	8.33	7.94	4.82	5.28	5.05	7.82	8.22	8.02	4.35	5.28	4.82
Mean	3.13	3.49		2.20	2.48		3.30	3.53		1.98	2.29	

	SEd	CD ($p = 0.05$)	SEd	CD ($p = 0.05$)	SEd	CD ($p = 0.05$)	SEd	CD ($p = 0.05$)
N	0.01	0.06	0.04	0.16	0.03	0.13	0.02	0.10
W	0.11	0.22	0.08	0.17	0.15	0.31	0.14	0.28
N at W	0.14	0.29	0.11	0.26	0.20	0.42	0.18	0.38
W at N	0.15	0.31	0.12	0.24	0.21	0.44	0.19	0.40

Weed control methods caused marked variation on P removal by weeds in all the seasons. Cultural + manual method (W_3) registered the lowest P removal (1.36 to 1.97 kg ha⁻¹) by weeds in all the seasons. However, this treatment was statistically on par with manual method (first crop), manual, chemical + manual and mechanical + manual methods (second and fourth crops) and manual and chemical + manual methods (third crop) in restricting the P uptake by weeds.

The interaction between N management and weed control methods was significant in both years. Application of four splits of N with cultural + manual (first, third and fourth crops) or manual method (second crop) of weeding were most effective in lowering the P depletion by weeds.

4.2.5.6. Potassium removal by weeds at maturity stage of rice (Table 29)

Like N and P, K removal by weeds was also significantly higher under N_2 timing over N_1 timing of N management in all the seasons. (Table 29)

Potassium uptake was very high (27.09 to 52.11 kg ha⁻¹) under unweeded condition. All the weed control methods were efficient in minimizing K removal by weeds over control in both the years. Potassium uptake by weeds showed a similar trend as that of N uptake by weeds under different weed control methods at crop maturity. The cultural + manual method (W_3) recorded the lowest K uptake by weeds and was on par with manual (W_1) and mechanical + manual (W_2) methods (first and second crop) or significantly superior over rest of the treatments (third and fourth crops).

Table 29. Potassium removal (kg ha^{-1}) by weeds as influenced by interaction of N management practices and weed control methods at maturity stage of the crop

Treatment	Potassium removal (kg ha ⁻¹) at maturity stage											
	Kharif'98			Rabi' 98 - 99			Kharif' 99			Rabi' 99 - 2000		
	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean
W ₁ (manual)	9.85	10.66	10.26	7.80	9.19	8.50	11.12	13.08	12.10	7.27	7.64	7.46
W ₂ (mechanical + manual)	10.05	11.33	10.69	8.76	9.08	8.92	12.91	15.08	14.00	7.63	8.67	8.15
W ₃ (cultural + manual)	8.95	9.79	9.37	8.11	8.26	8.19	9.30	10.71	10.00	6.61	7.21	6.91
W ₄ (cultural + mechanical)	26.15	30.22	28.19	16.13	17.96	17.05	31.27	35.53	33.40	15.53	18.18	16.86
W ₅ (cultural + chemical + mechanical)	13.65	16.55	15.10	10.71	9.16	9.94	13.56	17.14	15.35	8.69	10.27	9.48
W ₆ (chemical + manual)	10.97	13.14	12.06	8.19	9.47	8.83	11.88	13.28	12.58	7.21	8.89	8.05
W ₇ (unweeded control)	45.18	50.65	47.92	27.75	30.70	29.23	50.08	54.13	52.11	25.38	28.79	27.09
Mean	17.83	20.34		12.49	13.40		20.02	22.71		11.19	12.81	

The interaction between split application of N and weed control methods was significant over seasons. Four splits of N with cultural + manual method (8.95, 9.30 and 6.61 kg ha⁻¹, respectively) in first, third and fourth crops and manual method (7.80 kg ha⁻¹) in second crop were most effective in reducing K uptake by weeds in comparison to other combinations of N management and weed control measures.

4.3. Effect of treatments on rice

4.3.1. Growth components of rice

4.3.1.1. Plant population (Table 30)

The mean number of plants m⁻² at 20 DAS did not vary significantly under different N management practices in all the crops. Similarly, weed control methods also did not show significant influence on plant population at 20 DAS over the seasons.

4.3.1.2. Plant height (Table 31 to 33)

The number of split application of N did not exert significant influence on the height in the ontogeny of the rice plants in any of the seasons of study. Weed control methods markedly influenced the plant height. The height of rice plants in weedy plot (W₇) was significantly lower than the other weed control treatments in all the crops and stages of crop growth, except at flowering stage (first crop) and at maturity stage (first, third and fourth crops), where plant height in cultural + mechanical (W₄) treated plot was similar to unweeded plot.

Table 30. Plant population m^{-2} of rice as influenced by N management practices and weed control methods at 20 DAS

Treatment	Plant population m^{-2} at 20 DAS			
	<i>Kharif 98</i>	<i>Rabi 98-99</i>	<i>Kharif 99</i>	<i>Rabi 99-2000</i>
N management				
N_1 (four splits)	369	376	306	365
N_2 (five splits)	360	378	313	370
SEd	3.2	5.2	2.5	3.6
CD ($p=0.05$)	NS	NS	NS	NS
Weed control methods				
W_1 (manual)	366	385	301	371
W_2 (mechanical + manual)	369	376	318	365
W_3 (cultural + manual)	366	380	307	361
W_4 (cultural + mechanical)	369	374	321	373
W_5 (cultural + chemical + mechanical)	350	372	308	366
W_6 (chemical + manual)	380	378	311	370
W_7 (unweeded control)	353	375	305	369
SEd	15	6.5	11.1	7.3
CD ($p=0.05$)	NS	NS	NS	NS

At tillering stage, plant height in all the weed control plots in first and third crops were comparable, while in second and fourth crops, manual, manual + mechanical, cultural + chemical + mechanical and chemical + manual methods recorded significantly taller plant height than the rest of the treatments (Table 31). Though, the height of plant varied due to weed control treatments at flowering stage in all the crops (Table 32), the variations were small and tallest plants were observed in cultural + manual (first, second and fourth crops) and chemical + manual (third crop) methods. At maturity stage of the crop also, cultural + manual method (W_3) recorded the tallest plant over other weed control methods in all the four crops and the figures were on par with W_1 , W_2 , W_5 and W_6 (first crop) or W_5 (second crop) or W_1 and W_5 (fourth crop) (Table 33). Manual, mechanical + manual, cultural + chemical + mechanical and chemical + manual methods were equally effective in influencing rice plant height at maturity stage in both the years.

4.3.1.3. Number of tillers m^{-2} (Table 34 to 36)

Spilt application of N did not result in significant variation in number of tillers m^{-2} in all the crops at tillering stage. However, the influence was significantly conspicuous from flowering and maturity stages in all the crops except at maturity stage of rice in first crop where both four or five splits of N showed statistically comparable tiller number.

Among the weed control methods, manual method (W_1) recorded significantly more number of tillers over other treatments in all the seasons, except in first crop, where cultural + chemical + mechanical (W_5) and chemical + manual (W_6) methods were equally effective with manual method to increase the tiller number at tillering stage (Table 34). In the other stages of observations, the trend was different where cultural + manual method

Table 31. Plant height (cm) as influenced by N management practices and weed control methods at tillering stage

Treatment	Plant height (cm) at tillering stage			
	<i>Kharif 98</i>	<i>Rabi 98-99</i>	<i>Kharif 99</i>	<i>Rabi 99-2000</i>
N management				
N ₁ (four splits)	43.5	42.6	37.3	43.1
N ₂ (five splits)	44.2	44.7	35.5	44.6
SEd	0.85	0.94	0.45	0.65
CD (p=0.05)	NS	NS	NS	NS
Weed control methods				
W ₁ (manual)	47.0	47.2	37.1	45.8
W ₂ (mechanical + manual)	45.7	46.8	37.1	46.0
W ₃ (cultural + manual)	42.5	42.2	36.1	43.8
W ₄ (cultural + mechanical)	42.9	42.9	36.3	43.0
W ₅ (cultural + chemical + mechanical)	42.3	44.6	37.1	44.5
W ₆ (chemical + manual)	46.4	46.7	38.0	45.0
W ₇ (unweeded control)	40.1	35.1	33.2	39.1
SEd	2.60	1.75	1.22	1.46
CD (p=0.05)	5.36	3.61	2.52	3.01

Table 32. Plant height (cm) as influenced by N management practices and weed control methods at flowering stage

Treatment	Plant height (cm) at flowering stage			
	<i>Kharif 98</i>	<i>Rabi 98-99</i>	<i>Kharif 99</i>	<i>Rabi 99-2000</i>
N management				
N ₁ (four splits)	77.6	71.9	76.0	73.3
N ₂ (five splits)	76.5	69.1	71.9	71.2
SEd	0.74	0.67	0.96	0.84
CD (p=0.05)	NS	NS	NS	NS
Weed control methods				
W ₁ (manual)	77.7	72.3	76.0	70.9
W ₂ (mechanical + manual)	76.6	69.1	73.9	71.7
W ₃ (cultural + manual)	79.5	74.5	75.8	76.6
W ₄ (cultural + mechanical)	74.2	69.0	72.2	71.8
W ₅ (cultural + chemical + mechanical)	78.5	72.8	75.1	75.6
W ₆ (chemical + manual)	79.1	71.4	77.9	73.3
W ₇ (unweeded control)	73.9	64.8	67.1	66.0
SEd	1.52	1.61	1.89	1.22
CD (p=0.05)	3.14	3.33	3.89	2.52

Table 33. Plant height (cm) as influenced by N management practices and weed control methods at maturity stage

Treatment	Plant height (cm) at maturity stage			
	<i>Kharif 98</i>	<i>Rabi 98-99</i>	<i>Kharif 99</i>	<i>Rabi 99-2000</i>
N management				
N ₁ (four splits)	86.2	76.4	82.2	78.9
N ₂ (five splits)	81.1	75.6	79.1	78.2
SEd	0.95	0.40	0.81	0.28
CD (p=0.05)	NS	NS	NS	NS
Weed control methods				
W ₁ (manual)	87.0	76.5	82.2	79.6
W ₂ (mechanical + manual)	86.3	75.7	79.5	78.2
W ₃ (cultural + manual)	90.9	81.3	86.2	82.9
W ₄ (cultural + mechanical)	83.3	75.3	78.4	74.5
W ₅ (cultural + chemical + mechanical)	88.6	77.9	81.6	79.9
W ₆ (chemical + manual)	86.4	75.4	80.3	78.5
W ₇ (unweeded control)	80.6	69.9	76.5	72.0
SEd	2.28	1.87	1.43	1.60
CD (p=0.05)	4.78	3.86	2.95	3.30

Table 34. Total tillers m⁻² as influenced by N management practices and weed control methods at tillering stage

Treatment	Total tillers m ⁻² at tillering stage			
	<i>Kharif 98</i>	<i>Rabi 98-99</i>	<i>Kharif 99</i>	<i>Rabi 99-2000</i>
N management				
N ₁ (four splits)	459	585	419	591
N ₂ (five splits)	468	695	426	606
SEd	2.0	6.8	5.6	4.2
CD (p=0.05)	NS	NS	NS	NS
Weed control methods				
W ₁ (manual)	490	657	467	663
W ₂ (mechanical + manual)	471	578	409	598
W ₃ (cultural + manual)	473	581	419	624
W ₄ (cultural + mechanical)	468	591	422	602
W ₅ (cultural + chemical + mechanical)	485	616	446	620
W ₆ (chemical + manual)	482	592	442	614
W ₇ (unweeded control)	378	514	347	540
SEd	6.9	9.3	5.1	8.7
CD (p=0.05)	14.3	19.1	10.6	18.0

(W₃) increased the tiller number. W₃ recorded significantly more number of tillers over rest of the treatments in all the crops, except in second and third crops where it was comparable with cultural + chemical + mechanical (second crop) and chemical + manual (third crop) methods at flowering stage (Table 35). At maturity, tiller number was significantly maximum in cultural + manual method (W₃) followed by cultural + chemical + mechanical method (W₅) in the first to fourth crops (Table 35).

The combined effect of split application of N and weed control methods was significant on tiller production at flowering and maturity stages (Table 35 and 36).

At flowering stage, difference in tiller production due to split application of N was not conspicuous with different weed control methods. However, cultural + manual method under both the nitrogen splits (first, second and fourth crops) or under four splits of N (second crop) was most effective to increase tiller numbers over other combinations (Table 35).

At maturity, irrespective of split application of N, cultural + manual method produced substantially more tillers over other combinations in first crop. Significantly maximum tiller number (700, 553 and 716 m⁻² for second, third and fourth crops respectively) were achieved with the combination of four splits of N with cultural + manual method (Table 36).

4.3.1.4. Leaf area index (LAI) of rice (Table 37 and 38)

Leaf area index at tillering stage of crop was not affected by split application of N in both the years (Table 37).

Table 35. Total tillers m⁻² as influenced by interaction of N management practices and weed control methods at flowering stage

Treatment	Total tillers m ⁻² at flowering stage											
	Kharif'98			Rabi' 98 - 99			Kharif' 99			Rabi' 99 - 2000		
	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean
W ₁ (manual)	591	573	582	701	687	695	530	504	517	727	697	712
W ₂ (mechanical + manual)	581	546	563	695	679	687	540	483	512	695	665	680
W ₃ (cultural + manual)	618	606	612	741	708	724	566	533	549	747	743	745
W ₄ (cultural + mechanical)	541	521	531	692	607	649	503	458	480	668	654	661
W ₅ (cultural + chemical + mechanical)	593	587	590	706	697	702	541	508	524	724	716	720
W ₆ (chemical + manual)	582	576	579	735	650	693	559	527	543	723	667	695
W ₇ (unweeded control)	465	449	457	579	603	591	453	441	447	624	614	619
Mean	567	551		693	662		527	494		701	679	

	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)
N	1.8	7.7	2.9	12.7	1.6	7.0	2.1	9.0
W	10.6	21.9	12.5	25.9	5.5	11.4	8.7	17.9
N at W	14.0	29.4	16.7	35.6	7.4	16.1	11.6	24.7
W at N	15.0	31.0	17.8	36.6	7.8	16.1	12.3	25.3

Table 36. Total tillers m^{-2} as influenced by interaction of N management practices and weed control methods at maturity stage

Treatment	Total tillers m^{-2} at maturity stage											
	Kharif 98				Rabi' 98 - 99				Kharif 99			
	N ₁	N ₂	Mean	SEd	N ₁	N ₂	Mean	SEd	N ₁	N ₂	Mean	SEd
W ₁ (manual)	521	496	509	4.2	661	609	635	4.2	489	477	483	3.2
W ₂ (mechanical + manual)	469	513	491	5.9	638	583	610	7.0	478	474	476	9.2
W ₃ (cultural + manual)	564	572	568	8.9	700	673	686	9.4	553	529	541	12.5
W ₄ (cultural + mechanical)	484	477	481	8.4	628	581	604	9.9	486	448	467	13.0
W ₅ (cultural + chemical + mechanical)	528	531	529	8.4	643	657	650	8.4	523	493	508	8.4
W ₆ (chemical + manual)	513	496	504	4.2	625	608	616	4.2	498	488	493	4.2
W ₇ (unweeded control)	467	461	464	5.1	551	563	557	5.1	437	447	442	5.1
Mean	511	502			635	611			495	479		
CD (p = 0.05)												
SEd												
N												
W												
N at W												
W at N												

Table 37. Leaf area index (LAI) as influenced by N management practices and weed control methods at tillering stage

Treatment	Leaf area index (LAI) at tillering stage			
	<i>Kharif 98</i>	<i>Rabi 98-99</i>	<i>Kharif 99</i>	<i>Rabi 99-2000</i>
N Management				
N ₁ (four splits)	2.76	2.34	2.51	2.37
N ₂ (five splits)	2.81	2.38	2.55	2.40
SEd	0.017	0.016	0.021	0.021
CD (p=0.05)	NS	NS	NS	NS
Weed control methods				
W ₁ (manual)	2.94	2.63	2.81	2.65
W ₂ (mechanical + manual)	2.89	2.31	2.45	2.39
W ₃ (cultural + manual)	2.83	2.33	2.51	2.49
W ₄ (cultural + mechanical)	2.81	2.36	2.53	2.41
W ₅ (cultural + chemical + mechanical)	2.91	2.47	2.68	2.48
W ₆ (chemical + manual)	2.83	2.37	2.65	2.46
W ₇ (unweeded control)	2.26	2.06	2.08	2.16
SEd	0.08	0.05	0.07	0.07
CD (p=0.05)	0.16	0.11	0.14	0.14

The difference in LAI due to weed control treatments was significant at tillering stage. The highest LAI was recorded with manual method of weed control (W_1) which was comparable with that of other weed control methods (first crop) and cultural + chemical + mechanical method (W_5) (third crop). Unweeded control plot consistently recorded lower LAI (2.06 to 2.26) in all the four crops at tillering stage.

Leaf area index at flowering stage of crop was significantly higher with four splits of N over that of five splits in all the crops (Table 38).

Among the weed control treatments, cultural + manual method (W_3) maintained higher LAI with values of 5.51, 4.65, 4.95 and 4.97 in first, second, third and fourth crop respectively at flowering stage and was on par with cultural + chemical + mechanical method (W_5) which in turn was comparable with W_1 and W_2 (first crop), W_1 , W_2 and W_6 (second and third crops) and W_1 and W_6 (fourth crop) treatments. Unweeded control plot consistently recorded lower LAI (3.85 to 4.21) over rest of the treatments in all the crops.

4.3.1.5. Dry matter production (DMP) of rice (Table 39 to 42)

The summary of data on DMP of rice at various growths stages viz. 20 DAS, tillering, flowering and maturity are presented in Table 39 to 42.

It is clear from the data that DMP was not influenced by N management treatments at 20 DAS and tillering stages in all the four crops. However, at flowering and maturity stages, split application of N significantly affected the DMP of rice and the highest being with four splits of N in all the crops.

Table 38. Leaf area index (LAI) as influenced by N management practices and weed control methods at flowering stage

Treatment	Leaf area index (LAI) at flowering stage			
	<i>Kharif 98</i>	<i>Rabi 98-99</i>	<i>Kharif 99</i>	<i>Rabi 99-2000</i>
N Management				
N ₁ (four splits)	5.11	4.47	4.75	4.71
N ₂ (five splits)	4.96	4.27	4.44	4.57
SEd	0.02	0.04	0.05	0.03
CD (p=0.05)	0.10	0.15	0.23	0.13
Weed control methods				
W ₁ (manual)	5.24	4.47	4.61	4.77
W ₂ (mechanical + manual)	5.21	4.42	4.65	4.58
W ₃ (cultural + manual)	5.51	4.65	4.95	4.97
W ₄ (cultural + mechanical)	4.78	4.20	4.33	4.47
W ₅ (cultural + chemical + mechanical)	5.31	4.51	4.72	4.82
W ₆ (chemical + manual)	5.07	4.46	4.89	4.66
W ₇ (unweeded control)	4.11	3.85	4.02	4.21
SEd	0.07	0.08	0.11	0.10
CD (p=0.05)	0.15	0.16	0.24	0.20

Table 39. Dry matter production (kg ha⁻¹) of rice as influenced by N management practices and weed control methods at 20 DAS

Treatment	Dry matter production (kg ha ⁻¹) at 20 DAS			
	<i>Kharif 98</i>	<i>Rabi 98-99</i>	<i>Kharif 99</i>	<i>Rabi 99-2000</i>
N Management				
N ₁ (four splits)	476	389	411	380
N ₂ (five splits)	549	417	441	440
SEd	17.0	7.5	9.1	14.3
CD (p=0.05)	NS	NS	NS	NS
Weed control methods				
W ₁ (manual)	504	410	429	422
W ₂ (mechanical + manual)	530	409	433	408
W ₃ (cultural + manual)	503	377	419	404
W ₄ (cultural + mechanical)	495	408	423	383
W ₅ (cultural + chemical + mechanical)	502	409	428	412
W ₆ (chemical + manual)	541	419	443	428
W ₇ (unweeded control)	511	388	408	416
SEd	22.5	29.3	20.3	11.3
CD (p=0.05)	NS	NS	NS	NS

Table 40. Dry matter production (kg ha⁻¹) of rice as influenced by N management practices and weed control methods at tillering stage

Treatment	Dry matter production (kg ha ⁻¹) at tillering stage			
	<i>Kharif 98</i>	<i>Rabi 98-99</i>	<i>Kharif 99</i>	<i>Rabi 99-2000</i>
N Management				
N ₁ (four splits)	3713	3178	3202	3290
N ₂ (five splits)	3851	3369	3343	3424
SEd	72.0	49.0	53.0	41.0
CD (p=0.05)	NS	NS	NS	NS
Weed control methods				
W ₁ (manual)	4230	3743	3644	3780
W ₂ (mechanical + manual)	3903	3271	3117	3341
W ₃ (cultural + manual)	3604	3199	3283	3272
W ₄ (cultural + mechanical)	3620	3159	3023	3170
W ₅ (cultural + chemical + mechanical)	3912	3310	3370	3393
W ₆ (chemical + manual)	3880	3409	3617	3584
W ₇ (unweeded control)	3328	2822	2860	2960
SEd	106.0	92.0	88.0	97.0
CD (p=0.05)	219.0	190.0	182.0	200.0

Table 41. Dry matter production (kg ha⁻¹) of rice as influenced by interaction of N management practices and weed control methods at flowering stage

Treatment	Dry matter production (kg ha ⁻¹) at flowering stage											
	Kharif 98			Rabi' 98 - 99			Kharif 99			Rabi' 99 - 2000		
	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean
W ₁ (manual)	9200	8941	9071	10240	8860	9550	9035	8270	8650	9651	8952	9302
W ₂ (mechanical + manual)	8412	8090	8251	9007	7739	8373	8850	7770	8310	8790	8033	8411
W ₃ (cultural + manual)	10141	9801	9973	10810	10674	10742	10273	9298	9786	10375	10023	10199
W ₄ (cultural + mechanical)	7870	7734	7802	8726	7974	8350	8213	6651	7432	9188	8470	8829
W ₅ (cultural + chemical + mechanical)	9645	9323	9484	10242	9026	9634	9670	9183	9426	9754	9350	9552
W ₆ (chemical + manual)	8862	8542	8702	9501	8481	8991	9080	7854	8466	9182	8761	8972
W ₇ (unweeded control)	7316	7034	7175	7300	5988	6644	6567	5017	5892	7181	6639	6910
Mean	8781	8492		9403	8391		8841	7720		9154	8604	

N	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)
	43.0	185.0	25.0	108.0	32.0	138.0	51.0	219.0
W	265.0	547.0	221.0	455.0	186.0	384.0	268.0	554.0
	349.0	733.0	289.0	602.0	245.0	516.0	355.0	749.0
N at W								
W at N	374.0	773.0	311.0	643.0	263.0	543.0	379.0	783.0

Table 42. Dry matter production (kg ha⁻¹) of rice as influenced by interaction of N management practices and weed control methods at maturity stage

Treatment	Dry matter production (kg ha ⁻¹) at maturity stage											
	Kharif 98			Rabi' 98 - 99			Kharif 99			Rabi' 99 - 2000		
	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean
W ₁ (manual)	14470	13336	13902	14715	13518	14116	13950	12790	13370	15580	14522	15051
W ₂ (mechanical + manual)	14420	12839	13629	14036	11967	13002	13560	12440	13000	14981	13843	14412
W ₃ (cultural + manual)	15815	14616	15215	16220	14913	15567	14780	14040	14410	17468	16572	17020
W ₄ (cultural + mechanical)	12737	10538	11637	13833	12830	13331	13750	10736	12240	14203	13403	13803
W ₅ (cultural + chemical + mechanical)	15062	14520	14790	14828	14031	14420	14756	13060	13908	16175	15345	15760
W ₆ (chemical + manual)	14180	13423	13802	14632	13470	14051	13696	12570	13133	15272	14158	14715
W ₇ (unweeded control)	9910	8030	8970	11975	9123	10549	10700	7640	9170	10610	9970	10290
Mean	13799	12472		14317	12836		13599	11896		14898	13973	
	SEd	CD (p = 0.05)		SEd	CD (p = 0.05)		SEd	CD (p = 0.05)		SEd	CD (p = 0.05)	
N	55.0	236.0		84.0	361.0		69.8	300.0		91.0	392.0	
W	106.0	219.0		280.0	577.0		188.0	387.0		219.0	452.0	
N at W	149.3	353.0		375.5	817.0		255.2	569.0		300.0	682.6	
W at N	150.0	309.7		395.3	816.0		265.2	547.3		309.7	639.2	

At early stage of crop growth (20 DAS), chemical + manual weeded plot recorded maximum DMP, but the weed control treatments did not show any marked variation on this growth parameter at this stage of observation in both the years.

At tillering, flowering and maturity stages, unweeded plot recorded the lowest dry matter of rice (Table 40, 41, 42) in all the seasons, except in third crop at tillering stage where cultural + mechanical method (W_4) of weed control was also on par with unweeded control.

At tillering stage, manual method registered higher DMP (3644 to 4230 kg ha⁻¹) in all the crops and was on par with chemical + manual method (third and fourth crops). However, mechanical + manual (W_2), cultural + chemical + mechanical (W_5) and chemical + manual (W_6) methods were equally effective (first and second crops) in increasing the crop DMP. The cultural + manual method (W_3) was as effective as cultural + mechanical method (W_4) (first, second and fourth crops) in increasing the phytomass over unweeded treatment, but former two (W_3 and W_4) treatments were comparatively less effective over other weed control methods (Table 40).

All the weed control methods studied (manual, mechanical, cultural and chemical) either alone or their combinations were effective in promoting DMP of rice to a considerable extent over unweeded control in all the four crops at flowering stage. Viewed over all the four crops, DMP of rice at flowering was higher with cultural + manual (W_3) and cultural + chemical + mechanical (W_5) methods and the latter one was on par with manual method in first, second and fourth crops. The mechanical + manual (W_2)

and cultural + mechanical (W_4) methods were comparatively less effective in influencing rice DMP over seasons (Table 41).

At maturity stage, the cultural + manual (W_3) and cultural + chemical + mechanical (W_5) methods had significantly increased the rice DMP over rest of the treatments in both the years, except in second crop, where this was comparable with W_1 and W_6 . These two treatments (W_1 and W_6) were also equally effective and exerted greater influence in improving DMP of rice over mechanical + manual and cultural + mechanical methods of weed control (Table 42).

The interaction effect between split application of N and weed control methods was significant in all the crops at flowering and maturity stages (Table 41 and 42). Application of N in four splits in combination with cultural + manual method of weed control (N_1W_3) registered maximum DMP in all the crops. However, this combination was on par with the combination of N_1W_5 and N_2N_3 (first crop); N_1W_1 , N_1W_5 and N_2W_3 (second and fourth crops) and significantly superior over all other treatment combinations (third crop) at flowering stage. In contrast to flowering stage, at maturity stage all weed control methods increased the rice DMP irrespective of N management and were significantly superior compared to unweeded control in all the crops. The combination of N_1W_3 was significantly superior over rest of the combinations in all the four crops, except in the third crop, where it was on par with N_1W_5 to enhance rice DMP.

4.3.1.6. Crop growth rate (CGR) (Table 43)

The crop growth rate between 20 DAS to tillering (20 DAS-T), tillering to flowering (T – F) and flowering to maturity (F – M) for all the four crops are presented in Table 43.

CGR did not show any significant variation under two N management practices during the early crop stage. Whereas, N_1 was significantly superior to N_2 in the subsequent stages, except at T – F of first crop and F – M of fourth crop.

Weed control methods had significant influence on CGR in all the crops. At the early stage (20 DAS – T), manually weeded plot recorded higher CGR value over rest of the treatments in all the crops, except in third and fourth crops, but remained at par with chemical + manual method (W_6). Apart from this variation, all weed control methods recorded more or less similar CGR in all the four crops at this stage.

During T – F stage, maximum growth rate was observed under W_3 followed by W_5 in both the years. However, CGR was intermediary in W_1 , W_2 , W_4 and W_6 treatments over seasons. Significantly lower CGR was observed under unweeded plot (W_7) in all the crops, but was on par with W_2 and W_4 in first crop.

The influence of weed control treatment was not consistent on CGR at F - M stage in both years. It is quite clear that CGR in W_7 was significantly lower than rest of the weed control treatments in all the crops, except in second crop, where it was on par with W_1 treatment. All other weed control treatments were equally effective in influencing per day growth of crop during F-M stage in all the four crops.

Table 43. Crop growth rate ($\text{g m}^{-2} \text{ day}^{-1}$) of rice as influenced by interaction of N management practices and weed control methods

Crop growth rate (g m ⁻² day ⁻¹)														
Treatment	Kharif 98			Rabi' 98 - 99			Kharif 99			Rabi' 99 - 2000				
	20-T	T-F	F-M	20-T	T-F	F-M	20-T	T-F	F-M	20-T	T-F	F-M		
N management														
N ₁ (four splits)	22.5	12.3	16.7	19.9	10.9	15.3	19.6	13.7	15.9	19.4	12.2	15.9		
N ₂ (five splits)	21.1	12.0	13.3	18.4	9.48	13.0	18.4	11.3	13.9	19.8	10.8	14.9		
SEd	0.34	0.37	0.59	0.53	0.21	0.21	0.37	0.35	0.41	0.27	0.21	0.28		
CD (p = 0.05)	NS	NS	2.2	NS	0.90	1.32	NS	1.49	1.77	NS	0.92	NS		
Weed control methods														
W ₁ (manual)	24.8	12.1	16.1	22.2	10.5	13.8	21.4	12.5	15.8	22.4	11.5	15.9		
W ₂ (mechanical + manual)	22.5	10.9	17.9	19.1	9.2	14.0	17.9	13.0	15.6	19.5	10.5	16.6		
W ₃ (cultural + manual)	20.7	15.9	17.5	18.8	13.7	14.6	19.1	16.3	15.4	19.1	14.4	18.9		
W ₄ (cultural + mechanical)	20	10.5	12.8	18.3	9.4	15.1	17.4	11.0	16.0	18.6	12.1	13.4		
W ₅ (cultural + chemical + mechanical)	22.7	13.9	17.7	19.3	11.5	14.5	19.6	15.1	15.0	19.9	12.8	17.2		
W ₆ (chemical + manual)	22.3	12.1	17.0	19.9	10.1	15.3	21.2	12.1	15.6	21.0	10.9	16.3		
W ₇ (unweeded control)	18.8	9.6	6.0	16.2	6.9	11.8	16.3	7.6	10.9	17.0	8.23	9.39		
SEd	0.88	0.78	0.87	1.06	0.51	0.92	1.02	0.88	0.97	0.96	0.75	1.00		
CD (p = 0.05)	1.82	1.62	1.79	2.18	1.06	1.90	2.11	1.82	1.98	1.98	1.55	2.08		
20 represents 20 DAS T: Tillering F: Flowering M: Maturity														

4.3.1.7. Total chlorophyll content (mg g^{-1} fresh weight) of rice

4.3.1.7.1. Tillering stage (Table 44)

The total chlorophyll content at tillering stage was not influenced by N management practices in both the years under study.

Weed control treatments also failed to show any significant influence on chlorophyll content in all the crops, except in first crop where cultural + manual treatment significantly increased the chlorophyll content over mechanical + manual, cultural + mechanical and unweeded control treatments. In general, cultural method of weed control (W_3 , W_4 and W_5 treatments) resulted in more chlorophyll content over rest of the treatments (second to fourth crops) and unweeded control treatment always recorded lower chlorophyll content in both the years.

4.3.1.7.2. Panicle initiation (PI) stage (Table 45)

Nitrogen management practices had significant influence on total chlorophyll content at panicle initiation stage. Application of four splits of N resulted in higher chlorophyll content over five splits of N in all the seasons of the study.

Among the weed control methods, cultural + manual method (W_3) recorded highest chlorophyll content (2.60 to 2.98 mg g^{-1} fresh weight) which was followed by cultural + chemical + mechanical method (W_5), but it remained on par with W_1 and W_6 in all the four crops except in second year where W_3 was significantly superior over W_6 . The unweeded plot had significantly lowest chlorophyll content in fourth crop, but was on par with W_2 , W_4 and W_6 (first and second crops) and W_2 and W_4 (third crop).

Table 44. Total chlorophyll content (mg g^{-1} of fresh leaf) as influenced by N management practices and weed control methods at tillering stage

Treatment	Total chlorophyll content (mg g^{-1} of fresh leaf) at tillering stage			
	<i>Kharif 98</i>	<i>Rabi 98-99</i>	<i>Kharif 99</i>	<i>Rabi 99-2000</i>
N Management				
N ₁ (four splits)	1.93	1.73	1.92	1.73
N ₂ (five splits)	1.98	1.79	1.95	1.83
SEd	0.03	0.02	0.03	0.05
CD ($p=0.05$)	NS	NS	NS	NS
Weed control methods				
W ₁ (manual)	1.98	1.79	1.91	1.80
W ₂ (mechanical + manual)	1.89	1.69	1.87	1.70
W ₃ (cultural + manual)	2.10	1.80	2.01	1.88
W ₄ (cultural + mechanical)	1.82	1.83	1.96	1.83
W ₅ (cultural + chemical + mechanical)	2.05	1.88	2.02	1.84
W ₆ (chemical + manual)	1.90	1.70	1.94	1.75
W ₇ (unweeded control)	1.86	1.64	1.86	1.70
SEd	0.10	0.15	0.06	0.06
CD ($p=0.05$)	0.20	NS	NS	NS

Table 45. Total chlorophyll content (mg g⁻¹ of fresh leaf) as influenced by N management practices and weed control methods at panicle initiation stage

Treatment	Total chlorophyll content (mg g ⁻¹ of fresh leaf) at panicle initiation stage			
	<i>Kharif 98</i>	<i>Rabi 98-99</i>	<i>Kharif 99</i>	<i>Rabi 99-2000</i>
N Management				
N ₁ (four splits)	2.80	2.49	2.79	2.54
N ₂ (five splits)	2.72	2.38	2.58	2.42
SEd	0.02	0.02	0.01	0.01
CD (p=0.05)	0.07	0.08	0.05	0.05
Weed control methods				
W ₁ (manual)	2.80	2.52	2.73	2.60
W ₂ (mechanical + manual)	2.70	2.39	2.69	2.54
W ₃ (cultural + manual)	2.98	2.60	2.83	2.65
W ₄ (cultural + mechanical)	2.68	2.32	2.59	2.48
W ₅ (cultural + chemical + mechanical)	2.85	2.55	2.76	2.61
W ₆ (chemical + manual)	2.72	2.40	2.71	2.60
W ₇ (unweeded control)	2.60	2.30	2.53	1.88
SEd	0.08	0.07	0.08	0.04
CD (p=0.05)	0.16	0.15	0.17	0.08

4.3.1.8. SPAD value of rice leaf

4.3.1.8.1. Tillering stage (Table 46)

The chlorophyll meter readings (SPAD values) clearly showed that SPAD value was not influenced by split application of N at tillering stage of all the four crops.

Among the weed control methods, unweeded control treatment recorded significantly lower SPAD value (29.2 to 32.0) in all the four crops. The maximum SPAD value was observed in W_5 and the value was comparable with W_1 , W_3 and W_4 treatments in first and fourth crops and W_1 and W_3 in second crop, but did not differ significantly among the weed control treatments in the third crop.

4.3.1.8.2. Panicle initiation stage (Table 47)

SPAD value was significantly higher under four splits of N as compared to five splits at panicle initiation stage in all the four crops.

SPAD value was invariably lower in unweeded plot at panicle initiation stage over seasons. Among the weed control methods, cultural + manual method (W_3) recorded maximum value over seasons and was on par with cultural + chemical + mechanical (W_5), manual (W_1) and chemical + manual (W_6) method of weed control (first and fourth crops) and W_1 and W_5 (third crop). However, in second crop all the weed control methods showed similar SPAD values with small variations.

Table 46. Chlorophyll meter readings (SPAD –502 values) as influenced by N management practices and weed control methods at tillering stage

Treatment	chlorophyll meter readings (SPAD –502 values) at tillering stage			
	<i>Kharif 98</i>	<i>Rabi 98-99</i>	<i>Kharif 99</i>	<i>Rabi 99-2000</i>
N Management				
N ₁ (four splits)	35.4	33.0	34.5	34.7
N ₂ (five splits)	35.8	34.4	33.8	33.8
SEd	0.36	0.38	0.49	0.40
CD (p=0.05)	NS	NS	NS	NS
Weed control methods				
W ₁ (manual)	36.3	34.1	34.1	34.8
W ₂ (mechanical + manual)	34.8	32.9	34.4	34.3
W ₃ (cultural + manual)	37.0	35.2	35.4	35.5
W ₄ (cultural + mechanical)	36.6	33.5	35.2	34.7
W ₅ (cultural + chemical + mechanical)	37.3	35.8	35.4	36.5
W ₆ (chemical + manual)	35.4	33.6	33.7	34.6
W ₇ (unweeded control)	32.0	30.8	30.9	29.2
SEd	0.75	0.89	0.94	0.85
CD (p=0.05)	1.55	1.83	1.95	1.76

Table 47. Chlorophyll meter readings (SPAD – 502 values) as influenced by N management practices and weed control methods at panicle initiation stage

Treatment	chlorophyll meter readings (SPAD –502 values) at panicle initiation stage			
	<i>Kharif 98</i>	<i>Rabi 98-99</i>	<i>Kharif 99</i>	<i>Rabi 99-2000</i>
N Management				
N ₁ (four splits)	38.3	35.3	37.2	36.5
N ₂ (five splits)	34.6	33.9	35.2	34.8
SEd	0.28	0.23	0.40	0.36
CD (p=0.05)	1.24	1.01	1.72	1.54
Weed control methods				
W ₁ (manual)	37.2	35.3	36.8	36.4
W ₂ (mechanical + manual)	36.5	35.1	36.3	35.3
W ₃ (cultural + manual)	38.8	36.3	38.4	37.6
W ₄ (cultural + mechanical)	34.9	34.2	35.6	34.9
W ₅ (cultural + chemical + mechanical)	38.5	36.2	37.4	36.5
W ₆ (chemical + manual)	36.8	34.7	35.9	35.8
W ₇ (unweeded control)	32.3	30.5	33.2	32.8
SEd	0.98	1.05	0.85	0.92
CD (p=0.05)	2.02	2.16	1.76	1.90

4.3.2. Nutrient uptake by rice

4.3.2.1. Nitrogen uptake at various growth stages of rice (Table 48 to 51)

In accordance with the DMP of rice, N uptake of rice at 20 DAS was not significantly influenced by split application of N as well as weed control methods. However, N uptake by rice under five split of N was comparatively more than four splits (N_1) in all crops at 20 DAS. Among weed control methods, chemical + manual method (W_6) resulted in comparatively higher N uptake by rice over rest of the treatments in all the four crops.

With the advancement of growth, the amount of N uptake by rice also increased (Table 48 to 51). At tillering stage, the split application of N did not have any significant influence on N uptake by rice over seasons. However, N uptake by rice at flowering and maturity stages was significantly enhanced under four splits of N (N_1) over five splits (N_2) treatment in all crops.

All weed control treatments had significant positive influence on N uptake by rice over unweeded treatment at tillering, flowering and maturity stages in all the crops. At tillering stage, manual weeding significantly increased N uptake (49.37 to 54.15 kg ha^{-1}) over seasons and was on par with cultural + chemical + mechanical and chemical + manual method (second and fourth crops) and chemical + manual method (third crop) (Table 49). However, at flowering and maturity stages, N uptake was significantly higher under cultural + manual treatment in all the crops, followed by cultural + chemical + mechanical method and both these two treatments were comparable at flowering stage (third crop) and at maturity stage (first to fourth crops) of the crop. The W_1 , W_2 and W_6 treatments

Table 48. Nitrogen uptake (kg ha^{-1}) by rice as influenced by N management practices and weed control methods at 20 DAS

Treatment	Nitrogen uptake (kg ha^{-1}) at 20 DAS			
	<i>Kharif 98</i>	<i>Rabi 98-99</i>	<i>Kharif 99</i>	<i>Rabi 99-2000</i>
N Management				
N ₁ (four splits)	4.56	3.97	4.16	3.92
N ₂ (five splits)	5.27	4.17	4.76	4.37
SEd	0.17	0.05	0.15	0.12
CD ($p=0.05$)	NS	NS	NS	NS
Weed control methods				
W ₁ (manual)	4.84	4.11	4.49	4.34
W ₂ (mechanical + manual)	5.12	4.16	4.58	4.30
W ₃ (cultural + manual)	4.79	3.98	4.40	4.28
W ₄ (cultural + mechanical)	4.76	4.04	4.41	3.90
W ₅ (cultural + chemical + mechanical)	4.84	4.09	4.41	4.20
W ₆ (chemical + manual)	5.19	4.21	4.64	4.35
W ₇ (unweeded control)	4.89	3.88	4.32	4.16
SEd	0.22	0.19	0.17	0.25
CD ($p=0.05$)	NS	NS	NS	NS

Table 49. Nitrogen uptake (kg ha^{-1}) by rice as influenced by N management practices and weed control methods at tillering stage

Treatment	Nitrogen uptake (kg ha^{-1}) at tillering stage			
	<i>Kharif 98</i>	<i>Rabi 98-99</i>	<i>Kharif 99</i>	<i>Rabi 99-2000</i>
N Management				
N ₁ (four splits)	47.01	44.50	44.37	46.46
N ₂ (five splits)	48.78	46.61	46.06	48.19
SEd	0.46	0.57	0.55	0.49
CD ($p=0.05$)	NS	NS	NS	NS
Weed control methods				
W ₁ (manual)	54.15	49.37	49.94	51.03
W ₂ (mechanical + manual)	49.28	45.78	43.61	47.43
W ₃ (cultural + manual)	45.62	45.73	45.42	47.41
W ₄ (cultural + mechanical)	46.49	44.18	43.28	45.01
W ₅ (cultural + chemical + mechanical)	50.07	46.68	46.68	48.48
W ₆ (chemical + manual)	48.78	47.28	49.61	50.48
W ₇ (unweeded control)	40.93	39.90	37.97	41.44
SEd	1.59	1.52	1.20	1.44
CD ($p=0.05$)	3.28	3.14	2.48	2.97

Table 50. Nitrogen uptake (kg ha^{-1}) by rice as influenced by interaction of N management practices and weed control methods at flowering stage

Nitrogen uptake (kg ha ⁻¹) at flowering stage												
Treatment	Kharif'98			Rabi' 98 - 99			Kharif' 99			Rabi' 99 - 2000		
	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean
W ₁ (manual)	80.2	78.0	79.1	94.4	77.5	86.0	80.3	73.3	76.8	89.7	83.2	86.5
W ₂ (mechanical + manual)	72.4	69.7	71.0	80.0	71.2	75.6	78.7	68.9	73.8	80.9	73.9	77.4
W ₃ (cultural + manual)	89.1	86.1	87.6	94.3	93.0	93.7	89.4	80.6	85.0	97.6	94.2	95.9
W ₄ (cultural + mechanical)	68.1	66.9	67.5	78.5	71.7	75.1	72.1	61.7	66.9	81.7	78.0	79.8
W ₅ (cultural + chemical + mechanical)	84.5	81.7	83.1	101.5	72.1	86.8	88.5	75.1	81.8	90.7	87.0	88.8
W ₆ (chemical + manual)	79.3	76.4	77.9	80.0	79.8	79.9	80.7	69.7	75.2	83.6	77.1	80.4
W ₇ (unweeded control)	63.1	60.7	61.9	63.5	56.1	59.8	58.1	47.8	53.0	63.2	58.4	60.8
Mean	76.7	74.2		84.6	74.5		78.3	68.2		83.9	78.8	
	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)
	0.46	1.96	1.00	4.33	1.01	4.36	0.90	3.87				
N	1.64	3.39	1.82	3.76	1.65	3.40	1.56	3.21				
W	2.20	4.75	2.59	6.21	2.38	5.88	2.23	3.41				
N at W	2.33	4.80	2.57	5.31	2.33	4.81	2.20	4.54				
W at N												

Table 51. Nitrogen uptake (kg ha^{-1}) by rice as influenced by interaction of N management practices and weed control methods at maturity stage

Treatment	Nitrogen uptake (kg ha ⁻¹) at maturity stage											
	Kharif'98			Rabi' 98 - 99			Kharif' 99			Rabi' 99 - 2000		
	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean
W ₁ (manual)	117.1	99.6	108.3	112.7	100.9	106.8	110.5	98.8	104.6	120.0	111.8	115.9
W ₂ (mechanical + manual)	108.8	100.0	104.4	106.6	98.5	102.6	106.8	98.3	102.6	118.8	109.8	114.3
W ₃ (cultural + manual)	121.2	114.9	118.0	124.1	106.5	115.3	118.2	109.0	113.6	132.9	126.1	129.5
W ₄ (cultural + mechanical)	106.0	89.8	97.9	105.1	97.5	101.3	100.0	86.8	93.4	109.6	103.5	106.5
W ₅ (cultural + chemical + mechanical)	119.6	105.7	112.7	115.8	105.9	110.8	115.3	103.5	109.4	126.4	119.8	123.1
W ₆ (chemical + manual)	113.3	96.3	104.9	119.9	87.5	103.7	110.6	97.2	103.9	114.8	106.4	110.6
W ₇ (unweeded control)	87.1	71.1	79.1	85.4	78.9	82.1	68.7	69.6	69.2	81.2	73.1	77.2
Mean	110.4	96.8		109.9	96.5		104.3	94.7		114.8	107.2	

	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)
N	0.56	2.39	0.47	2.03	0.42	1.81	0.73	3.15
W	2.90	6.10	2.60	5.50	3.10	6.40	3.29	6.80
N at W	3.91	8.25	3.49	7.36	4.08	8.52	4.38	9.31
W at N	4.18	8.63	3.74	7.72	4.39	9.05	4.66	9.62

were intermediary in respect of N uptake by rice at maturity stage (first to fourth crops) and cultural + mechanical + method (W_2) recorded the lowest N uptake in all the four crops at flowering and maturity stages.

The interaction between split application of nitrogen and weed control methods was significant in both years at flowering and maturity stages of the crop. At flowering stage, four splits of N with cultural + manual (N_1W_3) method recorded the highest N uptake in the first, third and fourth crops, while in second crop, cultural + chemical + mechanical method with four splits of N (N_1W_5) was significantly superior in enhancing N uptake over other treatment combinations. At maturity stage also the combination of N_1W_3 registered the highest N uptake over seasons and was on par with N_1W_1 , N_1W_5 , N_1W_6 and N_2W_3 (first crop), N_1W_5 (second crop), N_1W_1 , N_1W_5 and N_1W_6 (third crop) and N_1W_5 and N_2W_3 (fourth crop). In unweeded control plot under four splits of N recorded the lowest N uptake by rice at maturity stage in first to fourth crops.

4.3.2.2. Phosphorus uptake at maturity (Table 52)

The phosphorus uptake by rice at maturity stage was significantly enhanced by application of N in four splits (N_1) over five splits of N (N_2).

All the weed control methods significantly influenced phosphorus uptake of rice at maturity stage over control in all the seasons. Cultural + manual method (W_3) was more effective in maximizing phosphorus uptake (22.6 to 28.6 kg ha⁻¹) in first to fourth crops and was comparable with cultural + chemical + mechanical (over seasons) and manual method (third crop). Apart from the cultural + manual method, the manual (W_1), cultural

Table 52. Phosphorus uptake (kg ha^{-1}) by rice as influenced by interaction of N management practices and weed control methods at maturity stage

Phosphorus uptake (kg ha ⁻¹) at maturity stage												
Treatment	Kharif'98			Rabi' 98 - 99			Kharif' 99			Rabi' 99 - 2000		
	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean
W ₁ (manual)	23.0	20.5	21.7	22.5	21.3	21.9	22.5	19.2	20.9	25.2	23.9	24.5
W ₂ (mechanical + manual)	22.2	20.0	21.1	20.7	18.8	21.5	21.3	18.1	19.7	24.2	21.9	23.1
W ₃ (cultural + manual)	25.3	23.4	24.3	25.2	24.6	24.9	23.2	22.0	22.6	29.2	28.0	28.6
W ₄ (cultural + mechanical)	21.7	18.5	20.1	22.1	21.0	19.8	20.4	17.3	18.8	23.1	21.1	22.1
W ₅ (cultural + chemical + mechanical)	24.9	22.4	23.7	23.3	22.9	23.1	22.9	20.2	21.6	26.0	24.8	25.4
W ₆ (chemical + manual)	23.0	20.2	21.6	22.8	20.8	21.8	20.6	18.9	19.8	24.2	22.3	23.2
W ₇ (unweeded control)	14.8	15.0	14.9	16.7	14.5	15.6	15.2	12.1	13.6	16.3	14.3	15.3
Mean	22.1	20.0		21.9	20.6		20.9	18.3		24.0	22.3	
	SEd	CD (p = 0.05)		SEd	CD (p = 0.05)		SEd	CD (p = 0.05)		SEd	CD (p = 0.05)	
N	0.29	1.20		0.21	0.90		0.11	0.46		0.32	1.38	
W	1.00	2.10		0.73	1.50		0.89	1.84		1.60	3.30	
N at W	1.36	2.94		0.97	2.11		1.17	2.44		2.12	4.48	
W at N	1.44	2.97		1.03	2.12		1.26	2.60		2.26	4.67	

+ chemical + mechanical (W_5) and chemical + manual (W_6) methods which were statistically on par, increased the phosphorus uptake of rice in all the seasons. But the phosphorus uptake was least with cultural + mechanical method (W_4) followed by mechanical + manual method (W_2) among the weed control treatments in both the years.

The interaction effect between split application of N and weed control methods was significant in both the years. The best combination in terms of highest P uptake in each crop was four splits of N with cultural + manual method (25.3, 25.2, 23.2 and 29.2 kg ha⁻¹ in first to fourth crops, respectively) and was on par with the combinations of N_1W_1 , N_1W_5 , N_1W_6 , N_2W_3 and N_2W_5 (first crop) or N_1W_5 and N_2N_3 (second crop) or N_1W_1 , N_1W_2 , N_1W_5 and N_2W_3 (third crop) or N_1W_1 , N_1W_5 and N_2W_3 (fourth crop). Over all, unweeded plots applied with N in four or five splits registered the lowest uptake of P compared to other treatment combinations where weeds were controlled by any of the method.

4.3.2.3. Potassium uptake at maturity (Table 53)

Split application of N had significant influence on K uptake by rice. Application of N in four splits resulted in significantly higher K uptake over five splits of N in all the crops.

All weed control measures enhanced the K uptake of rice and were significantly superior over unweeded control plot. Control of weeds by cultural + manual method registered the highest K uptake (162.9 to 180.6 kg ha⁻¹ for first to fourth crop) followed by cultural + chemical + mechanical method and both were equally effective in first and third crops. However, the K uptake was reduced considerably under cultural + mechanical and mechanical + manual methods of weed control in both years.

Table 53. Potassium uptake (kg ha^{-1}) by rice as influenced by interaction of N management practices and weed control methods at maturity stage

Treatment	Potassium uptake (kg ha ⁻¹) at maturity stage											
	Kharif'98			Rabi' 98 - 99			Kharif' 99			Rabi' 99 - 2000		
	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean
W ₁ (manual)	175.8	153.1	164.5	170.6	157.2	163.9	170.5	145.0	157.8	176.0	164.4	170.2
W ₂ (mechanical + manual)	161.6	141.2	151.4	151.0	144.0	148.0	156.2	143.3	149.8	160.3	151.9	158.0
W ₃ (cultural + manual)	177.5	159.9	168.7	176.5	169.3	172.9	172.9	152.9	162.9	184.1	177.2	180.6
W ₄ (cultural + mechanical)	143.8	126.7	135.3	153.8	142.3	147.5	154.0	130.5	142.2	164.3	151.7	156.1
W ₅ (cultural + chemical + mechanical)	178.9	156.1	167.5	174.1	154.5	164.3	164.3	155.5	159.9	177.0	167.1	172.1
W ₆ (chemical + manual)	175.9	150.1	163.0	171.8	155.6	163.7	166.8	141.8	154.3	172.8	163.4	168.1
W ₇ (unweeded control)	91.1	92.8	92.0	110.2	100.3	105.2	105.0	84.2	94.6	106.3	96.3	101.3
Mean	157.8	140.0		158.3	146.2		155.6	136.2		163.0	153.2	

	SED	CD (p = 0.05)	SED	CD (p = 0.05)	SED	CD (p = 0.05)	SED	CD (p = 0.05)
N	0.93	4.00	1.24	5.34	0.82	3.53	1.07	4.60
W	2.97	6.15	2.56	5.30	2.17	4.49	1.99	4.10
N at W	4.01	8.76	3.58	8.36	2.96	6.63	2.81	6.72
W at N	4.21	8.70	3.63	7.50	3.08	6.35	2.81	5.80

Considering the interaction effects (Table 53), the best combination found to enhance the potassium uptake was four splits of N with cultural + manual method (N_1W_3) (177.5, 176.5, 172.9 and 184.1 kg ha⁻¹ in the four cropping seasons respectively). The treatment combination N_1W_3 was comparable with N_1W_1 , N_1W_5 and N_1W_6 in the first and second crops and N_1W_1 and N_1W_6 in the third crop and significantly superior to all other combinations in the fourth crop to enhance K uptake by rice. Lowest K uptake value was under five splits of N in the unweeded plot in all the cropping seasons except in the first crop, where much variation was not observed for the N management practices in the unweeded treatment.

4.3.3. Yield components

4.3.3.1. Panicles m⁻² (Table 54)

Split application of N and weed control methods influenced the number of ear bearing tillers (panicles) in all the seasons. Application of N in four splits registered maximum panicles m⁻² (522, 432 and 537 in second, third and fourth crops, respectively) and was significantly more than that recorded in five splits of N. In the case of first crop, the panicles m⁻² between the two N management practices did not differ significantly.

The number of panicles m⁻² was very much enhanced by the weed control methods over unweeded control in all the seasons. However, in first and third crops, panicles m⁻² under the cultural + mechanical method (W_4) was comparable with unweeded control plots. The cultural + manual method (W_3) ranked first (464 to 593 m⁻²) in enhancing panicles m⁻² in all the four crops and was on par with manual (W_1), cultural + chemical + mechanical (W_5) and chemical + manual (W_6) methods in the first crop, cultural + chemical + mechanical (W_5) in the second crop and significantly superior to

Table 54. Panicles m⁻² as influenced by interaction of N management practices and weed control methods

Treatment	Panicles m ⁻²											
	Kharif 98			Rabi' 98 - 99			Kharif 99			Rabi' 99 - 2000		
	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean
W ₁ (manual)	468	474	470	527	511	519	441	415	428	564	524	544
W ₂ (mechanical + manual)	439	452	446	518	501	510	393	427	410	525	489	507
W ₃ (cultural + manual)	513	473	493	562	553	558	490	439	464	602	584	593
W ₄ (cultural + mechanical)	425	418	422	520	482	501	408	387	397	513	493	503
W ₅ (cultural + chemical + mechanical)	493	485	489	555	534	544	449	424	437	571	551	561
W ₆ (chemical + manual)	459	457	458	531	491	511	447	408	428	555	515	535
W ₇ (unweeded control)	393	412	402	443	419	431	396	362	379	429	405	417
Mean	456	453		522	499		432	409		537	509	
	SEd	CD (p = 0.05)		SEd	CD (p = 0.05)		SEd	CD (p = 0.05)		SEd	CD (p = 0.05)	
N	2.60	NS		3.8	16.4		1.4	6.0		3.2	13.7	
W	17.7	36.5		12.6	26.0		9.6	19.8		14.1	29.1	
N at W	23.3	48.7		16.9	26.9		12.6	26.4		18.7	39.9	
W at N	25.0	51.6		17.8	36.		13.5	27.9		19.9	41.2	

all other weed control methods in the third and fourth crops. The effect of W_1 , W_2 and W_6 (first to third crops) and W_1 and W_6 (fourth crop) treatments in increasing the panicles m^{-2} was comparable and these treatments were significantly superior over unweeded treatment.

The interaction effect of split application of N and weed control methods on panicles production was significant in all the four crops. Combination of four splits of N and cultural + manual method (N_1W_3) recorded the maximum number of panicles m^{-2} in all the crops and was on par with five splits of N with cultural + manual method (N_2W_3) in both years, except in the third crop, where N_1W_3 was significantly superior over rest of the treatment combinations in enhancing the number of panicles m^{-2} .

4.3.3.2. Filled grains panicle⁻¹ (Table 55)

Filled grains panicle⁻¹ was substantially influenced by split application of N across the seasons. Filled grains panicle⁻¹ was significantly more under four splits of N (80.5 to 96.6) over five splits (76.6 to 87.1).

All the weed control methods significantly influenced the filled grains panicle⁻¹ compared to unweeded crop. Though cultural + manual method recorded significantly higher values of filled grains, it was on par with cultural + chemical + mechanical method in all the four crops. Among the weed control methods, filled grains panicle⁻¹ was considerably lower under cultural + mechanical method of weed control over seasons.

Table 55. Filled grains panicle⁻¹ as influenced by interaction of N management practices and weed control methods

Filled grains panicle ⁻¹													
Treatment	Kharif 98			Rabi' 98 - 99			Kharif 99			Rabi' 99 - 2000			
	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean	
W ₁ (manual)	93.7	87.7	90.7	83.0	79.0	81.0	95.2	93.5	94.4	84.2	79.4	81.8	
W ₂ (mechanical + manual)	95.0	80.5	87.7	83.0	75.0	79.0	98.7	84.2	91.5	83.1	75.3	79.2	
W ₃ (cultural + manual)	101.7	95.3	98.5	84.3	83.7	84.0	101.3	95.2	98.3	89.5	85.2	87.4	
W ₄ (cultural + mechanical)	89.1	81.9	85.5	77.0	75.0	76.0	94.3	80.7	87.5	78.3	76.2	77.3	
W ₅ (cultural + chemical + mechanical)	101.0	95.0	98.0	84.0	84.0	84.0	101.0	91.2	96.1	87.4	83.4	85.4	
W ₆ (chemical + manual)	94.7	89.9	92.3	83.0	78.0	80.0	99.0	85.7	92.4	83.3	76.4	79.9	
W ₇ (unweeded control)	82.7	76.3	79.5	69.3	61.3	65.3	86.7	79.3	83.0	70.1	60.5	65.3	
Mean	94.0	86.7		80.5	76.6		96.6	87.1		82.3	76.8		
	SEd	CD (p = 0.05)		SEd	CD (p = 0.05)		SEd	CD (p = 0.05)		SEd	CD (p = 0.05)		
N	0.80	3.40		0.87	3.74		1.20	5.13		1.14	4.90		
W	1.47	3.04		1.37	2.84		1.69	3.50		1.79	3.70		
N at W	2.08	4.34		2.00	4.98		2.51	6.45		2.61	6.50		
W at N	2.08	4.30		1.95	4.02		2.39	4.93		2.53	5.23		

The interaction between split application of N and weed control methods was significant in both the years. Maximum number of filled grains panicle⁻¹ was due to the interaction effect of N₁W₃ and ranged from 84.3 to 101.7 filled grains panicle⁻¹ in first to fourth crops. Such a promotional effect on this yield component was also seen in the combination of cultural + chemical + mechanical method and four splits of N. In general, W₃ and W₅ influenced the filled grains production panicle⁻¹ favourably compared to other treatments irrespective of number of nitrogen splits. Evidently lowest filled grains panicle⁻¹ (60.5 to 79.3) was observed in unweeded and fertilized in more splits.

4.3.3.3. Unfilled grains panicle⁻¹ (Table 56)

The percentage of unfilled grains panicle⁻¹ varied significantly with split application of N and weed control methods. Percentage of unfilled grains was more under five splits of N as compared to four splits irrespective of the seasons.

Among the weed control methods, cultural + manual method (W₃) recorded least percentage of unfilled grains panicle⁻¹ and it was on par with cultural + chemical + mechanical method (W₅) in all the four crops. These two treatments were also significantly superior over rest of the treatments in all the crops except in second crop, where W₅ was on par with manual (W₁), mechanical + manual (W₂) and chemical + manual (W₆) methods. The treatments W₁, W₂ and W₆ were comparable and significantly superior over unweeded control treatment in both the years.

Table 56. Percentage of unfilled grains panicle⁻¹ as influenced by N management practices and weed control methods

Treatment	Unfilled grains panicle ⁻¹ (per cent)			
	<i>Kharif 98</i>	<i>Rabi 98-99</i>	<i>Kharif 99</i>	<i>Rabi 99-2000</i>
N Management				
N ₁ (four splits)	12.9	14.6	13.1	14.3
N ₂ (five splits)	14.5	16.3	14.2	15.7
SEd	0.31	0.38	0.22	0.28
CD (p=0.05)	1.35	1.63	1.63	1.21
Weed control methods				
W ₁ (manual)	13.6	15.3	13.3	15.1
W ₂ (mechanical + manual)	13.8	15.0	13.2	14.9
W ₃ (cultural + manual)	12.1	14.2	11.8	13.0
W ₄ (cultural + mechanical)	14.8	16.6	15.1	16.1
W ₅ (cultural + chemical + mechanical)	12.3	14.5	12.0	13.3
W ₆ (chemical + manual)	13.5	15.2	13.7	15.4
W ₇ (unweeded control)	16.0	17.5	16.5	17.3
SEd	0.49	0.37	0.51	0.44
CD (p=0.05)	1.01	0.76	1.05	0.91

4.3.3.4. 1000 grain weight (Table 57)

The 1000 grain weight did not differ significantly between the different split application of N. Though 1000 grain weight was significantly varied for the weed control treatments, the difference between the unweeded control and other treated plots was however, only marginal. The highest 1000 grain weight was recorded under cultural + manual method (W_3), but most of the weed control treatments were on par to produce similar grain weight in all the crops. Unweeded crop invariably had the lowest weight of grains over seasons.

4.3.3.5. Grain yield (Table 58)

Split application of N substantially influenced the grain yield in both the years. Application of N in four splits skipping basal dose (N_1) significantly enhanced the grain yield of rice over five splits including basal application (N_2) in all the four crops. The increase in grain yield with N_1 over N_2 ranged from 2.6 to 4.2 per cent over the seasons.

Absence of weed control measure drastically reduced the grain yield in all the four crops (3941 to 4111 kg ha⁻¹) compared to the maximum grain yield obtained with cultural + manual method (W_3) of weed control that ranged from 6332 to 6846 kg ha⁻¹ which was followed by cultural + chemical + mechanical method (W_5) across the seasons. However, W_3 was significantly superior over W_5 in both the years. The other weed control methods produced significantly lower grain yields compared to the above two (W_3 and W_5) treatments in all the seasons. In both the years, cultural + manual weeding (W_3) recorded an yield increase of 58.4 to 66.9 per cent over unweeded control plots.

Table 57. 1000 grain weight (g) as influenced by N management practices and weed control methods

Treatment	1000 grain weight (g)			
	<i>Kharif 98</i>	<i>Rabi 98-99</i>	<i>Kharif 99</i>	<i>Rabi 99-2000</i>
N Management				
N ₁ (four splits)	22.05	18.21	23.21	18.32
N ₂ (five splits)	21.81	18.15	22.63	18.14
SEd	0.08	0.02	0.14	0.05
CD (p=0.05)	NS	NS	NS	NS
Weed control methods				
W ₁ (manual)	22.05	18.25	23.15	18.26
W ₂ (mechanical + manual)	22.17	18.25	22.90	18.25
W ₃ (cultural + manual)	22.68	18.32	23.48	18.31
W ₄ (cultural + mechanical)	21.43	18.10	22.43	18.25
W ₅ (cultural + chemical + mechanical)	22.47	18.30	23.30	18.28
W ₆ (chemical + manual)	21.80	18.21	23.03	18.26
W ₇ (unweeded control)	20.93	17.85	22.15	18.01
SEd	0.49	0.07	0.30	0.13
CD (p=0.05)	1.01	0.15	0.62	0.27

Table 58. Grain yield (kg ha^{-1}) as influenced by interaction of N management practices and weed control methods

Grain yield (kg ha ⁻¹)											
Treatment	Kharif 98			Rabi' 98 - 99			Kharif 99			Rabi' 99 - 2000	
	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂
W ₁ (manual)	6327	6136	6232	5664	5346	5505	6261	5920	6090	5808	5680
W ₂ (mechanical + manual)	6232	5711	5972	5227	5110	5168	5877	5639	5758	5601	5393
W ₃ (cultural + manual)	6871	6821	6846	6355	6308	6332	6671	6542	6607	6517	6505
W ₄ (cultural + mechanical)	5642	5546	5594	5227	5027	5127	5493	5433	5463	5313	5087
W ₅ (cultural + chemical + mechanical)	6432	6460	6446	5973	5918	5946	6328	6231	6280	6215	5939
W ₆ (chemical + manual)	6198	5986	6092	5527	5209	5368	6060	5922	5991	5738	5306
W ₇ (unweeded control)	4363	3842	4103	4182	3700	3941	4073	4042	4058	4141	4081
Mean	6009	5786		5450	5231		5823	5676		5618	5427
	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	SEd	CD (p = 0.05)	
N	39.5	170.0	33.1	142.0	25.8	110.9	38.4	165.2			
W	72.7	150.0	67.6	139.5	52.2	107.7	109.0	225.0			
N at W	103.0	246.5	94.4	220.7	73.0	171.1	147.8	327.4			
W at N	102.7	212.1	95.6	197.3	73.8	152.3	154.2	318.2			

Manual method (W_1) of weed control recorded significantly higher grain yield (5505 to 6232 kg ha⁻¹) over mechanical + manual (W_2) and cultural + mechanical (W_4) methods, but was on par with chemical + manual method (W_6) in all the crops. The treatment W_6 recorded significantly higher grain yield than W_4 in second and third crops but both these two treatments were statistically on par in terms of grain yield produced in first and fourth crops. Cultural + mechanical method (W_4) was found to be less effective in increasing grain yield compared to other weed control treatments but there was increase in grain yield significantly under this treatment over unweeded plot in both the years.

The interaction effect between split application of N and weed control methods was significant in both years. The best treatment combination in terms of maximizing grain yield in every crop was four splits of N with cultural + manual method (N_1W_3) which registered grain yield of 6871, 6355, 6671 and 6517 kg ha⁻¹ in first to fourth crops respectively and was also comparable with combination of five splits of N with cultural + manual method (N_2W_3) in all the four crops. The yield under these two treatment combinations were significantly superior over all other treatment combinations in all the crops, except in the fourth crop, where combination of four splits of N with cultural + chemical + mechanical method (N_1W_5) produced similar grain yield. Among the all treatment combinations, lowest grain yield was observed under five splits of N with unweeded plot in all the crops.

4.3.3.6. Weed index (Table 59)

Magnitude of yield reduction due to weed competition was estimated through weed index. It was evident from grain yield data presented in Table 59, weed

Table 59. Weed index (per cent)

Treatment	Weed index (per cent)			
	<i>Kharif 98</i>	<i>Rabi 98-99</i>	<i>Kharif 99</i>	<i>Rabi 99-2000</i>
Weed control methods				
W ₁ (Manual)	9.0	13.1	7.8	11.8
W ₂ (Mechanical + Manual)	12.8	18.4	12.9	15.6
W ₃ (Cultural + Manual)	-	-	-	-
W ₄ (Cultural + Mechanical)	18.3	19.0	17.3	20.1
W ₅ (Cultural + Chemical + Mechanical)	5.8	6.1	4.9	6.7
W ₆ ((Chemical + Manual)	11.0	15.2	9.3	15.1
W ₇ (Unweeded control)	40.1	37.8	38.6	36.9

competition was rather low in the plots where cultural + manual weeding (W_3) was done. The yield obtained in this treatment was taken as the possible maximum yield that could be obtained under this situation and other weed control treatments were compared with it.

Chemical + cultural + mechanical method (W_5) of weed control proved to be the second best treatment recording a marginal yield reduction of 4.9 to 6.7 per cent over the seasons. Manual method (hand weeding twice) was also effective in recording an yield reduction of only 7.8 to 13.1 per cent followed by chemical + manual method (9.3 to 15.2 per cent) compared to cultural + manual method of weed control. Largest yield reductions of 40.1, 37.8, 38.6 and 36.9 per cent occurred in first to fourth crops, respectively in the unweeded plots, emphasizing the need for effective control of weeds to obtain high yields in wet seeded lowland rice.

4.3.3.7. Straw yield (Table 60)

Rice straw yield was enhanced by split application of N in both the years. Application of N in four splits with no basal dose registered more straw yield of 6770, 6875, 6852 and 6788 kg ha⁻¹ from first to fourth crops, respectively compared to five splits of N (6585, 6606, 6415 and 6559 kg ha⁻¹ from first for fourth crops, respectively).

Straw yield in different weed control methods followed the same trend as that of grain yield. The highest straw yield of 7342 to 7786 kg ha⁻¹ from first to fourth crops were obtained in cultural + manual method (W_3) and this was followed by cultural + chemical + mechanical method (W_5). Manual (W_1) and chemical + manual (W_6) methods were equally effective in enhancing the straw yield of rice in all the crops. The straw yield was generally lower under cultural + mechanical and mechanical + manual methods in all the four crops.

Table 60. Straw yield (kg ha⁻¹) as influenced by interaction of N management practices and weed control methods

Treatment	Straw yield (kg ha ⁻¹)											
	Kharif'98			Rabi' 98 - 99			Kharif 99			Rabi' 99 - 2000		
	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean	N ₁	N ₂	Mean
W ₁ (manual)	7076	6981	7029	7118	6655	6995	7032	6643	6838	6913	6733	6823
W ₂ (mechanical + manual)	6887	6670	6779	6445	6527	6486	6488	6369	6429	6876	6622	6749
W ₃ (cultural + manual)	7662	7470	7566	7927	7645	7786	7635	7419	7527	7425	7259	7342
W ₄ (cultural + mechanical)	6540	6488	6514	7300	6691	6686	6649	6206	6428	6685	6551	6618
W ₅ (cultural + chemical + mechanical)	7255	7118	7187	7454	7382	7418	7617	6950	7284	7062	6742	6902
W ₆ (chemical + manual)	6997	6742	6870	6891	6482	6886	7290	6719	7005	6982	6676	6829
W ₇ (unweeded control)	4973	4623	4798	4991	4864	4927	5255	4598	4926	5571	5327	5449
Mean	6770	6585		6875	6606		6852	6415		6788	6559	
SEd												
CD (p = 0.05)												
N	6.6	28.5		8.2	35.2		11.8	50.6		11.1	47.6	
W	85.8	177.0		92.1	190.0		100.2	206.9		89.6	185.0	
N at W	112.5	233.0		120.8	250.6		121.8	274.3		117.9	245.6	
W at N	121.3	250.3		130.2	268.7		141.7	292.6		126.7	261.6	

The best treatment combination to maximize straw yield was four splits of N with cultural + manual method (7662, 7927, 7635 and 7425 kg ha⁻¹ in first to fourth crops, respectively) and was statistically on par with five splits of N with cultural + manual method (first, third and fourth crops) and four splits of N with cultural + chemical + mechanical method (third crop). Unweeded plots with four splits of N (first and third crops) or irrespective of nitrogen splits (second and fourth crops) produced significantly lower straw yield over other treatment combinations.

4.3.3.8. Harvest index (Table 61)

Split application of N had no influence on harvest index in all the four crops. Similarly weed control methods also failed to show any significant influence on harvest index in all crops, except in the fourth crop, where unweeded control plot recorded significantly lower harvest index value (0.430) over rest of the weed control methods. In general, cultural + manual method (W₃) resulted in higher harvest index (0.449 to 0.475) as compared to other weed control methods in both the years.

4.3.4. Correlation studies (Table 62 and Fig 4 and 5)

The correlation co-efficient values (r) was worked out for grain yield versus various weed characters and growth and yield parameters of the crop.

Grain yield of rice had positive significant correlation with crop dry matter production at maturity, N uptake by rice at maturity, leaf area index at flowering, panicles m⁻² and filled grains panicle⁻¹ in all the four crops. It had negative significant correlation with total weed population, weed dry matter production and N removal by weeds at flowering stage, respectively in all the four crops. (Table 62).

Table 61. Harvest index (HI) of rice as influenced by N management practices and weed control methods

Treatment	Harvest index (HI)			
	<i>Kharif 98</i>	<i>Rabi 98-99</i>	<i>Kharif 99</i>	<i>Rabi 99-2000</i>
N Management				
N ₁ (four splits)	0.470	0.442	0.458	0.451
N ₂ (five splits)	0.460	0.441	0.469	0.449
SEd	0.009	0.006	0.007	0.007
CD (p=0.05)	NS	NS	NS	NS
Weed control methods				
W ₁ (manual)	0.470	0.444	0.471	0.457
W ₂ (mechanical + manual)	0.468	0.443	0.472	0.449
W ₃ (cultural + manual)	0.475	0.449	0.468	0.470
W ₄ (cultural + mechanical)	0.461	0.423	0.459	0.437
W ₅ (cultural + chemical + mechanical)	0.473	0.445	0.462	0.463
W ₆ (chemical + manual)	0.470	0.445	0.461	0.447
W ₇ (unweeded control)	0.460	0.444	0.451	0.430
SEd	0.015	0.016	0.011	0.018
CD (p=0.05)	NS	NS	NS	0.038

Table 62. Correlation co-efficient as influenced by N management practices and weed control methods

Sl.No.	Y	X	Correlation co-efficient (r) (n=14)			
			Kharif'98	Rabi'98-99	Kharif'99	Rabi'99-2000
1	Grain yield (kg ha ⁻¹)	Weed DMP (kg ha ⁻¹)	-0.9466*	-0.872*	-0.955*	-0.890*
2	Grain yield (kg ha ⁻¹)	N removal by weeds (kg ha ⁻¹)	-0.948*	-0.864*	-0.955*	-0.815*
3	Grain yield (kg ha ⁻¹)	Rice DMP (kg ha ⁻¹)	0.960*	0.924*	0.882*	0.987*
4	Grain yield (kg ha ⁻¹)	N uptake by rice (kg ha ⁻¹)	0.902*	0.838*	0.956*	0.979*
5	Grain yield (kg ha ⁻¹)	Leaf area index (LAI)	0.975*	0.924*	0.865*	0.969*
6	Grain yield (kg ha ⁻¹)	Panicles m ⁻²	0.849*	0.973*	0.785*	0.977*
7	Grain yield (kg ha ⁻¹)	Total weed population m ⁻²	-0.968*	-0.886*	-0.956*	-0.892*
8	Grain yield (kg ha ⁻¹)	Filled grains panicle ⁻¹	0.848*	0.935*	0.704*	0.941*

* Significant at 5 per cent level

The correlation co-efficient values (r) and regression equation were also worked out for SPAD values at tillering (Fig 4) and panicle initiation stages (Fig 5) with grain yield of rice in all the four crops.

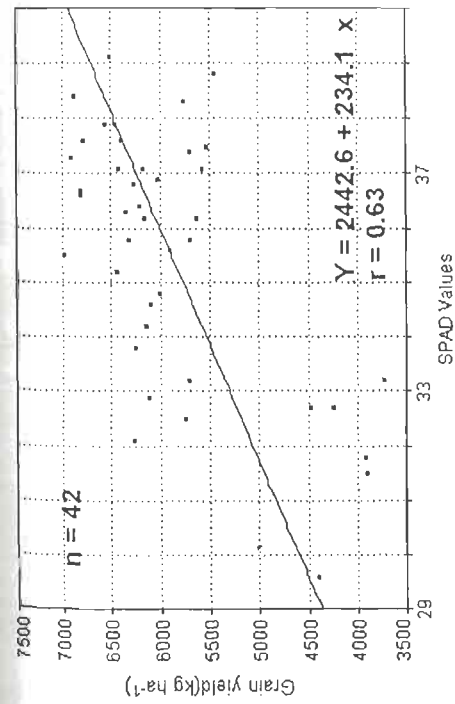
Correlation co-efficient values showed that there was a significant positive correlation between SPAD values of both the stages with grain yield in respective crops (Fig 4 and 5). Regression equation showed that every unit increase in SPAD values at tillering stage increased the grain yield by 223.4 to 234.1 and 143.7 to 271.4 kg of grain during *kharif* (Fig. 4 a & c) and *rabi* (Fig. 4 b & d) seasons, respectively in both the years. Similarly, regression equation indicated that at PI stage, every unit of SPAD value increase by crop, there was an increase of 216.1 to 232.7 and 201.8 to 196.4 kg of grain yield during *kharif* (Fig. 5 a & c) and *rabi* (Fig. 5 b & d) seasons, respectively in both the years.

4.3.5. Post harvest soil fertility status

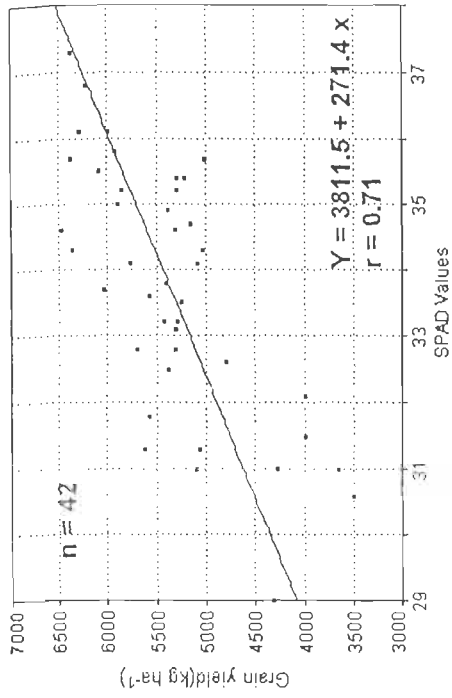
4.3.5.1. Organic carbon (Table 63)

The organic carbon content in the post harvest soil was not influenced by split application of N in any season. However, there was a marginal improvement in soil organic carbon in all the treatments compared to the initial level.

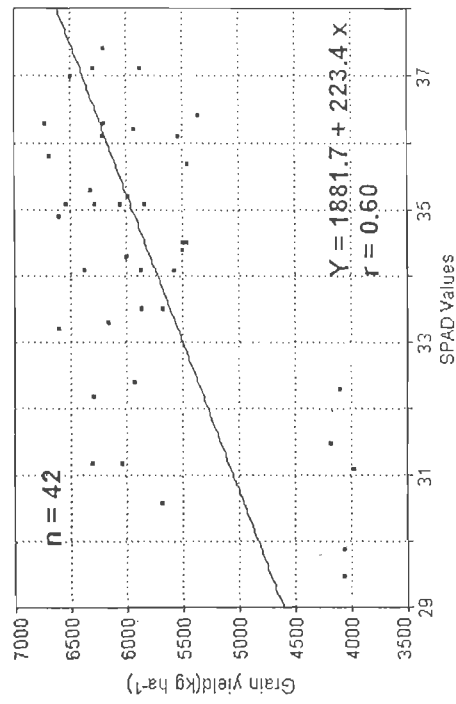
Among the weed control methods, cultural + manual method (W_3) where green manure was intercropped and manually incorporated recorded significantly higher organic carbon content (0.65 to 0.71 per cent from first to fourth crops) over other non-cultural (W_1 , W_2 and W_6) methods of weed control treatments. However, W_3 was comparable with cultural + mechanical (W_4) and cultural + chemical + mechanical (W_5) methods of



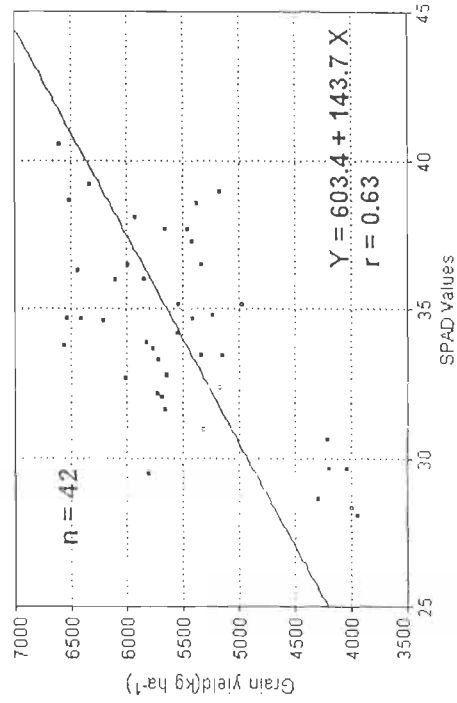
a. Kharif '98



b. Rabi '98-99

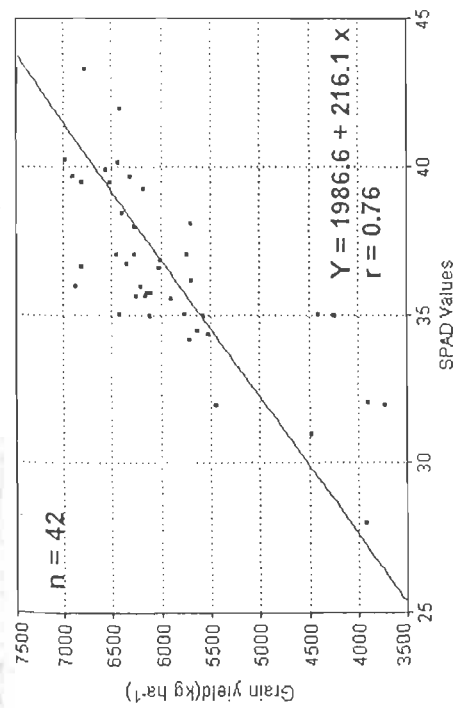


c. Kharif '99

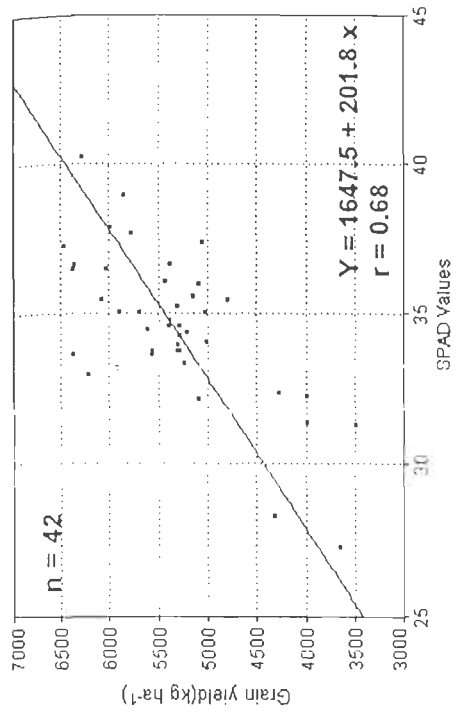


d. Rabi '99-2000

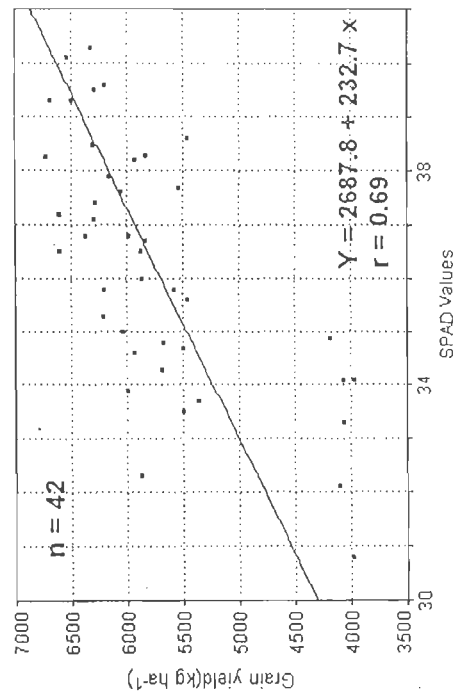
Fig. 4. Linear regression of SPAD values at tillering stage and grain yield of rice



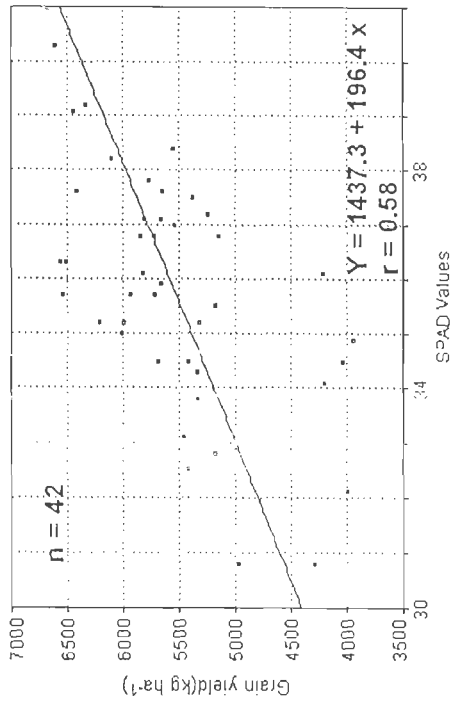
a. Kharif '98



b. Rabi '98-99



c. Kharif '99



d. Rabi '99-2000

Fig. 5. Linear regression of SPAD values at panicle initiation stage and grain yield of rice

Table 63. Post harvest organic carbon content (per cent) of soil

Treatment	Organic carbon (per cent)			
	<i>Kharif 98</i>	<i>Rabi 98-99</i>	<i>Kharif 99</i>	<i>Rabi 99-2000</i>
N Management				
N ₁ (four splits)	0.62	0.63	0.58	0.66
N ₂ (five splits)	0.58	0.61	0.59	0.64
SEd	0.019	0.007	0.004	0.008
CD (p=0.05)	NS	NS	NS	NS
Weed control methods				
W ₁ (manual)	0.58	0.60	0.59	0.64
W ₂ (mechanical + manual)	0.57	0.60	0.55	0.63
W ₃ (cultural + manual)	0.66	0.69	0.65	0.71
W ₄ (cultural + mechanical)	0.63	0.66	0.60	0.67
W ₅ (cultural + chemical + mechanical)	0.64	0.66	0.63	0.70
W ₆ (chemical + manual)	0.59	0.60	0.58	0.62
W ₇ (unweeded control)	0.53	0.55	0.52	0.58
SEd	0.017	0.015	0.013	0.024
CD (p=0.05)	0.035	0.032	0.026	0.05

weed control in all the crops, except in the third crop where W_4 was on par with W_5 , but inferior to W_3 in respect of organic carbon content in post harvest soil. In general, manual (W_1), mechanical + manual (W_2) and chemical + manual (W_6) methods recorded comparable and lower organic carbon content over seasons. Invariably, in all crops lowest organic carbon was observed in unweeded control (0.52 to 0.58 per cent).

4.3.5.2. Available nitrogen (Table 64)

The available N status after the harvest of the crop was slightly lower than initial level in all the crops. However, post harvest soil N status did not vary much under different N management practices.

Among the weed control treatments, cultural + manual (W_3), cultural + mechanical (W_4) and cultural + chemical + mechanical (W_5) methods were equally effective and recorded significantly higher post harvest available N over rest of the treatments in all the four crops. Invariably, in all the crops, lowest available N was observed in unweeded plots which in turn were on par with non – cultural methods (W_1 , W_2 and W_6) of weed control.

4.3.5.3. Available phosphorus and potassium (Table 65 and 66)

Different nitrogen management practices did not have any influence on the status of soil post harvest available phosphorus. In general, post harvest available soil phosphorus was comparatively higher in cultural method of weed control (W_3 , W_4 , and W_5) compared to other non-cultural weed control treatments (W_1 , W_2 and W_6) in all the four crops. Yet, the variations were small and comparable among different weed control treatments. Unweeded plot

Table 64. Post harvest available N content (kg ha⁻¹) of soil

Treatment	Available N (kg ha ⁻¹)			
	<i>Kharif</i> 98	<i>Rabi</i> 98-99	<i>Kharif</i> 99	<i>Rabi</i> 99-2000
N Management				
N ₁ (four splits)	150.1	139.3	140.5	184.0
N ₂ (five splits)	156.5	142.2	145.5	192.1
SEd	2.03	1.31	2.47	2.46
CD (p=0.05)	NS	NS	NS	NS
Weed control methods				
W ₁ (manual)	133.0	126.3	127.6	169.1
W ₂ (mechanical + manual)	135.0	122.4	126.2	166.3
W ₃ (cultural + manual)	181.9	162.4	164.6	225.1
W ₄ (cultural + mechanical)	177.8	166.0	162.9	212.2
W ₅ (cultural + chemical + mechanical)	179.8	164.9	169.0	218.0
W ₆ (chemical + manual)	132.7	123.2	125.8	168.7
W ₇ (unweeded control)	132.9	119.9	125.0	157.0
SEd	5.5	6.9	4.0	8.0
CD (p=0.05)	11.5	14.2	8.2	16.6

Table 65. Post harvest available P content (kg ha⁻¹) of soil

Treatment	Available P (kg ha ⁻¹)			
	<i>Kharif 98</i>	<i>Rabi 98-99</i>	<i>Kharif 99</i>	<i>Rabi 99-2000</i>
N Management				
N ₁ (four splits)	20.8	23.1	21.6	21.0
N ₂ (five splits)	22.0	24.3	22.4	23.3
SEd	0.71	0.58	0.43	0.60
CD (p=0.05)	NS	NS	NS	NS
Weed control methods				
W ₁ (manual)	20.0	24.7	21.2	22.5
W ₂ (mechanical + manual)	21.4	23.3	21.2	21.3
W ₃ (cultural + manual)	22.5	26.7	23.1	23.6
W ₄ (cultural + mechanical)	22.9	25.9	24.5	22.7
W ₅ (cultural + chemical + mechanical)	22.4	25.0	22.4	23.8
W ₆ (chemical + manual)	20.2	20.8	21.5	21.7
W ₇ (unweeded control)	20.4	19.6	20.1	19.5
SEd	1.1	1.3	1.5	1.2
CD (p=0.05)	2.3	2.7	3.2	2.6

Table 66. Post harvest available K content (kg ha⁻¹) of soil

Treatment	Available K (kg ha ⁻¹)			
	<i>Kharif 98</i>	<i>Rabi 98-99</i>	<i>Kharif 99</i>	<i>Rabi 99-2000</i>
N Management				
N ₁ (four splits)	460.3	449.4	417.0	503.8
N ₂ (five splits)	476.0	460.6	435.0	528.2
SEd	11.3	7.01	6.83	10.3
CD (p=0.05)	NS	NS	NS	NS
Weed control methods				
W ₁ (manual)	468.0	457.0	425.0	518.4
W ₂ (mechanical + manual)	481.5	463.1	431.2	529.8
W ₃ (cultural + manual)	465.5	449.0	422.1	498.0
W ₄ (cultural + mechanical)	452.0	436.0	420.3	508.5
W ₅ (cultural + chemical + mechanical)	461.0	456.3	415.8	514.5
W ₆ (chemical + manual)	469.0	458.5	428.1	519.9
W ₇ (unweeded control)	480.0	465.0	439.4	523.0
SEd	25.7	22.8	19.7	22.5
CD (p=0.05)	NS	NS	NS	NS

recorded lowest available soil phosphorus and was on par with rest of the treatments except W_4 (first and third crops), W_6 (second crop) and W_1 , W_2 and W_6 (fourth crop).

Both N management and weed control methods did not significantly influence the available soil potassium status in all the four crops.

4.3.6. Economics (Table 67)

The net income and B : C ratio of rice cultivation with nitrogen management practices and weed control methods are presented in Table 67. The details of computations of economics are given in Appendices IV, V and VI.

The influence of split application of N on net income was evident in all crops. Higher net income was observed under four splits of N (Rs. 20458, Rs. 22631, Rs. 19550 and Rs. 23597 ha^{-1} , respectively in first to fourth crops). It is evident that return per rupee invested (B: C ratio) was also higher in the four splits of N over five splits in all the four crops.

Among the weed control treatments, highest net income of Rs. 23919, Rs. 27266, Rs. 22765 and Rs. 28120 ha^{-1} and B:C ratio of 3.06, 3.23, 2.96 and 3.30 for first, second, third and fourth crops, respectively were obtained in cultural + manual method (W_3) followed by cultural + chemical + mechanical method (W_5). This was followed by chemical + manual method (W_6) in terms of B:C ratio in all the crops. Lowest net income and B:C ratio were obtained from unweeded crops. Comparatively lower economic indices were evident with cultural + mechanical method also. In general, net income with hand weeding twice (manual method) was reasonably higher than chemical +

Table 67. Net income (Rs ha⁻¹) and B:C ratio of rice cultivation as influenced by N management practices and weed control methods

Treatment	Net income (Rs ha ⁻¹)				B : C ratio			
	Kharif'98	Rabi'98-99	Kharif'99	Rabi'99-2000	Kharif'98	Rabi'98-99	Kharif'99	Rabi'99-2000
N management								
N ₁ (four splits)	20458	22631	19550	23597	2.88	2.96	2.79	3.05
N ₂ (five splits)	19304	21241	18653	22383	2.77	2.84	2.70	2.94
Weed control methods								
W ₁ (manual)	21199	22540	20382	23951	2.90	2.89	2.81	3.03
W ₂ (mechanical + manual)	20365	20974	19066	22989	2.90	2.85	2.76	3.03
W ₃ (cultural + manual)	23919	27266	22765	28120	3.06	3.23	2.96	3.30
W ₄ (cultural + mechanical)	18473	20834	17739	21147	2.73	2.83	2.65	2.86
W ₅ (cultural + chemical + mechanical)	22456	25496	21624	26046	3.04	3.19	2.95	3.24
W ₆ (chemical + manual)	20876	22033	20415	23081	2.94	2.92	2.89	3.03
W ₇ (unweeded control)	11883	14410	11721	15596	2.25	2.41	2.23	2.53

Data not statistically analysed

manual method. However, B:C ratio was higher under chemical + manual method (W_6) compared to manual method (W_1) in both the years except in fourth crop where it was comparable among manual, mechanical + manual and chemical + manual methods of weed control. The highest net income (Rs. 23204 to 28197) and B:C ratio (3.00 to 3.30) were recorded under the treatment combination of four splits of N along with cultural + manual method of weed control over the rest of the treatment combinations in all the four crops (Appendix VI).

4.3.7. Energy budget for drum seeded rice production

Energy required in raising rice crop under varying nitrogen management and weed control methods had been worked out for the four crops and energy use efficiency (output : input ratio) and specific energy requirement are presented in Table 68 and Appendix VIII.

Results on energetic of rice production clearly showed that highest energy input was associated with cultural + manual (W_3) method of weed control and lowest energy input being with unweeded plots irrespective of nitrogen management practices (Appendix VIII).

Generally, higher the energy use efficiency, lower was the specific energy in all the four crops (Table 68).

Maximum energy use efficiency was observed under four splits application of N (7.89 to 8.04) compared to five splits of N in all the crops.

Table 68. Energy use efficiency (EUE) and specific energy (MJ Kg⁻¹) of rice cultivation as influenced by N management practices and weed control methods

Treatment	EUE						
	Kharij'98	Rabi'98-99	Kharij'99	Rabi'99-2000	Kharij'98	Rabi'98-99	Kharij'99
N management							
N ₁ (four splits)	8.04	7.89	7.95	7.91	3.64	3.93	3.77
N ₂ (five splits)	7.77	7.54	7.60	7.64	3.82	4.13	3.87
Weed control methods							
W ₁ (manual)	8.33	7.94	8.11	8.01	3.46	3.86	3.55
W ₂ (mechanical + manual)	8.06	7.47	7.69	7.83	3.60	4.08	3.73
W ₃ (cultural + manual)	8.94	8.87	8.76	8.74	3.19	3.38	3.31
W ₄ (cultural + mechanical)	7.73	7.62	7.44	7.48	3.86	4.14	3.95
W ₅ (cultural + chemical + mechanical)	8.52	8.62	8.46	8.25	3.36	3.60	3.46
W ₆ (chemical + manual)	8.19	7.72	8.20	7.92	3.52	3.93	3.58
W ₇ (unweeded control)	5.74	5.80	5.79	6.24	5.13	5.25	5.17

Data not statistically analysed

Weed control methods had a marked influence on energy use efficiency during both the years. Maximum energy use efficiency of 8.94, 8.87, 8.76 and 8.74 for first to fourth crops, respectively were recorded under cultural + manual method (W_3) followed by cultural + chemical + mechanical method (W_5) whereas the least was with unweeded control plot in both the years under studied.

The specific energy requirement or energy required to produce a kilogram of grain was more under five splits application of N over four splits. Among weed control methods, cultural + manual method (W_3) required less energy to produce a kilogram of grain (3.19 to 3.38 MJ kg⁻¹) followed by cultural + chemical + mechanical method (W_5) in all the crops. In contrast to EUE, unweeded plots required more specific energy to produce a kilogram of grain (5.13 to 5.25 MJ kg⁻¹) over seasons. Among all the treatment combinations studied, four splits of N with cultural + manual method of weed control registered highest EUE (8.79 to 9.03) with least specific energy requirement (3.18 to 3.30) in all the four crops (Appendix VIII).

DISCUSSION

CHAPTER V

DISCUSSION

Transplanting is the most common method in irrigated rice growing areas of South East Asian countries. But, this practice is increasingly being replaced by direct seeding as labour for transplanting is a scarce and costly (Ito, 1998). It is generally believed that the transplanting method gives more stable yield than direct seeding method. However, in many rice growing countries wet seeded rice produced similar or higher yield than transplanted rice (Moddy, 1993; Rachel and Martin, 1995). Early accumulation of vegetative biomass better leaf area, enhanced total and productive tillers with profused root system are the favourable characteristic features of wet seeded rice culture (Dingkuhn *et al.*, 1990a; Prabhakar and Narsa Reddy, 1997). Ramamoorthy and Subbaiah (1999) observed that wet seeded rice culture by drum seeder could be a viable alternative to transplanted rice in irrigated areas.

Semi arid soils are inherently N deficient, which limits rice yields. Nitrogen is well recognized as a promoter of vegetative growth. Apart from being a substrate for protein synthesis, it also stimulates meristamatic growth and cytokinin biosynthesis (Yoshida and Oritani, 1974; Beringer, 1980) which results in better growth and development of the crop. N requirement for the plant is not same throughout their growth period (Manjappa *et al.*, 1994). Therefore, to get maximum benefit from applied N, it is important to apply the right amount at right time. In this study, N management strategy of four splits and five splits of N application under the same dose of 120 kg N ha⁻¹ for *kharif* and 150 kg N ha⁻¹ for *rabi* season was undertaken to increase the nitrogen use efficiency.

Rice fields can be colonized by aquatic, semi-aquatic and terrestrial plants depending on cultivation methods and seasons (Moody and Droft, 1981). Though, wet seeded rice is becoming popular and alternative to transplanted rice, heavy weed infestation and competition are the major constraints for getting higher yield (Kandasamy and Sivaperumal, 1997; Jayadeve *et al.*, 1998). Weeds growing in association with the rice crop reduced the vegetative potential of the crop which ultimately resulted in substantial yield losses (Kim *et al.*, 1979; Caton *et al.*, 1997). Effective weeding practices reduce weed growth and consequently increase the crop yield. Weeds vary in their growth habit and life cycle. Therefore, no single method gives continuous and effective weed control. This could be achieved through direct methods (physical and chemical methods) used within system of indirect methods such as land preparation, water control, fertility management, smother crop etc. (De Datta, 1989; Moody, 1991; Wyse, 1994).

In the present study, various weed control methods such as manual method (hand weeding), mechanical method (using conoweeder), chemical method (pre emergence application of ready mix pretilachlor + fencloirim as safener) and cultural method (growing and incorporation of *Sesbania rostrata* as smother intercrop) were integrated to achieve maximum weed control in wet seeded rice.

The results of the study on the interactive effect of split application of N and weed control methods on wet seeded rice and associated weeds are discussed hereunder.

Dual cropping of green manure crop as smother intercrop in rice was found to reduce the weed growth and supplement N to rice on its incorporation and decomposition (Mathew and Alexander, 1995; Angadi and Umapathy, 1997). Growth and N

contribution of row intercropped *Sesbania rostrata* did not vary very much for the weed control methods under the respective treatments. Application of N in five splits where basal dose of N was included gave marginal benefit on the growth and biomass production of the smother intercrop. Averaged across the season and crops, the smother intercrop *Sesbania rostrata* produced a biomass of 11.58 t ha⁻¹ on wet basis and contributed 72.7 kg⁻¹ N ha⁻¹ (Table 3). Vigorous growth at early stage and better canopy coverage biologically smothered the weed growth in between the crop rows. N supplementation by the intercrop as green manure after incorporation also promoted the crop growth to efficiently compete with the weeds as well as to produce higher yields.

N management practice and degree of weed control do not just act independently, rather they strongly interact with each other on weed growth and control as well as growth and yield of wet seeded rice.

5.1. Studies on weeds

5.1.1. Weed flora of the experimental field

The wet seeded rice was infested with composite weed flora comprising of grasses (32.9 to 38.2 per cent of total weeds), sedges (25.1 to 34.6 per cent) and broad leaved weeds (27.8 to 40.1 per cent) in all the four cropping seasons at flowering stage of experimental crops. Irrespective of the growing seasons, the major graminaceous weeds were *Echinochloa crus galli* and *Echinochloa colona*, common cyperaceae were *Cyperus difformis*, *Cyperus rotundus* and *Cyperus iria* and six families of dicot of which *Eclipta alba* (Asteraceae), *Monochoria vaginalis* (Pontederiaceae), *Ammania baccifera* (Lytharaceae) and *Ludwigia parviflora* (Onagraceae) were predominant in all the four

crops (Table 4). Similar wide spectrum of dominant weeds in direct seeded puddled rice was reported by many workers (Kandasamy and Palaniappan, 1990; Tripathy and Vaishya, 1993; Malik and Moorthy, 1996; Singh *et al.*, 1998).

An analyses of weed flora recorded in unweeded plots at flowering stage of the crop (Table 5) showed that weed infestation during dry seasons (*kharif*) (185.2 to 196.6 m²) was relatively severe than that in the wet season (*rabi*) (145.5 to 163.4 m²). This was due to the favourable weather conditions that prevailed during the *kharif* season compared to *rabi* season which was characterized by heavy rains, low temperature and cloudy weather thereby resulting in relatively lower weed seed germination and density. Higher number of weeds during *kharif* season than in *rabi* season reported by Karuppiah (1995) support the present findings.

Study on the relative density of weeds in the different cropping seasons (Table 5) revealed that, broad leaved weeds dominated the weed flora constituting 40.1 and 38.5 per cent of the total weeds in the *kharif* seasons (first and third crops) in both the years while during *rabi* season the grassy weed densities were higher (36.2 and 38.2 per cent to total weeds in second and fourth crops, respectively). It was clear that the monocot weeds (grasses + sedges) dominated the dicot weeds (broad leaved species) in all the four crops (Table 5 and Fig 6). Under direct seeded conditions of Kerala dominance of grasses and sedges in the weed flora was reported by Joy *et al.* (1991), however, Bharathi (1996) opined that broad leaved weeds were predominant followed by grasses and sedges in wet seeded rice grown in Tamil Nadu. The kind and number of weed species associated with different rice culture was strongly affected by the biotic factor and cultural practices in a given environment (Moody, 1980).

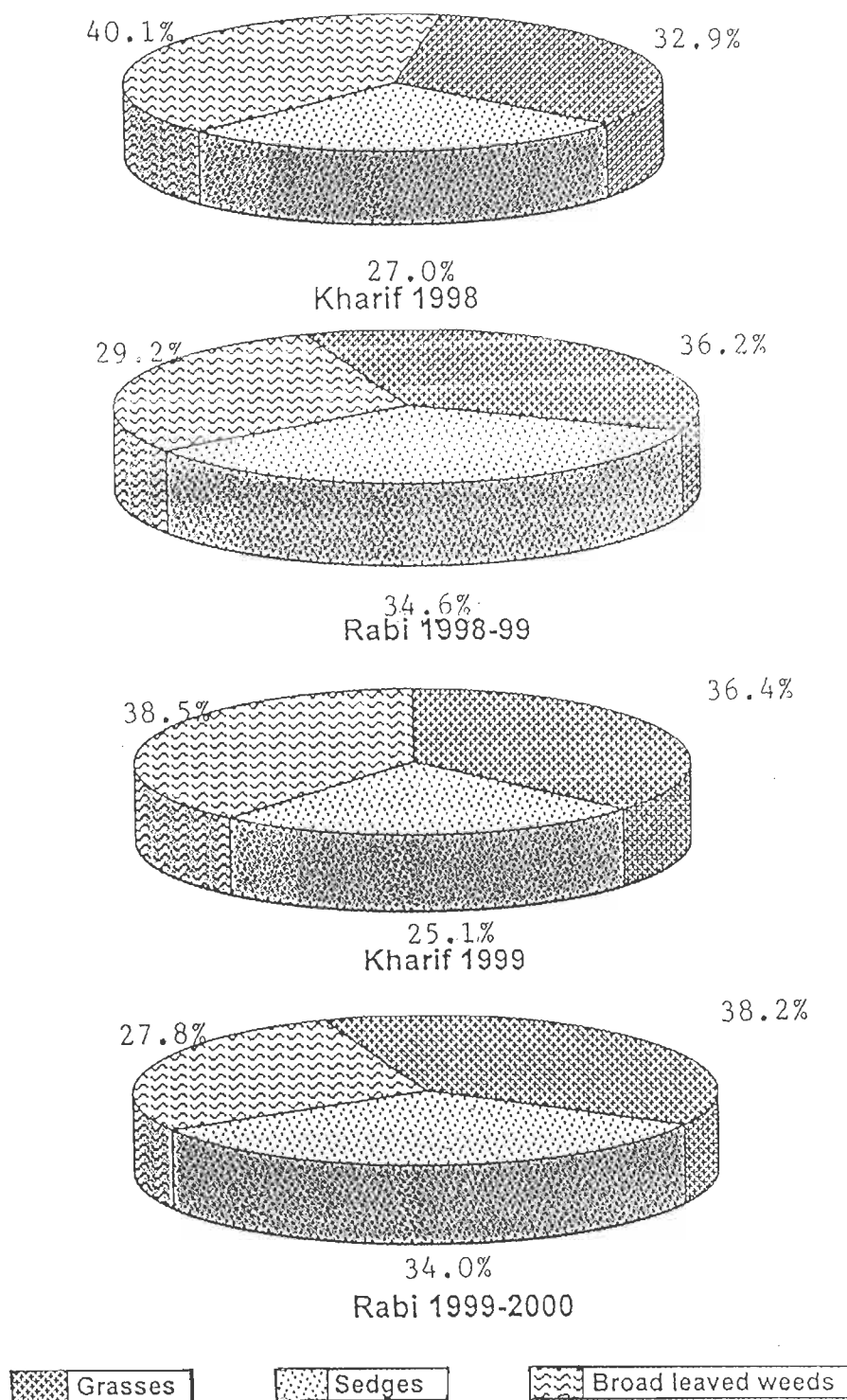


Fig.6. Relative density of grasses, sedges and broad leaved weeds in the experimental fields

Among grasses, *Echinochloa crus-galli* was the most dominant species representing 21.1 to 23.8 per cent of the total weeds over all the four crops. Likewise, *Cyperus difformis* (15.7 to 20.6 per cent) among sedges and *Eclipta alba* (11.0 to 16.4 per cent) among broad leaved weeds were the most dominant species found at the flowering stage of wet seeded rice. Dominance of *E. crus-galli*, *C. difformis* and *Eclipta alba* in direct seeded puddled rice was also reported by Srinivasan and Palaniappan (1994) and Mutanal *et al.* (1997). Most of the dominant weeds are C₄ plants and severely compete with rice plants (Mortimer, 1996).

5.1.2. Weed density

In general, the total weed density (monocot and dicot weeds) increased upto flowering stage of the crops and then declined (Fig 7 and 8). It could be attributed to the intensity of early germinated weeds and suppression of late germinated weeds at later stages of crop growth. Chinnamuthu (1990) and Umapathi (1998) also opined that irrespective of the season, the weed population increased upto the critical period of crop growth and declined thereafter. At the same dose of N, number of split application influenced the weed density substantially. Application of N in four splits as top dressing without any basal dose (N₁) consistently recorded lower monocot and dicot weeds, which reflected in total weed density as compared to five splits of N (N₂) in all stages of crop growth in both the years. Such effect was more pronounced at early (20 DAS) and tillering stages of the crops. This might be due to more splits as well as the higher amount of nitrogen applied in early part of crop growth under N₂ treatment which enhanced more weed seed germination (Everaarts, 1992; Ho, 1996). However, in later stages of the crop (flowering and maturity), variation in monocot, dicot as well as total

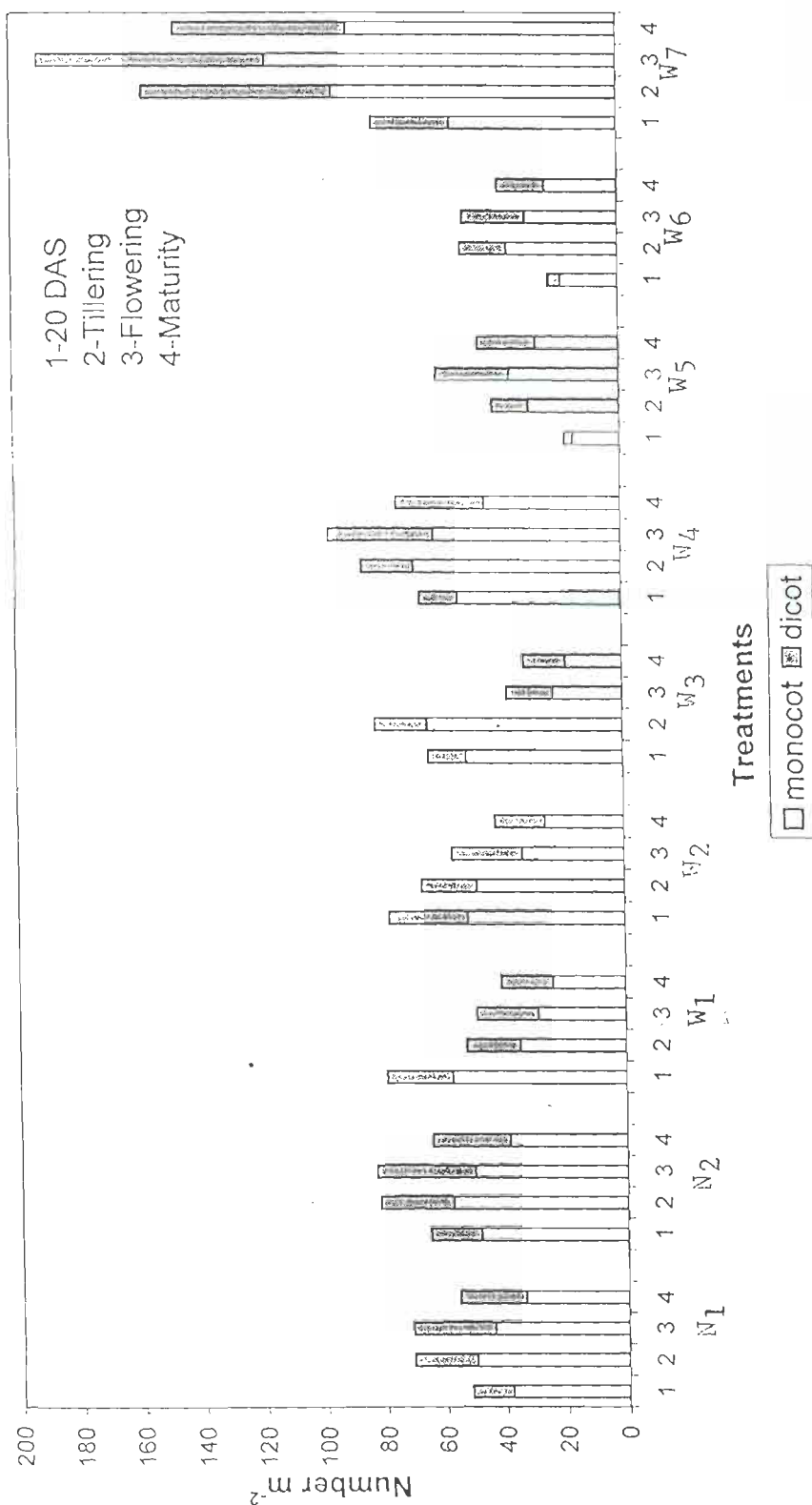


Fig. 7. Monocot and dicot weed density (m^{-2}) during *kharif* seasons (mean) at different growth stages

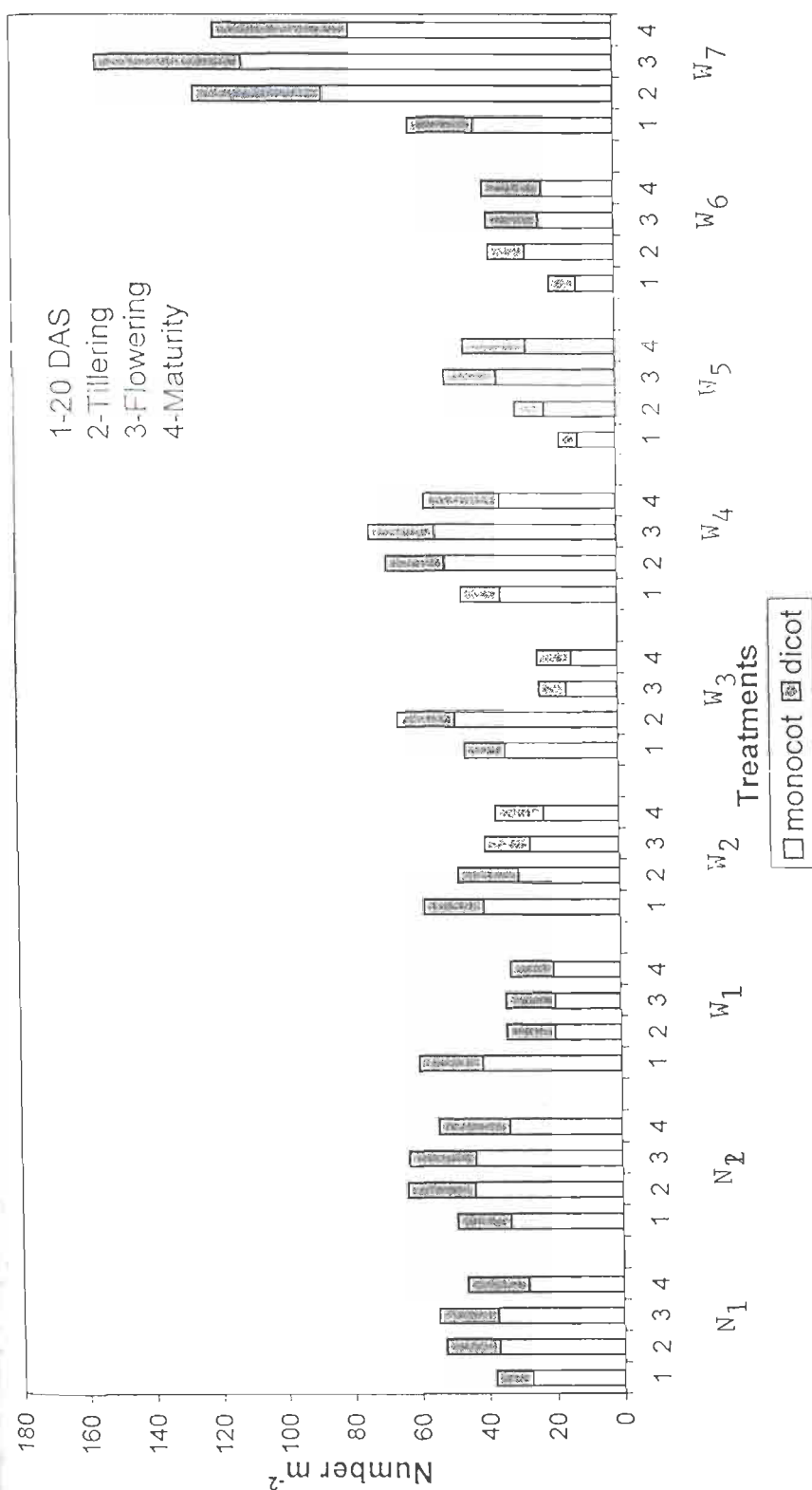


Fig. 8. Monocot and dicot weed density (m^{-2}) during Rabi seasons (mean) at different growth stages

weed density under both the N management practices were not much varied, though larger amount of N was applied in N₁ treatment at active tillering (AT) and panicle initiation (PI) stages compared to N₂ treatment. Higher amount of N application at critical period of crop growth under N₁ treatment might have encouraged the growth of rice and thereby suppressed weed seed/propagules establishment and growth of weeds.

It is evident from the data on weed density presented in Table 6, 7 and 8 that, among the weed control treatments wherever the pre emergence application of pretilachlor was included as integrated method of weed control (W₅ - cultural + chemical + mechanical and W₆ - chemical + manual) the weed seed germination was inhibited very much as seen from the lowest weed density in these treatments. Pretilachlor gave excellent control of many grasses, sedges and broad leaved weeds in wet seeded rice (Ramesh and Veerabadran, 1997; Choudhury and Thakuria, 1998). Besides W₅ and W₆ treatments, manual method (W₁) also showed effective control of weeds at tillering stage which might be due to thorough removal of weeds done in W₁ treatment at 20 DAS. Cultural method alone was not much effective (as evident from W₃ and W₄ treatments at 20 DAS) in reducing weed population as many weeds grew in vacant interspaces of rice and intercrop. However, at later part (20 - 35 DAS) due to faster growth and canopy coverage by the intercrop, the germination and growth of weeds were effectively reduced in W₃ and W₄ at tillering stage as compared to unweeded treatment. Mathew and Alexander (1995) and Angadi and Umapathy (1997) also opined that intercropping of *Sesbania* suppressed weeds effectively in semi dry rice.

Extended period of weed control was achieved upto flowering and maturity stages of the crop, when *Sesbania* was intercropped and manually incorporated with simultaneous manual weeding at 35 DAS (W_3). This might be due to smothering effect of *Sesbania* on weeds upto tillering stage of the crop and the incorporated biomass might have provided a thick layer of organic mulch in the interspace preventing weed seed germination for a longer period of time. The results obtained in this experiment are in agreement with the findings of Mathew and Alexander (1995), Angadi and Umapathy (1997) and Masiunas (1998). Supplementary chemical weeding was found to be essential as cultural + mechanical method recorded higher weed density compared to W_3 and W_5 treatments. This might be due to the absence of chemical control at early stage of the crop which resulted in more weed growth and subsequent mechanical method was not effective against most of the well established weeds. Moody (1991) also reported that push type rotary weeder is not effective in removing the weeds that are too big. Effective removal of weeds by manual method at 20 DAS and tillering stages may be the reasons for lower weed density in W_1 treatment. In the soil, herbicide dissipated through different mechanisms; physical removal through adsorption, volatilization, uptake by plants and degradation through chemical, photochemical and microbial decomposition (Chen, 1981). Therefore, most of the herbicidal effects of pretilachlor might have lost in 25-30 days after application and weeds started reappearing. To check them one hand weeding is necessary on 30 to 35 DAS (Thirumurugan *et al.*, 1998). As an integrated method of weed management, combination of four splits of N with cultural + manual method of weed control (N_1W_3) kept the weed density at lower levels in all the four crops.

5.1.3. Dry matter of weeds

As a crop management method of weed suppression, appropriate split application of N could reduce the weed growth and biomass production. Application of N in four splits (N_1) where no basal dose was applied did not favour the total weed dry matter accumulation over five equal splits of N (N_2) where one split was at sowing of the sprouted rice seeds. The minimum weed competition in terms of density and biomass and better crop growth and yield with four splits application of N clearly indicated the advantage of amount and time of application of N in four splits in wet seeded rice. As N being the most important factor for growth (Yoshida, 1981), larger application of fertilizer N before tillering stage in N_2 treatment resulted in better germination and growth of weeds.

In the later stage of crop growth also, the weed growth was very much suppressed in four splits application of N (N_1), as the weed suppression ability of the crop was enhanced due to larger dressing of N under this treatment during AT and PI stages compared to five equal split application of N (N_2) starting from basal to heading stages. Similar observations on weed growth being modified by N management in rice have been reported earlier in lowland rice ecosystem (Dās and Saharay, 1996; Pandey *et al.*, 1997).

Among the weed control methods, cultural + chemical + mechanical (W_5) and chemical + manual (W_6) treatments recorded lower weed dry matter at the early stage of crop (Table 9) as these treatments received pre emergence application of pretilachlor that effectively controlled the germination and growth of predominant rice weeds (Mabbayad and Moody, 1992) in wet seeded puddled rice and was very selective to the rice crop.

The selectivity is attributed by the fenclorim which mediated reduction in the root uptake of pretilachlor and an enhancement of the metabolism of pretilachlor via enzymatic or non-enzymatic conjugation with glutathion which offered protection to rice seedlings (Deng *et al.*, 1997; Usui *et al.*, 1999). Though manual and mechanical methods of weed control restricted the weed growth before competitive level at tillering stage of the crop, a late manual weeding (35 DAS) as in cultural + manual method (W₃) and hand weeding twice (W₁) was essential to restrict the weed growth upto flowering and maturity stages of all the four crops. Among the weed control methods, cultural + manual method recorded lowest weed DMP at flowering stage irrespective of the seasons and weed DMP was more during *kharif* season than that of *rabi* season irrespective of the weed control methods (Fig 9). This might be due to effective removal of most of the weeds by manual weeding and also suppression of weeds by incorporated biomass of green manure (Mathew and Alexander, 1995; De Datta and Baltazar, 1996). This result is further confirmed from the comparatively higher weed dry matter recorded under cultural + chemical + mechanical method (W₅) where no manual weeding was given. It might be due to the fact that mechanical weeder did not remove weeds within rows or close to the rice hills and also improper trampling of weeds that are too big (Moody, 1991; De Datta and Baltazar, 1996).

5.1.4. Weed control efficiency (WCE)

Though manual (W₁) and manual + mechanical (W₂) methods registered better WCE over rest of the treatments (Table 23) at tillering stage in all the crops, pretilachlor applied treatments were more effective even from germinating stage of crop (before 20 DAS), since first weeding operation either manual or mechanical was given

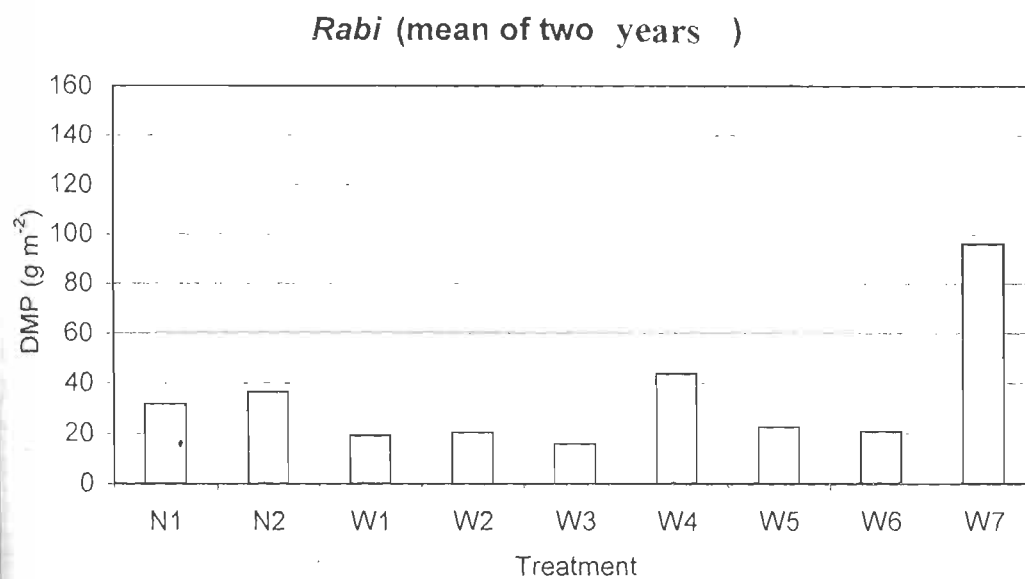
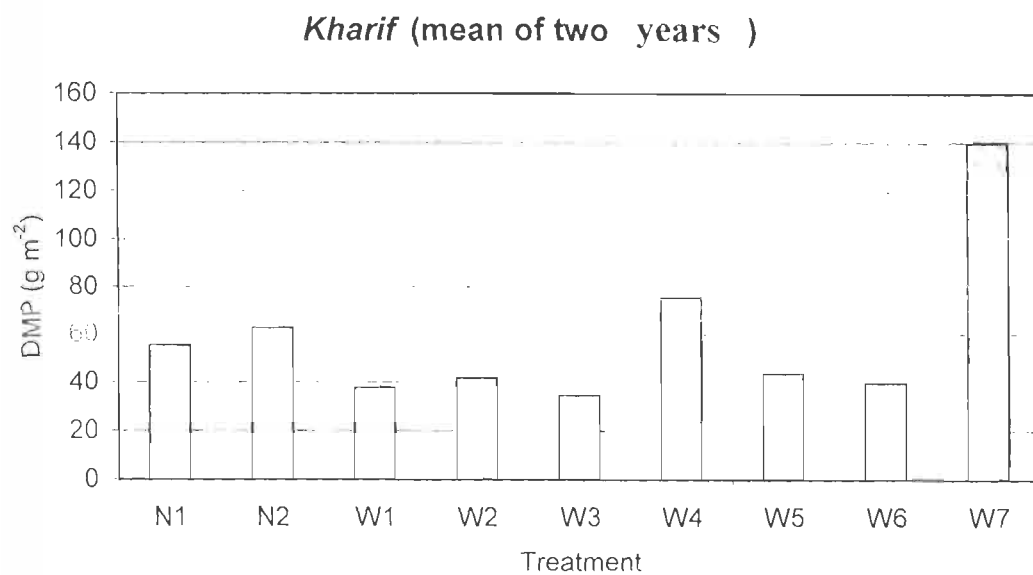


Fig. 9. WEED DMP AT FLOWERING STAGE OF THE CROP

only at 20 DAS. Greater reduction of weed dry matter by manual method than herbicide application was reported by Raju and Reddy (1986). However, in later stages of the crop, cultural + manual method (W_3) was most effective in checking the weed growth and improved the WCE which ranged from 74.6 to 83.8 per cent at flowering stage and 72.1 to 80.3 per cent at maturity stage of the crop (Table 23 and Fig 10). This might be due to the combined action of maximum weed removal in inter and intra rows of crop by manual weeding and smothering effect of greenmanure crop (Gupta and Lamba, 1978; Datta and Gogoi, 1994; Mathew and Alexander, 1995).

5.1.5. Nutrient depletion by weeds

Nitrogen management practices had a noticeable influence on N uptake by weeds in all the growth stages of rice across the cropping seasons. Weeds removed substantial amounts of N under five splits of N (N_2) over four splits of N application (N_1), as the weed density and growth was very much encouraged by five equal splits of N including basal. Nutrient depletion is a function of dry weight and nutrient content in weed plants. Weeds usually grow faster than crop plants which absorb added nutrients more rapidly and in larger quantities than by crops (Moody, 1991; De Datta and Baltazar, 1996). Early application of N as basal encouraged more germination and growth of weeds which in turn resulted in higher N depletion by weeds in N_2 treatment over N_1 . Das and Saharay (1996) and Pandey *et al.* (1997) also reported that weed biomass was reduced when N was applied less at the time of sowing and resulted in lower nutrient depletion by weeds. Comparatively larger amount of N applied at AT and PI stages of crop in N_1 treatment over N_2 resulted in better crop growth rather than weed growth. This has resulted in restricted availability and uptake of N by weeds at later stages of the crop

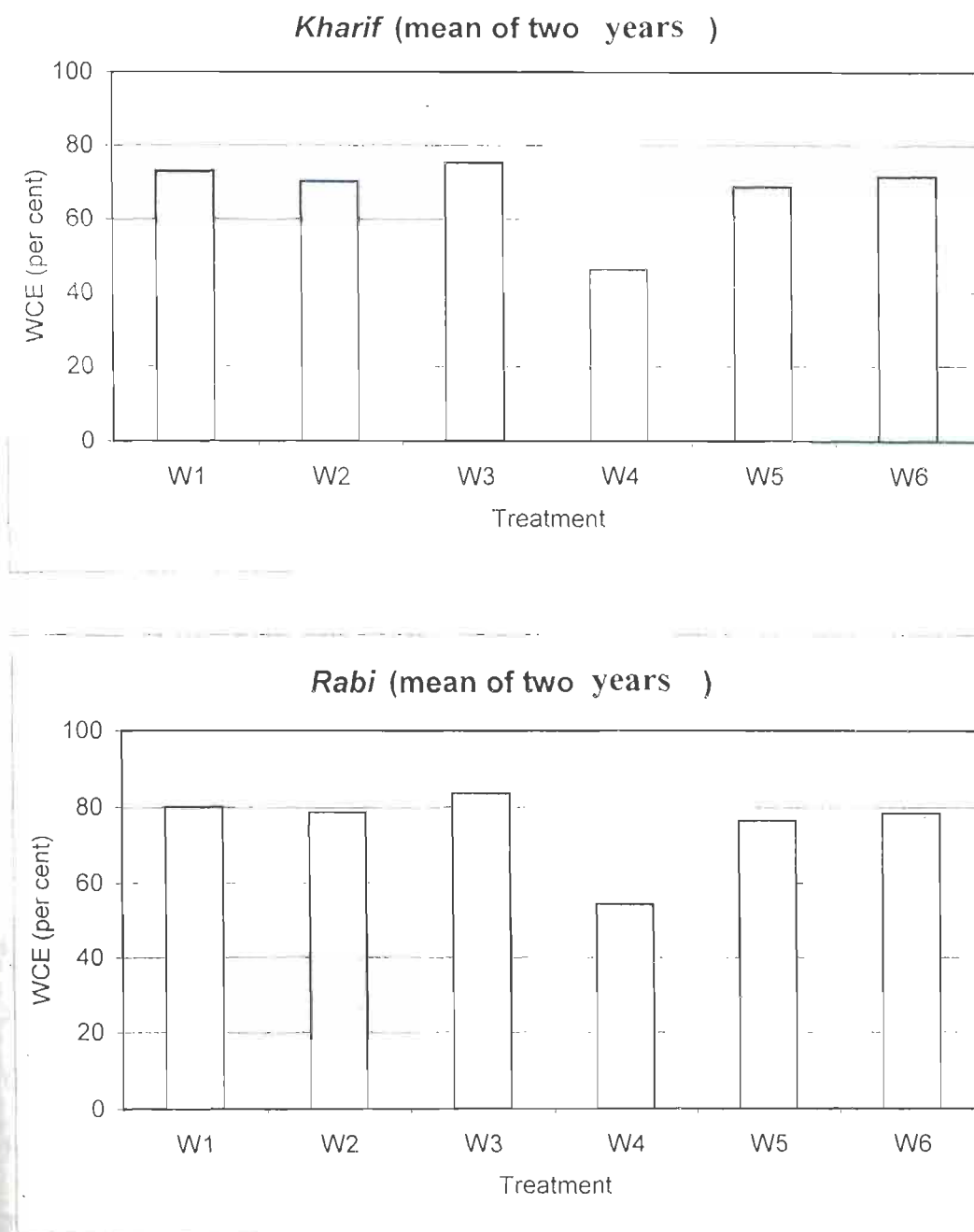


Fig. 10. WEED CONTROL EFFICIENCY OF DIFFERENT WEED CONTROL METHODS AT FLOWERING STAGE OF THE CROP

under N_1 treatment. Singh and Sharma (1995) also opined that enhancing the crop growth could suppress the weeds and their competition for nutrients. The trend in P and K depletion by weeds at maturity stage of the crop was also similar to N depletion by weeds under the N management practices in all the four crops.

Herbicide application reduced the N depletion appreciably by checking the weed seed germination at early stage (20 DAS) of crop growth. However, at tillering stage, N removal by weeds was minimum under manual (W_1) and manual + mechanical (W_2) methods of weed control. This might be due to comparatively lower weed population and growth upto tillering stage as manual or mechanical weeding was done at 20 DAS. However, at flowering and maturity stages cultural + manual method (W_3) recorded lowest value of N removal (Table 26 and 27) by weeds. Similarly, P and K uptake by weeds were also lower under this treatment over the rest at maturity stage in all the four crops. Better WCE as a result of lower weed dry matter in cultural + manual weeding has restricted the nutrient depletion by weeds as observed by Mathew and Alexander (1995). Unchecked weed growth in the weedy plot resulted in the highest depletion of nutrients throughout the crop growth period. The uptake of nutrients by weeds in unweeded treatment compared to best weed control treatment of cultural + manual method (W_3) was as high as 4 to 6 times of N, 3 to 4 times of P and 4 to 5 times of K at maturity stage of the crop. Madhu and Nanjappa (1996) also reported substantial removal of N, P and K by weeds in unweeded plot. The interaction revealed that removal of N, P and K by weeds was minimum under the combination of four splits of N with cultural + manual method as a result of lower weed population and weed dry weight and better WCE.

The pattern of nutrient removal by weeds showed that wherever effective control was achieved, the nutrient loss due to weeds was minimum. The nutrient removal by weeds in different seasons varied with the intensity of weeds and their dry weight. Among the seasons, *kharif* season in both the years registered higher amount of nutrient depletion by weeds than *rabi* season (Fig.11). This might be due to prevalence of favourable weather for better weed growth in *kharif* season (Srinivasan and Choudhury, 1994; Umapathi, 1998) than *rabi* season.

5.2.0. Studies on crop

5.2.1. Plant population

Split application of N and weed control methods did not influence the crop stand. Similarly, neither the chemical nor the non-chemical methods of weed control (including intercrop of *Sesbania*) included in the study affected wet seeded rice plant population. Though pretilachlor without antidote was reported to be marginally selective to wet seeded rice, use of ready mix pretilachlor + fenclorim (safener) did not affect the germination and stand of wet seeded rice (Table 30). Usui *et al.* (1999) reported that pretilachlor + safener was non-toxic on wet seeded rice.

5.2.2. Growth parameters

In the present investigation, plant height did not respond to different N management practices. Bhattacharya and Singh (1992) also observed that plant height was not significantly influenced under different split application of N. Growth of rice is influenced by many biological factors, including weeds growing in association with the crop. This is evident from the present investigation as satisfactory control of weeds by

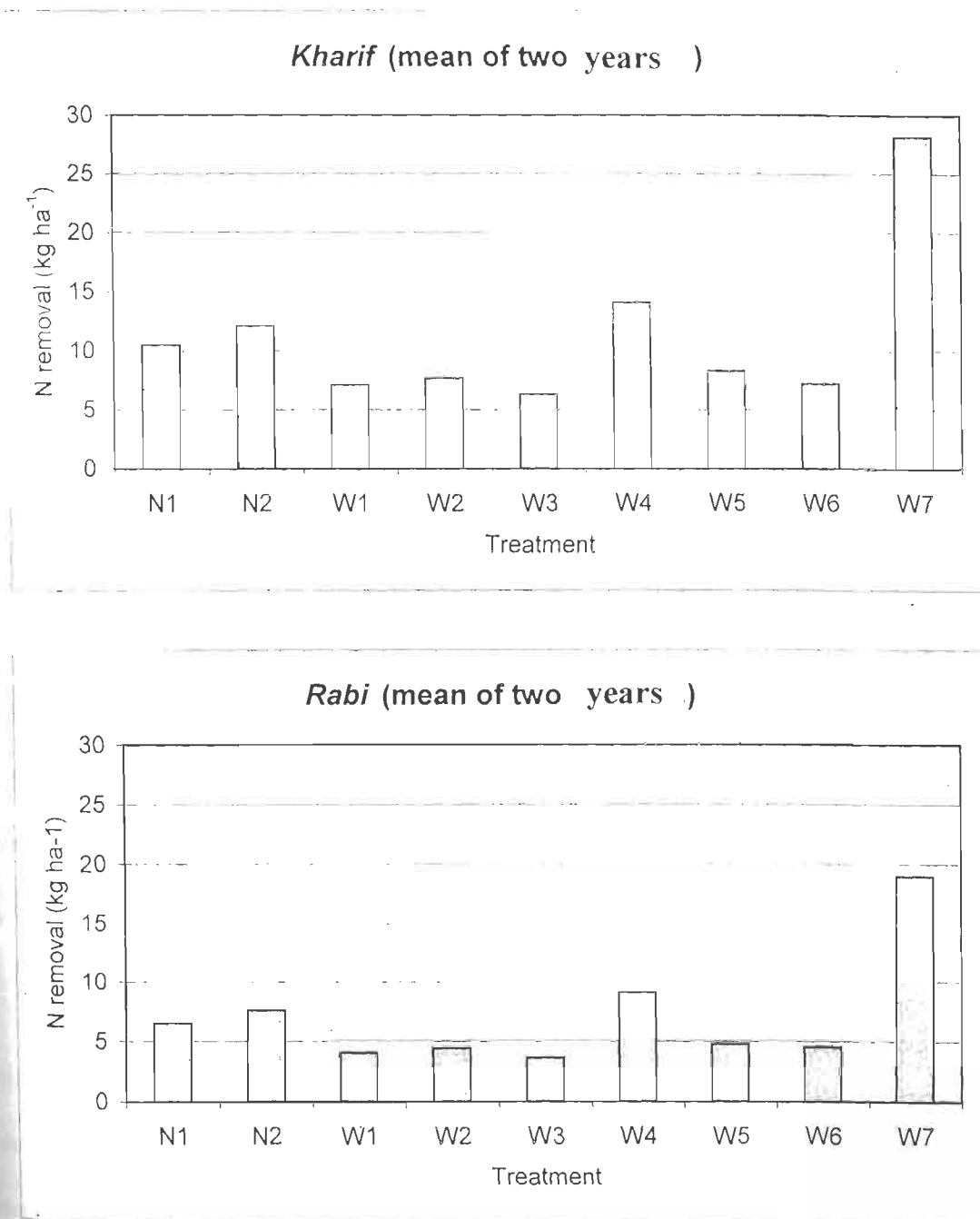


Fig. 11. NITROGEN REMOVAL BY WEEDS AT FLOWERING STAGE OF THE CROP

any of the weed control methods favoured the crop growth and yield attributes. As a result of severe competition for resources exerted by uncontrolled weeds, the plant height lowered throughout the growth period in all the crops.

In general, plant height was maximum in cultural + manual method (W_3) at flowering and maturity stages in all the seasons. This might be due to better weed control and better utilization of available resources for the crop growth. Mineralisation of organic N from incorporated intercrop, an additional source of N for rice crop, might also have helped in increasing the plant height. Srinivasan and Palaniappan (1994) observed higher plant height, tillers m^{-2} , LAI and DMP of rice in weed free plot. Plant height, a parameter of growth, is mainly governed by the factors such as light, space, water and nutrients. Higher weed population under unweeded and less effective weed control treatments competed for all these factors with rice crop, resulting in reduced plant height (Kempuchetty, 1997). Comparatively, lower plant height under cultural + mechanical method (W_4) could be attributed to the higher crop weed competition as mechanical method was not much effective to remove the weeds in inter and intra rows of rice (Moody, 1991).

Leaf area index (LAI) under different split application of N did not vary significantly at tillering stage in all the four crops. Among the weed control methods, due to effective control of weeds at an early stage in manual method (W_1), higher LAI was observed compared to unweeded treatment (W_7) in all the four crops. However, at later stages, four splits of N recorded higher LAI compared to five splits of N. This might be due to larger amount of N applied at AT and PI stages in N_1 treatment compared

to N_2 , that influenced better expansion of leaf area, not only due to increased availability of nutrients but also due to restricted nutrient depletion by weeds in this treatment. The data clearly brings out the superiority of N_1 over N_2 treatment for optimum leaf area expansion of rice. The availability of N at later stage (flowering) significantly contributed to the sustained photosynthetic surface as there was lesser competition from weeds for N (Vijayalakshmi, 1994; Pandey *et al.*, 1997).

The difference in LAI due to weed control methods was significant in all the crops. Severe weed competition with rice crop in unweeded treatment consistently recorded minimum LAI at tillering and flowering stages in all the four crops. Cultural + mechanical method (W_4) also showed lower LAI values compared to other weed control methods at flowering stage. This might be due to higher weed competition caused by less effective mechanical weed control. Reduction in crop growth and LAI due to weed competition was reported by Kandasamy (1987). On the other hand, effective control of weeds by manual method combined with smothering effect of intercrop (Mathew and Alexander, 1995; Bhan and Sushilkumar, 1996) and also, the mineralisation of organic N from the incorporated intercrop provided additional source of N for rice crop and this contributed to the increased LAI of crop (Broadbent, 1979; Umapathi, 1998).

The reduction in tiller production under five splits of N (N_2) compared to four splits (N_1) could be attributed to the increased weed competition (Biswas and Sattar, 1992). Lower amount of N supplied at AT and PI stages in N_2 compared to N_1 , might also be the reason for lower tiller number recorded at flowering stage. Thiyagarajan *et al.* (1993) also opined that late application of initial dose of N could increase the tiller production and leaf N concentration in lowland rice.

Though manual method (W_1) of weed control reduced the weed competition at early stage and increased the tiller production, such advantage in tiller production at later stages (flowering) was evident with cultural + manual method (W_3) due to effective manual removal of weeds and incorporation of greenmanure intercrop which provided an additional amount of N for more tiller production (Becker *et al.*, 1991; Mati Wade and Sheelavanter, 1994a; Karuppiyah, 1995) as adequate N content of rice plants stimulated the growth and production of tillers.

Tiller production in rice largely depends upon the stage at which weeds compete with the crop for space and nutrients. Weed competition during the vegetative phase largely affected the tiller production of direct seeded lowland rice (Mercado and Talatala, 1977). Upto 45 DAS weeds did not affect the crop growth and productivity, but beyond 45 DAS, considerable yield reduction of drum seeded puddled rice was reported by Ramamoorthy (1999). Significantly lower tiller numbers were recorded in unweeded treatment over other weed control methods, which might be due to severe competition of weeds with rice there by resulting in lower production of tillers (Srinivasan and Palaniappan, 1994) and higher tiller mortality due to severe weed competition as reported by Caton *et al.* (1997).

5.2.3. Dry matter production of rice

Though split application of N did not significantly influence DMP of rice at seedling and tillering stages of rice, higher DMP was observed at flowering and maturity stages under four splits of N (N_1) as compared to five splits of N (N_2). This might be due to restricted weed growth at the critical stages of crop-weed competition and application

of more N at AT and PI stages of the crop growth under N_1 treatment benefited the crop rather than the weeds for utilizing applied N (De Datta and Buresh, 1989; Dingkuhn *et al.*, 1992).

At early crop growth stage, weed control methods had no significant influence on rice DMP. However, at tillering stage, manual method (W_1) recorded higher crop DMP which was closely followed by chemical + manual method (W_6). The comparatively weed free condition provided by manual weeding had enhanced the LAI and tiller production and resulted in higher DMP of rice. Higher DMP was also observed in pretilachlor applied plot, which was due to their broad spectrum weed control and selectivity to rice crop (Karuppiiah, 1995). Lowest DMP of rice under unweeded condition might be due to severe competition exerted by weeds throughout the growth period of rice. This observation is in conformity with the reports of Caton *et al.* (1997) and Ramamoorthy (1999). At flowering and maturity stages, cultural + manual (W_3) and cultural + chemical + mechanical (W_5) methods registered higher crop DMP in all the seasons. This might be due to effective control of weeds which resulted in higher plant height, LAI and better crop growth. Incorporation of intercrop *Sesbania* also might have contributed additional amount of N to the rice crop to accumulate higher DMP (Becker *et al.*, 1991; Matiwade and Sheelavantar, 1994b). In addition to the provision of N and other mineral nutrients for the immediate need of the growing rice crop, there was a rapid and abundant evolution of CO_2 during *Sesbania* decomposition which might have benefited the rice crop under intercropping system, for enhanced photosynthetic activity (Bhardwaj and Dev, 1985).

5.2.4. Total leaf chlorophyll content and SPAD meter readings

Chlorophyll and accessory pigments are required to absorb the radiant energy for photosynthesis. However, chlorophyll was generally considered as a non-limiting compound unless the plant was subjected to severe nutritional deficiencies (Leidi *et al.*, 1991). In the present study, the total chlorophyll content registered in the different treatments did not vary substantially at tillering stage in all the four crops, but at PI stage, there was substantial variation among the treatments. The soil as well as applied N under both the N management practices were not limiting for the growth of the crop at tillering stage which could have brought an equal and non significant amount of chlorophyll content in the leaves of rice crop. During the PI Stage, the chlorophyll content was improved in N₁ treatment due to larger amount of N applied at AT stage in N₁ treatment compared to N₂ treatment. This is in conformity with the earlier findings of Devi, 1990; Laza *et al.*, 1993.

Among the weed control methods, cultural + manual (W₃) and cultural + chemical + mechanical (W₅) methods recorded higher chlorophyll content at PI stage in all the four crops. The reason attributed for the improved chlorophyll content may be due to the incorporation of *Sesbania* intercrop in addition to effective weed control. The weeds which are more efficient in assimilating N for their growth were effectively controlled in cultural + manual (W₃) and cultural + chemical + mechanical (W₅) methods and hence, the relatively higher amount of N available for the crop might have improved chlorophyll content of rice crop. Singh and Ram (1991) reported comparable effect of herbicide, mechanical and manual weed control methods on the chlorophyll content of rice. The increase in chlorophyll content recorded in W₃ and W₅ treatments substantially

improved the dry matter accumulation of the crop which formed as an important 'source' for the final translocation of the assimilates to the 'sink'. This substantiate the appropriate reason for the higher grain yield registered in these two treatments.

The SPAD meter readings are closely related to the chlorophyll content and in turn the N concentration of the leaves as N is an essential constituent of chlorophyll (Green wood *et al.*, 1991; Liangthuan and QinNan, 1999). In the present study, no significant variation was observed under the different split application of N practices at tillering stage of all the four crops. As the N was available equally in both the treatments and the chlorophyll content also was not altered significantly, the SPAD values were comparable. However, unweeded treatment (W₇) recorded minimum values of SPAD in all the crops which might be due to severe competition from weeds for available resources. There was substantial differences in SPAD values among N management practices as well as weed control methods. Application of N in four splits recorded higher SPAD values compared to five splits of N. It may be due to larger amount of N applied in N₁ treatment at AT stage and also less weed competition. Among the weed control methods, similar to chlorophyll, W₃ treatment recorded maximum SPAD value followed by W₅ in all the crops. This may be due to lesser competition from weeds and conversion of organic N from intercrop incorporation provided additional N to the crop. The additional N helped in the formation of more chlorophyll and darker green leaves and thus, higher SPAD values. The results of positive relationship between SPAD values (chlorophyll meter readings) and grain yield at tillering stage ($r = 0.60$ to 0.71) and PI stage ($r = 0.58$ to 0.76) in all the four crops observed in the present study allows prediction of plant N status based on SPAD values. Liangthuan and QinNan (1999) observed significant

positive correlation between SPAD values and leaf chlorophyll content of rice at mid tillering and panicle differentiation stages and also established the relationship between grain yield and SPAD values.

5.2.5. Nutrient uptake by crop

One way to achieve better use of the applied N is to apply the fertilizer at a time best to meet the demand of the rice plant (De Datta, 1981). In the case of direct seeded rice, the seedlings take some time to establish and start absorbing the applied nutrients, as the foraging capacity of roots are limited immediately after germination. Further, nutrients in the seeds are sufficient to sustain about 15 days of seedling growth (Maurya and Vaish, 1984).

In the present study, basal application of N under five splits of N (N_2) did not have much influence on N uptake by rice during the early (20 DAS) and tillering stages of crop growth over four splits of N in all the four crops. This may be due to more volatilization loss of basal applied N (Sharma and Mahapatra, 1990) and less crop uptake of N in early growth stage. Advantages of delaying first dose of N upto first weeding or maximum tillering stage of 30-40 DAS was reported by Mahapatra *et al.*, (1986). However, at flowering and maturity stages of the crop, N uptake was substantially increased in four splits of N (N_1) where larger quantities of N was applied at AT and PI stages as compared to five equal splits of N (N_2). Increased availability of applied N besides lower competition from weeds in N_1 over N_2 treatment enabled the crop to forage more N in N_1 treatment. The results revealed that growth and economic yield could be better even if the crop was maintained with a low N status in the early stage of growth

provided a continued optimum N supply during active vegetative and reproductive phases was maintained. Samantary *et al.* (1990), Thiyagarajan *et al.* (1994) and Johnkutty (1996) also reported that N uptake was high between vegetative and reproductive stages of rice.

Considering the N uptake values (Table 49) under different weed control methods, relatively weed free environment provided by manual method (W_1) in the early growth period enhanced the crop N uptake. However, during the later stages of the crop (flowering and maturity stages), higher amount of N was utilized by the rice crop in cultural + manual method (W_3) followed by cultural + chemical + mechanical method (W_5) irrespective of the seasons (Fig 12). Effective control of weeds in these two treatments restricted N depletion by weeds and favoured the crop to utilize maximum amount of N in their critical growth stages. Apart from this, biological N supply made by decomposing incorporated *Sesbania*, might have enabled the crop to absorb more amount of available N (Vaiyapuri *et al.*, 1995; Rangasamy *et al.*, 1997). In the cultural + mechanical method (W_4) of weed control, relatively poor control of weeds at early stage of the crop without any subsequent manual removal of established weeds has resulted in cumulative increase in weed biomass at flowering and maturity stages in all the crops. This caused severe competition of weeds for nutrients and recorded poor crop growth and resulted in less N uptake.

The P and K uptake estimated at maturity stage of rice varied with different N management practices. Since nutrient uptake is a function of both DMP and the nutrient concentration, the high DMP under N_1 treatment increased the uptake of these nutrients as well.

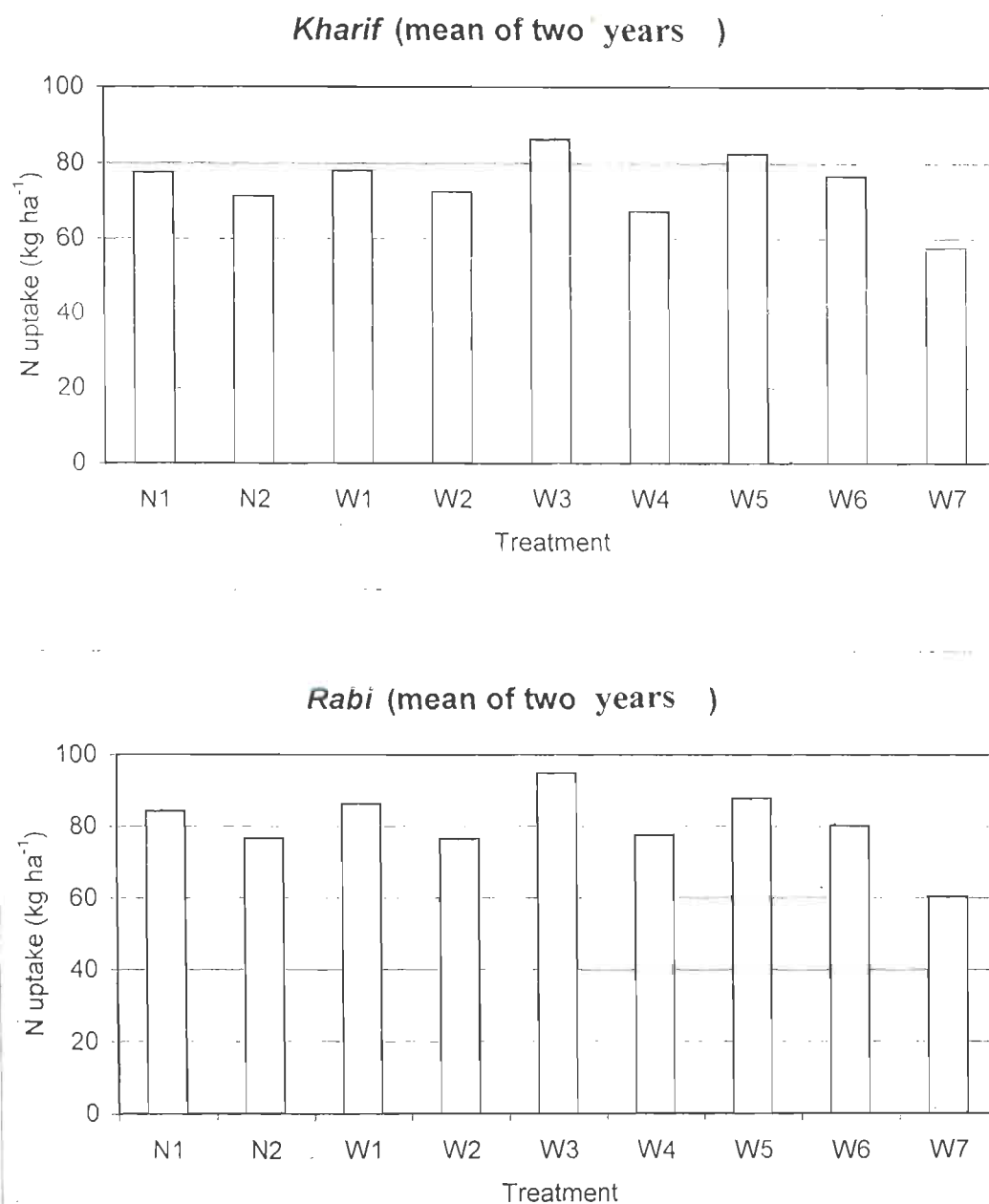


Fig. 12. NITROGEN UPTAKE BY RICE AT FLOWERING STAGE

With regard to weed control treatments also, the cultural + manual method (W_3) which had double advantage of restricted weed DMP and reduced weed nutrient uptake and additional nutrient supplied by incorporated intercrop (64.6 to 82.8 kg N ha⁻¹ in first to fourth crops, Table 3) resulted in increased nutrient uptake by the crop. Many researchers also agree that, weeds being more vigorous competitors, end up using a greater portion of the fertilizer applied to the rice crop, thereby reducing the growth of the crop as well as nutrient uptake (Lee and Moody, 1989; Karuppiyah, 1995; Baltazar and De Datta, 1992).

5.2.6. Yield components

The yield potential of rice is determined by panicle number m⁻², spikelet number panicle⁻¹ and size of the hull (Singh and Bhattacharjee 1988). The N management practices showed marked influence on the all yield components of rice

The panicles m⁻² and filled grains panicle⁻¹ were significantly higher under four splits of N compared to five splits of N. Though both these N management practices showed no significant influence on 1000 grain weight of rice, there was observed a numerical increase in N_1 treatment over N_2 in all the four crops. This might be due to comparatively larger amount of N applied at AT and PI stages and lesser weed competition under N_1 treatment which favoured better growth of rice as evidenced by higher plant height, tiller number, LAI and chlorophyll contents in leaves and consequently higher dry matter production. Enhanced growth of rice resulted in better expression of yield components such as panicles m⁻², number of filled grains panicle⁻¹ and 1000 grain weight resulting in higher grain yield. This is in conformity with the earlier findings of Vijayalakshmi *et al.* (1992).

Among the weed control methods, substantial differences were noticed in utilization of resources and response of the yield components of the crop to the degree of weed control achieved. Growing of *Sesbania* as intercrop and its manual incorporation at the early stage of wet seeded rice followed with a manual weeding on 35 DAS (W_3) recorded higher values of yield components viz., panicles m^{-2} , filled grains panicle $^{-1}$ and 1000 grain weight, which was followed by cultural + chemical + mechanical method (W_5). Both these treatments were equally effective to register higher value of panicles m^{-2} (first and second crop), filled grains panicle $^{-1}$ and 1000 grain weight and less percentage of unfilled grains panicle $^{-1}$ in all the four crops. This might be due to weed free condition prevailed during critical period of crop growth and additional nutrient supply by the decomposition of incorporated intercrop which increased the sink capacity of the crop as discussed earlier. Manual (W_1), manual + mechanical (W_2) and chemical + manual (W_6) methods of weed control were equally effective among them to register higher yield components over unweeded control treatment in all the seasons. However, combination of cultural + manual method (W_3) of weed control can be adjudged to be the most effective method as it markedly increased panicles m^{-2} (22 to 42 per cent), filled grains panicle $^{-1}$ (18 to 39 per cent) and 1000 grain weight (2 to 8 per cent) over unweeded treatment, which in turn reflected in higher grain yield. Further, the same weed control treatment (W_3) enhanced the panicles m^{-2} by 5 to 9 per cent and filled grains panicle $^{-1}$ by 4 to 9 per cent over recommended practice of two hand weedings (manual method). Though, 1000 grain weight was significantly affected by weed control treatments, the difference between unweeded treatment and other treated plots, were only marginal, as this parameter is mainly governed by genetic make up of the plant and not

easily influenced by management factors, except in cases of severe biotic and / or abiotic stresses. The lowest number of panicles m^{-2} , filled grains panicle $^{-1}$ and 1000 grain weight was observed in the unweeded control plot in all the four crops. This was due to severe competition exerted by weeds for space, light and nutrients throughout the crop growth period (Choudhury and Thakuria, 1998; Angiras and Rana, 1998).

5.2.7. Grain and straw yields, weed index and harvest index

Nitrogen improves grain production since it is a prime substrate for synthesis of organic N compounds which constitute protoplasm and chloroplasts (Yoshida and Oritani, 1974; Beringer, 1980). In the present study also crop N uptake was influenced by different N management practices. The effective N management under four splits of N (N_1) skipping basal application supplemented with larger doses at peak demand stage enabled for the better utilization of N by the rice crop as evident from better crop growth and yield components resulting in higher grain yield as compared to five splits of N (N_2) (Fig 13). Many researchers also opined that delaying application of first dose of N a week after germination till maximum tillering stage favourably influenced the yield and yield components of direct seeded low land rice (Mahapatra *et al.*, 1986; Venu *et al.*, 1990; Uppal and Sarkar, 1992).

The positive effect of N management on growth and yield characters of rice in turn enhanced the yield potential of wet seeded rice. Grain yield was positively related to LAI, DMP, N uptake by rice, panicles m^{-2} , filled grains panicle $^{-1}$ and negatively related to total weed population, weed DMP and N removal by weeds (Table 62). Similar result was also observed by Umapathi (1998).

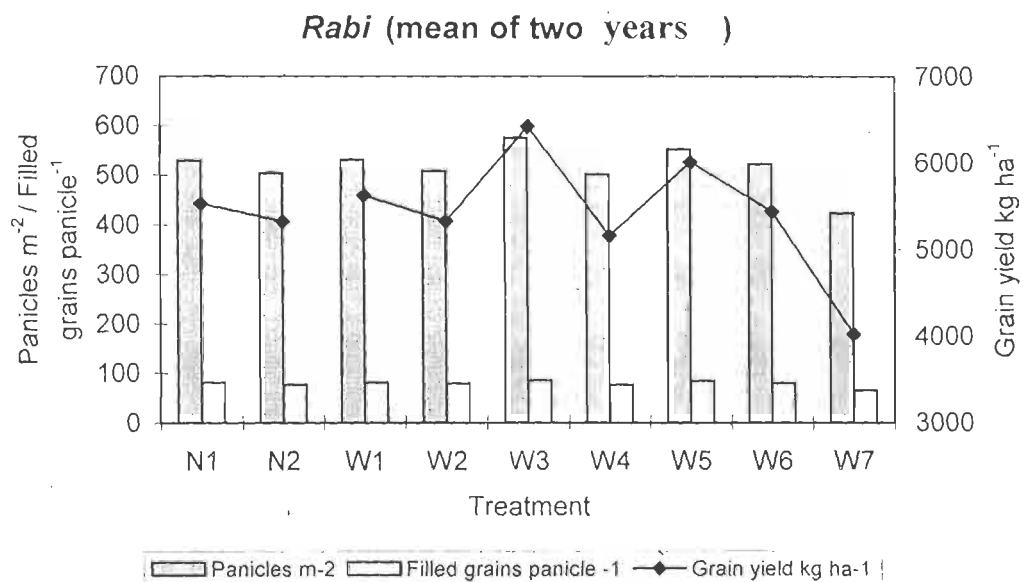
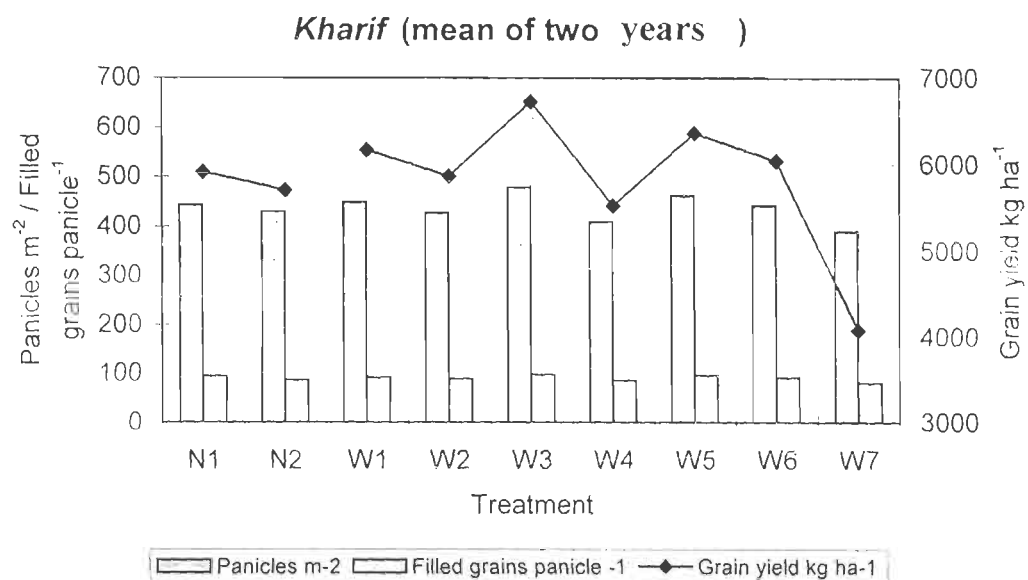


Fig. 13. YIELD AND YIELD COMPONENTS OF RICE UNDER DIFFERENT N MANAGEMENT AND WEED CONTROL METHODS

Substantial increase in grain yield (6332 to 6846 kg ha⁻¹ over the crops) was obtained with cultural + manual method of weed control (W₃) and the yield increase was as high as 58 to 66 per cent over unweeded control and 8.5 to 15 per cent higher yield over recommended practice of two hand weedings (manual method). This was due to effective suppression of weeds, restricting the nutrient drain by weeds, while increasing the nutrient uptake by crop which helped the crop to express its yield potential as discussed earlier. The next best grain yield (5946 to 6446 kg ha⁻¹) was obtained from cultural + chemical + mechanical method (W₅) and the increase in yield was 48 to 57 per cent over unweeded control over the four cropping seasons. Apart from effective weed control, better mineralisation of nutrients, increased LAI and chlorophyll content in leaves (Table 38, 45) and yield components might have contributed higher grain yield (Table 58, Fig 13) in these two treatments compared to rest of the treatments (Jayachandran and Veerabadran 1996a and b; Somasundaram, 1996; Islam *et al.*, 1999).

Manual method (hand weeding twice) and chemical + manual method produced comparable grain yield and recorded significant superiority over unweeded control. This might be due to effective control of weeds and the resultant better crop growth which increased yield attributes and the ultimate grain yield. However, these two treatments (W₁ and W₆) recorded 9.0 to 15.1 per cent lower yield as compared to the best treatment (W₃) over the seasons (Table 59). This might be due to additional N supplied in W₃ treatment through mineralisation of incorporated *Sesbania* intercrop and in addition to this, the supplied organic matter reduced the loss of applied N resulting in higher yield in W₃ treatment (Matiwade and Sheelavantar, 1994b). Comparable grain yields with pre emergence herbicide (pretilachlor) application followed by one hand weeding at

35 DAS and hand weeding alone, was reported by Nandal and Hari Om (1998). Mechanical + manual method (W_2) recorded comparatively lower yield over recommended practice of manual method (W_1). Mechanical damage of seedlings at early stage of the crop and the resultant lower number of panicles m^{-2} as well as the uncontrolled inter and intra row weeds might have reduced the yield under mechanical + manual method of weeding as observed by De Datta (1981) and De Datta and Baltazar (1996). Unweeded treatment invariably recorded lowest grain yield recording an yield loss of 36.9 to 40.1 per cent as compared to the best treatment (W_3) over the cropping seasons (Table 59).

Under direct seeded rice culture, crop and weed seeds germinate simultaneously and the latter one being more competitive, suppress crop growth. Higher yields are directly related to a high net photosynthesis. Competition for light between rice and weed (Rao, 1983; Kempuchetty, 1997) causes mutual shading and reduce the net crop photosynthesis. This might have resulted in greater reduction in growth and yield of rice in unweeded control or where weeds were not effectively controlled.

Combination of cultural + manual method of weed control with four splits of N (N_1W_3) registered highest grain yield and was comparable with combination of cultural + manual method under five splits of N (N_2W_3). Both these combinations recorded substantially higher grain yield over rest of the other treatment combinations. This might be due to effective suppression of weeds as well as additional supply of mineralized organic N through effective incorporation of *Sesbania* intercrop by manual method which resulted in increased growth and yield attributes as well as yield of rice (Table 58).

Nitrogen management strategy had a pronounced effect on straw yield, though the dose of N was the same for the both split application methods. Application of N in four splits (N_1) where no basal dose was given and larger dressing at grand growth stage (AT and PI stages) had enhanced the leaves, tillers and DMP of the crop and resulted in more straw yield (Table 60) compared to five splits of N (N_2) applied in equal splits starting from basal to heading stage. Further, as the basal application was skipped in N_1 treatment, the vigour and DMP of weed growth at the non-competitive growth stage of the crop (seedling) was reduced resulting in better crop growth from the initial stage itself to end with higher biomass yield.

Relatively weed free environment and addition of organic and inorganic N to the soil in cultural + manual method of weed control (W_3) resulted in higher DMP of the crop during the growth stages and higher straw yield at the end. This treatment registered 35 to 58 per cent higher straw yield over unweeded treatment and 7.6 to 11.3 per cent over recommended practice of two hand weedings (manual method). Weed control by cultural + chemical + mechanical method (W_5) also produced higher straw yield as that of cultural + manual method (W_3). Severe competition exerted by weed for nutrient, light and space throughout the crop growth in the unweeded situation caused substantial reduction in straw yield which ranged from 20.1 to 31.7 per cent over recommended practice of manual method (W_1) in all the four crops (Biswas and Sattar, 1992; Ramamoorthy, 1999).

Weed index is a measure of yield loss caused by varying degree of weed competition compared to the relatively weed free situation with maximum yield. In this study, cultural + manual method (W_3) recorded highest grain yield and the yield recorded

in other weed control treatments are related as yield loss as compared to W_3 . Cultural + chemical + mechanical method (W_5) proved to be the second best treatment recording a marginal yield reduction of 4.9 to 6.7 per cent over the best treatment (W_3) in all the crops. Manual method (W_1) was also effective in recording a yield reduction of only 9.0 to 13.1 per cent followed by chemical + manual method (W_6) (9.3 to 15.2 per cent) compared to cultural + manual method. Largest yield reduction of 37.8 to 40.1 per cent occurred in unweeded check over W_3 emphasizing the need for effective control of weeds to obtain higher yield in direct seeded lowland rice. Many earlier workers from different countries have reported yield losses of similar magnitude due to weed competition (Moody, 1990b; Hassan and Rao, 1996; Choudhury and Thakuria, 1998). Reduction in grain yield was caused by decrease in growth and yield components of rice under increasing pressure of weed competition for space, light, nutrient etc. (Madhu and Nanjappa, 1995; Angiras and Rana, 1998).

The small variation in harvest index (HI) values between two N management treatments indicate that the magnitude of influence of N application either in four or five splits was equal both on the biological and economic yield of wet seeded rice, though the yield levels are different between the N treatments. Weed control methods also did not cause a conspicuous difference in HI in all the crops and lowest HI values was recorded with unweeded treatment (0.430 to 0.460) in all the four crops (Table 61). However, numerical increase was observed in all weed control methods over unweeded treatment. This might be due to higher economic and biological yields obtained in weed control methods over unweeded control. Thus, it can be stated that, because of favourable effect

of these treatments on growth and yield components, there was greater translocation of the photosynthate from source to sink, resulting in higher HI. These results are in conformity with the earlier findings of Kandasamy (1987) and Ramamoorthy (1999).

5.2.8. Post harvest nutrient status of the soil

In general, there was an increase in organic carbon (OC) after harvesting of each crop compared to initial status (Table 63), as considerable quantities of crop residues were incorporated into the soil. Among weed control methods the treatment involving cultural method (intercropping) viz., cultural + manual (W₃), cultural + mechanical (W₄) and cultural + chemical + mechanical (W₅) methods recorded significantly higher OC as green manure not only supplied N to rice but also improved the soil physical and chemical properties by increasing OC in soils (Buresh and De Datta, 1991; Somasundaram *et al.*, 1996).

In the present study, soil available N declined from initial level in all the treatments. This might be due to increased crop uptake as well as N removal by weeds. Comparing different split application of N, the difference in N status was not evident indicating that the split application strategy did not alter the soil available N content significantly. Weed control methods showed significant influence on post harvest soil N. Cultural practice of growing intercrop *Sesbania rostrata* for weed suppression (W₃, W₄ and W₅) recorded significantly higher available post harvest N compared to other non-cultural weed control methods (W₁, W₂ and W₆) and unweeded control treatment in all the four crops. This indicated that incorporation of *Sesbania* intercrop resulted in gradual build up of soil available N status, which resulted in improved soil

fertility and crop yield. The beneficial effect of green manure on soil fertility status has already been established by several workers (Buresh and De Datta, 1991; Rangsamy *et al.*, 1997).

The difference in soil available P under N_1 and N_2 treatments was not evident indicating that split application strategy did not affect the post harvest available soil P. However, green manure intercrop incorporated treatments (W_3 , W_4 and W_5) recorded substantially higher available soil P over unweeded treatments. This might be due to addition of P through greenmanure incorporation and possible solubilization of soil P during the process of decomposition of green manure. Similar results have been reported by Lekha Sreekantan and Palaniappan (1990).

Better growth of crops with N supply resulted in increased uptake of K, thus depleting the soil available K at post harvest stage of each crop. However, neither split application strategy of N nor the weed control methods affected the post harvest available soil K.

5.2.9. Economics and energetics of wet seeded rice cultivation

The influence of N management practices on net income and benefit cost ratio (B:C) was conspicuous in all the crops. The treatment, four splits of N (N_1) gave the highest net return (Rs. 19,550 to Rs. 20,458 ha^{-1} in *kharif* and Rs. 22,631 to Rs. 23,597 ha^{-1} in *rabi*) and B:C ratio (2.79 to 2.88 in *kharif* and 2.96 to 3.05 in *rabi*) (Fig 14) compared to five splits of N (N_2). The details on cost of cultivation (Appendix VI) showed that, it was not altered much by changing the strategy of split application of N. But, N_1 treatment showed significant increase in grain yield over N_2 . The higher grain yield in this treatment (N_1) due to higher recovery of applied N was reflected in the

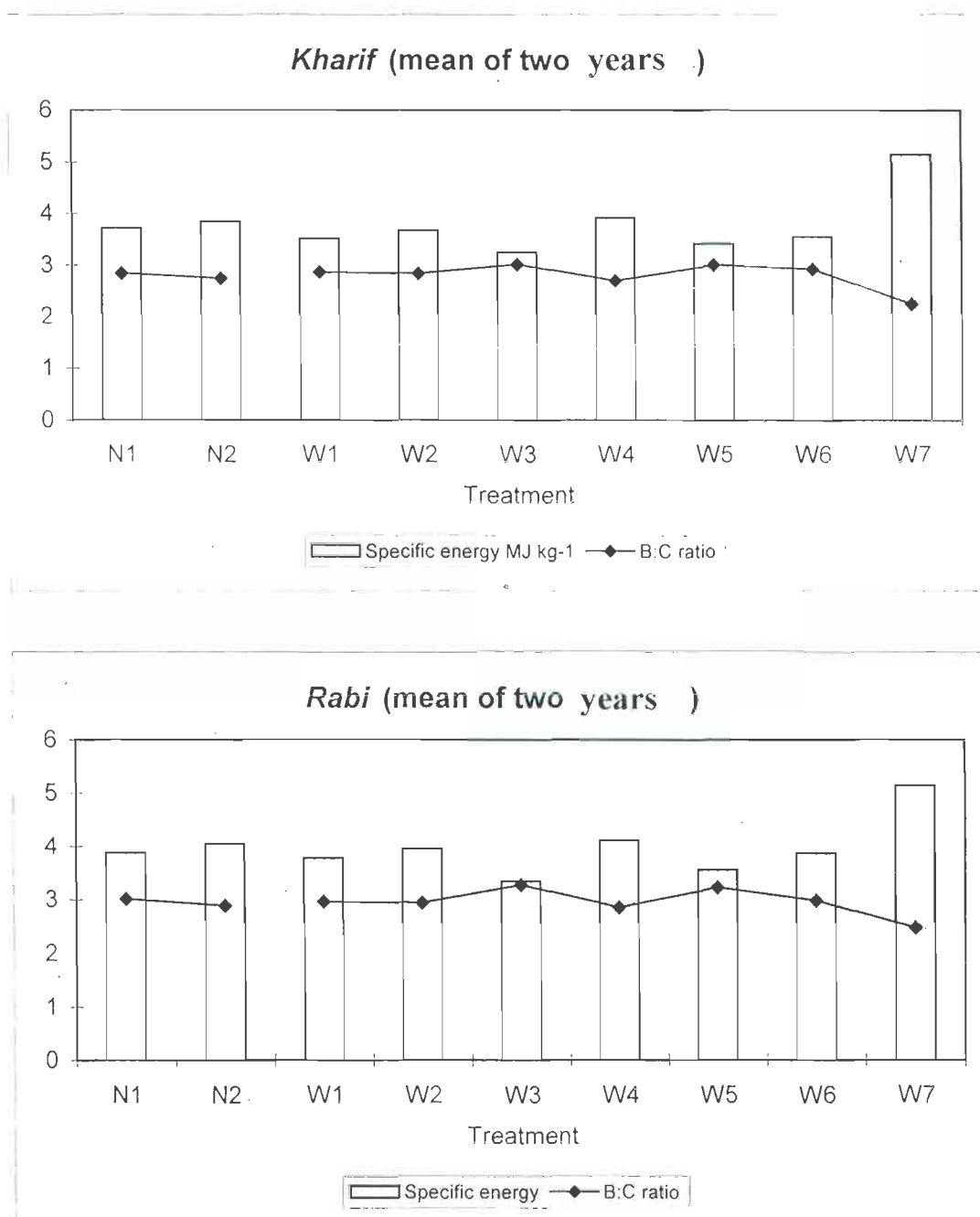


Fig. 14. B:C RATIO AND SPECIFIC ENERGY IN RICE PRODUCTION UNDER DIFFERENT N MANAGEMENT AND WEED CONTROL METHODS

advantages of economic indices such as net income and B:C ratio. Among the weed control methods, cultural + manual method (W_3) recorded highest net income (Rs. 22,765 to Rs. 28120ha⁻¹) and B:C ratio (2.96 to 3.30) followed by cultural + chemical + mechanical method (W_5) in all the four crops as increased grain and straw yields were obtained in these treatments. Though recommended practice of two hand weedings (manual method) recorded higher net income than chemical + manual method (W_6), B:C ratio was slightly better under W_6 . This was due to increased cost of manual weeding compared to chemical control (Thirumurugan *et al.*, 1998). Combination of four splits of N with cultural + manual method (N_1W_3) gave the highest net income and B:C ratio in all the crops. This indicates that higher economic returns and profitability could be achieved by growing *Sesbania* intercrop and incorporating it manually with follow up hand weeding combined with proper N management strategy.

The highest energy use efficiency (EUE) was associated with the treatment N_1 (four splits of N) compared to N_2 (five splits of N) in all the four crops. Higher energy output and less human energy involved for N fertilizer application under N_1 resulted in the increased EUE. Among the weed control treatments, cultural + manual method (W_3) recorded maximum EUE which was 7.3 to 11.7 per cent higher as compared to manual method (W_1) in all the four crops.

The increased EUE was possible due to higher output obtained from this treatment (W_3) as a result of effective weed control (Singh and Ghosh, 1994; Bhuvaneswari, 1998). Cultural + chemical + mechanical method (W_5) was the second best weed control method in terms of higher EUE.

Specific energy, a measure of energy required to produce one kg of rice was lowest in four splits of N (N_1). Specific energy showed considerable differences in various weed control methods irrespective of the seasons (Fig 14). Among weed control methods cultural + manual method (W_3) recorded lowest specific energy (3.19 to 3.38 MJ kg^{-1} in first to fourth crops) as the economical yield was more in this treatment as compared to rest of the weed control methods in all the four crops. Specific energy required in W_3 treatment was 6.8 to 12.4 and 34.2 to 37.8 per cent lower as compared to normal practice of manual method (W_1) and unweeded control (W_7) treatments respectively in all the four crops over the respective seasons.

SUMMARY AND CONCLUSIONS

CHAPTER VI

SUMMARY AND CONCLUSIONS

Field experiments were conducted at Tamil Nadu Agricultural University, Coimbatore, during *kharif* and *rabi* seasons of 1998-99 and 1999-2000, to study the effect of integrated methods of weed control (manual, mechanical, cultural and chemical) and split application of N on growth, productivity and nutrient uptake of wet seeded lowland rice. The experiments were laid out in a split-plot design with two N management practices (four splits of N - 1/6 at 10 DAS + 1/3 at active tillering (AT) + 1/3 at panicle initiation (PI) + 1/6 at heading and five splits of N - 1/5 at basal + 1/5 at 10 DAS + 1/5 at AT + 1/5 at PI + 1/5 at heading stage) as main plot treatments and seven weed control methods (manual, mechanical + manual, cultural + manual, cultural + mechanical, cultural + chemical + mechanical, chemical + manual and unweeded control) as sub plot treatments, replicated thrice. The varieties used were ADT 36 during *kharif* and ADT 39 in *rabi* season. The summary of results and conclusions drawn from the study are presented hereunder.

The growth and N contribution of row intercropped *Sesbania rostrata* did not vary very much for different split application of N and weed control methods under the respective treatments. The early growth and canopy coverage by intercrop *Sesbania rostrata* (as cultural method of weed control), biologically smothered the weed growth in between crop rows and also supplemented N through *in situ* incorporation, thereby promoting the crop growth to efficiently compete with the weeds and as well as to produce higher yields.

The weed spectrum of the experimental field consisted of fifteen weed species, of which were five grasses, four sedges and six broad leaved weeds. Weed infestation during *kharif* season was considerably severe than that of *rabi* season. Broad leaved weeds dominated during *kharif* (first and third crops), while grasses dominated in *rabi* season (second and fourth crops). However, monocots (grasses + sedges) were dominant over dicot weed in all the crops. *Echinochloa crus-galli* among the grasses, *Cyperus difformis* in sedges and *Eclipta alba* in broad leaved weeds were the predominant weed species observed. Application of N in four splits without any basal dose effectively and consistently kept the density of monocot, dicot and total weeds on lower side at the early stages (20 DAS and tillering stages) and weed dry matter throughout crop growth period compared to five splits of N, where basal application was included. However, as the growth stage of the crop advanced, the N management practices did not affect the density of weeds.

Effective weed control in terms of weed density and bio-mass was brought out by cultural + manual method of weed control including intercropping of *Sesbania rostrata* and its manual incorporation simultaneously with a manual weeding at 35 DAS. In addition to the smothering effect of *Sesbania* itself on weeds, the additional N (64.6 to 82.8 kg ha⁻¹ over seasons) provided to the crop, improved the crop growth rate and quick canopy coverage to compete with the weed.

Though, hand weeding twice (manual method) recorded higher weed control efficiency (WCE) followed by mechanical + manual method at tillering stage, cultural + manual method was the most effective integrated method to check weed growth and improved the WCE (74.6 to 83.3 per cent) at flowering stage and gave higher yields.

Nutrient depletion by weeds was more in the five splits of N over four splits. The cultural + manual method was the most efficient method of weed control to limit the weed dry weight as well as nutrients removal by weeds (6.64 to 8.43 kg N ha⁻¹, 1.36 to 1.97 kg P ha⁻¹ and 6.91 to 10.0 kg K ha⁻¹) at maturity stage in all the four crops. Weeds under unweeded control plots, depleted as high as 4 to 6 times more N, 3 to 4 times more P and 4 to 5 times more K compared to the figures with the efficient weed control method (cultural + manual). Combination of four splits of N with cultural + manual method recorded the lowest N, P and K removal by weeds.

Crop growth components (Plant DMP, chlorophyll content at PI stage, LAI at flowering, tiller numbers) and yield attributes (panicles m⁻² and filled grains panicle⁻¹) were higher under four splits of N over five splits which resulted in the increased grain yield in all the crops. However, plant height was not affected by different split application of N.

Among the weed control methods, cultural + manual method recorded the maximum tiller production, plant DMP, total chlorophyll at PI stage, LAI at flowering stage and yield attributes. This method markedly increased panicles m⁻² (22 to 42 per cent), filled grains panicle⁻¹ (18 to 39 per cent) and 1000 grain weight (2 to 8 per cent) over unweeded control which in turn reflected in higher yields in all the four crops.

The N uptake by crop also was higher under four splits of N over five splits. Among the weed control treatments, cultural + manual method recorded maximum nutrient uptake (113.6 to 129.5 kg ha⁻¹, 22.6 to 28.6 kg P ha⁻¹ and 162.9 to 180.6 kg K ha⁻¹ in all the crops) followed by cultural + chemical + mechanical method.

The total weed population and dry matter as well as nutrient uptake by weeds had a negative correlation with grain yield, while a highly significant positive correlation was noticed between the crop characteristics (LAI, SPAD values, DMP, panicles m^{-2} , filled grains panicle $^{-1}$, 1000 grain weight) and grain yield.

Rice grain yield under five splits of N ranged from 5231 to 5786 kg ha^{-1} , while there was substantial increase in the yield in four splits of N (2.6 to 4.2 per cent) over the four cropping seasons as a result of better crop growth and source - sink relationship.

Higher grain yields (6332 to 6846 kg ha^{-1}) were obtained in cultural + manual method and this yield increase was 58 to 66 per cent over unweeded control and 8.5 to 15.0 per cent over farmer's practice (manual method) in all the four crops. The next best grain yield was obtained from cultural + chemical + mechanical method which recorded a marginal yield reduction of 4.9 to 6.7 per cent over cultural + manual method. Highest yield reduction of 37.8 to 40.1 per cent occurred in unweeded control compared to cultural + manual method. The most effective combination of split application of N and weed control method for higher yield was four splits of N and cultural + manual method of weed control.

Improvement of straw yield due to split application of N and weed control methods followed the same trend as that of grain yield.

Post harvest soil analyses for organic carbon (OC), available N, P and K indicated a general decline in N and K content in all the cropping seasons, however a slight increase in OC and available P was observed compared to initial level.

Nitrogen management strategy did not show marked variation on post harvest soil organic carbon and available N, P and K content in all the four crops.

Among the weed control methods, cultural method adopted treatments (cultural + manual; cultural + mechanical and cultural + chemical + mechanical methods) recorded substantially higher OC and available N, P and K over unweeded control in all the four crops.

The maximum net profit of Rs. 19,550 to Rs. 20,458 ha⁻¹ in *kharif* seasons and Rs. 22,631 to Rs. 23,597 ha⁻¹ in *rabi* seasons and higher B: C ratio (2.79 to 2.88 in *kharif* and 2.96 to 3.05 in *rabi* seasons) were recorded in both the years under four splits of N.

Among the weed control methods, cultural + manual method recorded the highest net income (Rs. 22765 to Rs. 23919 in *kharif* and Rs. 27266 to Rs. 28120 in *rabi* seasons of both the years) and B: C ratio (2.96 to 3.06 in *kharif* and 3.23 to 3.30 in *rabi* seasons of both the years) followed by cultural + chemical + mechanical method. Combination of four splits of N with cultural + manual method of weed control gave the highest net income and B:C ratio in all the four crops.

The four splits of N had higher energy use efficiency (EUE) and thus required less energy to produce a kg of grains (specific energy). Because of higher EUE and lower specific energy with cultural + manual method of weed control, this integrated method of weed management could be regarded as the most energy efficient method. It was followed by cultural + chemical + mechanical method in all the crops. The treatment combination of four splits of N with cultural + manual method of weed control recorded maximum energy use efficiency (8.79 to 9.03) with less specific energy (3.18 to 3.30 MJ kg⁻¹) in all the four crops.

It could be concluded from the results of two years study that application of N in four splits at 10 DAS, AT, PI and heading stages of crop did not favour weed density and growth while promoted the growth, yield and economic and energetic indices of wet seeded lowland rice, grown during *kharif* (var. ADT36) and *rabi* (var. ADT39) seasons. The weeds which are the major problem in wet seeded rice could be effectively controlled through integrated method of growing *Sesbania* as a smother intercrop and incorporating manually *in situ* along with manual weeding at 35 DAS (cultural + manual method) by which the growth, yield, economic and energetic indices of wet seeded low land rice could be maximized. Where labour is a limitation, pre emergence application of pretilachlor @ 0.45 kg ha⁻¹ at 7 DAS, growing *Sesbania* as intercrop and incorporation of it by mechanical conoweeder along with weeding on 35 DAS could be a suitable alternative for effective weed control. Combination of four splits of N along with cultural + manual method of weed control can be judged as the best weed control method studied on the basis of better weed control, crop yield, economic and energetic indices and also for improvement of soil fertility in wet seeded lowland rice.

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APPENDICES

APPENDIX I

WEATHER DATA DURING THE CROPPING PERIODS (KHARIF AND RABI)

Period	Standard Week	Rainfall (mm)	No of rainy days	Mean Temperature		RH (per cent)		Mean daily pan evapora-tion. (mm)	Mean sun shine hours day ⁻¹
				Max	Min	07.22 hrs	14.22 hrs		
1	2	3	4	5	6	7	8	9	10
1998 -99									
June 11-17									
June 18 -24	24	-	-	32.7	24.6	69	57	6.5	NA
June 25 - July 1	25	3.8	1	32.0	23.9	69	58	7.1	NA
July 2-8	26	48.0	5	29.3	23.5	75	74	5.8	NA
July 9 - 15	27	23.5	3	29.5	23.0	73	56	5.8	NA
July 16 - 22	28	1.0	-	31.7	23.6	81	52	5.9	NA
July 23 - 29	29	23.0	2	31.7	22.6	89	59	4.0	NA
	30	-	-	30.7	23.5	81	56	5.8	NA
July 30 - Aug 5	31	6.5	1	31.7	23.4	84	59	5.2	NA
Aug 6 - 12	32	-	-	30.4	23.3	83	61	5.3	NA
Aug 13 - 19	33	10.8	3	31.8	23.3	90	61	4.0	NA
Aug 20 - 26	34	8.1	1	30.9	22.9	84	58	4.1	NA
Aug 27 - Sept2	35	54.0	1	31.9	21.9	83	54	5.0	NA
Sept. 3 -9	36	40.6	1	30.8	23.0	88	64	3.8	NA
Sept. 10 -16	37	2.0	-	30.8	23.4	74	52	6.8	7.0
Sept. 17-23	38	-	-	32.2	22.1	79	48	6.6	8.8
Sept - 24 - 30	39	73.9	2	29.4	22.3	90	71	2.4	2.9
Oct -1 -7	40	2.0	-	31.5	22.8	86	56	3.9	4.6
Oct 8 - 14	41	5.0	1	30.3	23.4	83	64	4.6	3.0
Oct 15 - 21	42	-	-	30.6	21.5	77	51	5.7	8.6
Oct 22 - 28	43	8.0	1	32.0	21.5	88	52	4.6	6.3

Oct 29 - Nov. 4	44	-	103.0	3	29.9	21.8	91	68	3.7	4.2
Nov 5 -11	45	213.4	4	28.4	22.4	91	64	64	1.5	4.3
Nov. 12 -18	46	2.0	-	31.0	19.7	88	53	53	4.0	8.5
Nov 19-25	47	-	-	31.2	20.8	87	55	55	3.4	7.6
Nov 26 - Dec 2	48	39.6	1	30.2	19.6	90	53	53	2.9	6.6
Dec 3 - 9	49	-	-	28.4	21.0	88	56	56	3.1	4.2
Dec 10 - 16	50	122.0	5	26.0	21.2	92	82	82	2.0	1.0
Dec 17 - 23	51	-	-	28.4	19.1	91	55	55	2.8	7.2
Dec 24 - 31	52	-	-	28.3	18.4	90	52	52	3.5	6.1
Jan 1 - 7	1	-	-	29.2	17.3	90	46	46	3.6	8.5
Jan 8 - 14	2	-	-	29.9	19.2	89	46	46	3.9	7.5
Jan 15 -21	3	-	-	29.3	17.9	88	44	44	3.9	7.0
Jan 22 -28	4	-	-	29.9	14.2	89	33	33	3.6	8.0
Jan 29- Feb 4	5	-	-	31.7	17.2	89	40	40	4.2	9.6
Feb 5 - 11	6	-	-	32.0	21.6	88	45	45	4.1	7.8

1999-2000

May 28 - June'3	22	-	-	32.6	23.4	84	50	6.1	7.3
June 4 - 10	23	5.0	1	32.5	22.7	83	52	5.9	6.7
June 11 - 17	24	9.0	2	30.9	22.9	78	58	6.5	5.3
June 18 - 24	25	10.0	1	30.1	22.6	77	51	5.9	5.3
June 25 July 1	26	-	-	32.9	20.8	87	41	6.8	9.6
July 2-8	27	-	-	32.6	22.2	86	49	7.0	7.2
July 9 - 15	28	1.0	-	31.9	22.4	83	49	6.5	4.6
July 16 -22	29	21.0	4	28.3	22.4	79	69	4.7	1.2
July 23 - 29	30	3.8	-	29.5	23.3	74	56	7.0	4.1
July 30 - Aug5	31	-	-	30.9	23.2	71	49	7.0	5.4
Aug 6 - 12	32	3.0	1	31.2	23.1	81	55	6.6	4.8
Aug 13 - 19	33	0.2	-	32.7	22.3	87	50	5.7	8.2
Agu 20 - 26	34	18.7	1	32.0	21.8	88	52	4.3	5.6
Aug 27 Sept. 2	35	-	-	32.2	21.9	85	46	5.6	7.2
Sept. 3 - 9	36	-	-	32.3	22.3	78	43	7.1	7.9
Sept. 10 - 16	37	-	-	33.0	21.4	83	43	6.9	9.3

Sept. 17 - 23	38	-	-	33.7	22.4	89	50	5.6	8.0
Sept 24 - 30	39	28.0	3	33.5	22.9	91	46	3.7	6.1
Oct. 1-7	40	72.3	4	29.9	22.5	94	68	2.8	3.9
Oct 8 - 14	41	31.9	3	30.9	22.3	93	60	4.2	7.7
Oct. 15 - 21	42	155.4	6	29.5	21.9	95	74	1.9	3.4
Oct 22 - 28	43	44.5	3	29.8	22.5	94	65	2.6	5.5
Oct. 29- Nov4	44	2.0	-	30.2	20.2	94	64	3.2	6.9
Nov. 5 - 11	45	64.2	2	29.9	19.8	91	51	2.5	8.0
Nov. 12 - 18	46	-	-	29.7	18.4	88	47	3.6	9.9
Nov. 19 - 25	47	35.0	3	27.4	21.0	93	71	3.0	3.5
Nov. 26, Dec.-2	48	6.4	1	28.4	21.0	91	63	3.2	6.3
Dec. 3 - 9	49	-	-	28.3	19.1	91	59	2.7	5.6
Dec. 10 - 16	50	3	1	26.2	19.3	91	62	2.9	6.1
Dec. 17 - 23	51	10	1	27.9	18.3	88	57	2.9	5.2
Dec. 24 - 31	52	8.8	1	26.8	19.3	90	54	3.2	7.6
Jan 1 - 7	1	-	-	28.3	19.9	87	52	3.4	5.7
Jan 8 - 14	2	2.0	-	28.1	20.5	87	62	3.5	2.9
Jan 15 - 21	3	-	-	30.5	18.1	91	39	4.1	9.2

NA : Not available

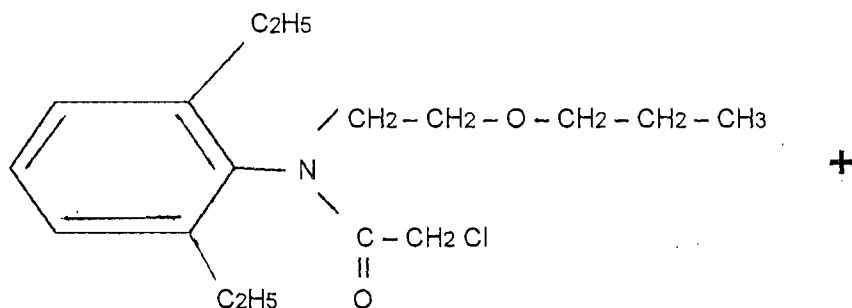
APPENDIX II

CHEMICAL STRUCTURE AND FORMULATION OF THE HERBICIDE USED IN THE EXPERIMENT

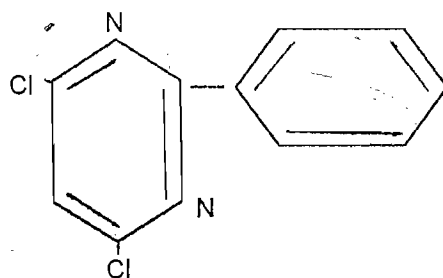
PRETILACHLOR PLUS SAFENER (= Fenclorim)

Family and group : Acetanilides
Trade name and Formulation : SOFIT 30 EC
Manufacturer : Novartis
Chemical name of herbicide : 2 - chloro - 2', 6' diethyl - N - (2 - propoxyethyl) -
(= pretilachlor) acetanilide
SAFENER CGA123407 : 4,6 - dichloro - 2 phenyl - pyrimidine
(= Fenclorim)

Structural formula :



Pretilachlor



Fenclorim

APPENDIX III
CALENDER OF OPERATION

Operation (s)	Date			
	1998 - 99		1999-2000	
	<i>Kharif</i>	<i>Rabi</i>	<i>Kharif</i>	<i>Rabi</i>
1. Ploughing the field and breaking clod	12.06.98	21.09.99	01.06.99	30.08.99
2. Ploughing and puddling	15.06.98 & 16.06.98	25.09.99 & 26.09.99	02.06.99 & 03.06.99	04.9.99& 06.09.99
3. Levelling and layout of plots with bund and channels	20.06.98	27.09.98	05.06.99	07.09.99
4. Application of basal dose of N (as per the treatment), P ₂ O ₅ & K ₂ O	22.06.98	28.09.98	07.06.99	08.09.99
5. Seeding	22.06.98	28.09.98	07.06.99	08.09.99
6. Application of pre emergence herbicide (W ₅ and W ₆)	28.06.98	05.10.98	14.06.99	15.09.99
7. Application of first top dressing of N (as per the treatment)	02.07.98	08.10.98	16.06.99	18.09.99
8. (a) Manual weeding (W ₁)	12.07.98	18.10.98	27.06.99	28.09.99
(b) Mechanical weeding (W ₂)	12.07.98	18.10.98	27.06.99	28.09.99
9. Weeding and intercrop trampling:				
(a) Manually (W ₁ , W ₂ , W ₃ & W ₆)	27.07.98	02.11.98	12.07.99	12.10.99
(b) Mechanically (W ₄ & W ₅)	27.07.98	02.11.98	12.07.99	12.10.99
10. Application of second top dressing of N	28.07.98	03.11.98	13.07.99	14.10.99
11. Application of third top dressing of N	17.08.98	02.12.98	02.08.99	13.11.99
12. Application of fourth top dressing of N	07.09.98	22.12.98	21.08.99	02.12.99
13. Harvesting, threshing and cleaning	08.10.98	29.01.99	24.09.99	04.01.2000

APPENDIX IV

DETAILS ON FIXED COST OF RICE CULTIVATION

Sl.No.	Particulars	Inputs	Rate	Total cost (Rs ha ⁻¹)
1	Preparatory cultivation			
	(a) Tractor ploughing twice and levelling	1 tractor for 10 hours	Rs. 135 ha ⁻¹	1350
	(b) Trimming, plastering and levelling	20 man days	Rs. 39.60 day ⁻¹	792
2	Seeds and sowing			
	i) Cost of seeds			
	a) ADT 36 (<i>kharif</i>)	80 kg	Rs. 16.00 kg ⁻¹	1280.00 (<i>kharif</i>)
	b) ADT 39 (<i>rabi</i>)	75 Kg	Rs. 20.00 kg ⁻¹	1500.00 (<i>rabi</i>)
	ii) Seed treatment			
	Bavistin	150 g	Rs. 610 kg ⁻¹	91.5
	iii) Rent of drum seeder	1 day	Rs. 75 day ⁻¹	75
	iv) Sowing	4 man days ha ⁻¹	Rs. 39.60 day ⁻¹	158.4
3	Fertilizers and application charges*			
	1) Cost of fertilizers			
	a) Urea	266.4 kg (<i>kharif</i>)	Rs. 4.00 kg ⁻¹	1065.60 (<i>kharif</i>)
		333.0 kg (<i>rabi</i>)		1332.00 (<i>rabi</i>)
	b) SSP	237.5 kg (<i>kharif</i>)	Rs. 2.90 kg ⁻¹	688.75 (<i>kharif</i>)
		312.5 kg (<i>rabi</i>)		906.25 (<i>rabi</i>)
	c) MOP	63.5 kg (<i>kharif</i>)	Rs. 3.70 kg ⁻¹	234.80 (<i>kharif</i>)
		83.5 kg (<i>rabi</i>)		308.95 (<i>rabi</i>)
	ii) Application charges	1 man day	Rs. 39.60 day ⁻¹	39.6

Sl.No.	Particulars	Inputs	Rate	Total cost (Rs ha ⁻¹)
4	Plant protection			
	a) Application charges	3 man days	Rs.39.60 day ⁻¹	118.8
	b) Cost of chemicals			
	Dimacron	500ml	392.5 l ⁻¹	196.25
	Nuvacron	1000 ml	364.0 l ⁻¹	364.6
	Hinosan	200 ml	628.0 l ⁻¹	124
5	Irrigation			
	Guiding water	12 man days (<i>kharif</i>)	Rs. 39.60 day ⁻¹	475.20 (<i>kharif</i>)
		10 man days (<i>rabi</i>)	Rs. 39.60 day ⁻¹	396.00 (<i>rabi</i>)
6	Harvesting			
	Harvesting, threshing, cleaning and Transporting	20 man days	Rs. 39.60 day ⁻¹	792
		36 woman days	Rs. 35.20 day ⁻¹	1276.4
7	Land rent	1 season	Rs. 300 ha ⁻¹	300
	Total			9413.90 (<i>kharif</i>) 10, 112.75 (<i>rabi</i>)

* Application charges for N are not included.

APPENDIX V
COST OF WEED CONTROL METHODS

Particulars	Total cost (Rs. ha ⁻¹)			
	<i>Kharif'98</i>	<i>Rabi'98-99</i>	<i>Kharif'99</i>	<i>Rabi'99-2000</i>
W ₁ (manual)	1689.6	1690.0	1760.0	1584.0
W ₂ (mechanical + manual)	1188.0	1117.6	1333.2	1097.0
W ₃ (cultural + manual)	2103.4	2033.0	2103.4	2033.0
W ₄ (cultural + mechanical)	1179.4	1179.4	1258.6	1179.4
W ₅ (cultural + chemical + mechanical)	1515.0	1435.8	1594.2	1435.8
W ₆ (chemical + manual)	1286.0	1286.0	1321.2	1180.4
W ₇ (unweeded control)	-	-	-	-

Cost of inputs : *Sesbania rostrata* (seeds) - Rs. 25 kg⁻¹;

Pretilachlor (SOFIT 30 EC) - Rs.370 l⁻¹

APPENDIX VI

DETAILS OF CALCULATION OF ECONOMICS IN EACH TREATMENT COMBINATION

Treatment	Total cost Rs ha ⁻¹	Yield (kg ha ⁻¹)		Gross income (Rs ha ⁻¹)		Net income/ loss (Rs ha ⁻¹) cost ratio**	
		Grain	Straw	Grain	Straw	Total	
1	2	3	4	5	6	7	8
							9
Kharif'98							
N1W1	11203	6327	7076	30053	2831	32884	21681
W2	10701	6232	6887	29602	2755	32357	21656
W3	11616	6871	7662	32637	3065	35702	24086
W4	10692	5641	6540	29795	2616	29411	18719
W5	11027	6432	7255	30552	2902	33454	22427
W6	10799	6198	6997	29440	2799	32239	21440
W7	9513	4363	4973	20724	1989	22713	13200
N2W1	11222	6136	6981	29146	2792	31938	20716
W2	10721	5711	6670	27127	2668	29795	19074
W3	11636	6821	7470	32400	2988	35388	23752
W4	10712	5546	6488	26344	2595	28939	18227
W5	11047	6460	7118	30685	2842	33532	22485
W6	10819	5986	6742	28434	2696	31130	20311
W7	9533	3842	4623	18250	1849	20099	10566
Rabi'98-99							
N1W1	11902	5664	7300	32568	2920	35488	23586
W2	11330	5137	6445	29538	2578	32116	20786
W3	12245	6445	7927	37059	3171	40230	27985
W4	11391	5227	7118	30055	2848	32903	21512
W5	11648	5973	7454	34344	2982	37326	25678
W6	11498	5527	6891	31780	2756	34537	23039
W7	10212	4182	4991	24047	1996	26043	15831

(contd . . .)

1	2	3	4	5	6	7	8	9
N2W1	11922	5346	6691	30740	2676	33416	21494	2.80
W2	11350	5200	6527	29900	2611	32511	21161	2.86
W3	12265	6218	7645	35754	3058	38812	26547	3.16
W4	11411	5027	6655	28905	2662	31567	20156	2.77
W5	11668	5918	7382	34029	2953	36981	25313	3.17
W6	11518	5209	6481	29952	2592	32544	21026	2.83
W7	10232	3700	4864	27968	1946	23221	12989	2.27
Kharif'99								
N1W1	11273	6261	7332	29740	2933	32673	21400	2.90
W2	10846	5877	6488	27916	2595	30511	19665	2.81
W3	11617	6671	7835	31687	3134	34821	23204	3.00
W4	10772	5493	6649	26092	2660	28751	17979	2.67
W5	11108	6328	7617	30058	3047	33105	21997	2.98
W6	10834	6060	7090	28785	2836	31621	20787	2.92
W7	9513	4073	4955	19347	1982	21329	11816	2.24
N2W1	11293	5920	6343	28120	2537	30657	19364	2.71
W2	10866	5639	6369	26785	2548	29332	18466	2.70
W3	11637	6542	7219	31075	2889	33962	22325	2.92
W4	10791	5433	6207	25807	2483	28290	17499	2.62
W5	11127	6231	6950	29597	2780	32377	21250	2.91
W6	10854	5922	6920	28130	2768	30896	20042	2.85
W7	9533	4042	4898	19200	1959	21159	11626	2.22
Rabi'99-2000								
N1W1	11796	5808	6913	33396	2765	36161	24365	3.07
W2	11309	5601	6876	32206	2750	34956	23647	3.09
W3	12245	6517	7425	37473	2970	40442	28197	3.30
W4	11391	5313	6685	30550	2674	33224	21833	2.92
W5	11648	6215	7062	35736	2825	38461	26913	3.30
W6	11392	5738	6982	32994	2793	35786	24394	3.14
W7	10212	4141	5571	23811	2228	26039	15827	2.55

(contd ...)

1	2	3	4	5	6	7	8	9
N2W1	11816	5680	6733	32660	2693	35353	23537	2.99
W2	11329	5393	6622	31010	2649	33659	22330	2.97
W3	12265	6505	7259	37404	2904	40307	28042	3.29
W4	11411	5087	6551	29250	2620	31871	20460	2.79
W5	11668	5939	6742	34149	2697	36946	25178	3.17
W6	11412	5306	6676	30510	2670	33180	21768	2.91
W7	10232	4081	5327	23466	2131	25597	15365	2.50

* Total cost : Fixed cost + cost of inputs

** Benefit - cost ratio : Gross income / total cost

Price of produce : Grain - Rs. 4.75 kg⁻¹ (ADT 36) ; Rs. 5.75 kg⁻¹ (ADT 39)

Straw - Rs. 0.40 kg⁻¹

APPENDIX VII

ENERGY UNIT CONVERSION FACTORS

Equivalents for direct and indirect sources of energy

Particulars	Unit	Equivalent Energy, MJ	Remarks
A. INPUTS			
1. Human Labour			
a. Adult man	Man-hour	1.96	1 Adult Woman - 0.8 adult man
b. Woman	Woman-hour	1.57	1 Adult Woman - 0.8 adult man
2. Diesel	Litre	56.31	It includes the cost of lubricant
3. Petrol	Litre	48.23	It includes the cost of lubricant
4. Electricity	kwh	11.93	
5. Machinery			
a. Electric motor	Kg	64.80	Distribute the weight of the machinery equally over the total life span of the machinery (in hours). Find the use of machinery (hours) for the particular operation in a crop
b. Primemovers other than electric motors (including self - propelled machines)	Kg	64.80	
c. Farm Machinery	Kg	62.70	
6. Chemical fertilizers			
i. N	Kg	60.60	Estimate the quantity of N, P ₂ O ₅ and K ₂ O in the chemical fertilizer. Then compute the amount of energy input from Chemical fertilizer
ii. P ₂ O ₅	Kg	11.1	
iii. K ₂ O	Kg	6.7	
7. Chemicals			
i. Superior	Kg	120	Chemical requiring dilution at the time of application DDT, gypsum or any other chemicals not requiring dilution at the time application
ii. Zinc sulphate	Kg	20.9	
iii. Inferior chemicals	Kg	10.0	
8. Seed			
Output of crop production system and not processed			Same as that of output of crop production system
B. OUTPUT			
MAIN PRODUCT			
Cereal crops such as wheat, maize, sorghum bajra, barley, oats, paddy (not shelled rice)	Kg (Dry mass)	14.7	The main output is grains
BY PRODUCT			
Straw	Kg (Dry mass)	12.5	

APPENDIX VIII

Details of energy budget of wet seeded lowland rice cultivation (as referred by Mittal *et al.* 1985)

Treatment	Total energy input (MJ ha ⁻¹)	Total energy output (MJ ha ⁻¹)	Energy use efficiency	Specific energy MJ kg ⁻¹
1	2	3	4	5
<i>Kharif '98</i>				
N ₁ W ₁	21558	181457	8.42	3.41
N ₁ W ₂	21412	177698	8.30	3.44
N ₁ W ₃	21831	196779	9.01	3.18
N ₁ W ₄	21546	164673	7.64	3.82
N ₁ W ₅	21658	185238	8.55	3.37
N ₁ W ₆	21406	178573	8.34	3.45
N ₁ W ₇	20955	126299	6.03	4.80
N ₂ W ₁	21566	177462	8.23	3.51
N ₂ W ₂	21419	167327	7.81	3.75
N ₂ W ₃	21839	193644	8.87	3.20
N ₂ W ₄	21554	162626	7.55	3.89
N ₂ W ₅	21666	183937	8.49	3.35
N ₂ W ₆	21414	172269	8.04	3.58
N ₂ W ₇	20963	114264	5.45	5.46
<i>Rabi '98-99</i>				
N ₁ W ₁	21214	174511	8.23	3.75
N ₁ W ₂	21043	156076	7.42	4.10
N ₁ N ₃	21462	193829	9.03	3.30
N ₁ N ₄	21203	165812	7.82	4.06
N ₁ N ₅	21283	187725	8.82	3.59
N ₁ W ₆	21062	167384	7.95	3.81
N ₁ W ₇	20612	123863	6.01	4.93
N ₂ W ₁	21222	162224	7.64	3.97
N ₂ W ₂	21051	158028	7.51	4.05
N ₂ W ₃	21470	186967	8.71	3.45
N ₂ W ₄	21211	157084	7.41	4.22
N ₂ W ₅	21291	179270	8.42	3.60

APPENDIX VIII (Contd...)

1	2	3	4	5
N ₂ W ₆	21070	157585	7.48	4.04
N ₂ W ₇	20620	115190	5.59	5.57
<i>Kharif'99</i>				
N ₁ W ₁	21583	183687	8.51	3.45
N ₁ W ₂	21465	167492	7.80	3.65
N ₁ W ₃	21831	196001	8.98	3.27
N ₁ W ₄	21578	163860	7.59	3.93
N ₁ W ₅	21689	188234	8.68	3.43
N ₁ W ₆	21419	177707	8.30	3.53
N ₁ W ₇	20955	121811	5.81	5.14
N ₂ W ₁	21591	166312	7.70	3.65
N ₂ W ₂	21473	162506	7.57	3.81
N ₂ W ₃	21839	186405	8.54	3.34
N ₂ W ₄	21586	157453	7.29	3.97
N ₂ W ₅	21697	178471	8.23	3.48
N ₂ W ₆	21427	173553	8.10	3.62
N ₂ W ₇	20963	120642	5.76	5.19
<i>Rabi'99-2000</i>				
N ₁ W ₁	21177	171790	8.11	3.65
N ₁ W ₂	21035	168285	8.00	3.76
N ₁ W ₃	21462	188612	8.79	3.29
N ₁ W ₄	21203	160601	7.57	3.99
N ₁ W ₅	21283	179636	8.44	3.42
N ₁ W ₆	21025	171624	8.16	3.66
N ₁ W ₇	20612	130510	6.33	4.98
N ₂ W ₁	21185	167659	7.91	3.73
N ₂ W ₂	21043	160974	7.65	3.90
N ₂ W ₃	21470	186361	8.68	3.30
N ₂ W ₄	21211	156666	7.39	4.17
N ₂ W ₅	21291	171578	8.06	3.58
N ₂ W ₆	21033	161448	7.68	3.96
N ₂ W ₇	20620	126578	6.14	5.05



Plate 3. General view of the experimental field



Plate 4. Manual method of weed control

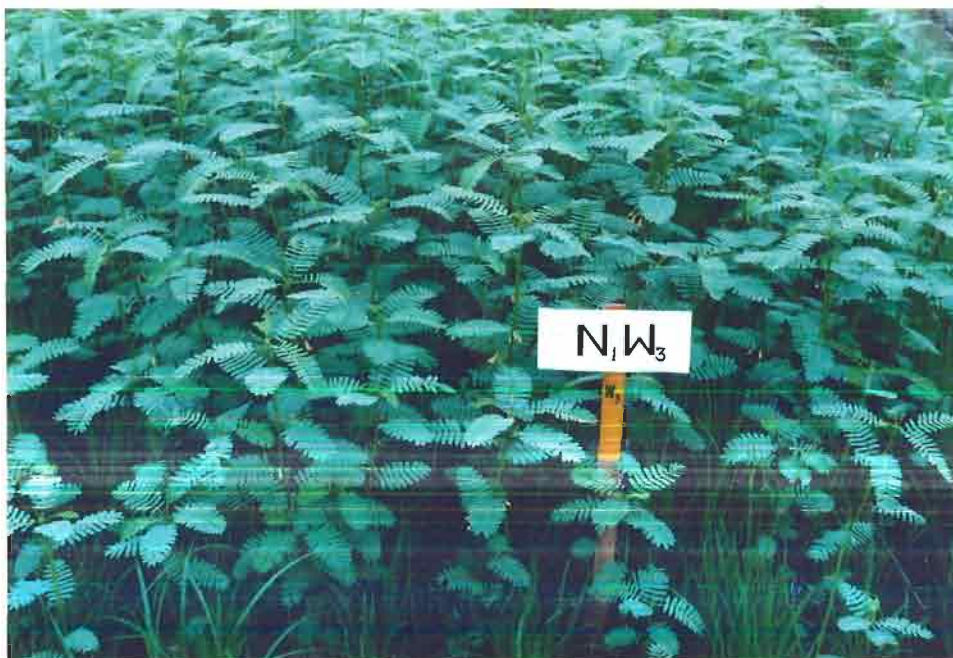


Plate 5. Cultural + manual method of weed control



Plate 6. Mechanical + manual method of weed control



Plate 7. Manual vs cultural + mechanical method of weed control



Plate 8. Unweeded control plot