NITROGEN UTILIZATION, GROWTH AND YIELD OF RICE AS AFFECTED BY GREEN MANURING AND TIMING OF ISOTOPE AND NON-ISOTOPE N

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By

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CERTIFICATE

This is to certify that the thesis entitled **"NITROGEN UTILIZATION, GROWTH AND YIELD OF RICE AS AFFECTED BY GREEN MANURING AND TIMING OF ISOTOPE AND NON-ISOTOPE N"** submitted in part fulfilment of the requirements for the award of the degree of Agronomy to the Tamil Nadu Agricultural University, Coimbatore is a record of bonafide research work carried out by **Mr. I. JOHNKUTTY** 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 or 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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Green manure is a good source of N for lowland rice which enhances soil fertility and crop productivity. The primary goal of improved N fertilizer management practices should be to maximize the uptake, recovery and use efficiency of applied N by the crop by minimising the N transformation processes that lead to losses of N from the soil-water eco-system. A two year field experiment (1994-'96) was conducted on a Typic Haplustalf soil at Tamil Nadu Agricultural University, Coimbatore to determine the effects of green manuring and timings of N application on growth and yield of lowland rice. The experiments were laidout in a Split-plot design with four main-plot treatments (sesbania, cowpea, parthenium and no green manure treatment) and five

sub-plot treatments comprising timing of N application (150 kg N ha^{-1}) at varying number of splits and quantities at different growth stages of the crop compared with unfertilized control.

The soil NH_4^+-N flux, time course behaviour of N concentration, biomass accumulation and N uptake in the crop; uptake and recovery of isotope ^{15}N and non-isotope N; leaf chlorophyll-N relationship; efficiency of applied N; and growth and yield of rice were closely monitored. Based on the observed data, prediction models were also developed to best suit the natural behaviour of different parameters (soil NH_4^+-N flux, leaf-N time course and SPAD-leaf N relationships) in the soil-plant system.

Green manuring and N fertilization increased the growth and yield of rice. The strategy of applying 150 kg N ha^{-1} in six equal splits from planting to heading was found to be the best N timing for enhancing the growth and yield of rice. Application of 150 kg N ha^{-1} in three equal splits at early tillering, panicle initiation and heading was also found equally effective. These N timings increased the yield by 11-33 per cent over other N timings. The net income and B:C ratio were increased by green manuring. The cost of cultivation did not vary widely by increasing the number of split application. Nitrogen splits extending upto heading increased the economic returns and B:C ratios substantially. The average net income by split N application upto heading ranged from Rs.21809/- to 23073/- in *kharif* and from Rs. 14455/- to 17533/- in *rabi*. The B:C ratios ranged from 3.11 to 3.23 in *kharif* and from 2.49 to 2.80 in *rabi*.

The difference between N timings on various factors and components of growth and yield got narrowed down by heading stage. The yield response of the crop behaved more or less as a function of N fertilization at heading. The rate and amount of biomass accumulation and N uptake during the post-anthesis period was substantially increased by N fertilization at heading stage. The peak NH_4^+-N release in soil from green- manures occurred between the second and fourth week after transplanting rice. During the peak period, the soil NH_4^+-N in green manure plots got increased by 7.90 to 21.89 ppm over non-green manure plots. Split application of N starting from planting or early tillering and continued upto heading stage maintained a steady NH_4^+-N supply in soil and N concentration in plant throughout the crop growth at optimum levels for better yield.

The ^{15}N studies proved the continued uptake of N by the crop even after heading and the increased N uptake of the crop by heading stage fertilization. Both apparent N recovery (ANR) and agronomic efficiency (AE) were increased by application of N at heading stage. Application of larger dose of fertilizer-N at planting or panicle initiation stage resulted in low ANR, AE, harvest index, yield, net income and B:C ratio.

The practice of repeated application of green manure improved the soil fertility besides crop yield. Rice cropping without green manures and fertilizer-N depleted the status of organic carbon and N in soil.

The strong relationship between SPAD value and leaf-N (r=0.75) confirm the usefulness of SPAD meter for assessing the plant N concentration and suggest the timing of N side-dressing. The mathematical model developed (Lorentzian model) allows the prediction of leaf N status based on SPAD value. Mathematical models to predict the soil NH_4^+-N flux from green manures and leaf N status under different N timing strategies were also developed based on the observed data. The simulated values confirmed the observed values of the field experimentation.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS USED

AE	agronomic efficiency
ANR	apparent nitrogen recovery
ANRH	ANR at heading
ANRM	ANR at maturity
B:C	benefit-cost ratio
C	celcius
cal	calories
CEC	cation exchange capacity
cm	centimetre
CD	critical difference
C:N	carbon-nitrogen ratio
dH	days after heading
dPI	days after panicle initiation
dS	deci Simen
DT	days after transplanting
ET	early tillering
EC	electrical conductivity
evap.	evaporation
et al.	co-workers
F	flowering
FltN	flag leaf total nitrogen
Fnl	flag leaf nitrogen concentration
g	gram
H	heading
ha	hectare
HI	harvest index
kg	kilogram
Kmph	kilometre per hour
MT	maximum tillering
MM	mid maturity
M	maturity
m	metre
mm	millimetre
mol	mole
MSL	mean sea level
NUE	nitrogen use efficiency
nL	leaf nitrogen concentration
OC	organic carbon
PE	physiological efficiency
PI	panicle initiation
P	probability
ppm	parts per million
r	coefficient of correlation
sd	standard deviation
t	tonne
TDMP	total dry matter production
wt	weight

INTRODUCTION

Chapter I

INTRODUCTION

The foundation of intensive agriculture in India was laid in the third Five Year Plan with the advent of input-responsive high yielding varieties of crops, especially rice. Increased use of fertilizers and improved agronomic practices, ushered in the Green Revolution in the country to achieve self sufficiency in food production. However, difficult tasks are still before us. It has been projected that the foodgrain production has to be increased from the current status of 182 million tonnes (m.t.) to 230 m.t. by 2000 AD and to 320 m.t. by 2030 AD to feed the then population of 1 billion (b) and 1.6 b, respectively (Shekhon, 1994). Of this, the share of rice is calculated to be about 42 per cent which emphasize the importance of rice among the food grains in the country, though the area occupied by the crop is only 23 per cent of the total foodgrains (186 m.ha). In order to meet the rising demand for rice, it is imperative to maximize and sustain its productivity as the scope for further increase in area under plough is very limited. The present national average productivity of rice, 2200 kg ha^{-1} is far below the potential yield (Fertilizer Association of India, 1993).

About half of the total increase in rice production in the post-Green Revolution era has been attributed to the use of fertilizers (Randhawa, 1992). Crop yield is influenced, often decisively by the extent to which the nutrient requirement can be satisfied. The nutrient removal - consumption gap by 2000 AD is expected to be 16 m.t. (Hegde and Dwivedi, 1993) which would be further widened in the future years. Intensive agriculture with very high nutrient turnover in soil-plant system, coupled with imbalanced and inefficient fertilizer use results in deterioration of soil productivity and poses serious threats to long-term sustainability of crop production. This is further aggravated by rapid organic matter depletion because of the tropical climate of the country.

Among the three major nutrients, nitrogen (N) is the most important productive factor for rice and it largely determines the yield level. Low cost and easy availability of chemical fertilizers have made the use of organic manures including green manures, a practice almost forgotten in the post-Green Revolution period. It is paradoxical that the conditions favour better growth and yield of rice also accelerate the losses of N. Further, complete reliance on chemical fertilizers alone to meet the crop demands leads to multinutrient deficiencies and other ill-effects as has been experienced in Punjab and other Green Revolution belts. This situation can possibly be retrieved only through combined use of all sources of plant nutrients including organic manures and by taking appropriate steps to increase the nutrient use efficiency.

Green manure is a good source of N, which also enhances soil fertility through its effects on soil physico-chemical properties. Legumes like sesbania *(Sesbania rostrata)* and cowpea *(Vigna unguiculata)* have great potential in the tropics since they can be grown in the summer rice fallows. Another possibility is incorporation of parthenium *(Parthenium hysterophorus)* which is a noxious weed in many parts of India. Organic manures can substitute chemical fertilizers, but to meet the N demand over all growth stages and to sustain high yields of irrigated rice, chemical fertilizer must be used along with organic-N sources. Integrated use of green manures and inorganic fertilizers can reduce N losses, increase soil fertility and sustain the long-term productivity and ecological stability.

The primary goal of improved N management practices should be to maximize N uptake at critical growth stages and to minimize N transformation processes that lead to losses of N from soil-water system. To produce high yields, it is essential to maintain the leaf-N at fairly high level for high photosynthetic activity (Greenwood *et al.*, 1991). Recent experimental results suggest that late N application beyond panicle initiation (PI) could substantially increase grain yield (Iwasaki *et al.*, 1992) due to continued root uptake capacity (Cassman and Samson,1994). The recovery of N from both green manures and fertilizers can be increased if proper N-fertilizer management strategy, particularly timing of fertilizer-N application, is adopted. Earlier investigations on these aspects were focussed mainly on single component basis, either green manure alone or fertilizer alone. Studies on efficiency of absorbed N for yield formations and its time course behaviour due to changes in N management strategies like postponement of fertilizer-N topdressing upto heading with basal N supply through green manures are limited.

With this background the present investigation was made with the following major objectives:

1. to monitor the behaviour of rice crop in terms of growth, dry matter and N partitioning, N uptake, dry matter and N translocation, grain yield; and recovery and efficiency of N as influenced by green manure and timings of fertilizer-N,

2. to understand the N mineralization processes and ammonium-N release pattern under integrated nitrogen supply system,

3. to establish the possibility of using chlorophyll-N relationships for N management in lowland rice; and

4. to study the recovery and utilization of applied N at different growth stages with combined application of green manures and ^{15}N-urea.

REVIEW OF LITERATURE

Chapter II

REVIEW OF LITERATURE

Ever since the focus of policy and research was on increasing the productivity of rice, nitrogen (N) has been recognised as prime input and the attention on N is still sustained as the crop yield increase is substantial with N fertilization.

Among the N sources, urea accounts for more than 75 per cent of the total N fertilizer consumption in Asia (De Datta *et al.*, 1990). Despite the impressive growth in urea output and its use for rice production in Asia, research over the past 20 to 30 years has shown that use efficiency of fertilizer-N to rice crop seldom exceeds 40 per cent (Craswell and Vlek, 1979). 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). The nature of N fertilizer, method and time of application affect the N use efficiency.

During the past twenty years, use of organic manures including green manures, which were traditionally important sources, of nutrients, declined substantially as chemical fertilizers became cheaper and readily available. The rising cost of N fertilizers and the concern about the long-term health of soil and environment have now revived the interest of researchers to organic N sources, especially green manures.

Use of organic manures at least in partial substitution of inorganic N fertilizers is being recommended now.

The primary goal of improved N management practices should be to maximize N uptake at critical growth stages and minimize N transformation processes that lead to temporary or permanent losses of N from soil-water system. It is also important to understand the N transformation processes in soil and plant for timely adjustment of N management. Utilization of absorbed N by crop and its effect on dry matter production are now fairly well understood (Yoshida, 1981; and Kropff *et al.*, 1992). However, a gap still exists in our understanding of drymatter partitioning and sink formation as influenced by N uptake. which is a function of current N status of crop and chlorophyll-N relationships.

Research work on green manuring, and N fertilizer management in relation to crop growth, N uptake, partitioning of assimilates and chlorophyll-N relationships are reviewed and presented in this chapter.

2.1 Losses of fertilizer-N from rice soils

Losses of N from urea are reported to range from 60 to 80 per cent in rice soils (Stangel, 1977). Even under the best managed conditions the recovery of N seldom exceeds 40 per cent (Reddy and Patrick, 1977).

2.1.1 Causes of low N recovery

The low recovery of applied N is attributed to ammonia volatilization, denitrification, leaching and run off, immobilization and ammonium fixation (Craswell ad Vlek, 1979; and Savant and De Datta, 1982).

Volatilization

Most of the NH_3 volatilization occurs within three days of nitrogen application (Mikklesen *et al.*, 1978). Mahapatra *et al.* (1988) reported that the NH_4^+-N content in flood water decreased gradually to around two to six ppm within a week of fertilizer application and then to about two to three ppm on ninth day. Nitrogen loss by NH_3 volatilization is reported as a function of wind speed and the partial pressure of NH_3 (Fillery *et al.*, 1984; and Freney *et al.*, 1985). Ammonia volatilization increases under high flood water pH, temperature and wind speed (De Datta *et al.*, 1987a). Volatilization loss of urea applied at transplanting (P) was more than that applied at 10 days after panicle initation (PI). Since rice canopies were well developed at PI the flood water temperature and pH were reduced. These conditions were not conducive to high volatilization losses. Katyal and Gadalla (1990) observed N volatilization within two days of urea application due to high PNH_3.

Denitrification and immobilization

It has been reported that 10 to 30 per cent of the applied N is lost to the atmosphere in gaseous form (Westerman *et al.*, 1972). A strong correlation between soil denitrifying capacity and water soluble organic carbon or mineralizable carbon has been observed by Burford and Bremner (1975). Addition of organic compounds are reported to stimulate denitrifying activity (Firestone, 1982). However, John *et al.* (1989b) observed no effect on denitrification loss (N_2O + N_2) due to incorporation of *in situ* cowpea at planting of rice.

Under optimum conditions for microbial activity and in the presence of an available C source, added ^{15}N was rapidly immobilized (Kai *et al.*, 1973). However, immobilization of N is not a total N loss mechanism as it only amounts to a temporary shortage of N supply to the current crop.

Leaching losses

Normally, 5 to 10 per cent of applied N may be lost by leaching (Westerman *et al.*, 1972). Leaching loss of urea-N was influenced by the number of splits, mode of application, N rates and soil types. With a single application it was two times than that with three splits (13 per cent vs 6 per cent) (Singh *et al.*, 1991). Rekhi *et al.* (1982) observed negligible losses via leaching of ^{15}N-urea applied in three equal split doses to low-land rice. Cao *et al.* (1983) and Craswell *et al.* (1984) reported 35 to 60 per cent N loss with surface application or soil incorporation of urea-N. Nitrogen loss through leaching increased with rate of applied-N (Fillery and Vlek, 1982).

Katyal *et al.* (1985) reported that the leaching loss of N was not significant n clayey soils. However Velu *et al.* (1988) reported 6 to 13 kg N ha^{-1} as leaching loss in clayey soils of Tamil Nadu.

2.2 Effects of green manuring

According to Ladha *et al.* (1988) the two the major possible sources of organic manures are farm yard manure (FYM) and green manures. Farm yard manure is the best organic manure but its availability is limited because dung is widely used a source of fuel and the farm animal population is declining. As an alternative, green manuring with N-fixing legumes can contribute to a substantial part of rice N requirement and supply organic matter to wet land rice soils (Bouldin, 1988). Integrated use of green manures and inorganic fertilizers can contribute to increase the availability of N in rice soils as well as to the increase in long-term productivity and ecological sustainability (Gill and Meelu, 1982).

2.2.1 Addition of nutrients

The benefits credited to green manures include increase in organic matter content and available plant nutrients. Of these, the role of green manures in supplying plant nutrients, particularly N is most prominent (Rinaudo *et al.*, 1983).

Among several types of aquatic green manures, *Sesbania rostrata* is an important one, because it fixes large quantity of N_2 and grows quickly (Ladha *et al.*, 1989). Beri and Meelu (1981) have shown that green manuring rice with two months old *S. aculeata* was as effective as application of 60 kg N ha^{-1} through urea. Food legumes can also be used as green manure and incorporated prior to their maturity (Morris *et al.*, 1986a). John *et al.* (1989c) reported that incorporation of cowpea green manure increased the rice yield and its N accumulation. Cowpea green manuring contributed 12 to 26 kg N ha^{-1} to rice and increased the uptake of ^{15}N labelled urea applied with the green manure. Legumes grown in rice fallows can scavenge soil nitrate which might otherwise be lost while flooding the soil for rice production (Buresh and De Datta, 1991). Studies by Rao (1982) with noxious weeds like parthenium showed that it could be a very good green manure for lowland rice. Purushothaman *et al.* (1990) observed more residual effect from parthenium than from leucaena leaf as evidenced by higher rice yields in the second season.

The triggering of oxidation - reduction reactions, particularly in flooded soils and increased chelation capacity brought about by the addition of green manures, enhance the transformation and availability of micronutrients, particularly Fe and Mn (Maskina *et al.*, 1985). On mineralization, green manures liberate plant available form of P in the soil. Organic acids formed during the course of decomposition of green manures interact with soil components and enrich the pool of available P (Watanabe, 1984). In water-logged soils green manuring can markedly increase the availability of Ca, Mg and S (Katyal, 1977; and Khind *et al.*, 1987). Zia *et al.* (1992b) observed 16 to 18 per cent increase in N content of soil by green manuring with sesbania but P content of soil was not appreciably affected.

2.2.2 Reduction in losses of N

Leaching loss

According to Singh *et al.* (1992) leaching losses of green manure-N are normally expected to be smaller than that of inorganic fertilizers, as it must be mineralized before leaching. Bhagat *et al.* (1988) reported that leaching loss from basally applied urea was about three times the N loss observed with green manure application. Velu *et al.* (1988) reported that leaching loss of N from a clay loam soil was lower from green manure plus urea plots than urea alone plots. Such reduction in leaching loss of applied N; was ascribed to temporary immobilization of applied N and adsorption of fertilizer-N as well as green manure-N.

Volatilization and denitrification

Green manuring is reported to reduce volatilization loss of ammonia, especially in high pH soils. Rao and Batra (1983) reported the denitrification loss of N as 4.5 per cent in sesbania treatment compared to 29 per cent in urea alone treatment. In an incubation study, Venkatakrishnan (1980) observed that addition of green manure @ 5.4 t ha^{-1} in sodic soils initially caused a reduction in ammonia volatilization but after 10 days of flooding, marked volatilization occurred and 23 per cent of the green manure N was lost in 63 days. However, John *et al.* (1989b) found no effect by cowpea green manuring on N loss from urea either incorporated at transplanting or broadcast at 15 days (d) after transplanting.

Addition of readily decomposable organic matter is known to enhance denitrification potential due to narrow C/N ratio and rapid release of N (Bremner and Shaw, 1958). But addition of residues with a high C/N ratio can reduce N loss through enhanced immobilization of N (Yoshida and Padre, 1975). According to Rekhi and Bajwa (1993), *S. aculeata* amendment in wetland rice soils limited volatilization losses of N in addition to supply of N. Mahapatra *et al.* (1988) recommended integrated nutrient management (INM) to minimize NH_3

volatilization by keeping the flood water pH near neutral, and NH_4^+-N and NO_3^--N contents low.

2.2.3 Priming effect

An added effect of applied organic and fertilizer N on rice productivity is through enhanced mineralization and availability of soil N (Westcott and Mikklesen, 1985). This is generally attributed to 'priming effect' (Hauck and Bremner, 1976), meaning induced mineralization of native soil N by comparatively small addition of fertilizer N. Addition of energy rich organic materials increased microbial activity and lead to enhanced mineralization of native soil organic matter (Jansson and Persson, 1982).

2.2.4 Grain yield

Substantial yield increase by addition of green manures has been reported by several workers. Morris *et al.* (1986a) demonstrated that a fast growing legume can accumulate more than 80 kg N ha^{-1} in 45 days and that rice yield response exceeding 2 t ha^{-1} were possible from green manure incorporation. Green manure application that supplied 40 kg N ha^{-1} plus 40 kg N ha^{-1} as urea gave similar yield to that obtained by application of 80 kg N ha^{-1} as fertiliser N.

Combined application of sesbania and urea gave significantly higher yield than split application of 80 kg N ha^{-1}

as urea. This increase in rice yield was accomplished by an increase in panicle number and filled spilekets per panicle with green manuring (Mahapatra and Sharma, 1989). Rabindra *et al.* (1989) from Karnataka reported that at same N rates, yield increased significantly with 30 kg N as *S. rostrata* applied 5 d before planting and 70 kg N as urea, applied in two splits (half at planting and half at PI), over 100 kg N as urea applied in three equal splits (half at planting, 1/4 at tillering and 1/4 at PI). The cost involved in supplying N through *S. rostrata* was less compared to that of urea. Application of *S. rostrata* @ 20 t ha^{-1} along with prilled urea @ 60 kg N ha^{-1} doubled the yield as compared to urea alone at the same N level (Kalidurai and Kannaiyan, 1990). Diekmann *et al.* (1993) reported that *S. rostrata* was as effective as urea at the same N levels on producing rice grain yield. Similar results were obtained by Morris *et al.* (1989). However, Bhandari *et al.* (1992) found that grain yield by substitution with *S. aculeata* at 25 to 50 per cent N level was inferior to 100 per cent as urea-N.

2.3 NH_4^+-N release pattern of green manures

Green manure must undergo decomposition and mineralization before its N becomes available to the crops. Nitrogen release pattern under green manuring in flooded soils has been studied by several workers (Nagarajah, 1988; and Singh *et al.*, 1992).

2.3.1 Factors influencing NH_4^+-N release

The rate of NH_4^+-N release is determined by the green manures' chemical composition, C:N ratio and temperature (Singh *et al.*, 1992). Green manure contains two N fractions: that decomposing during the first crop (fast-N) and the other decomposing slowly over several years (slow-N). With most green manures, the first fraction is 50-80 per cent of the total N. Therefore, young succulent plants high in N and low in lignin will decompose more rapidly than mature, low N and high lignin residues (Alexander, 1977). As the plant matures, its N content, protein and water soluble constituents steadily decrease while the amount of fibre, hemicellulose and lignin and C:N ratio increase. Frankenberger and Majid (1985) found a highly significant positive correlation between total N content in legume residues and the cumulative amount of N mineralized in soil and they have fixed the critical value of N content as 1.73 per cent.

Organic residues with wide C:N ratio often have a slow rate of decomposition. In many cases the critical C:N ratio falls between 15 and 33 (Black, 1968). The C:N ratio of cowpea at flowering was 17-18 compared to 25-27 in cowpea residue after harvest (John *et al.*, 1992). Nagarajah (1988) reported faster initial N release by sesbania (N=2.72%) than sunnhemp (N=1.68%) or cowpea (N=2.43%). Nagarajah *et al.* (1989) reported 9 per cent lignin content in in 50 days old *S. rostrata*.

Aspiras (1966) reported increase in NH_4^+-N release from sesbania with increase in temperature from 20 to 40°C.

2.3.2 Peak NH_4^+-N -release

The decomposition and release of N from green manures proceed very rapidly during the first few weeks followed by much slower phases thereafter (Singh *et al.*, 1981; Bhardwaj and Dev, 1985). The net recovery of N as NH_4^+, from five grain legumes at 50 days of incubation in flooded soils, ranged from 16 to 20 per cent and it correlated directly with N percentate and inversely with C:N ratio of the legumes (Nagarajah, 1988). Residues of grain legumes, which frequently have a lower N content than that of green manures, also released NH_4^+-N^+ rapidly in tropical flooded soils.

Significant increase in soil NH_4^+-N cowpea green manure and cowpea residue addition, over fallow treatments has been observed by John *et al.* (1989a) at IRRI, Philippines. Soil NH_4^+-N increased dramatically from 3 days before transplanting (5-10 kg ha^{-1}) to 6 days after transplanting (DT) (35-40 kg N ha^{-1}) and then gradually decreased to 5-15 kg at 24 DT and 10 kg at 36 DT. Khind *et al.* (1985) obtained a peak NH_4^+-N release at 7 to 15 days of incubation followed by a rapid decrease due to N losses. Singh *et al.* (1981) reported that sesbania released 31 per cent of N in 20 days and 49 per cent in 30 days after flooding. Similar results have been reported by Sharma and Mahapatra (1987) and Nagarajah (1988).

Incorporation of *S. rostrata* provided N continuously to rice even after 45 DT (Buresh *et al.*, 1993b). Similar observation has been made by Anilakumar *et al.* (1989) on incorporation of *S. aculeata* in laterite soils at Pattambi, Kerala.

2.3.3 Loss of green manure-N

Several studies revealed large losses of N from green manure on decomposition and mineralization (Bhardwaj and Dev, 1985; and Beri *et al.*, 1989). Initial rapid release of N from green manures resulted in losses of N from soil either as NH_3 through volatilization or N_2 and N_2O through denitrification of nitrates or through leaching of nitrates (Singh *et al.*, 1992). Studies with ^{15}N-urea indicated that similar amount of legume-N and fertilizer-N are lost to the environment (Papendick *et al.*, 1987; and Bezedecek and Granastein, 1989) which contradicts the belief that legume-N is less susceptible than fertilizer-N to losses in the soil-plant system.

Rice readily assimilated NH_4^+-N released by mineralization of incorporated green manure (Buresh *et al.*, 1993a) *S. rostrata* readily decomposed and released N for young rice plants. Therefore, contrary to the general belief that at least 15 day decomposition period is to be allowed before planting rice, maximum rice yield was obtained when rice was planted almost immediately after incorporation of the green manure (Bhardwaj, 1982). Increasing the time for decomposition resulted in significant yield reduction (Balasubramanian and Palaniappan, 1992).

2.4 Residual effect of green manures

Residual effect of green manures depend in their chemical composition and the rate of mineralization and also the frequency of application. Lower the C:N ratio of green manure, lower was the amount of residual N recovered in the soil organic fraction and higher was the amount of residue N mineralized. During decomposition of low-N green manures, soil N may be transformed into highly stable and complex compounds rendering the soil N unavailable to the subsequent crop for a long time (Wagger, 1989).

The fast-N fraction determines the supply of N to the first crop and the slow-N fraction determines the residual effect of N supply and soil organic matter.

Continuous application of green manure increased the organic N content in soil. Changes in soil organic N content due to short term application of organic matter for 2-3 years are gradual rather than drastic (Bremner, 1965). Ventura and Watanabe (1991) observed residual effect with a continuous application of green manure on the grain yield only after nine crops. Low green manure-N level of 85 kg N ha^{-1} did not effect any residual effect even after 4 years of application (Morris *et al.*, 1986a) Bhardwaj and Dev (1985) reported a slight build up of soil N status following rice harvest. However, the effect of green manures on subsequent wheat yield was not significant. Whereas green manuring to supply more than 120 kg N ha^{-1} resulted in occasional residual effects on second crop itself (Meelu and Morris, 1988; and Morris *et al.*, 1989). Though residual effects of green anures are relatively small on short term application, the cumulative effects of annual application are expected to be appreciable (Bouldin, 1988). Zia *et al.* (1992b) observed lowest residual effect by sesbania application compared to rice straw and FYM, and concluded that rapid decomposition associated with lower C:N ratio of green manures registered low residual effect.

2.5 Timing of N application

Nitrogen application rate and time are more important in determining its availability and uptake. Effective N management centers around maximising N uptake at critical stages and ensuring that N absorbed by the plant is used for grain production (De Datta, 1987).

2.5.1 Early N application

Reddy and Patrick (1978) recorded 26 to 30 per cent efficiency for early N application and 46 to 50 per cent efficiency for N applied at PI stage. Nitrogen absorbed during vegetative stage is stored for use at late growth stages according to Tanaka *et al.* (1959). While reviewing the research work done on N use efficiency (NUE) of rice, Pillai (1981) suggested that incorporation of basal N followed by two splits each at tillering and one week before PI would be ideal for most of the rice growing areas of India. Yoshida (1981) stated that N application at PI keeps leaf green after heading (H) and contribute to active photosynthesis for grain production. But application of very high rate of N at or after PI reduced ripening percentage and decreased yield (Sasahara and Ito, 1989). De Datta *et al.* (1987b) suggested incorporation of basally applied N to give higher yields and NUE than late split application.

2.5.2 Late N application

The earlier emphasis on basal application of N has been shifted now to late application (Berge *et al.*, 1992). Greenwood *et al.* (1991) suggested to maintain the leaf N at fairly high level for high photosynthetic activity for high yields. Leaf N concentration should be high, particularly from tillering to flowering to attain high yields as most of the N is translocated to the grain during grain filling (Thiyagarajan *et al.*, 1994b). High leaf N level can be maintained by promoting continued absorption of N by the crop even after H (Yoshida, 1981). Cassman and Samson (1994) reported that root capacity of rice to acquire N did not decrease in the period from PI to early grain filling but it is the lack of soil-N limiting N uptake and yield. Iwasaki *et al.* (1992) observed that N-15 administered at later stages of ripening increased N accumulation in inferior spikelets even after 20 days of H.

More leaching loss of N (13%) occurs if applied at transplanting than from late application (0.2%) (Singh *et al.*, 1991) since the rice roots exhibited limited ability to absorb and assimilate N (Meelu and Gupta, 1980). Palm *et al.* (1988) felt that it was not necessary to apply basal dressing before transplanting or seeding due to less absorption at early stages and high N demand from active tillering stage onwards. Yanagisawa and Takahashi (1964) reported that rice in the highly productive soils in the cooler parts of Japan derived 60 to 80 per cent of the total N uptake from the soil during the late growth stages. Guindo *et al.* (1994) found that N accummuated in panicle was derived from the uptake of native soil N and from N translocated from vegetative tissues. Reports reveal that more than 100 kg N ha^{-1} was taken up by the plant after flowering (Wopereis *et al.*, 1994). However, studies of Thiyagarajan *et al.* (1994a) emphasized the need for N application before PI to ensure sufficient biomass production and yield increase.

Makarim *et al.* (1994) observed high yields by timing N application upto H as a result of increase in the number of productive tillers. They recommended application of 280 kg N

ha^{-1} in 6 equal splits from 12 DT onwards or even postponement of first N application upto PI. Similar results have been reported by Sivasamy *et al.* (1994). Dash *et al.* (1994) found that when 100 kg N ha^{-1} was applied at PI to a crop of low N status, total N uptake increased rapidly. In general, N application at sowing/planting had limited effect on N uptake. Further, when soil N is high, early N application may cause excessive vegetative growth and lodging (Heenan and Bacon, 1987).

2.6 Uptake and recovery of N

A very important yield determining factor for irrigated rice is its N uptake capacity. Genetic, edaphic and biotic factors affect the N uptake and recovery processes in rice.

2.6.1 Fertilizer-N

It has been reported that a rice crop yielding 5 t ha^{-1} would need an uptake of 80 kg N ha^{-1} (Morris *et al.*, 1986b). 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 N ha^{-1}) application of N in the form of green manure alone or in combination with urea only succeeded in achieving this benefit.

A wide variation in apparent N recovery (ANR) ranging from 10 to 70 per cent for rice has been reported by Sismayate *et al.* (1990). According to Allison (1966) and Stanford (1973) a well managed rice crop recovers 50 to 70 per cent of the applied fertilizer-N. Upto 62 per cent recovery of the applied N fertilizer have been reported by Broadbent and Tunseem (1971) and Patrick and Reddy (1976). In a survey of eight experiments reported from widely varying environments, Keulen and Heemst (1982) summarised that ANR of inorganic N by rice was linearly related to the quantity applied. When N source was entirely inorganic, N uptake was significantly higher over organic sources alone, at PI stage and at harvest stage (Dascalsota *et al.*, 1986).

2.6.2 *Green manure-N*

Nagarajah *et al.* (1989) reported 29 to 45 per cent ANR from sesbania green manure. Furoc and Morris (1989) observed similar recovery at moderate N levels as green manure or chemical fertilizer (50 to 100 kg N ha^{-1}). Similar efficiency range of 15 to 25 kg grain kg^{-1} N both for green manure and chemical fertilizer has been reported by Yoshida (1981) and Morris *et al.* (1989). Increase in N application above 100 kg N ha^{-1} as green manure gave low ANR (Broadbent, 1980).

2.6.3 **Combined application**

Results of field trials conducted by John *et al.* (1989a) at IRRI, Philippines, showed that incorporation of cowpea green manure increased the total plant N uptake at maturity. Diekmann *et al.* (1993) observed significantly higher recoveries when

S. rostrata equivalent to 30 kg N ha^{-1} was applied with 30 or 60 kg N ha^{-1} as urea as basal dose, than urea alone. Increased recovery of fertilizer-N when combined with organic residues has been reported by Huang and Broadbent (1989) also.

2.6.4 N levels vs N uptake and recovery

The primary goal of improved N management practices should be to maximize N uptake at critical growth stages and to minimize N losses (De Datta *et al.*, 1987b). Wells and Shockley (1975) observed 2-3 times N uptake on application of 120 kg N than unfertilized control with more than one-half of uptake occurring after PI. Balasubramanian and Palaniappan (1992) found that N uptake was increased by N application upto 150 kg N ha^{-1} beyond which the increase was not significant. However, according to Krishnakumar and Subramanian (1992), though N-uptake increased upto 225 kg N ha^{-1} recovery per cent decreased beyond 150 kg N ha^{-1}. In contrast, Diekmann *et al.* (1993) observed strong linear relationship between N uptake and N application rate and suggested even more than 210 kg N ha^{-1} may be beneficial provided N is applied at maximum tillering or PI stage. Bacon (1985) also observed strong linear increase in N uptake even upto 300 kg N ha^{-1}, which was evident from rapid increase in N demand beyond tillering stage of the crop.

2.6.5 Timing of N vs uptake and recovery

Higher N uptake and recovery with postponement of basal N application to 14 DT and 30 DT has been observed by Makarim *et al.* (1994). According to Thiyagarajan *et al.* (1994a) ANR can be increased by postponing the basal application of N upto 16 DT, while further delay decreased recovery. Reddy and Patrick (1976) observed that, for urea applied at 30 DT the recovery was almost double than that of urea applied at planting. Similar results were observed by Rosemani and Chulan (1992).

Total nitrogen uptake by rice is reported to increase from transplanting upto maturity with a peak at PI stage (Dash *et al.*, 1994). Whereas, Sobhana and Chandrasekharan (1991) observed highest N uptake during flowering and a decline thereafter. Sivasamy *et al.* (1994) obtained very high values of ANR (65-87 per cent) when 100 kg N was applied at PI stage.

The average recovery of N applied at active tillering, PI and flowering was 21.6, 37.5 and 55 per cent respectively (Keulen, 1977). These figures show that N demand increases with increase in crop stage. Diekmann *et al.* (1993) observed no variation in the amount of N uptake from green manure and urea applied on equal N basis. No significant N uptake occurred beyond PI in green manure treatment, whereas in split applied urea treatments, N uptake increased significantly even at later stages.

2.7 ^{15}N studies

The stable isotope of nitrogen, ^{15}N has been used in many studies to gain additional insight into the fate of fertilizer-N applied to rice. The ^{15}N atoms from the enriched fertilizers are presumed to undergo the same chemical and microbial transformations as ^{14}N atoms in the soil (Buresh *et al.*, 1982). Analysis of the ^{15}N content in the plant and soil system at selected times during the growth period allows calculation of the actual fertilizer recovered at various stages of rice development (Vlek and Byrnes, 1986). The unrecovered ^{15}N serves as a measure of fertilizer-N lost from the soil-plant system.

2.7.1 Recovery of fertilizer-^{15}N

From various studies, Craswell and Vlek (1979) reported recoveries of ^{15}N ranging from 7 to 68 per cent at crop maturity. De Datta *et al.* (1988) estimated the plant ^{15}N recovery at maturity to be 47 per cent for broadcast-seeded rice and 37 per cent for transplanted rice. Rate of N application at various phenological stages of crop also affect the quantity of N recovery. Total ^{15}N recovery of 66 per cent and crop (grain + straw) recovery of 39 per cent was observed when 2/3 urea was applied as basal incorporated and 1/3 at PI, whereas the values were 59 and 38 per cent respectively when 1\2 urea was applied at 14 DT and 1/2 at 10 days after PI (De Datta *et al.*, 1987c). Lu *et al.* (1988) observed a total plant ^{15}N recovery of 38 to 51 per cent of the applied N and it was apportioned to 5 to 8 per cent in roots, 10 to 15 per cent in shoots and 22 to 29 per cent in grain.

Different N management strategies inflicted wide variations in total recovery of ^{15}N ranging from 17 to 60 per cent of applied ^{15}N as reported by many workers (Patrick *et al.*, 1974; Patrick and Reddy, 1976; Reddy and Patrick, 1978; Westcott *et al.*, 1986 and Norman *et al.*, 1989; 1992b).

2.7.2 Recovery of green manure-^{15}N

The ^{15}N recovery from labelled green manure was higher (90 per cent) than from urea treatments (65 per cent) (Diekmann *et al.*, 1993). Lu *et al.* (1988) estimated the percentage of N derived from soil (% Ndfs) ranged from 65 to 69 per cent and that from fertilizer (% Ndff) ranged from 31 to 35 per cent. Increased plant ^{15}N recovery by combined application of green manure and fertilizer N has been reported by Diekmann *et al.* (1993) and Rekhi and Bajwa (1993). The increase in plant N derived from soil following fertilizer-N application has been referred to as the 'priming effect' (Jansson and Persson, 1982) or the 'added N interaction' (ANI) (Jenkinson *et al.*, 1985).

2.7.3 Crop growth stages vs ^{15}N recovery

The ^{15}N balance sheet construction results in "unaccounted for" or "unrecovered-^{15}N". Usually, soil loss mechanisms are used to explain away the "unaccounted for" N. Buresh *et al.* (1989) reported 23 to 34 per cent loss of applied urea from puddled clay soil. John *et al.* (1989a) observed consistent recovery of less than 2 per cent of the added ^{15}N in 0.15 to 0.3 m soil layer indicating that leaching loss of applied ^{15}N was negligible.

Summarising the results of 50 experiments with ^{15}N-labelled fertilizer, Bouldin (1986) concluded that calculation of ^{15}N recovery at crop maturity underestimates the net effect of fertilizer on the accumulation of N by the plant. On estimation of ^{15}N in the rice plant at various growth stages highest fertilizer ^{15}N accumulation was observed at flowering stage (Wilson *et al.*, 1989). They have measured a loss of ^{15}N from the plant between late reproductive growth stage and maturity. Guindo *et al.* (1994) and Norman *et al.* (1992a) recorded ^{15}N recovery as 79 per cent at PI stage and 72 per cent at 14 days before heading suggesting that the loss of N from the rice plant could be an important mechanism. They have observed maximum ^{15}N accumulation at 21 days after heading and a decline towards maturity. The loss of fertilizer ^{15}N increased with fertilizer-N rates and was more pronounced at higher temperature during grain filling stage.

2.7.4 ^{15}N balance in soil

The amount of ^{15}N remaining in soil at crop maturity from basally applied urea was significantly lower (15-38%) than from basally applied green manure (44 to 49%) (Diekmann *et al.*, 1993). Lu *et al.* (1988) observed that ^{15}N remaining in the soil after harvest ranged from 14 to 24 per cent. About 34 per cent of ^{15}N applied was 'unaccounted for'. Early split application of urea recorded low proportion of 'unrecovered'-^{15}N (28%) compared to 34 per cent in delayed splits (John *et al.*, 1989a). Pre-planting application of green manure had no effect on the amount of 'unrecovered' ^{15}N.

2.8 Nitrogen concentration in plant parts

It can be assumed that a minimum concentration of N in the leaf is essential to attain a given yield level. When the supply is sub-optimal growth is retarded and senescence of older leaf is enhanced (Marschner, 1986). The concentration of a given nutrient in different plant parts are related to each other as well as to the concentration in the entire plant (Black, 1993). Yoshida (1981) recommended a critical leaf N concentration of 2 per cent for maintaining high photosynthetic rate in rice. Nitrogen can affect both source and sink activities of the crop. Decreasing leaf N content reduced the rate of photosynthesis (Penning de Vries *et al.*, 1990; and Kropff *et al.*, 1992).

2.8.1 N supply vs N concentration

Increase in N concentration in plant parts by N supply has been reported by many workers. Zia *et al.* (1992b) observed significant increase of N in straw and grain by N addition at late growth stages. and Budhar *et al.* (1994); and Rao *et al.* (1994) have also observed increase of N content in rice plant by N supply. Sivasamy *et al.* (1994) reported a quadratic relationship between the amount of N applied and N concentration over time. According to Thiyagarajan *et al.* (1991) the leaf N concentration in plant parts can be increased only to a certain level by N supply. They found that even at 400 kg N ha^{-1} level, the maximum leaf N concentration was only 41 g kg^{-1}. Wopereis *et al.* (1994) reported increased grain N concentration by N application at flowering.

Wopereis *et al.* (1994) recommended N application at flowering to maximize panicle N content to 18.3 g kg^{-1} from 8.7 g kg^{-1} recorded in unfertilized crops.

2.8.2 Crop growth stages vs N concentration

The fluctuation in N concentration over time depended upon the physiological stage and N supply (Matsushima, 1976; and Marschner, 1986). Pannangpetch (1993) observed maximum N concentration in vegetative parts at 31 days after transplanting, thereafter it declined gradually to the minimum values at crop maturity. Dash *et al.* (1994) observed maximum N concentration in leaf, stem and root at 22 days after planting. Similar results were reported by Budhar *et al.* (1994) also. Rao *et al.* (1994) reported that the total amount of leaf, stem and root N continued to increase until flowering after which it decreased. Wopereis *et al.* (1994) reported that maximum flag leaf N content was just before flowering (3.11%) and declined towards harvest (1.82%).

Nitrogen content of leaf was approximately 2.5 times higher than that of stem and root. However, N content of grain remained almost constant throughout the reproductive period with slightly higher values in the middle of the period. Westcott and Mikklesen (1987) observed that total plant N concentration at 30 days after planting ranged from 16.5 to 32.5 g kg^{-1} and thereafter it dropped asymptotically and tended to converge. They also reported that grain N concentration could be increased by N application at flowering.

2.8.3 N concentration vs yield

The need to maintain higher leaf N content to increase production potential of rice has been emphasized by Wopereis *et al.* (1994). According to Thiyagarajan *et al.* (1994b), to shift the yield target beyond 8 t ha^{-1} the N concentration in the leaf should be increased and the time course of leaf N curve should be moved up upto flowering stage of the crop. Yanagisawa *et al.*

(1967) found that N applied at PI or flowering stage reduced the rate of senescence of lower leaf.

2.9 Translocation of N

The hypothesis of N translocation from vegetative tissues to reproductive tissues was put forth by Reyes *et al.* (1962). When the rate of N uptake cannot fulfil the rate of N required for the biosynthesis of new tissues, certain amount of N is remobilized from leaf and stem to the growing tissues (Sinclair and de Wit, 1976). Grain yield was limited by assimilate sink capacity which, in turn, was dependent on assimilate supply during PI and flowering (Ingram *et al.*, 1991). Consequently N application method should be designed to achieve high shoot N content during PI and flowering. Budhar *et al.* (1994) observed decreases in stem weight after flowering suggesting translocation of carbohydrate to the panicle. Nitrogen is translocated to the grain, mostly from the leaf during grain filling stage (Thiyagarajan *et al.*, 1994b).

The redistribution of N from leaf and stem amounted to 50 to 100 kg N ha^{-1} which was 50 to 70 per cent of the total N absorbed by the plant (Penning de Vries *et al.*, 1988). Norman *et al.* (1992a) observed that leaf contained 60 per cent of the total plant N uptake just prior to heading but after heading N accumulation in panicle steadily increased at the expense of other plant parts.

Studies by Sivasamy *et al.* (1994) indicated that 32 per cent of N in grain was remobilized from leaf and 24 per cent from stem. The decrease in N content during reproductive phase was most apparent in leaf (72.34 kg N ha^{-1}) but substantial amount of N was also remobilized from stem (38.68 kg N ha^{-1}) during grain filling stage; and the amount of N remobilized from leaf and stem was approximately 70 per cent of that in grain. Ramasamy *et al.* (1994) reported that 19 to 34 kg N ha^{-1} from leaf and 27 to 45 kg N ha^{-1} from stem, which accounted for 52 to 79 per cent of the maximum N stored by these organs, was remobilized to grain during ripening stage of the crop. Dash *et al.* (1994) observed that root contribution to remobilized N pool was negligible (4.0 to 10.3 kg N ha^{-1}) whereas from leaf it was 8.2 to 51.8 kg ha^{-1} and from stem it was 10.9 to 46.8 kg ha^{-1}. The amount of N translocated from leaf and stem was influenced by N levels, number of splits and timing of N application (Wopereis *et al.*, 1994).

2.10 Dry matter partitioning

The weight of leaf blade, leaf sheath and stem in rice reached a peak around heading stage, then decreased gradually, but panicle weight increased progressively after heading (Mae and Ohira, 1981). Nitrogen application enhanced the biomass of roots, stem and leaf reaching the maximum at flowering stage (Dash *et al.*, 1994). Application of 100 kg N ha^{-1} at PI without any previous N application resulted in sudden increase in leaf, stem and root biomass in the reproductive stage.

Reproductive dry matter increased until complete grain formation or physiological maturity (Moore *et al.*, 1981; and Guindo *et al.*, 1994). According to Rao *et al.* (1994) total dry matter gradually increased with crop age and reached its maximum at harvest. They observed post-flowering reduction in stem biomass as a result of translocation of carbohydrates to the storage organs. The stem biomass decreased by 1 to 1.2 t ha^{-1} by the time of harvest compared to flowering stage. Such remobilization from stem accounted for 30 per cent for the crop fertilized compared to only 15 per cent stem remobilization contribution to grain yield in unfertilized crop. Similar decrease in stem weight after flowering due to translocation has been reported by Budhar *et al.* (1994) and Makarim *et al.* (1994).

2.11 Chlorophyll-Nitrogen relationships

Making accurate and timely N fertilization is crucial for achieving higher yields and N use efficiency (NUE) in irrigated lowland rice (Peng *et al.*, 1993). Leaf photosynthetic rate and leaf N concentration of rice are closely related (Greenwood *et al.*, 1991), since N is a essential constituent of chlorophyll. The chlorophyll meter (SPAD 501/SPAD 502) could make instant non-destructive and quick chlorophyll readings of plant leaf; and the SPAD meter readings were significantly correlated with extractable chlorophyll expressed on leaf area basis (Marquard and Tipton, 1987). Strong correlation between N concentration on dry weight basis (Ndw) and chlorophyll meter readings for rice has been demonstrated by Takabe *et al.* (1990).

Using SPAD value - leaf N relationships in rice the need for N fertilizer side-dressing has been predicted by Takabe *et al.* (1990); Turner and Jund (1991) and Peng and Cassman (1995). However, the relationship between SPAD meter values and Ndw may differ markedly depending on growth stage, genotype and environment (Takabe and Yoneyama, 1989).

There is also strong relationship between SPAD values and leaf N concentration on area basis (Na) than on dry weight basis (Ndw) and so SPAD values need not be adjusted for SLW for predicting the plant N status (Peng *et al.*, 1995). Therefore, SPAD can be used directly to estimate leaf N status and decide for N side-dressing. They found that during growing period, Ndw of leaf decreased with plant age while SPAD value remained relatively stable which indicate the necessity of deriving SPAD-N relationships for specific situations and specific growth stages.

2.12 Grain yield and N use efficiency

Improving the NUE has been a great challenge to the scientists world over. Considering the very low efficiency of applied N fertilizer and limited possibility of fertilizer-N substitution through organic manures to the rice crop in a system, it is imperative to integrate the use of organic and inorganic source of N for higher NUE.

2.12.1 Agronomic efficiency (AE)

Rice yield increased with increase in N fertilizer rates (Evans and De Datta, (1979). Management practices viz., methods of application and kind of urea materials affected agronomic efficiency (AE) ranging from 17 to 25 kg grain kg^{-1} N (Zia *et al.*, 1992a). Schnier *et al.* (1990) observed inverse relationship between level of N and AE. He obtained AE ranging from 24 to 60 kg grain kg^{-1} N on increasing the N level from 150 to 300 kg ha^{-1}. Krishnakumar and Subramanian (1992) reported that the AE was 30, 20 and 12 kg grain kg^{-1} N at 75, 150 and 225 kg N ha^{-1}, respectively. Reddy and Patrick (1978) found that early stage fertilization was less efficient with a 26 to 30 per cent efficiency while mid stage fertilization increased it to 46-50 per cent.

2.12.2 Physiological efficiency (PE)

Highly significant positive correlation between N uptake and grain production efficiency has been reported by Bacon (1990). Agronomic NUE varied greatly between early and late splits whereas physiological efficiency (PE) (grain yield per N uptake) did not vary much suggesting that yield depended mainly on the amount of N recovered by the plant rather than on efficiency of N use within the plant (Ingram *et al.*, 1991). According to Thiyagarajan *et al.* (1994a) postponing the fertilizer-N application until 16 DT increased overall NUE whereas further delay decreased the efficiency. They recorded highest yield (8.2 t ha^{-1}) with N supply of 150 kg N ha^{-1} in six equal splits as basal, 10 DT, active tillering (AT), maximum tillering (MT), PI and flowering stages. Makarim *et al.* (1994) reported grain production efficiency of 23 kg kg^{-1} N uptake. De Datta *et al.* (1987b) recommended topdressing of N at PI for higher yields due to higher N utilization by the crop.

2.12.3 NUE under integrated N management

Furoc and Morris (1989) reported same AE at moderate N levels (50 to 100 kg N ha^{-1}) as green manure and chemical fertilizer in the tropics. Morris *et al.* (1989) and Diekmann *et al.* (1993) reported that *S. rostrata* was as effective as urea at the same N rates in influencing grain yield. Lower grain production per unit weight of absorbed N from green manure than urea was reported by Ventura and Watanabe (1991). However, integrated use of *S. aculeata* at 12.5 t ha^{-1} with 40 kg N ha^{-1} was superior to urea alone at 80 kg N ha^{-1} (Ramasamy *et al.*, 1988). Morris *et al.* (1986b) qunatified the NUE as 29 and 31 kg grain kg^{-1} N derived from green manure and chemical fertilizer, respectively. They focussed that if N derived from soil exceeds 60 kg N ha^{-1}

response to additional green manure-N can be expected to be low.

Summarising the use efficiency of organic manures, Sharma and Mitra (1988) concluded that the average grain yield response could be 32 kg grain kg^{-1} N added through organic manures.

2.13 Yield components

In general, an increase in tiller number upto PI stage and then slow decrease upto harvest time has been observed by Makarim *et al.* (1994). Application of 280 kg N ha^{-1} applied at flowering increased tiller production upto 60 DT. Zia *et al.* (1992b) observed more number of productive tillers, higher grain yield and N uptake by crop supplied with sesbania green manure. Though high N rates resulted in more number of panicles and larger number of spikelets per panicle, a lower percentage of unfilled grain was evident due to less spikelet sterility (Wopereis *et al.*, 1994). Yield differences were mainly due to difference in panicles per unit area and number of spikelets per panicle which were determined by the crop N status during flowering through PI phases. Maskina *et al.* (1992) attributed the ability to produce more panicle density and spikelet number and not the test weight of grain to the better performance of rice cultivars at higher N levels.

The results covered by the above review confirm that green manures could substitute a part of fertilizer-N, if not full, and contribute to the increase in soil fertility and to the sustained productivity. Apart from the hitherto known green manures such as sesbania or cowpea, noxious weeds like parthenium also offer much opportunity to be used as green manures for rice. Combined application of green manures and fertilizer-N reduces losses of applied N and maintain higher level of crop productivity with increased NUE.

Nitrogen application rate and time are more important in determining its availability and uptake. Earlier findings indicate that green manure-N is readily available to crops. Further, fertilizer-N applied basally are subjected to various losses from the soil. During grain formation stage, N from vegetative tissues are translocated to panicle (sink). Hence to keep the remobilization pool (source) steady, sufficient N should be made available to the crop particularly during reproductive phases. Available literature on ^{15}N studies also reveal higher efficiency of N applied at late growth stages. These facts, points out the necessity of more investigations on postponement of N timings to start only from active growth stage of rice, especially under an INM system.

The results gone through also indicate that continuous application of organic manures is needed for residual effects in soils. The need for deriving chlorophyll-N relationships specific to the varieties and location, for determining N side-dressings is also established.

MATERIALS AND METHODS

Chapter III

MATERIALS AND METHODS

The present investigation was carried out to study the effect of organic manures and fertilizer nitrogen (N) management on N uptake, recovery and partitioning of applied N and yield of lowland rice. The field experiments were conducted at the Wetland Research Farm of Tamil Nadu Agricultural University (TNAU), Coimbatore, from 1994 to 1996. The details of the materials used and methods adopted for the investigations are described in this chapter.

3.1 Experimental site

3.1.1 Location and climate

The Wetland Research Farm, TNAU, Coimbatore is situated at 11°N latitude and 77°E longitude at an altitude of 427 meters (MSL). Agroclimatically, Coimbatore is classified as semi-arid tropical region of Tamil Nadu. The mean annual rainfall of 645 mm is received in 49 days. The mean maximum temperature ranges from 28 to 37°C and the minimum temperature from 17 to 25°C.

Informations on weather parameters prevailed during the cropping seasons are presented in Appendix I to IV and depicted in Fig.1.

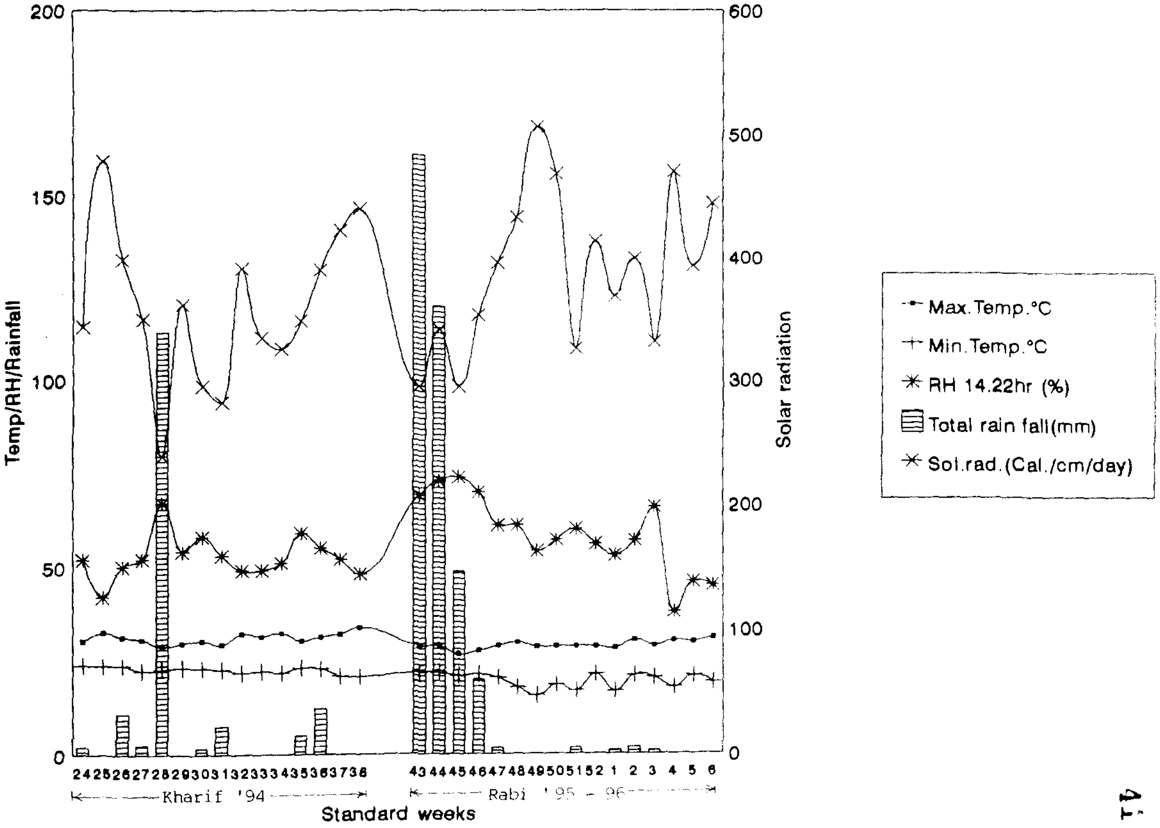
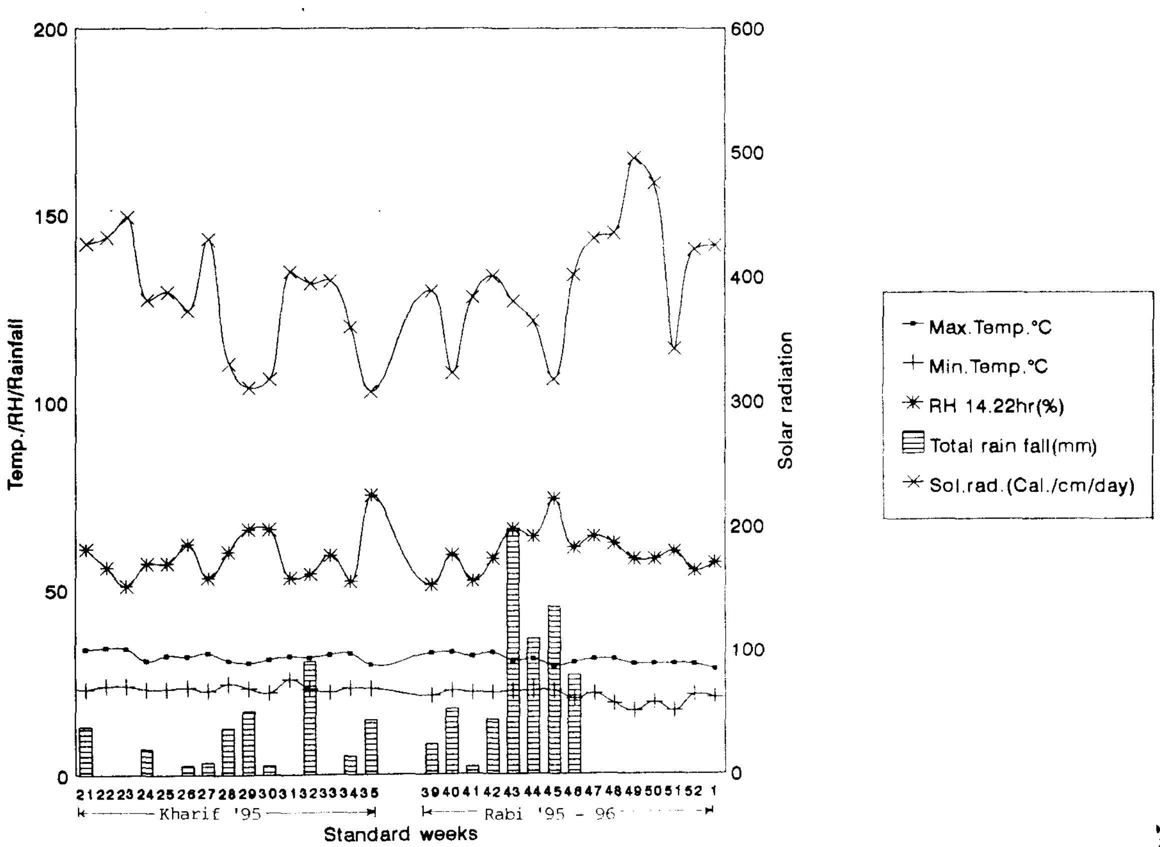


Fig. 1. Weather data for the crop seasons



200
150
100
50
0
600
500
400
300
200
100
0
Temp./RH/Rainfall
Solar radiation
21 22 23 24 25 26 27 28 29 30 31 32 33 34 35
39 40 41 42 43 44 45 46 47 48 49 50 51 52 1
Kharif '95
Rabi '95 - 96
Standard weeks
Max.Temp.°C
Min.Temp.°C
RH 14.22hr(%)
Total rain fall(mm)
Sol.rad.(Cal./cm/day)

3.1.2 Soil

The soil of the experimental site is classified as Typic Haplustalf (moderately drained deep clay-loam). The soil was low in available N and P_2O_5 and high in available K_2O. The physical and electro-chemical properties of the surface soil (20 cm depth) at the start of the experiment are presented in Table 1.

3.2 Experimental details

The varieties of the test crop of rice were ASD 18 and ADT 38 for *kharif* and *rabi* seasons, respectively. The variety ASD 18, a short duration one (110-115 days), recommended for *kharif* season was released from Ambasamudram, Tamil Nadu, the average yield being reported as 5.9 t ha^{-1}. The variety ADT 38, recommended for *rabi* season was released from Aduthurai, Tamil Nadu. The average duration and yield of the variety are 130-140 days and 6.2 t ha^{-1}, respectively.

In all seasons prilled urea (46%N) was used as N source for inorganic fertilizer-N treatments. A common dose of P_2O_5 and K_2O each at 50 kg ha^{-1} was applied to all crops, as single superphosphate (16%P_2O_5) and muriate of potash (50%K_2O) respectively. In addition, $ZnSO_4$ was applied @ 25 kg ha^{-1}. Superphosphate and $ZnSO_4$ were applied basally and MOP was applied in three equal splits at transplanting (P), maximum tillering (MT) and panicle (PI) stages. Water management of

Table 1. **The initial physical and electro-chemical properties of surface soil of the experimental site**

Soil properties	Average value	Methodology and author
A. Physical properties		
Textural composition		International pipette method (Piper, 1966)
Coarse sand	17	
Fine sand	25	
Silt	23	
Clay	33	
Textural class	clay-loam	
Bulk density ($g\ cm^{-3}$)	1.25	Core cutter method (Dakshinamurthi and Gupta, 1968)
Maximum water holding capacity (%)	35.5	-do-
Field moisture capacity (%)	24.2	-do-
B. Electro-chemical properties		
pH	8.1	Glass electrode, 1:2 soil water ratio (Jackson,1973)
EC (dSm^{-1})	0.25	Solubridge, 1:2 soil water ratio (Jackson, 1973)
CEC ($Cmol(P^{+})kg^{-1}$	25.8	Neutral normal ammonium acetate (Piper, 1966)
Available nutrients ($kg\ ha^{-1}$)		
N	110	Alkaline permanganate (Subbiah and Asija, 1956)
P_2O_5	19.5	Colorimetry (Olsen *et al.*, 1954)
K_2O	325	Flame photometry (Stanford and English,1949)

flooding the field with 3 ± 2 cm standing water from incorpo-ration of green manures upto transplanting and 5 ± 2 cm from transplanting upto two weeks before harvest was followed. Thereafter the soil was water-saturated upto crop maturity.

The plots were kept weed free by hand weeding. The crop was maintained pest and disease free by following chemical control measures, as suggested in the package of practices for rice.

The cropping details of the field experiments are given in Table 2.

Table 2. Cropping details of field experiments

Details	Kharif,94	Rabi,94	Kharif,95	Rabi,95
Variety	ASD 18	ADT 38	ASD 18	ADT 38
Seedling age (days)	20	25	21	26
Date of P	13 June 94	22 Oct. 94	22 May 95	24 Sept.95
Spacing	0.15x0.10m	0.20x0.10m	0.15x0.10m	0.20x0.10m
Seedlings/ hill	2	2	2	2
Time of PI	21 July 94	16 Jan 95	28 June 95	7 Nov. 95
Time of F	20 Aug 94	12 Feb 95	25 July 95	4 Dec. 95
Date of harvest	15 Sept.94	9 Mar 95	22 Aug. 95	7 Jan. 96
Field duration (days)	114	132	113	131

P = Planting; PI = Panicle initiation; F = flowering

3.3 Layout and treatment details

The experiment was laid out in Split-plot design with three replicates. The main plot treatments included three green manures viz., sesbania *(Sesbania rostrata)*, cowpea *(Vigna unguiculata)* and parthenium *(Parthenium hysterophorus)* and one 'no-green manure' treatment. Sub-plot treatments included application of 150 kg N ha^{-1} at different growth stages of the crop starting from P to heading (H) ie. 5-7 days (d) before panicle exertion and one control (no N). Treatment details are given in Table 3.

Table 3. The treatment details

i. **Main-plot treatments**

G_0 No green manure

G_1 Sesbania *(Sesbania rostrata)*

G_2 Cowpea *(Vigna unguiculata)*

G_3 Parthenium *(Parthenium hysterophorus)*

ii. **Sub-plot treatments**

	150 kg N ha^{-1} applied as splits at					
	P	10 DT	ET	MT	PI	H
N_0	0	0	0	0	0	0
N_1	75	0	0	37.5	37.5	0
N_2	0	0	50	0	50	50
N_3	25	25	25	25	25	25
N_4	0	0	50	0	100	0

P: transplanting; ET: early tillering;
MT: maximum tillering; PI: panicle initiation;
H: heading; DT: days after transplanting

The treatments were randomised to plots at the start of the experiment (*kharif*, 1994). In subsequent seasons, the respective treatments were imposed in the same plots. The layout of field experiments is depicted in Fig.2.

3.4 Application of green manures

Green manures were applied only for the *kharif* crops in both years. All green manures were applied on equal-N basis.

Sesbania rostrata and cowpea (var. CO 5) were raised in separate fields outside the experimental site. No fertilizer or manure was applied to green manures. Above-ground portion of green manures was harvested on 45th day after seeding, chopped to about 5 cm length and incorporated in the main plots seven days (d) before P. Above-ground portion of parthenium plants at pre-flowering stage was collected from the nearby areas and applied in the same manner. Sesbania was applied @ 6.25 t ha^{-1} which supplied 54 kg N. The quantity of other green manures was also adjusted to supply 54 kg N ha^{-1}.

The green manure samples collected before incorporation were dried to constant weight at 80°C and analysed for N, P, K and C by the standard methods. The properties of green manure plants are given in Table 4.

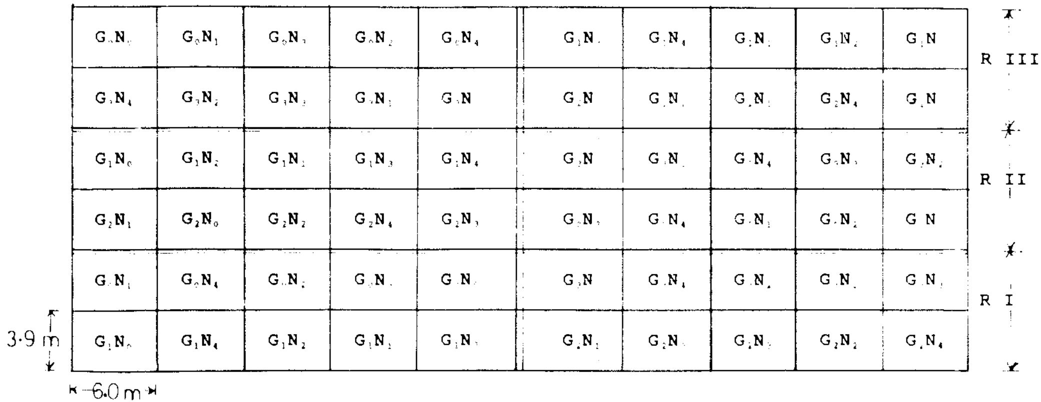


Fig. 2. Layout plan of the field experiments

Table 4. Proporties of green manure plants

Green manures	Biomass applied (wet) (t ha^{-1})	Nutrient content (dry wt. basis) N%	P%	K%	C:N
Sesbania	6.25	3.76 (0.87)	0.29 (0.05)	2.10 (0.39)	11.0
Cowpea	8.85	2.93 (0.61)	0.26 (0.05)	2.10 (0.36)	14.0
Parthenium	7.20	2.65 (0.75)	0.24 (0.11)	3.25 (1.50)	29.0

Figures in parenthesis are nutrient percentage on wet weight basis

3.5 Installation of microplots for ^{15}N studies

Studies on ^{15}N uptake and recovery were conducted during the *kharif* season of 1994. For ^{15}N application, microplots of the size 60 cm x 50 cm were installed within each sub-plot in one replication on the day of transplanting. Each microplot containing 20 hills of rice was enclosed with galvanised steel collars that extended to a depth of 15 cm below soil surface and 15 cm above soil surface (John *et al.*, 1989a; Guindo *et al.*, 1994). The collars minimized movement of fertilizer-N out of the microplots via flood water. Water was applied to the collared plots by hand and maintained at the same level as in the area outside the microplots.

All operations except ^{15}N fertilizer applications were same for the microplots as in the sub-plots outside the microplots (macroplot). Labelled ^{15}N-urea was applied to the microplots on equivalent N basis as the treatments in the macroplots. The collars were completely covered with polythene sheets at the time of applying non-labelled urea to the macroplots to avoid any possibility of adding that into the microplots.

Labelled urea-^{15}N (5 atom % excess) obtained from Rashtriya Chemicals and Fertilizers, Bombay was diluted with approximately the same quantity of LR grade non-labelled urea to get the "fertilizer ^{15}N-urea". The total N content and ^{15}N isotope content of the 'fertilizer urea' were estimated and found to be 44 and 2.57 atom per cent excess respectively.

Application of ^{15}N was confined to a single replication only, considering the high cost of ^{15}N-urea required for the experiment.

3.6 Soil and plant sampling

3.6.1 Soil sampling

Soil samples were analysed for ^{15}N, NH_4^+-N; total and available N and OC . For estimation of NH_4^+-N, wet-soil samples were collected periodically from three to four locations at 15 cm depth in the plot leaving border rows, using a wet soil sampler. Soil was collected in plastic containers and closed tightly. After scrapping a thin film of top soil and discarding it, the soil was mixed thoroughly and analysed for NH_4^+-N. A part of the wet soil was oven dried for estimating the moisture content. Post-harvest soil samples were collected and analysed for total and available N and OC.

For ^{15}N analyses, post-harvest samples at 15 cm depth were collected from the centre of four hills at four locations within the microplot in *kharif*, 1994; pooled, dried rapidly at 40°C and then ground to pass through a 1 mm sieve. Large roots were separated from the soil, dried at 60°C, ground separately to pass through a 1 mm sieve and added back to the bulk of ground soil sample, thoroughly mixed and subsampled for analyses (Buresh *et al.* 1982).

3.6.2 Plant sampling

Plant samples were drawn at different stages of crop growth for determination of the time course dry matter production and N concentration of the plant parts viz., root, stem, leaf and grain.

Sample selection

For drawing plant samples, the technique suggested by Thiyagarajan *et al.* (1994c) was followed.

In each sub plot, half area uniformly on one side in all the plots was demarked for plant sampling and the other half was allowed for harvest at physiological maturity. The sample size at every sampling was five hills per plot. Two border rows at the periphery of the plots were avoided for sampling. A hill in a row, at least five hills away from any corner of the plot was first located randomly and from that, ten hills on the same row were observed for their tiller number and noted down serially from 1 to 10. In the same fashion, 10 hills were counted for their tiller number on the diagonally opposite side. Then five hills were selected so that their average tiller number was same as that of the mean number of the marked 20 hills. This kind of sampling was found to follow relatively higher precision than the random sample selection.

Sampling technique

Plant sampling consisted of removing the entire plant including roots. Care was taken that no loose or dead leaf was lost from the plants during sampling. A hollow metallic cylinder of the same area and dimension as that of the ground area per hill was pushed down into the soil to 20 cm depth keeping a hill at the centre. While uprooting the plants the cylinder was carefully lifted to retain all the roots intact. The cylinder was removed and the soil mass adhering to the roots was washed over a screen-platform under a running tap.

For ^{15}N analyses also the same sampling technique was followed except that the size of the sample size was four alternate hills within the microplot.

All samplings were done before fertilizer application.

Sample processing

The plants of each hill were cleaned to remove surface contamination by washing in sequence in 0.2 per cent detergent solution and in 0.1 N HCl; the separated plant parts viz., roots, stems (culm + leaf sheath), leaves and panicle were desiccated by airdrying for two to three days and then oven dried at 80°C to constant weight. Dry weight of the plant parts was recorded by a precision balance. The samples were then reduced in particle size to homogenate for chemical analyses.

3.7 Growth and yield attributes

Plant height, total tillers and productive tillers were calculated based on the observations in the 20 hills in each plot selected for plant sampling. Plant height is expressed in cm and tiller number as number m^{-2}.

Twenty panicles collected from sample hills at maturity were used for the determination of spikelet number, filled grains and 1000 grain weight of filled grains. Filled grains and unfilled grains were separated by flotation technique using salt solution (Yoshida *et al.*, 1976).

3.8 Chlorophyll meter's estimate of rice leaf-N concentration

A chlorophyll meter (SPAD 502, Soil-Plant Analyses Development (SPAD) Section, Minolta Camera Co., Osaka, Japan) was used to obtain 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 and infra-red. 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 units which are values defined by 'Minolta' to indicate the relative amount of chlorophyll contained in plant leaves (Minolta Camera Co., Ltd., 1989).

3.8.1 SPAD measurement

At each observation stage upto heading, five uppermost fully expanded leaves were selected from each plot within the net plot. From heading onwards, the readings were taken on flag leaves. Three SPAD meter readings were taken around the mid point of each leaf blade 30 mm apart on one side of the mid rib. The fifteen SPAD readings were averaged to represent the mean SPAD value of each plot (Peng *et al.*, 1993).

After recording the SPAD values, the leaves were detached and pooled for measuring dry weight and N concentration. Dry weight was determined after oven-drying at 80°C to constant weight.

3.8.2 Leaf N concentration

It was determined by Bremner and Mulvaney (1982) method. Leaf N concentration is expressed on oven-dry basis (nL:g kg^{-1}). The average dry weight of five leaves was multiplied by nL to get total N $leaf^{-1}$.

3.9 Grain and straw yield

Crop from the area allowed for yield estimation in each sub-plot was harvested leaving two border rows on all sides and threshed; the grain winnowed, cleaned and dried in the sun for one day. Then the grain weight was recorded. Straw was sun dried for three days and the weight recorded. Grain yields are expressed on 14 per cent moisture basis and straw yield on sun-dry basis.

3.10 Chemical analyses

3.10.1 Soil analyses

Ammoniacal-N (NH_4^+-N)

Ammoniacal-N (NH_4^+-N) in wet soil samples were estimated following the procedure suggested by Bremner and Keeney (1966).

Soil extract with 2 M KCl, distilled with MgO in Bremner apparatus and the distillate collected in 2 per cent boric acid and titrated against 0.001 N H_2SO_4. Analyses were done on the same day of soil collection to avoid NO_3-N formation and are expressed as ppm on oven-dry basis. Soil NO_3-N was not estimated because of the negligible concentration apparent in flooded rice soils (Diekmann *et al.* 1993).

Organic carbon and N

Organic carbon (OC) in soils after harvest of each crop was estimated by the modified wet digestion method (Walkley and Black, 1934). It is expressed as percentage on oven-dry basis. The post-harvest soil samples collected after the last crop of the experiment (*rabi* '95) were analysed for total N (Piper, 1966) and available N (Subbiah and Asija, 1956).

3.10.2 Plant analyses

The rice plant parts viz., root, stem, leaf and grain were analysed for N, P and K concentrations. The green manures before incorporation were also analysed for N, P and K. Nitrogen in plant samples was analysed by semimicro-Kjeldahl method by digesting at 400°C for 2 hours (h) with conc. H_2SO_4 without a modification for inclusion of nitrate or nitrite (Bremner and Mulvaney, 1982). Triple acid extract of plant samples was used for the determination of P by Vanadomolybdophosphoric yellow colour method and K by flame photometry (Jackson, 1973).

3.11 Nitrogen-15 estimation

Total N and ^{15}N atom per cent excess in the 'fertilizer-urea', soil and plant samples were analysed for estimation of their ^{15}N content. To estimate total N in the samples, the methods were slightly modified from the standard procedure.

3.11.1 Fertilizer-urea

The 'fertilizer urea' was digested with conc. H_2SO_4 and the digest distilled for estimation of total N.

3.11.2 Soil

To recover the nitrate and nitrite forms of ^{15}N labelled fertilizer in soil, the ordinary Kjeldahl method of digestion was modified with salicylic acid and permanganate-reduced iron method (Bremner and Shaw, 1958) as suggested by Buresh *et al.* (1982). Distillation was done by macro-Kjeldhal method and the total N content estimated.

3.11.3 Plant parts

Plant samples digested in a mixture of conc. H_2SO_4, salicylic acid, $CuSO_4$, K_2SO_4 and Sodium thiosulfate was distilled by macro-Kjeldhal method for determination of total N.

The method described by Buresh *et al.* (1982) was adopted for ^{15}N estimation. The distillate after titration with standard H_2SO_4 for determination of total N was acidified with a few drops of 0.1 N H_2SO_4 and evaporated to dryness in glass vials. The isotope ratio analyses was done by Mass Spectrometry using a VG Micromass M.622 (VG Isogas Ltd., Cheshire, England) after converting NH_4^+-N to molecular N_2 with alkaline NaOBr. The isotope ratio was converted to atom per cent excess in the samples.

3.12 Derived parameters

The data collected from the field experiments and laboratory analyses were used to derive the following parameters.

3.12.1 Drymatter yield

The sum of the dry weight of all plant parts collected from the five hills per plot at various stages of crop growth is expressed as total drymatter on hectare basis.

3.12.2 N uptake

Nitrogen uptake of plant parts was calculated by multiplying the N concentration with dryweight of the concerned plant parts recorded at respective stage of crop growth.

3.12.3 Growth rate of crop and plant parts

Growth rates of crop and individual plant parts between two observation dates were calculated using the the formula suggested by Ahlawat and Sharma (1987).

$$\text{Growth rate during stage (n-1) to n} = \frac{(W_n - (W_{n-1})}{(DT_n - (DT_{n-1})} \text{ kg ha}^{-1}\text{d}^{-1}$$

where,

W_n is weight (kg ha^{-1}) of crop or plant part at stage n,

(W_{n-1}) is weight (kg ha^{-1}) of crop or plant part at stage (n-1),

DT_n is days after transplanting at stage n and

(DT_{n-1}) is days after transplanting at stage (n-1).

3.12.4 N Uptake rate in the crop

Rate of N uptake between the two observed dates was calculated and is expressed in a similar way as that of the growth rate of crop.

3.12.5 Apparent recovery of applied nitrogen (ANR)

It was calculated by the difference method (Harmsen and Moraghan, 1988) as cited by Diekmann *et al.* (1993).

$$ANR\ \% = \frac{NP - NP_o}{NF} \times 100$$

where,

NP is N uptake in fertilized plot (kg ha^{-1}),

NP_o is N uptake in control plot (kg ha^{-1}) and

NF is fertilizer or organic N applied (kg ha^{-1}).

3.12.6 Nitrogen use efficiency (NUE)

Agronomic efficiency (AE)

Agronomic efficiency (AE) represents the efficiency of organic or fertilizer N to produce rice and is expressed as kg of rough rice produced kg^{-1} N applied (Yoshida, 1981).

$$\text{Agronomic efficiency} = \frac{(\text{Grain yield in N applied treatment}) - (\text{Grain yield in control})}{\text{Amount of fertilizer (or) organic N applied for the treatment}}$$

where, grain yield and fertilizer doses are in kg ha^{-1}.

Physiological efficiency (PE)

The efficiency of N utilization by the crop for rice production is denoted as physiological efficiency and is expressed as kg of rough rice produced kg^{-1}N absorbed by the plant (Yoshida, 1981).

$$\text{Physiological efficiency} = \frac{(\text{Grain yield in N applied treatment}) - (\text{Grain yield in control})}{(\text{N uptake in fertilized treatment}) - (\text{N uptake in control})}$$

3.13 N translocation in the crop

The amount of N translocated from the leaf or stem was calculated as the difference in N uptake in the leaf or stem between the maximum amount of N uptake at any crop growth stage and the amount of N present at maturity stage; the data expressed in kg ha^{-1}.

3.14 ^{15}N recovery

3.14.1 ^{15}N recovery by plant

Recovery of N applied to the crop was calculated based on ^{15}N uptake by plants, by the isotope dilution method (Harmsen and Moraghan, 1988).

$$^{15}NRP = \frac{Yxp.NP}{Yxf.NF}$$

where,

^{15}NRP is ^{15}N recovery fraction by the plant,

Yxp is atom % ^{15}N excess in the plant,

Yxf is atom % ^{15}N excess in the fertilizer,

NP is total N uptake (kg ha^{-1}) and

NF is fertilizer-N applied (kg ha^{-1}).

3.14.2 ^{15}N recovery in soil

^{15}N balance in post harvest soil was calculated by the formula:

$$^{15}NRS = \frac{Yxs.NS}{Yxf.NF}$$

where,

^{15}NRS is ^{15}N recovery fraction in soil,

Yxs is atom % ^{15}N excess in the soil,

NS is total N content in soil (kg ha^{-1}), and Yxf and NF as in section 3.14.1

3.15 Statistical analysis

Statistical scrutiny (analysis of variance and correlation) of the data was carried out as per the procedures outlined by Snedecor and Cochran (1967). For some of the derived parameters such as growth rate, N uptake rate, N recoveries and N use efficiencies, variance analysis was not done as the resulting data no longer possessed the integrity of the experimental design adopted for the field experiments

For ^{15}N studies, since no information on LSD was available, a 10 per cent increase or decrease, was taken as the 'significant difference' for comparison, as suggested by Beverly and Hallmark (1992).

EXPERIMENTAL RESULTS

Chapter IV

EXPERIMENTAL RESULTS

The results of the field experiments conducted at Tamil Nadu Agricultural University, Coimbatore during the *kharif* and *rabi* seasons in '94-95 and '95-96, to study the influence of green manures and timings of N application on the changes in plant N concentration, biomass production; and N uptake and N recovery to understand the crop-N relationships; and on growth and yield of transplanted rice are presented in this chapter. The data on interaction effects are presented wherever significant and relevant.

4.1 Growth characters

The summary of data on growth characters viz. height of plant (Table 5 and 6) and number of tillers m^{-2} (Table 7 and 8) at various growth stages of rice from maximum tillering (MT) upto maturity (M) are presented in this section.

Effect of green manures

Application of green manures did not result in significant increase in plant height as well as number of tillers in *kharif* '94 but both were significant in *kharif* '95. The influence was significantly conspicuous on plant height from heading (H) to M, whereas it was evident at M alone in the case of number of tillers. Between the different green manures, the difference was not definite with respect to plant height or tiller number, though both these parameters were highest in sesbania (G_1) incorporated plots from panicle initiation (PI) stage onwards.

Effect of N timings

The effect of N application in increasing the plant height and tiller number could be observed from MT stage upto M as evident from the significantly lowest values in control (N_0) treatment. Between N timings (N_1, N_2, N_3 and N_4), the trend at any stage was rather similar over seasons. At MT and PI stages significantly highest values were recorded either in N_1 or N_3. Thereafter, the influence of N timings seemed to be inconsistent on this parameter over the seasons.

In the case of tiller number, the trend was almost similar to that of plant height upto PI stage, with either N_1 or N_3 holding the first rank. From H stage onwards, the trend became different with the first position for N_4, significantly higher than the rest of the treatments. It was followed by N_3 and N_2 whereas in N_1 it was corsiderably low. However at M, the tiller number was highest in N_3 or N_1, over the seasons.

Table 5. **Plant height (cm) at different growth stages of rice as influenced by green manures and N timings - *kharif* '94 and *rabi* '94-95**

Treatments	Kharif '94				Rabi '94-95			
	MT	PI	H	M	MT	PI	H	M
Green manures								
G_0	29.5	37.9	61.5	75.8	33.6	44.6	64.3	64.9
G_1	31.8	40.6	62.1	77.5	35.2	43.8	66.2	67.4
G_2	30.5	38.5	60.8	79.5	34.2	42.9	66.8	69.2
G_3	31.0	40.0	60.0	76.0	34.8	43.0	65.5	67.8
$S\bar{d}$	2.10	1.85	1.08	1.85	1.25	1.09	1.25	2.05
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
N timings								
N_0	26.5	35.2	55.0	72.0	24.9	37.9	58.7	62.5
N_1	35.5	40.8	64.0	75.2	41.2	47.8	69.2	66.5
N_2	29.7	38.5	63.2	79.5	34.1	42.6	64.0	70.6
N_3	33.2	42.6	63.2	80.2	39.5	46.5	6.7	71.1
N_4	28.6	39.2	60.1	79.1	32.5	43.1	68.9	66.1
$S\bar{d}$	0.83	1.03	0.93	1.03	1.08	1.23	0.83	1.18
CD (P=0.05)	1.70	2.11	1.90	2.10	2.20	2.52	1.70	2.42

Table 6. Plant height (cm) at different growth stages of rice as influenced by green manures and N timings - *kharif* '95 and *rabi* '95-96

Treatments	Kharif '95				Rabi '95-96			
	MT	PI	H	M	MT	PI	H	M
Green manures								
G_0	31.9	39.1	54.2	71.7	30.2	40.8	61.9	72.1
G_1	30.0	43.7	62.6	81.5	31.5	43.5	62.8	74.6
G_2	34.6	41.5	60.8	80.1	31.3	42.5	63.9	75.1
G_3	37.5	42.7	60.5	75.6	31.0	43.1	63.1	75.2
$S\bar{d}$	1.43	1.14	1.47	1.55	1.20	1.52	1.41	1.72
CD (P=0.05)	3.50	2.80	3.60	3.80	NS	NS	NS	NS
N timings								
N_0	38.2	52.7	71.2	28.2	35.6	55.2	68.8	
N_1	35.8	43.2	53.1	77.2	34.2	44.6	58.6	72.8
N_2	32.8	40.5	62.2	78.2	29.1	43.1	65.2	76.5
N_3	36.1	45.1	64.2	81.6	33.1	46.2	68.7	78.9
N_4	32.3	41.7	65.4	77.9	30.4	42.9	66.9	74.2
$S\bar{d}$	0.83	1.03	0.74	1.08	0.74	0.98	1.32	1.37
CD (P=0.05)	1.70	2.11	1.52	2.21	1.52	2.00	2.70	2.80

Table 7. Total number of tillers m^{-2} at different growth stages of rice as influenced by green manures and N timings - *kharif* '94 and *rabi* '94-95

Treatments	Kharif '94				Rabi '95-96			
	MT	PI	H	M	MT	PI	H	M
Green manures								
G_0	725	730	858	616	620	645	695	546
G_1	775	791	931	663	615	650	667	537
G_2	780	801	911	683	590	610	654	563
G_3	821	846	891	655	551	564	700	534
$S\bar{d}$	48	52	39	32	45	52	35	25
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
N timings								
N_0	600	603	596	490	450	451	433	391
N_1	925	931	918	603	660	675	647	507
N_2	683	730	931	738	575	605	693	570
N_3	931	951	978	776	690	710	772	617
N_4	737	744	1065	665	595	645	852	641
$S\bar{d}$	19	39	22	30	19	20	21	15
CD (P=0.05)	39	80	45	61	39	41	43	31

Table 8. Total number of tillers m^{-2} at different growth stages of rice as influenced by green manures and N timings - *kharif* '95 and *rabi* '95-96

Treatments	Kharif '95				Rabi '95-96			
	MT	PI	H	M	MT	PI	H	M
Green manures								
G_0	628	759	855	577	585	593	608	490
G_1	862	888	970	730	620	648	710	560
G_2	816	800	874	710	630	685	735	545
G_3	785	796	906	647	581	607	755	450
$S\bar{d}$	20	22	20	17	25	31	72	52
CD (P=0.05)	49	54	49	42	NS	NS	NS	NS
N timings								
N_0	595	616	603	496	450	455	425	355
N_1	951	978	938	614	715	748	745	495
N_2	730	749	958	759	590	605	735	600
N_3	905	940	974	785	690	710	745	595
N_4	683	771	1034	675	575	610	795	510
$S\bar{d}$	22	20	28	16	17	14	23	9
CD (P=0.05)	45	41	57	33	35	29	47	18

Interaction effect

The combined effect of green manures and N timings was significant on tiller production at MT and H stages in *kharif* '95 (Table 9 and 10 respectively).

At MT stage, the difference in tiller production due to green manure treatments was not conspicuous at any N timing, but significantly better than G_5 treatment. However, G_1 with N_1 and N_4 or G_2 with N_3 recorded higher tillers compared to other combinations.

As the stage of the crop advanced to H, the interaction effect was different. At this stage, irrespective of N timings, G_1 produced substantially more tillers over other green manures as well as no green manure. Significantly highest tiller number (1113) was achieved with the combination of G_1 N_4. The tiller number in G_1 with other N timings was intermediary, but significantly more than other combinations.

4.2 Dry matter production and partitioning

The summary of data on dry matter yield of root, stem, leaf and panicle; and total biomass (TDMP) at various growth stages viz. tillering, PI, H and M are presented in Tables 11 to 14.

Table 9. Total number of tillers m^{-2} at MT stage as influenced by the interaction between green manures and N timings - *kharif* '95

N timings	Green manures				
	G_0	G_1	G_2	G_3	Mean
N_0	484	664	628	604	595
N_1	773	1061	1004	966	951
N_2	593	814	771	742	730
N_3	735	1010	956	919	905
N_4	555	762	721	694	683
Mean	628	862	816	785	

For comparison between		$S\bar{d}$	CD(P=0.05)
Sub plot means at the same main plot	:	25	62
Main plot means at the same or different sub plot	:	30	72

Table 10. Total number of tillers m^{-2} at H stage as influenced by the interaction between green manures and N timings - *kharif* '95

N timings	Green manures				
	G_0	G_1	G_2	G_3	Mean
N_0	572	648	585	606	603
N_1	890	1010	910	943	938
N_2	909	1031	929	963	958
N_3	924	1048	945	979	974
N_4	981	1113	1003	1039	1034
Mean	855	970	874	906	

For comparison between		$S\bar{d}$	CD(P=0.05)
Subplot means at the same main plot	:	18	44
Main plot means at the same or different subplots	:	27	66

Effect of green manures

It is clear from the data that the root biomass was not influenced by green manures during *rabi* '94-95, while there was limited variation in this parameter at H and M stages of *kharif* '94, MT and H in *kharif* '95 and tillering stage in *rabi* '95-96. During *kharif* '94, cowpea (G_2) incorporation resulted in higher root biomass followed by parthenium (G_3) while sesbania (G_1) stood in the third place. On the contrary, in the second year sesbania (G_1) ranked first in enhancing the root biomass followed by parthenium (G_3) both in *kharif* '95 and *rabi* '95-96. The stem and leaf biomass was influenced by green manure incorporation in *kharif* '95 season. In general, the biomass of stem and leaf was lower in non-green manure (G_0) plots across the seasons. During *kharif* '95 significant increase in biomass of stem by green manure incorporation was evident from MT to H stage, but such an influence was found to be limited at maturity with respect to leaf biomass. Incorporation of parthenium (G_3) resulted in maintenance of stem biomass to the highest level both at MT (0.77 t ha^{-1}) and PI (1.34 t ha^{-1}) stages, while by H stage sesbania (G_1) stood in the first place (5.22 t ha^{-1}). However, over the stages, the biomass values for green manures were at par with its successive lower values. In the case of leaf biomass, highest value at MT stage was recorded in G_3 (0.75 t ha^{-1}) whereas at PI and M stages it was in G_1 plots. Superiority of any of the green manure over non-green manure was not definite in enhancing stem biomass at any stage. This was true in the leaf production also upto PI stage, but afterwards G_2 recorded significantly lowest values in the season.

Panicle biomass was also significantly increased in *kharif* '95 by green manure incorporation. The maximum biomass of panicle was possible with sesbania (G_1) followed by cowpea (G_2) and parthenium (G_3); and these three green manures were significantly better than non green manure (G_0). The trend in production of plant parts has been reflected in TDMP also, with highest position occupied by G_3 at MT stage and by G_1 thereafter.

Effect of N timings

Change in the N application strategy resulted in significant variations in root, stem and leaf production and consequently TDMP also, over the growth stages. Similarly, whatever be the timing of N application, applied N significantly increased the biomass weight over the control plot.

Over the growth stages, the response of root, stem, leaf as well as TDMP was almost similar for N timings. All these parameters were significantly higher either in N_1 or N_3 at early tillering (ET) stage. It is interesting to note that application of 75 kg N ha^{-1} (N_1) or 25 kg N ha^{-1} (N_3) at planting did not cause appreciable increase in dry matter at ET stage.

However by MT stage, highest biomass production was possible with N_3 timing followed by N_2 either significantly different or at par with each other. Similar trend was observed at PI stage also. In *kharif* '94 both these treatments were at par in stem, leaf and TDM production whereas in other seasons N_3 was significantly superior.

The consistentcy of N timings on dry matter production of root, stem or leaf was not clear at H stage. However, highest root, stem, leaf and TDMP was generally observed in N_3 timing with significant difference in *rabi* '94 and *kharif* '95. At maturity though significant variations for N timings over the seasons, could not be observed for stem and leaf biomass, TDMP showed significantly highest values for N_3 followed by N_2. The N_2 timing was also significantly superior to the rest of treatments, except in *rabi* '94, when it was at par with N_4. Application of 75 kg N at P and the balance N in two splits at MT and PI (N_1) resulted in significantly lower plant biomass at maturity. However, the performance of N_4 (50 kg at ET and 100 kg at PI) in retention of crop weight at maturity, especially stem and leaf was comparable to N_3 and N_2 timings.

Interaction effect

The interaction effect of green manures and N timings on TDMP was significant at M stage in *kharif* '95 only (Table 15). Markedly higher TDMP of 14.92 t ha^{-1} was obtained with the

Table 11. Dry matter production (t ha^{-1}) at different growth stages of rice as influenced by green manures and N timings - *kharif* '94

Crop growth stages	Green manures						N timings						
	G_0	G_1	G_2	G_3	$S\bar{d}$	CD (P=0.05)	N_0	N_1	N_2	N_3	N_4	$S\bar{d}$	CD (P=0.05)
Root biomas													
P	0.01	0.01	0.01	0.01	-	-	0.01	0.01	0.01	0.01	0.01	-	-
ET	0.16	0.17	0.15	0.16	0.01	NS	0.16	0.17	0.16	0.17	0.15	0.03	NS
MT	0.43	0.48	0.49	0.51	0.04	NS	0.33	0.58	0.41	0.61	0.45	0.02	0.05
PI	0.53	0.59	0.58	0.52	0.02	NS	0.36	0.64	0.54	0.67	0.54	0.03	0.06
H	1.34	1.44	1.50	1.48	0.04	0.11	0.96	1.59	1.56	1.56	1.52	0.05	0.11
M	1.08	1.15	1.20	1.18	0.03	0.08	0.77	1.28	1.25	1.25	1.22	0.04	0.09
Stem biomass													
P	0.02	0.02	0.02	0.02	-	-	0.02	0.02	0.02	0.02	0.02	-	-
ET	0.21	0.24	0.22	0.20	0.01	NS	0.19	0.29	0.19	0.24	0.20	0.01	0.02
MT	0.68	0.66	0.66	0.66	0.01	NS	0.41	0.80	0.69	0.77	0.65	0.03	0.05
PI	0.89	0.90	0.92	0.92	0.01	NS	0.62	1.05	0.98	1.03	0.88	0.05	0.10
H	5.69	5.63	5.67	5.62	0.04	NS	3.94	5.47	6.21	6.40	6.24	0.21	0.43
M	4.93	4.79	4.88	4.90	0.08	NS	3.37	4.68	5.33	5.83	5.16	0.21	0.43

Table 11 (Contd.)

Crop growth stages	Treatments												
	Green manures						N timings						
	G_0	G_1	G_2	G_3	$S\bar{d}$	CD (P=0.05)	N_0	N_1	N_2	N_3	N_4	$S\bar{d}$	CD (P=0.05)
Total leaf biomass													
P	0.02	0.02	0.02	0.02	-		0.02	0.02	0.02	0.02	0.02	-	
ET	0.22	0.22	0.23	0.21	0.01	NS	0.19	0.27	0.21	0.23	0.21	0.01	0.02
MT	0.59	0.64	0.63	0.63	0.05	NS	0.37	0.76	0.61	0.71	0.62	0.05	0.10
PI	0.74	0.88	0.73	0.75	0.07	NS	0.50	0.97	0.78	0.86	0.78	0.08	0.16
H	2.39	2.52	2.69	2.47	0.13	NS	1.46	2.86	2.76	2.87	2.63	0.10	0.21
M	2.09	2.29	2.40	2.30	0.14	NS	1.36	2.32	2.51	2.74	2.43	0.10	0.21
Panicle biomass													
M	4.97	5.31	5.32	5.13	0.19	NS	3.68	5.21	5.79	6.02	5.21	0.18	0.37
Total biomass													
P	0.05	0.05	0.05	0.05	-	-	0.05	0.05	0.05	0.05	0.05	-	-
ET	0.60	0.63	0.60	0.58	0.03	NS	0.53	0.73	0.56	0.65	0.56	0.03	0.03
MT	1.70	1.78	1.77	1.80	0.07	NS	1.11	2.07	1.71	2.10	1.72	0.07	0.12
PT	2.16	2.37	2.34	2.18	0.09	NS	1.48	2.66	2.31	2.55	2.20	0.09	0.16
H	9.43	9.59	9.86	9.57	0.20	NS	6.37	9.92	10.53	10.83	10.40	0.63	1.29
M	13.07	13.55	13.80	13.51	0.35	NS	9.18	13.48	14.88	15.83	14.03	0.30	0.59

Table 12. Dry matter production (t ha^{-1}) at different growth stages of rice as influenced by green manures and N timings - *rabi* '94-95

Crop growth stages	Green manures						*N* timings						
	G_0	G_1	G_2	G_3	$S\bar{d}$	CD (P=0.05)	N_0	N_1	N_2	N_3	N_4	$S\bar{d}$	CD (P=0.05)
Root biomass													
P	0.01	0.01	0.01	0.01	-	-	0.01	0.01	0.01	0.01	0.01	-	-
ET	0.19	0.22	0.21	0.19	0.02	NS	0.19	0.21	0.17	0.25	0.19	0.01	0.02
MT	0.52	0.58	0.59	0.56	0.03	NS	0.43	0.58	0.56	0.70	0.55	0.01	0.02
PI	0.65	0.64	0.68	0.69	0.03	NS	0.48	0.64	0.74	0.77	0.68	0.01	0.02
H	1.06	1.18	1.02	1.16	0.08	NS	0.88	1.08	1.10	1.32	1.14	0.01	0.03
M	0.83	0.93	0.81	0.91	0.06	NS	0.70	0.84	0.85	1.02	0.95	0.01	0.02
Stem biomass													
P	0.02	0.02	0.02	0.02	-	-	0.02	0.02	0.02	0.02	9.02	-	-
ET	0.27	0.29	0.26	0.27	0.01	NS	0.22	0.32	0.24	0.32	0.26	0.02	0.04
MT	0.89	0.91	0.89	0.91	0.01	NS	0.65	1.06	0.89	1.08	0.81	0.04	0.08
PI	1.19	1.27	1.29	1.34	0.07	NS	1.01	1.38	1.26	1.48	1.26	0.04	0.08
H	4.10	4.07	4.08	4.02	0.11	NS	3.24	3.76	4.32	4.81	4.21	0.05	0.11
M	2.87	2.82	2.81	2.86	0.10	NS	1.70	2.39	3.21	3.60	3.29	0.05	0.09

Table 12 (Contd.)

Crop growth stages	Green manures						N timings						
	G_0	G_1	G_2	G_3	$S\bar{d}$	CD (P=0.05)	N_0	N_1	N_2	N_3	N_4	$S\bar{d}$	CD (P=0.05)
Total leaf biomass													
P	0.02	0.02	0.02	0.02	-	-	0.02	0.02	0.02	0.02	0.02	-	-
ET	0.21	0.28	0.25	0.26	0.03	NS	0.19	0.30	0.21	0.31	0.24	0.01	0.03
MT	0.72	0.79	0.75	0.83	0.06	NS	0.48	0.89	0.76	0.97	0.76	0.04	0.08
PI	0.77	0.88	0.81	0.85	0.05	NS	0.62	0.93	0.80	0.99	0.81	0.05	0.10
H	1.71	1.85	1.90	1.74	0.08	NS	1.07	1.75	1.88	2.19	2.09	0.06	0.12
M	1.50	1.70	1.71	1.61	0.12	NS	0.98	1.58	1.85	1.90	1.84	0.04	0.08
Panicle biomass													
M	3.93	3.87	3.97	4.21	.16	NS	2.85	3.85	4.38	5.05	3.84	0.19	0.38
Total biomass													
P	0.05	0.05	0.05	0.05	-	-	0.04	0.05	0.04	0.05	0.04	-	-
ET	0.68	0.79	0.72	0.71	0.06	NS	0.60	0.82	0.63	0.88	0.69	0.01	0.02
MT	2.14	2.28	2.22	2.30	0.08	NS	1.57	2.53	2.20	2.75	2.13	0.04	0.08
PI	2.61	2.79	2.78	2.88	0.13	NS	2.11	2.95	2.80	3.23	2.74	0.04	0.08
H	6.87	7.09	6.99	6.91	0.12	NS	5.19	6.60	7.29	8.31	7.44	0.07	0.15
M	9.13	9.32	9.30	9.58	0.22	NS	6.23	8.65	10.30	11.57	9.92	0.19	0.39

Table 13. Dry matter production (t ha^{-1}) at different growth stages of rice as influenced by green manures and N timings - *kharif* '95

Crop growth stages	Green manures						N timings						
	G_0	G_1	G_2	G_3	$S\bar{d}$	CD (P=0.05)	N_0	N_1	N_2	N_3	N_4	$S\bar{d}$	CD (P=0.05)
Root biomass													
P	0.01	0.01	0.01	0.01	-	-	0.01	0.01	0.01	0.01	0.01	-	-
ET	0.20	0.20	0.20	0.21	0.01	NS	0.19	0.22	0.19	0.22	0.19	0.01	0.02
MT	0.63	0.76	0.70	0.71	0.01	0.06	0.51	0.79	0.72	0.84	0.64	0.01	0.03
PI	0.86	0.92	0.88	0.98	0.06	NS	0.70	1.01	0.81	1.17	0.84	0.03	0.05
H	1.18	1.49	1.21	1.25	0.06	0.15	1.01	1.28	1.26	1.56	1.31	0.03	0.05
M	0.95	1.10	1.06	1.00	0.07	NS	0.75	1.04	1.01	1.24	1.10	0.03	0.06
Stem biomass													
P	0.02	0.02	0.02	0.02	-	-	0.02	0.02	0.02	0.02	0.02	-	-
ET	0.14	0.15	0.16	0.13	0.01	NS	0.14	0.16	0.13	0.17	0.13	0.01	0.01
MT	0.63	0.69	0.67	0.77	0.03	0.08	0.51	0.80	0.66	0.83	0.65	0.02	0.03
PI	1.12	1.24	1.32	1.34	0.06	0.15	0.88	1.42	1.22	1.49	1.25	0.04	0.08
H	4.95	5.22	4.98	4.90	0.11	0.27	4.25	5.38	4.94	5.57	4.91	0.03	0.06
M	3.20	3.41	3.44	3.35	0.12	NS	2.81	3.19	3.18	3.79	3.75	0.02	0.05

Table 13 (Contd.)

Crop growth stages	Green manures						N timings						
	G_0	G_1	G_2	G_3	$S\bar{d}$	CD (P=0.05)	N_0	N_1	N_2	N_3	N_4	$S\bar{d}$	CD (P=0.05)
Total leaf biomass													
P	0.01	0.01	0.01	0.01	-	-	0.01	0.01	0.01	0.01	0.01	-	-
ET	0.15	0 15	0.15	0.14	0.00	NS	0.01	0.18	0.14	0.19	0.13	0.00	0.01
MT	0.62	0.69	0.72	0.75	0.03	0.08	0.87	0.76	0.71	0.85	0.69	0.02	0.05
PI	1.21	1.68	1.23	1.35	0.06	0.16	0.78	1.51	1.42	1.67	1.46	0.03	0.06
H	2.12	2.41	2.35	2.35	0.02	0.06	1.37	2.64	2.52	2.56	2.47	0.03	0.07
M	1.98	2.25	2.20	2.20	0.02	0.05	1.24	2.48	2.37	2.31	2.39	0.04	0.09
Panicle biomass													
M	5.38	6.00	5.71	5.67	0.08	1.98	4.41	5.54	6.68	6.94	4.89	0.09	0.18
Total biomass													
P	0.05	0.05	0.05	0.05	-	-	0.05	0.05	0.05	0.05	0.05	-	-
ET	0.49	0.50	0.51	0.49	0.01	NS	0.43	0.56	0.46	0.58	0.45	0.01	0 02
MT	1.88	2.14	2.09	2.23	0.08	0.21	1.49	2.34	2.09	2.52	1.99	0.04	0.08
PI	3.19	3.83	3.43	3.67	0.21	0.52	2.36	3.94	3.46	4.34	3.55	0.05	0.10
H	8.25	9.12	8.55	8.50	0.22	0.56	6.62	9.30	8.71	9.69	8.69	0.12	0.25
M	11.51	12.76	12.40	12.23	0.17	0.44	9.22	12.25	13.24	14.29	12.13	0.10	0.21

Table 14. Dry matter production (t ha^{-1}) at different growth stages of rice as influenced by green manures and N timings - *rabi* '95-96

Crop growth stages	Green manures						N timings						
	G_0	G_1	G_2	G_3	$S\bar{d}$	CD (P=0.05)	N	N_1	N_2	N_3	N_4	$S\bar{d}$	CD (P=0.05)
Root biomass													
P	0.01	0.01	0.01	0.01	-	-	0.01	0.01	0.10	0.01	0.01	-	-
ET	0.20	0.27	0.25	0.21	0.03	0.06	0.20	0.29	0.20	0.28	0.20	0.03	0.05
MT	0.44	0.54	0.47	0.53	0.02	0.05	0.45	0.47	0.50	0.57	0.49	0.04	0.08
PI	0.71	0.73	0.74	0.74	0.02	NS	0.58	0.77	0.73	0.82	0.74	0.04	0.08
H	1.26	1.33	1.28	1.34	0.04	NS	1.05	1.31	1.37	1.43	1.33	0.06	0.11
M	1.01	1.10	1.09	1.00	0.05	NS	0.86	1.10	1.07	1.12	1.09	0.04	0.09
Stem biomass													
P	0.02	0.02	0.02	0.02	-	-	0.02	0.02	0.02	0.02	0.02	-	-
ET	0.26	0.23	0.23	0.23	0.01	NS	0.19	0.29	0.21	0.30	0.20	0.00	0.01
MT	0.75	0.82	0.85	0.82	0.06	NS	0.53	0.88	0.82	0.98	0.82	0.04	0.08
PI	1.44	1.69	1.72	1.65	0.15	NS	1.31	1.63	1.65	1.84	1.69	0.05	0.12
H	4.29	4.32	4.28	4.46	0.09	NS	3.07	4.34	4.77	4.91	4.60	0.20	0.41
M	2.80	3.20	2.98	2.95	0.19	NS	1.63	2.77	3.52	3.65	3.35	0.17	0.35

Table 14 (Contd.)

Crop growth stages	Green manures						N timings						
	G_0	G_1	G_2	G_3	$S\bar{d}$	CD (P=0.05)	N_0	N_1	N_2	N_3	N_4	$S\bar{d}$	CD (P=0.05)
Total leaf biomass													
P	0.02	0.02	0.02	0.02	-	-	0.02	0.02	0.02	0.02	0.02	-	-
ET	0.26	0.24	0.22	0.28	0.03	NS	0.23	0.32	0.19	0.33	0.20	0.02	0.05
MT	0.62	0.68	0.71	0.67	0.04	NS	0.45	0.70	0.68	0.82	0.69	0.06	0.12
PI	1.33	1.36	1.23	1.26	0.06	NS	0.91	1.30	1.17	1.30	1.78	0.10	0.20
H	1.97	2.13	2.10	1.91	0.13	NS	1.28	2.03	2.19	2.45	2.18	0.09	0.18
M	1.75	1.89	1.82	1.75	0.07	NS	1.10	1.73	2.09	2.09	2.01	0.11	0.22
Panicle biomass													
M	4.43	4.41	4.20	4.35	0.16	3.80	3.05	4.20	4.88	5.49	4.32	0.12	0.24
Total biomass													
P	0.05	0.05	0.05	0.05	-	-	0.05	0.05	0.05	0.05	0.05	-	-
ET	0.72	0.75	0.71	0.73	0.03	NS	0.62	0.90	0.60	0.91	0.60	0.02	0.04
MT	1.81	2.04	2.02	2.02	0.11	NS	1.44	2.05	2.00	2.37	2.00	0.07	0.13
PI	3.48	3.77	3.70	3.65	0.16	NS	2.81	3.71	3.55	4.44	3.74	0.20	0.43
H	7.52	7.78	7.66	7.70	0.21	NS	5.41	7.67	3.82	8.80	8.11	0.31	0.63
M	9.98	10.60	10.09	10.04	0.32	NS	6.63	9.78	11.57	12.35	10.76	0.33	0.67

Table 15. **Total dry matter production (t ha^{-1}) at maturity as influenced by the interaction between green manures and N timings - *kharif* '95**

N timings	Green manures				
	G_0	G_1	G_2	G_3	Mean
N_0	8.68	9.63	9.36	9.20	9.22
N_1	11.54	12.80	12.44	12.26	12.26
N_2	12.46	13.82	13.44	13.23	13.24
N_3	13.45	14.92	14.50	14.28	14.29
N_4	11.42	12.67	12.31	12.13	12.13
Mean	11.51	12.77	12.41	12.23	

For comparison between

		$S\bar{d}$	CD (P=0.05)
Sub plot means at the same main plot	:	0.34	0.81
Main plot means at the same or different sub plots	:	0.32	0.76

interaction effect of G_1N_3 which was followed by G_1N_2 combination (13.82 t ha^{-1}). Irrespective of the green manures, N_2 and N_3 timings recorded more TDMP. The performance of N timings was better in green manure applied plots than in non-green manure plots.

Time course of dry matter accumulation

The temporal behaviour of rice plant on dry matter accumulation as influenced by green manure application and N management was obtained from the data on biomass recorded at various phenological stages (Tables 11 to 14). Over the growth stages, the time course accumulation of biomass was similar both for green manures and N treatments.

The stem and leaf biomass increased from planting onwards attaining maximum at H stage and decreased thereafter, whereas the total biomass of crop continued to increase after H also attaining maximum at maturity. The increase in weight of plant parts and TDMP was rapid during PI-H period. The increase in weight during PI-H stage as well as decrease during H-M stage was higher in stem compared to leaves.

4.3 Crop growth analyses

The rate of growth of stem (SGR), leaf (LGR) and the whole crop (CGR) estimated at different growth periods in different seasons are presented in Tables 16 to 19. The rate of growth was derived from the mean values for biomass production and hence not analysed statistically.

4.3.1 Growth rate over phases

The SGR and LGR increased steadily as crop age advanced to heading and decreased thereafter. The rate of increase in biomass accumulation in these plant parts and their effect on whole plant was rapid during PI-H phase compared to early vegetative stages, the values ranging from 93.0 to 314.0 kg ha^{-1} day^{-1} for SGR, 19.1 to 106.0 kg for LGR and 137.0 to 435.0 kg for CGR. Such wide range in this parameter was due to treatmental and seasonal influences.

As already seen, during H-M stage the growth rate of stem and leaf was negative, while the CGR was positive indicating decrease in stem and leaf while accumulation in the reproductive parts is still continued. The reduction in stem biomass was at a higher rate than that of leaf. The CGR during H-M phase was lower than the CGR during PI-H phase, but comparable to the CGR during ET-PI stage.

4.3.2 Influence of treatments

The influence of treatments on biomass production had reflected in the growth rate as well. It is clear from the data that the rate of biomass accumulation was not much influenced by green manures but profoundly influenced by N timings.

The growth was invariably slowest in unfertilized plots (N_0) but in other plots it was dependent on the timing of N application. During P-ET stage highest growth rate was observed in N_2 or N_3, the difference between them being very narrow. During the succeeding phase (ET-PI) also the first rank of N_3 was upheld but it was closely followed by N_1, N_2 or N_4. The difference between the N applied treatments were neither consistent nor appreciable over the seasons.

During PI-H stage, SGR was comparatively high in N_3 and N_4 whereas LGR was high in N_3 and N_2 than in other treatments. However, the magnitude of change in CGR with N_2, N_3 and N_4 was meagre.

It is quite clear that consistently high CGR during H-M stage was depicted with N_3 and N_2 (Fig.15), though during the previous growth stages such definite trend was not evident over seasons. The per day accumulation of biomass (CGR) during H-M stage was invariably more with N_3 (85.0 to 135.2 kg ha^{-1}) and N_2 (77.0 to 122.2 kg ha^{-1}) over the seasons compared to lower figures with other N timings.

4.4 Ammonium-N (NH_4^+-N) content in soil

The influence of green manures applied one week before transplanting to *kharif* crops and N timings to both *kharif* crops and the first *rabi* crop on NH_4^+N content in soil (ppm on oven dry soil

Table 16. Growth rate (kg ha^{-1} day^{-1}) of rice during different growth periods - *kharif* '94

Crop growth periods	Green manures				N timings				
	G_0	G_1	G_2	G_3	N_0	N_1	N_2	N_3	N_4
Stem growth rate									
P-ET	10.7	12.2	11.4	10.3	9.3	14.9	9.4	12.3	10.0
ET-PI	32.4	31.7	33.4	34.2	20.8	36.3	37.7	37.6	32.4
PI-H	252.0	249.0	250.0	247.0	175.0	233.0	275.0	283.0	282.0
H-M	-20.4	-22.6	-21.6	-19.5	-15.4	-21.2	-23.9	-15.4	-29.2
Leaf growth rate									
P-ET	11.2	11.2	11.6	10.7	9.5	13.7	10.4	11.7	10.6
ET-PI	24.9	31.5	24.3	25.5	14.6	33.5	27.4	29.9	27.3
PI-H	86.9	86.2	102.5	90.7	50.8	99.5	104.0	105.9	97.4
H-M	-8.2	-6.2	-7.7	-4.6	-2.7	-14.7	-6.8	-3.6	-5.4
Total crop growth rate									
P-ET	30.4	32.4	30.8	29.6	27.1	37.7	28.3	32.7	28.3
ET-PI	74.7	82.9	82.7	76.4	45.0	92.0	83.4	91.4	78.1
PI-H	382.0	380.0	396.0	389.0	257.0	382.0	433.0	435.0	432.0
H-M	98.5	107.1	106.5	106.6	76.1	96.2	117.5	135.2	98.2

Table 17. Growth rate (kg ha^{-1} day^{-1}) of rice during different growth periods - *rabi* '94-95

Crop growth periods	Green manures				N timings				
	G_0	G_1	G_2	G_3	N_0	N_1	N_2	N_3	N_4
Stem growth rate									
P-ET	9.0	9.5	8.7	8.82	7.0	10.5	8.0	10.8	8.7
ET-PI	46.1	49.4	51.5	53.6	39.8	53.1	51.0	57.7	49.2
PI-H	138.0	133.0	133.0	127.0	106.0	114.0	145.0	159.0	141.0
H-M	-32.4	-33.0	-33.4	-30.5	-40.6	-36.3	-29.1	-31.7	-24.1
Leaf growth rate									
P-ET	6.9	9.4	8.3	8.2	6.2	9.9	6.7	10.4	7.7
ET-PI	27.7	29.9	28.0	30.2	21.3	31.4	29.4	33.9	28.7
PI-H	44.9	45.9	51.6	42.0	21.6	39.0	51.7	57.0	61.0
H-M	-5.6	-3.7	-4.8	-3.3	-2.5	-4.3	-0.8	-7.6	-6.5
Total crop growth rate									
P-ET	22.5	26.3	24.1	23.6	19.6	27.6	20.6	29.7	23.0
ET-PI	96.8	100.3	102.9	108.5	75.5	106.2	108.9	117.7	102.4
PI-H	203.0	205.0	201.0	192.0	147.0	174.0	214.0	242.0	224.0
H-M	59.7	58.7	60.7	70.2	27.5	54.2	79.0	85.7	65.3

Table 18. Growth rate (kg ha^{-1} day^{-1}) of rice during different growth periods - *kharif* '95

Crop growth periods	Green manures				N timings				
	G_0	G_1	G_2	G_3	N_0	N_1	N_2	N_3	N_4
Stem growth rate									
P-ET	7.1	7.4	8.0	6.9	6.8	8.4	6.5	8.7	6.4
ET-PI	42.7	47.0	50.7	52.5	32.3	54.8	47.5	57.7	48.7
PI-H	294.0	307.0	281.0	274.0	259.0	305.0	286.0	314.0	282.0
H-M	-47.4	-48.9	-41.7	-42.0	-38.9	-59.3	-47.6	-48.2	-31.3
Leaf growth rate									
P-ET	7.9	8.1	7.9	7.6	5.5	9.8	7.2	10.1	6.9
ET-PI	46.2	66.6	47.1	52.4	29.3	57.6	55.9	64.7	57.9
PI-H	70.1	55.9	86.2	77.2	45.0	87.1	84.2	67.9	77.7
H-M	-3.9	-4.4	-4.3	-4.1	-3.4	-4.3	-4.1	-6.7	-2.3
Total crop growth rate									
P-ET	26.1	26.8	27.3	26.0	22.8	30.5	24.3	31.2	23.8
ET-PI	117.5	144.7	127.1	138.3	83.7	146.8	130.3	163.7	134.9
PI-H	389.0	407.0	393.0	372.0	328.0	412.0	405.0	412.0	395.0
H-M	87.9	98.6	104.2	100.7	70.1	79.8	122.2	124.2	92.9

Table 19. Growth rate (kg ha^{-1} day^{-1}) of rice during different growth periods - *rabi* '95-96

Crop growth periods	Green manures				N timings				
	G_0	G_1	G_2	G_3	N_0	N_1	N_2	N_3	N_4
Stem growth rate									
P-ET	10.1	8.9	8.7	8.8	7.3	11.3	7.9	11.7	7.5
ET-PI	62.3	6.6	78.5	74.6	58.7	70.7	75.9	81.1	78.4
PI-H	150.0	139.0	135.0	148.0	93.0	142.0	164.0	162.0	153.0
H-M	-35.7	-26.7	-31.0	-36.0	-34.6	-37.5	-29.8	-30.1	-29.9
Leaf growth rate									
P-ET	9.8	9.2	8.4	10.8	8.6	12.3	6.8	12.7	7.5
ET-PI	56.2	58.6	53.1	51.5	36.1	51.9	51.6	76.5	57.9
PI-H	33.9	40.5	45.4	33.9	19.1	38.0	53.8	35.1	46.2
H-M	-5.2	-5.6	-6.5	-3.8	-4.3	-7.2	-2.4	-8.5	-4.1
Total crop growth rate									
P-ET	27.7	29.0	27.3	28.2	23.8	35.2	22.7	35.6	22.9
ET-PI	145.4	159.3	157.4	153.3	115.0	148.0	155.5	186.0	165.0
PI-H	213.0	211.0	208.0	213.0	137.0	209.0	251.0	229.0	231.0
H-M	59.0	67.0	58.0	56.0	29.0	50.0	77.0	85.0	58.0

weight basis) at different intervals from planting onwards are presented in Tables 20 to 22.

Effect of green manures

The peak concentration of soil NH_4^+-N reached at 30 days after transplanting (DT) during *kharif* '94 whereas in the succeeding *kharif* it was much earlier (17 DT). Throughout the crop growth period, the NH_4^+-N content in non-green manure plots (G_0) was lower than green manure applied plots on most of the sampling dates, the superiority of any green manure over other green manures was not significant. However, the difference between green manures and non-green manure and also among the green manures was more conspicuous for a fortnight period between 17 and 30 DT in both years when the NH_4^+-N concentration was highest.

In *kharif* '94, while parthenium (G_3), recorded significantly high NH_4^+-N content upto 8 DT over other treatments, such effect on soil NH_4^+-N was evident with sesbania (G_1) and cowpea (G_2) at 17 and 30 DT. During this year NH_4^+-N concentration reached a peak of 51.79, 45.58 and 43.57 ppm for G_1, G_2 and G_3 respectively, compared to 29.90 ppm in non-green manured plot.

In *kharif* '95, superiority of any green manure between them or over non-green manure treatment was not significant upto 2 DT but from 4 DT to 8 DT, cowpea (G_2) recorded significantly more

NH_4^+-N than other treatments, whereas as G_3 and G_1 were at par with G_2. As in *kharif* '94 notable difference in soil NH_4^+-N content between treatments was depicted from 17 to 30 DT when the NH_4^+-N content was higher. On 17 DT, highest NH_4^+-N content was observed in cowpea (G_2) followed by sesbania (G_1) and parthenium (G_3). The same trend was observed on 30 DT also. Maximum NH_4^+-N content for G_2, G_1 and G_3 i.e., 32.43, 30.43 and 26.00 ppm respectively were recorded on 17 DT. In both years green manures did not vary in their effect on NH_4^+-N at early stages and late stages of crop growth, though the concentration was significantly more with green manured plots compared to non-green manured plot.

Application of green manures in *kharif* season did not exert any residual effect on soil NH_4^+-N content in the *rabi* season.

Effect of N timings

In *kharif*, substantial variation in the soil NH_4^+-N content was observed due to variation in N timings. The plots applied with N at planting (N_1 and N_3) recorded substantially higher NH_4^+-N content upto 8 DT in both *kharif* seasons compared to non-fertilized plots at that stage. Here again, plots received more N (N_1) at that stage had more NH_4^+-N content than lower dose of N (N_3). At this stage the level of NH_4^+N with N_0, N_2 and N_4

timings were at par with each other and significantly lower than N_2 and N_3.

When soil NH_4^+-N was estimated at 17 DT (following the application of N at 10 DT) N_3 recorded significantly higher content (36.38 ppm in *kharif* '94 and 35 ppm in *kharif* '95) compared to all other treatments which were at par with each other. The results obtained on 30 DT revealed the inconsistent performance of N timings over seasons. In *kharif* '94, N_4 recorded the highest NH_4^+ content (48.57 ppm) followed by N_2 (44.93) and N_3 (43.18) whereas in *kharif* '95, N_2 recorded the highest NH_4^+-N content (24.98 ppm) followed by N_3 (23.02 ppm) and N_4 (22.46 ppm). During both seasons, the content was significantly lower for N_1 and N_0.

The effect of N application at MT, PI or H stages till the successive stages was evident only in *kharif* '94 whereas in the succeeding year there was no difference between any treatments after 38 DT. In *kharif* '94, NH_4^+-N content in soil, immediately prior to fertilizer application at PI (38 DT) NH_4^+-N was highest in N_2 (30.68 ppm) which was superior to all other N timings. Nitrogen application at PI stage exerted its influence upto H stage in N_1, N_2, N_3 and N_4 over control treatment (N_0). At H stage significantly more NH_4^+-N content was observed in N_2 (21.83 ppm) then in N_1, N_3 and N_4 which were at par. The variation in NH_4^+-N concentration due to N timings was evident upto heading

Table 20. Extractable soil NH_4^+-N (ppm) as influenced by green manures and N timings - *kharif* '94

Treatments	Days after transplanting									
	0	2	4	6	8	17	30	38	55	85
Green manures										
G_0	14.20	16.94	17.08	15.92	16.31	18.11	29.91	23.43	15.63	13.77
G_1	13.89	17.55	17.01	16.72	17.82	33.82	51.79	29.72	22.07	15.01
G_2	13.95	20.62	18.51	17.23	17.25	30.66	45.58	30.67	19.07	14.44
G_3	14.59	22.00	20.90	19.49	19.09	25.64	43.57	28.63	19.43	14.23
$s\bar{d}$	0.39	0.94	0.86	0.69	1.21	1.35	2.00	1.16	1.33	0.61
CD (P=0.05)	NS	2.30	2.10	1.70	NS	3.30	4.90	2.85	3.25	NS
N timings										
N_0	13.53	14.78	16.88	15.93	17.13	23.68	36.48	23.87	14.50	13.96
N_1	13.78	28.76	24.01	20.73	20.63	25.95	40.42	30.68	20.14	14.19
N_2	13.98	14.93	15.63	15.50	15.98	24.11	44.93	28.66	21.83	14.34
N_3	14.93	23.27	19.65	18.45	18.10	36.38	43.18	29.44	19.25	14.44
N_4	14.58	14.65	15.68	16.08	16.24	25.17	48.57	27.92	19.53	14.87
$s\bar{d}$	0.78	1.00	0.88	0.42	0.57	0.75	1.03	0.59	0.74	0.63
CD (P=0.05)	NS	2.05	1.80	0.85	1.16	1.52	2.10	1.20	1.50	NS

Table 21. Extractable soil NH_4^+-N (ppm) as influenced by green manures and N timings - *kharif* '95

Treatments	Days after transplanting									
	0	2	4	6	8	17	30	38	55	85
Green manures										
G_0	14.08	13.64	13.31	13.83	15.32	18.13	17.44	5.73	5.30	13.86
G_1	14.73	18.07	16.05	16.05	16.80	30.43	21.95	7.76	7.47	13.50
G_2	12.89	17.47	18.72	19.15	20.81	32.43	27.26	7.88	7.98	13.87
G_3	14.53	19.13	14.50	15.16	17.05	26.00	20.47	7.69	7.63	13.98
$S\bar{d}$	0.91	1.61	0.76	0.78	0.82	2.60	1.04	0.69	0.45	0.51
CD (P=0.05)	NS	3.95	1.85	1.90	2.00	6.30	2.55	1.70	1.10	NS
N timings										
N_0	14.18	12.38	11.64	12.29	13.96	23.18	17.16	6.95	6.77	12.63
N_1	13.66	25.41	23.88	23.46	24.21	26.04	21.35	7.33	7.12	14.00
N_2	13.96	12.30	11.81	12.56	14.50	24.77	24.98	7.23	7.27	14.60
N_3	14.00	22.62	18.02	18.26	19.18	35.00	23.02	7.43	7.23	14.85
N_4	14.48	12.68	12.88	13.68	15.61	24.75	22.46	7.38	7.08	12.94
$S\bar{d}$	0.67	0.77	0.74	0.78	1.03	0.82	0.59	0.35	0.41	2.10
CD (P=0.05)	NS	1.58	1.51	1.60	2.11	1.68	1.20	NS	NS	NS

stage (55 DT) in *kharif* '94, whereas such influence existed only upto PI stage in *kharif* '95.

The *rabi* season NH_4^+-N flux was studied only in 1994-95 (Table 22) since any definite release pattern could not be observed except that a sudden spurt of NH_4^+-N content immediately after N application.

In general, soil NH_4^+-N content was comparatively low in *rabi* season compared to *kharif* seasons. On 11 DT higher NH_4^+-N content was recorded in N_2 (9.88 ppm) and N_3 (9.48 ppm) compared to other treatments which were yet to receive N application. At 15 DT also N_2 and N_3 continued to exhibit similar complementary effect on NH_4^+-N content. However, the magnitude of increase in NH_4^+-N content with N_2 and N_3 in comparison to other N timings was not substanial at 27 DT. On 40 DT, higher and comparable NH_4^+ content was noticed in N_4 (16.83 ppm) and N_2 (16.73 ppm) compared to other N treatments and the lowest with N_0 (6.79 ppm). Similar difference in NH_4^+-N content was observed on 47 DT and 51 DT also while such influence of N timing was not apparent beyond 51 DT. As expected, markedly low soil NH_4^+-N content was noticed in unfertilized plots (N_0) at all growth stages.

Time course of NH_4^+N release

The NH_4^+-N release pattern over time during different crop seasons viz., *kharif* '94, *kharif* '95 and *rabi* '94-95 are depicted in Fig.3 and 4.

Table 22. Extractable soil NH_4^+-N (ppm) as influenced by green manures and N timings - *rabi* '94-95

Treatments	Days after transplanting								
	0	11	15	27	40	47	51	68	90
Green manures									
G_0	7.3	8.5	8.5	9.8	12.5	5.6	6.1	7.7	5.2
G_1	7.2	8.8	8.7	10.2	12.8	6.3	6.3	8.1	5.1
G_2	7.4	8.9	8.8	10.1	12.9	6.2	6.2	7.9	4.9
G_3	7.2	9.2	8.6	10.1	12.6	6.2	6.5	8.0	5.0
$S\bar{d}$	0.28	0.32	0.26	0.25	0.31	0.35	0.28	0.30	0.19
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
N timings									
N_0	7.80	7.89	7.38	9.59	6.79	3.48	3.40	7.08	4.71
N_1	7.00	9.88	9.75	9.95	8.72	7.78	4.93	7.70	5.22
N_2	7.00	8.15	8.26	9.96	16.73	4.58	6.86	7.70	5.16
N_3	7.00	9.48	9.75	10.06	14.48	7.95	6.97	8.90	5.13
N_4	7.00	8.70	8.01	10.63	16.83	6.93	9.23	8.15	5.03
$S\bar{d}$	0.26	0.10	0.47	0.71	0.60	0.54	0.61	0.97	0.85
CD (P=0.05)	NS	0.21	0.95	NS	1.23	1.10	1.25	NS	NS

In general, the soil NH_4^+-N content gradually increased with time after rice planting, reaching a peak by two to four weeks and thereafter declined with steady values at late growth stages across green manure and N timing treatments. However the change in NH_4^+-N level was inconsistent over the seasons and crop growth stages.

In *kharif* '94, the peak NH_4^+-N level in all treatments was observed at 30 DT, highest being with sesbania (G_1) followed by cowpea (G_2), parthenium (G_3) and the lowest in non-green manure plot (G_0). The gaps between the peaks were widest between 17 and 38 DT. In *kharif* '95, the peak values were attained earlier than that in *kharif* '94 i.e., by 17 DT. Here the gaps between peaks were widest between 8 and 30 DT. In *kharif* '94, the increase from 17 DT to 30 DT and the decline from 30 DT to 38 DT was rapid in all treatments whereas such increase occurred from 8 DT and the decline after 30 DT in *kharif* '95.

The position of peaks, as influenced by N timings over time was also inconsistent, though the highest peak in all treatments was observed on 30 DT in *kharif* '94 and on 17 DT in *kharif* '95. The position of peaks at any time depended on the duration between N application and the time of sampling. In *kharif* '95, a slight increase at 85 DT over 55 DT was evident for green manure and N timing treatments.

In *rabi* '94-95 NH_4^+-N content analyses over time showed a gradual increase upto 27 DT and a rapid increase at 40 DT followed by a sharp decline towards 51 DT. Again a small peak of soil NH_4^+-N content at 68 DT and a decline thereafter could be observed. The position of NH_4^+-N curve at any stage during *rabi* season was dependent on the time and quantity of N received by the treatment earlier to the estimation.

4.5 N concentration in plant parts

The N concentration in plant part viz., root, stem and leaf as influenced by treatments are presented in this section.

4.5.1 Root N concentration

The N concentration in root (RNC) was comparatively lower than that in stem or leaf. None of the treatments (green manure or N timings) depicted notable difference in RNC at any stage of the crop over seasons. The RNC values averaged over the same crop stage across the seasons are presented in Table 23. The RNC showed declining trend with the advancement of crop growth stages attaining minimum values at maturity.

Table 23. Root N concentration (g kg^{-1}) at different growth stages of rice (averaged over treatments)

Crop season	Crop growth stages					
	P	ET	MT	PI	H	M
Kharif '94	9.85	10.55	8.00	8.58	7.16	6.07
Rabi '94-95	7.90	8.39	7.91	7.84	7.35	6.69
Kharif '95	10.60	10.50	8.10	8.82	7.91	6.13
Rabi '95-96	11.36	8.44	7.74	7.16	6.66	6.75

4.5.2 Stem N concentration

The changes in stem N concentration (SNC) influenced by the green manure and N timings over the crop growth stages in *kharif* and *rabi* seasons of '94-96 are presented in Tables 24 to 27 ,and depicted in Fig.7.

Effect of green manures

Green manures failed to effect any significant influence on SNC except at PI and H stages in *kharif* '94; and at MT and PI stages in *kharif* '95. In *kharif* '94, at PI stage highest SNC was observed in G_3 (13.41 g kg^{-1}) but at H stage it was in G_2 (7.94 g). In *kharif* '95, both at MT and PI stages highest SNC was observed in G_2 (16.12 and 15.80 g kg^{-1} respectively). The variation in SNC at different growth stages of crop were small and the values were statistically at par with the succeeding lower values, indicating the limited response of SNC to green manure incorporation.

Effect of N timings

The data presented in Tables 24 to 27 reveal significant influence of N timings on SNC at all stages of crop growth over seasons.

At ET stage, significantly higher SNC was observed in N_1 in *kharif* '94 (15.93 g kg^{-1}), *kharif* '95 (18.62 g kg^{-1}) and in *rabi* '95-96 (15.50 g) seasons. In *rabi* '94-95, though N_3 was having the first rank, N_2 was at par with it, while other treatments were inferior in all seasons. The N_3 timings was the second best treatment in enhancing the SNC significantly than other treatments except in *kharif* '94. In that season, N_2 and N_4 were at par with N_3.

At MT stage, though N_4 recorded highest SNC, it was at par with N_2 in *kharif* '94 and significantly lower to N_3 in *rabi* '95-96. The SNC with N_1, N_2 and N_3 were more or less similar at MT stage in *kharif* '94 and *rabi* 95-96 seasons.

The influence of N timings on SNC at PI stage was more or less similar in al seasons, with highest values in N_3 or N_1. At heading and maturity stages marked difference in SNC between N

Table 24. Stem N concentration (g kg^{-1}) at different growth stages of rice as influenced by green manures and N timings - *kharif* '94

Treatments	Crop growth stages						
	P	ET	MT	PI	H	MM	M
Green manures							
G_0	9.90	13.73	13.15	11.54	6.17	6.78	4.22
G_1	9.90	14.62	13.26	11.25	7.38	8.02	4.25
G_2	9.90	15.28	13.59	12.31	7.94	6.83	4.30
G_3	9.90	13.47	14.18	13.41	7.01	6.22	4.23
$S\bar{d}$	-	0.74	0.52	0.45	0.43	0.81	0.12
CD (P=0.05)	-	NS	NS	1.11	1.05	NS	NS
N timings							
N_0	9.90	13.72	10.95	10.34	5.18	4.62	3.78
N_1	9.90	15.93	12.95	13.71	6.45	5.04	3.61
N_2	9.90	14.04	14.65	10.66	8.95	8.69	4.94
N_3	9.90	14.19	13.95	14.95	7.84	7.65	5.15
N_4	9.90	13.51	15.20	10.97	7.23	8.82	3.77
$S\bar{d}$	-	0.71	0.62	0.67	0.80	0.14	0.04
CD (P=0.05)		1.44	1.26	1.36	1.63	0.28	0.09

Table 25. Stem N concentration (g kg^{-1}) at different growth stages of rice as influenced by green manures and N timings - *rabi* '94-95

Treatments	Crop growth stages						
	P	ET	MT	PI	H	MM	M
Green manures							
G_0	6.20	9.29	9.17	9.19	8.31	6.72	4.02
G_1	6.20	10.03	8.59	8.59	7.89	7.05	4.51
G_2	6.20	9.28	9.15	8.30	8.54	6.41	4.51
G_3	6.20	10.03	9.36	9.50	8.34	6.27	4.02
$S\bar{d}$	-	0.41	0.41	0.52	0.41	0.42	0.31
CD (P=0.05)	-	NS	NS	NS	NS	NS	NS
N timings							
N_0	6.20	8.78	6.58	6.53	6.27	4.39	2.85
N_1	6.20	10.98	9.56	9.93	8.85	5.35	4.08
N_2	6.20	8.78	10.04	8.89	8.62	7.52	5.02
N_3	6.20	11.29	8.97	10.08	8.79	7.60	5.01
N_4	6.20	8.47	10.21	9.06	8.81	8.47	4.40
$S\bar{d}$	-	0.16	0.09	0.09	0.12	0.29	0.16
CD (P=0.05)	-	0.32	0.18	0.19	0.25	0.59	0.32

Table 26. Stem N concentration (g kg^{-1}) at different growth stages of rice as influenced by green manures and N timings - *kharif* '95

Treatments	Crop growth stages						
	P	ET	MT	PI	H	MM	M
Green manures							
G_0	10.60	14.78	14.12	12.26	9.57	6.92	5.83
G_1	10.60	17.12	16.12	15.80	10.53	7.43	6.05
G_2	10.60	17.25	15.66	14.66	10.08	6.93	6.96
G_3	10.60	15.08	15.46	12.98	9.86	6.92	6.79
$S\bar{d}$	-	1.21	0.76	0.66	0.61	0.35	0.61
CD (P=0.05)	-	NS	1.85	1.62	NS	NS	NS
N timings							
N_0	10.60	14.49	12.60	11.45	7.74	4.62	4.63
N_1	10.60	18.62	13.30	15.48	9.94	5.04	6.30
N_2	10.60	15.68	16.50	12.45	10.92	8.68	7.64
N_3	10.60	16.94	16.38	16.08	9.82	8.08	6.77
N_4	10.60	14.56	17.93	14.18	11.63	8.82	6.72
$S\bar{d}$	-	0.42	0.07	0.49	0.12	0.09	0.28
CD (P=0.05)		0.85	0.14	1.00	0.25	0.18	0.57

Table 27. Stem N concentration (g kg^{-1}) at different growth stages of rice as influenced by green manures and N timings - *rabi* '95-96

Treatments	Crop growth stages						
	P	ET	MT	PI	H	MM	M
Green manures							
G_0	11.25	11.70	9.66	9.10	10.20	7.10	3.85
G_1	11.25	13.08	10.87	8.95	11.10	7.30	3.91
G_2	11.25	13.40	10.36	8.80	10.05	7.10	4.00
G_3	11.25	11.98	8.26	8.79	10.03	7.10	3.91
$S\bar{d}$	-	0.73	1.25	0.35	0.61	0.59	0.09
CD(P=0.05)	-	NS	NS	NS	NS	NS	NS
N timings							
N_0	11.25	11.63	7.42	6.98	7.00	4.50	2.15
N_1	11.25	15.50	10.28	10.69	10.08	5.60	3.92
N_2	11.25	11.20	10.47	8.26	9.80	7.90	4.52
N_3	11.25	13.14	10.69	10.92	10.40	8.10	4.95
N_4	11.25	11.20	10.08	7.70	14.44	9.70	4.05
$S\bar{d}$	-	0.56	0.47	0.42	0.35	0.40	0.31
CD(P=0.05)	-	1.15	0.95	0.85	0.72	0.81	0.63

timings could not be observed. But at mid maturity (MM) stage, the SNC in N_1 was substantially low compared to N_2, N_3 and N_4 treatments. As the crop growth stage advanced, the magnitude of variation in SNC between fertilizer applied and control plots differed very much with significantly lower values with N_0.

Time course of stem N concentration

Irrespective of N timings, SNC showed an increase from planting to ET stage of crop and then gradually declined over time with minor exceptions of increase or decrease influenced by N application. The gradual decline in SNC over crop growth stages was clearly evident in unfertilized crop. Over seasons the SNC at planting ranged from 6.2 to 11.25 g kg^{-1} which got dropped to 2.15 to 4.63 g kg^{-1} by maturity.

The flux of SNC (Fig.7) in N applied plots were different in some stages, though the general trend of decline with crop age was consistent. In N_1, there was a slight increase at PI over MT, stage whereas in N_2 and N_3 timings such increase was observed at MT and H stages. In N_4, maximum SNC was observed at MT stage (10.21 to 17.93 g kg^{-1}), which declined thereafter reaching lowest at maturity (3.77 to 6.72 g kg^{-1}). In general, the SNC in N_3 and N_2 were almost steady without much increase or decrease at least upto H stage. Afterwards SNC in these treatments were often higher compared to other N timing strategies.

4.5.3 Leaf N concentration

The N concentration of composite green leaf samples (nL) estimated at different growth stages of crop are presented in Tables 28 to 31.

Effect of green manures

It is quite clear from the data that green manures had no marked influence on nL at ET stage in *rabi* '94-95 and at MT stage in *kharif* '95. Though nL was highest with sesbania (G_1) in *rabi* '94-95 and cowpea in *kharif* '95, the values were always statistically at par with its successive figures of other green manures as well as non-green manure plot.

Effect of N timings

Significant difference in nL was caused by timing of N application. Evidently, plants in N_0 plots had significantly lower nL than N applied treatments, particularly from MT to M stage. At ET stage, the nL in N_0, N_2 and N_4 were almost similar, but lower than N_1 and N_3. The highest nL at ET was always noted in N_1 followed by N_3 and these two were mostly at par and significantly superior to other treatments. The nL at this stage in N_1 ranged from 27.61 to 32.62 g kg^{-1} and in N_3 from 26.3 to 30.91 g kg^{-1} over the seasons. At MT stage, highest nL was

Table 28. Leaf N concentration (g kg^{-1}) at different growth stages of rice as influenced by green manures and N timings - *kharif* '94

Treatments	Crop growth stages						
	P	ET	MT	PI	H	MM	M
Green manures							
G_0	21.70	28.45	27.3	24.90	17.12	11.95	5.80
G_1	21.70	28.11	27.5	24.63	18.25	12.20	5.40
G_2	21.70	28.17	26.1	25.35	18.66	12.80	5.20
G_3	21.70	26.67	25.9	26.23	17.63	12.61	5.74
$S\bar{d}$	-	0.92	0.75	0.78	0.81	0.51	0.45
CD (P=0.05)		NS	NS	NS	NS	NS	NS
N timings							
N_0	21.70	27.05	18.2	21.90	14.22	8.60	4.78
N_1	21.70	29.05	24.0	28.72	15.40	9.90	4.97
N_2	21.70	27.38	29.8	24.10	20.41	14.60	5.75
N_3	21.70	28.49	31.6	28.06	18.97	14.20	6.18
N_4	21.70	27.28	29.9	23.61	20.59	14.65	5.96
$S\bar{d}$	-	0.78	0.93	0.60	0.43	0.32	0.24
CD (P=0.05)		1.50	1.9	1.23	0.88	0.65	0.49

Table 29. Leaf N concentration (g kg^{-1}) at different growth stages of rice as influenced by green manures and N timings - *rabi* '94-95

Treatments	Crop growth stages						
	P	ET	MT	PI	H	MM	M
Green manures							
G_0	21.20	21.90	18.67	21.04	18.32	11.77	7.55
G_1	21.20	26.84	21.16	23.56	20.32	12.30	8.47
G_2	21.20	23.05	18.82	21.60	17.06	12.50	7.55
G_3	21.20	25.30	20.63	21.07	19.82	12.80	7.42
$S\bar{d}$	-	1.12	1.21	1.31	0.98	0.60	0.59
CD (P=0.05)	-	2.75	NS	NS	NS	NS	NS
N timings							
N_0	21.20	21.44	15.30	18.41	13.48	8.20	5.33
N_1	21.20	27.61	18.37	24.64	19.45	9.50	6.90
N_2	21.20	23.17	22.58	21.20	19.13	13.60	8.58
N_3	21.20	26.30	20.83	23.42	20.08	14.50	9.00
N_4	21.20	22.83	22.03	21.43	22.26	15.80	8.93
$S\bar{d}$	-	0.69	0.27	0.54	0.42	0.59	0.21
CD (P=0.05)	-	1.40	0.56	1.10	0.85	1.20	0.43

Table 30. Leaf N concentration (g kg^{-1}) at different growth stages of rice as influenced by green manures and N timings - *kharif* '95

Treatments	Crop growth stages						
	P	ET	MT	PI	H	MM	M
Green manures							
G_0	20.50	27.90	25.40	25.48	22.66	13.77	8.18
G_1	20.50	28.24	29.02	26.68	24.46	16.17	10.08
G_2	20.50	29.68	31.32	27.76	24.00	14.33	10.42
G_3	20.50	29.00	27.78	25.52	21.16	15.35	11.20
$S\bar{d}$	-	1.62	1.26	1.98	2.81	2.18	2.61
CD (P=0.05)	-	NS	3.09	NS	NS	NS	NS
N timings							
N_0	20.50	25.36	24.23	23.23	16.44	10.63	6.86
N_1	20.50	32.20	26.40	30.18	25.20	11.61	9.80
N_2	20.50	28.42	31.95	25.18	25.00	17.78	11.48
N_3	20.50	30.24	28.97	28.55	21.43	16.29	11.90
N_4	20.50	27.30	30.35	24.68	27.28	18.19	9.80
$S\bar{d}$	-	0.49	0.81	0.36	0.39	0.18	0.22
CD (P=0.05)	-	0.96	1.65	0.73	0.80	0.37	0.45

Table 31. **Leaf N concentration (g kg^{-1}) at different growth stages of rice as influenced by green manures and N timings - *rabi* '95-96**

Treatments	Crop growth stages						
	P	ET	MT	PI	H	MM	M
Green manures							
G_0	24.50	27.00	23.47	19.80	21.85	13.20	7.65
G_1	24.50	28.98	23.26	20.20	23.91	14.10	7.25
G_2	24.50	29.46	25.00	20.15	24.95	13.90	7.94
G_3	24.50	28.45	22.92	20.70	24.20	14.40	8.00
$S\bar{d}$	-	1.12	0.93	0.51	1.41	0.54	0.50
CD (P=0.05)	-	NS	NS	NS	NS	NS	NS
N timings							
N_0	24.50	27.16	20.72	15.46	16.64	9.50	4.95
N_1	24.50	32.62	23.21	21.57	23.42	12.60	7.15
N_2	24.50	25.62	24.72	20.11	25.90	14.80	9.10
N_3	24.50	30.91	25.26	23.82	23.43	14.20	9.20
N_4	24.50	26.04	24.45	20.10	28.00	17.10	8.15
$S\bar{d}$	-	0.77	0.45	0.48	0.65	0.47	0.35
CD (P=0.05)	-	1.58	0.91	0.98	1.32	0.95	0.72

observed either in N_3 or N_2 followed by N_4. However the difference in nL between these treatments was not appreciable.

By PI stage, N_2 or N_3 gave highest nL, mostly in N_3 (in the first three seasons). Further, it was noted that N_1 and N_4 had lower nL compared to N_2 or N_3 at this stage. At H stage, N_4 timing recorded highest nL (20.59 to 28.00 g kg^{-1} over season) which was significantly superior to all other treatments except in *kharif* '94. The difference between N_1, N_2 or N_3 were inconsistent over the seasons. By mid maturity (MM) N_4 took up the highest rank in nL and it was followed by N_3 or N_2 and the latter two treatments were at par in three reasons. The nL in N_2, N_3 and N_4 was very much higher than N_1 and N_0.

Time course of leaf N concentration

The time course of nL in different seasons are presented in Fig.8. High values of nL achieved during active crop growth period (ET and MT) was more or less maintained upto PI stage. Afterwards it declined gradually upto heading with a rapid decrease thereafter reaching the minimum at maturity stage. The decline in nL over growth stages was more conspicuous in N_0 and N_1 with minor exceptions in one or two seasons. In other treatments, there were small increases at some stages depending on the dose of N application at the preceding stage.

4.5.4 N concentration and total N content in flag leaf

The data on flag leaf N concentration (FnL: g kg^{-1}) and the total amount of N in a flag leaf (Flt N: mg $leaf^{-1}$)) from its emergence upto 30 days after heading (30 dH) in *kharif* '95 are presented in Tables 32 and 33, respectively.

Neither FnL nor FltN was influenced by green manures but greatly influenced by N timings.

Throughout the second phase of reproductive period, i.e., from boot leaf emergence upto maturity FnL in N_0 was significantly low and the difference from N applied treatments was very large (Table 32). Though N_1 timing increased FnL over unfertilized crop, the values were significantly lower compared to other N timings.

At boot leaf formation (H), highest N concentration (29.19 g kg^{-1}) was observed in N_4 treatments followed by N_2 (26.49 g kg^{-1}). After this stage, N_2 gave highest values followed by N_4 and N_3 upto 24 days after heading (dH). However, 30 dH, the FnL under N_4 timing was lower than N_2 and N_3. It is important to note that variations in FnL between N_2, N_3 and N_4 at various stages was not appreciable.

On perusal of the data on Flt N (Table 33) it could be observed that FltN behaved almost in a similar fashion as FnL to N timings. Though N_1 resulted in highest FltN at H stage (3.6

mg leaf^{-1}) such a stimulatory effect was true with N_2 thereafter. Other N timings (N_1, N_3 or N_4) closely followed N_2 without any appreciable difference.

Time course behaviour of FnL and Flt N

Both FnL and FltN displayed a declining trend with crop age. Maximum N concentration (FnL) was observed at 6 dH and it declined thereafter, the drop being gradual upto 18 dH and rapid from 18 dH to 24 dH with a small decline by 30 dH. A more or less similar trend was observed with FltN also. The decline was more pronounced in N_0 and N_1 at each stage, whereas in other treatments it was rather steady upto 18 dH.

4.5.5 **Chlorophyll meter (SPAD) values**

The SPAD meter readings are presented in Tables 34 and 35. The main objective of these observations were to work out relationship between leaf N concentration, SPAD values and grain yield; and to asses the possibility of using SPAD meter readings as an index for N side-dressing in rice especially at later growth stages.

Critical comparison of the SPAD values at different times of observations reveals insignificant influence of green manures but profound influence of N application on SPAD values (chlorophyll content). At all sampling dates, SPAD values in N_0 were significantly lower compared to all other treatments. At

Table 32. Flag leaf N concentration (FnL: g kg^{-1}) as influenced by green manures and N timings – *kharif* '95

Treatments	Crop growth stages					
	H	6 d H	12 d H	18 d H	24 d H	30 d H
Green manures						
G_0	24.85	25.20	23.20	21.25	14.90	13.15
G_1	25.42	26.10	24.25	21.62	15.52	14.20
G_2	25.56	26.50	25.10	20.85	16.10	13.50
G_3	25.59	25.90	24.15	21.76	15.53	13.33
S$\bar{d}$	0.95	1.06	0.98	1.09	0.87	0.76
CD (0.05)	NS	NS	NS	NS	NS	NS
N timings						
N_0	21.55	21.01	18.77	17.52	11.07	11.29
N_1	24.72	24.84	24.35	20.92	13.58	12.66
N_2	26.49	28.95	27.04	23.87	19.60	15.26
N_3	24.83	26.63	24.43	21.79	16.52	15.27
N_4	29.19	28.20	26.29	22.75	16.79	13.24
S$\bar{d}$	0.80	0.54	0.76	0.63	0.75	0.81
CD (P=0.05)	1.64	1.10	1.56	1.28	1.52	1.65

dH = days after heading

Table 33. Flag leaf total N (FltN: mg leaf^{-1}) as influenced by green manures and N timings - *kharif* '95

Treatments	Crop growth stages					
	H	6 d H	12 d H	18 d H	24 d H	30 d H
Green manures						
G_0	2.86	3.18	3.16	2.85	2.02	1.75
G_1	3.15	3.31	3.14	2.91	2.15	1.81
G_2	3.20	3.29	3.17	2.87	2.12	1.78
G_3	3.17	3.39	3.16	2.90	2.07	1.79
$S\bar{d}$	0.25	0.18	0.45	0.56	0.18	0.08
CD (0.05)	NS	NS	NS	NS	NS	NS
N timings						
N_0	1.74	1.86	1.77	1.47	0.79	0.77
N_1	3.60	3.62	3.53	3.01	1.74	1.86
N_2	3.41	4.06	3.81	3.53	2.92	2.12
N_3	3.22	3.50	3.12	3.09	2.47	2.09
N_4	3.51	3.42	3.56	3.31	2.53	2.07
$S\bar{d}$	0.14	0.19	0.20	0.14	0.04	0.03
CD (P=0.05)	0.28	0.38	0.41	0.29	0.08	0.06

PI stage (*rabi* '94-95) highest SPAD was recorded in N_4 (34.14) followed by N_3 (33.67). At 10 days after PI (dPI) (*rabi* '94-95) and at 15 dPI (*kharif* '94) N_4 gave the highest SPAD values followed by N_3 and N_1. After heading stage the difference between various N applied treatments was inconsistent with very narrow difference between them.

The SPAD values across the date of observations did not vary much, especially in the first two seasons. A decline in SPAD values with ageing of flag leaf was clearly evident in N_0 and N_2 plots in *kharif* '95 (Table 35). In other treatments it was rather steady upto 18 dH and dropped afterwards. Substantial reduction of SPAD values in N_2 and N_0 reached at an earlier stage (18 dH to 24 dH) compared to other treatments. The overall decline from heading to maturity differed with N timings. It was by 12.66, 11.23, 9.56 and 16.00 in N_1, N_2, N_3 and N_4 respectively.

4.5.6 chlorophyll - N relationships

The observations on chlorophyll meter readings (SPAD), leaf N concentration (nL) and total N in flag leaf (FltN) were used to work out the relationships between them and with grain yield. The values of correlation coefficients (r) between different parameters are given in Table 36.

Table 34. Chlorophyll meter readings (SPAD values) of rice as influenced by green manures and N timings - *kharif* '94 and *rabi* '94-95

Treatments	Kharif '94			Rabi '94-95			
	Crop growth stages			Crop growth stages			
	15 d PI	H	5 d H	PI	10dPI	H	10dH
Green manures							
G_0	36.70	35.00	37.80	31.70	31.20	32.60	35.90
G_1	36.90	35.72	38.10	32.20	32.30	33.95	36.20
G_2	37.10	35.82	32.50	33.00	31.80	33.80	37.10
G_3	37.00	36.54	38.40	31.40	31.60	34.90	38.60
$S\bar{d}$	1.20	2.02	1.95	1.26	1.52	1.65	2.10
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS
N timings							
N_0	25.52	30.74	32.72	28.50	25.51	31.58	32.08
N_1	40.42	38.60	39.30	32.67	32.57	34.98	37.42
N_2	39.18	35.17	40.32	31.38	32.43	32.97	38.85
N_3	37.68	36.51	40.66	33.67	33.10	35.68	38.25
N_4	41.80	37.83	38.04	34.14	35.06	33.80	38.13
$S\bar{d}$	1.08	0.74	0.54	0.25	0.37	0.27	0.40
CD (P=0.05)	2.20	1.50	1.10	0.50	0.76	0.56	0.82

dPI - days after panicle initiation

Table 35. Chlorophyll meter readings (SPAD values) of rice as influenced by green manuresand N timings - *kharif* '95

Treatments	Crop growth stages					
	H	6 d H	12 d H	18 d H	24 d H	30 d H
Green manures						
G_0	35.25	36.25	37.10	37.95	29.20	25.90
G_1	36.95	37.86	36.25	36.83	28.70	26.80
G_2	36.92	38.21	37.75	38.20	28.60	27.10
G_3	37.90	38.40	35.77	37.64	27.97	27.00
$S\bar{d}$	1.75	1.24	0.98	1.12	0.85	0.80
CD (P=0.05)	NS	NS	NS	NS	NS	NS
N timings						
N_0	27.42	31.31	30.43	30.04	19.34	21.57
N_1	37.57	36.74	35.75	36.59	25.69	25.15
N_2	40.01	41.42	40.77	42.13	36.80	32.49
N_3	37.70	38.22	37.70	40.03	32.78	28.21
N_4	41.08	40.68	38.94	39.48	28.48	26.09
$S\bar{d}$	0.42	0.30	0.29	0.29	0.17	0.17
CD (P=0.05)	0.86	0.62	0.60	0.60	0.35	0.35

A significant linear relationship (r) existed between SPAD and nL at all sampling dates from PI to 30 dH. The relationship was equally strong when the data were pooled over individual seasons (r=0.53 to 0.82) or over all seasons (r=0.75). Similarly the coefficients of relation between FltN and SPAD were highly significant on individual samplings (r=0.58 to 0.87) and also on pooling the data (r=0.80). These 'r' values were comparable to those between nL and SPAD on individual sampling or on pooling the data over the seasons.

The SPAD, nL and FltN was related to grain yield. These relationships were significantly linear at almost all stages. However the relationship of nL vs yield and FltN vs yield was poor compared to the closeness of SPAD and yield on individual sampling. On pooling the data over seasons the 'r' value between nL and yield (r=0.61) was comparatively improved than that between SPAD and yield (r=0.53).

Linear equations (worked out on the pooled values), between different parameters are presented in Table 37.

Table 36. Coefficients of correlation (r) between SPAD, nL, FltN and yield of rice

Growth stages	SPAD vs nL	SPAD vs FltN	SPAD vs yield	nL vs yield	FltN vs yield
1. Kharif '94					
15 dPI	0.52**		0.60**	0.34**	
Heading	0.55**		0.45**	0.35**	
5 dH	0.76**		0.69**	0.72**	
Pooled	0.56**		0.54**	0.44**	
2. Rabi '94					
PI	0.77**		0.28**	0.27*	
10 dPI	0.76**		0.33**	0.37**	
Heading	0.71**		0.12	0.21	
10 dH	0.74**		0.43**	0.51**	
Pooled	0.53**		0.24**	0.32**	
3. Kharif '95					
Heading	0.77**	0.85**	0.49**	0.13	0.41**
6 dH	0.83**	0.70**	0.51**	0.42**	0.59**
12 dH	0.66**	0.73**	0.57**	0.37**	0.41**
18 dH	0.69**	0.87**	0.69**	0.29*	0.56**
24 dH	0.73**	0.70**	0.66**	0.62**	0.50**
30 dH	0.67**	0.58**	0.68**	0.75**	0.40**
Pooled	0.82**	0.80**	0.43**	0.27**	0.40**
Pooled over all seasons	0.75**		0.53**	0.61**	0.51**

* Significant at P=0.05
** Significant at P=0.01

nL - leaf N concentration
FltN - Flag leaf total N

Table 37. **Linear relationships between nL, FltN, SPAD units and grain yield**

	Cause (X)	Effect (y)	Coefficient of correlation (r)	Regression equation
1.	nL (g kg^{-1})	SPAD units	0.75	y = 19.82+0.721 x
2.	FltN (mg $leaf^{-1}$)	SPAD units	0.80	y = 24.25+4.02 x
3.	SPAD units	Grain yield (t ha^{-1})	0.53	y = 0.623+0.147 x
4.	nL (g kg^{-1})	Grain yield (t ha^{-1})	0.61	y = 0.564+0.207 x
5.	FltN (g $leaf^{-1}$)	Grain yield (t ha^{-1})	0.51	y = 3.796+0.711 x

4.6 Uptake of N

The data on N uptake by root, stem, leaf and the crop at different growth stages are summarised in Tables 38 to 41.

The trend of influence of N treatments on N uptake was similar to their effect on the N concentration and dry matter accumulation at different stages.

4.6.1 N uptake by root

The uptake of N by root was found to be unaffected by green manure treatments, whereas N timings caused significant variation.

Upto PI stage, higher values of N accumulation in root was with N_2 at ET stage and with N_3 thereafter. The N uptake in N_2 and N_3 at ET stage ranged from 1.82 to 2.73 kg ha^{-1} with narrow difference between the two over the seasons. At MT and PI stages also N_3 and N_1 positively influenced root N uptake either at par with each other or significantly different. However, by H stage such influence by N timings was evened out. The same trend of results could be observed at maturity also. Though not significant, N_3 had an edge over the other treatments in influencing root N uptake.

4.6.2 N uptake by stem

Effect of green manures

Incorporation of green manures significantly increased accumulation of N in stems during *kharif* '94 and *kharif* '95 only. However, in these seasons also the influence was not evident in early and late stages of crop growth. During mid growth stages of crop also the promotary effect of green manure was not well distinct though non-green manure (G_0) plots recorded generally lower stem N uptake compared to green manured plots.

In *kharif* '94, Sesbania (G_1) incorporation resulted in higher N uptake in stem (3.48 kg ha^{-1}) at ET stage followed by cowpea (3.41 kg), whereas at PI and H stages highest N uptake was recorded in G_3 and G_2 in the order. At PI stage the second position was hold by G_2 which was significantly lower than G_3.

At H stage, G_2 was followed by G_1 but both were at par. After H stage the difference between green manure treatments was not evident. In the second *kharif* season (1995) also a clear difference between green manure treatments was evident only at PI and H stages. Incorporation of Sesbania (G_1) resulted in highest N uptake at both these stages. Though, Sesbania was at par with other green manures at PI stage, it was significantly superior at H stage.

Effect of **N** timings

As evident from the data in Tables 38 to 41, N timing strategy displayed a marked variation in stem N content through stages and over seasons. Irrespective of timings of N, applied N significantly increased N uptake in stem over control plot, particularly beyond MT stage.

At ET and MT stages, N_2 or N_3 timing produced a positive stimulatory effect on N uptake in stem. At ET stage N_1 and N_3 were at par except in *kharif* '94, when N_1 had significantly higher values than N_3. In other seasons, N_3 recorded the highest N uptake. The trend was similar at MT and PI stages also with either N_3 or N_2 holding the first position and the other in the second position except in *kharif* '95 at MT stage. In this season, the second place in the ranking was occupied by N_4 but significantly lower than N_3, the first one.

Beyond heading stage, the benefit of N_1 on stem N uptake was not carried over in any season. During the first year in both seasons, at heading N_4 timing recorded highest N uptake in stem followed by N_3 both significantly different and superior to other treatments. On the contrary, in the second year experiments, either N_3 or N_2 stood in the first place or second place, the position of N_4 being third always. At maturity, stem N content was generally highest in N_3 followed by N_2 except in *kharif* '94 when N_4 was in the second slot.

4.6.3 N uptake by leaf

Effect of green manures

Unlike on stem N uptake, the influence of green manures on leaf N uptake was evident in more seasons and at more stages. However, the trend was not consistent over stages and seasons. In *kharif* '94, the influence was observed from PI to H stage, in *kharif* '95 from MT upto maturity and in *rabi* '95-96 from ET upto heading stages. In *rabi* '94-95 at none of the stages the green manure effect was observed. Throughout the crop growth over seasons, leaf N uptake in non-green manure plots was generally low. However, definite superiority of any of the green manure over the other was not evident over the seasons.

Effect of N timings

As in the case of stem N uptake, N fertilization significantly increased N uptake in leaves as evident from significantly low values in N_0 treatment throughout the growth stages.

The trend of influence of N timings on leaf N uptake at any stage was more or less similar to stem N uptake. Upto PI stage, the higher quantity of N uptake in leaf either in N_3 or N_1 timings. By heading stage, treatments N_3, N_2 and N_4 took up higher positions while N_1 was significantly lower. Over the seasons, the difference between N_3, N_2 or N_4 was not definite.

At maturity, significantly more leaf N uptake was observed in N_3 in all the seasons, except *kharif* '95. In *kharif* '95 N_2 timing was superior to N_3, nevertheless at par with N_3. In the first two seasons the second position was occupied by N_4 and in the last season by N_2.

4.6.4 N uptake by panicle

Observations recorded on N uptake in grains are summarised in Tables 38 to 41. Incorporation of green manures significantly influenced this parameter in *kharif* '95 only. Highest N uptake was in Sesbania plots (81.83 kg ha^{-1}) followed by cowpea (G_2) and parthenium (G_3), the lowest being in control plot (G_0). All treatments differed significantly. In all seasons, the magnitude of change in N uptake by panicle with N timing was clearly evident. The accumulation of N in grain was highest in N_3 followed by N_2 both significantly varying and superior to other treatments.

4.6.5 Total N uptake by crop

The data pertaining to the total N uptake by the crop are presented in Tables 38 to 41. The pattern of total N uptake in the crop, being a cumulative effect of stem uptake and leaf uptake, depicted similar trend upto heading. At maturity it was decided by the panicle N uptake and the N absorption after heading.

Effect of green manures

The influence of green manures on total N uptake was evident from PI to maturity in *kharif* '95, whereas in *kharif* '94 it was observed at H only; and in *rabi* '95 at MT and H stages only. It is evident that N uptake by the plant in G_0 plots was low. In almost all observation timings sesbania (G_1) and cowpea (G_2) were at par and superior to G_0. However, the superiority of parthenium (G_3) over G_0 was not consistent.

Effect of N timings

Application of N consistently increased N uptake by the plant. As in the case of plant parts, at ET stage N_3 or N_1 was

Table 38. Nitrogen uptake (kg ha^{-1}) at different growth stages of rice as influenced by green manures and N timings - *kharif* '94

Crop growth stages	Green manures						N timings						
	G_0	G_1	G_2	G_3	$S\bar{d}$	CD (P=0.05)	N_0	N_1	N_2	N_3	N_4	$S\bar{d}$	CD (P=0.05)
Root N uptake													
P	0.09	0.09	0.09	0.09	-	-	0.09	0.09	0.09	0.09	0.09	-	-
ET	1.68	1.74	1.72	1.70	0.05	NS	1.60	1.91	1.70	1.82	1.56	0.11	0.22
MT	3.41	3.78	3.92	4.13	0.35	NS	2.28	4.78	3.38	5.08	3.70	0.20	0.40
PI	4.61	5.09	5.03	4.20	0.39	NS	3.05	5.49	4.70	5.80	4.62	0.26	0.53
B	9.50	10.51	10.55	10.81	1.52	NS	6.86	11.45	11.29	11.21	10.91	0.40	0.82
M	6.59	6.92	7.40	7.10	1.12	NS	4.66	7.76	7.60	7.63	7.42	0.27	0.56
Stem N uptake													
P	0.18	0.18	0.18	0.18	-	-	0.18	0.18	0.18	0.18	0.18	-	-
ET	2.90	3.48	3.41	2.75	0.23	0.56	2.56	4.55	2.62	3.39	2.67	0.19	0.38
MT	8.94	8.70	8.97	9.36	0.35	NS	4.49	10.26	10.11	9.90	9.88	0.17	0.35
PI	10.30	10.16	11.36	12.36	0.39	0.95	6.44	14.32	10.41	15.20	9.60	0.73	1.48
B	35.10	41.52	45.04	39.39	2.03	4.97	20.41	35.07	55.09	50.05	45.03	2.56	5.23
M	20.81	20.35	20.97	20.73	2.15	NS	12.75	16.90	26.31	30.02	19.46	2.06	4.21

Table 38 (Contd.)

Crop growth stages	Green manures						N timings						
	G_0	G_1	G_2	G_3	$S\bar{d}$	CD (P=0.05)	N_0	N_1	N_2	N_3	N_4	$S\bar{d}$	CD (P=0.05)
Total leaf N uptake													
P	0.40	0.40	0.40	0.40		-	0.40	0.40	0.40	0.40	0.40	-	-
ET	6.29	6.28	6.42	5.42	0.08	NS	5.16	7.72	5.69	6.59	5.70	0.24	0.48
MT	16.11	17.60	16.80	16.27	0.71	NS	6.73	18.24	18.18	22.44	18.54	1.69	3.45
PI	18.78	21.72	18.70	19.94	0.86	2.10	10.90	27.86	18.80	23.99	18.43	2.38	4.86
H	40.98	46.61	50.70	42.36	3.97	3.50	21.12	44.11	56.23	54.54	54.05	2.08	4.24
M	12.35	12.57	12.70	13.40	0.51	NS	6.51	11.50	14.37	16.83	14.56	0.63	1.28
Panicle N uptake													
M	59.14	63.61	63.51	61.65	2.95	NS	34.18	64.13	71.21	77.92	67.55	2.45	4.91
Total N uptake													
P	0.67	0.67	0.67	0.67	-	-	0.67	0.67	0.67	0.67	0.67	-	-
ET	10.87	11.50	11.55	9.87	0.81	NS	9.32	14.18	10.01	11.80	9.93	0.32	0.66
MT	28.46	30.08	29.07	29.76	0.95	NS	13.50	33.28	31.67	37.42	32.12	2.06	4.20
PT	33.69	36.97	35.09	36.50	4.10	NS	20.39	47.67	33.91	44.99	32.65	1.81	3.69
H	85.58	98.64	96.29	92.56	3.04	7.45	48.39	90.63	102.61	115.80	110.00	3.02	6.17
M	98.89	103.45	104.58	102.88	3.14	NS	58.10	100.29	119.49	132.40	109.00	2.48	5.06

Table 39. Nitrogen uptake (kg ha^{-1}) at different growth stages of rice as influenced by green manures and N timings - *rabi* '94-95

Crop growth stages	Green manures						N timings						
	G_0	G_1	G_2	G_3	$S\bar{d}$	CD (P=0.05)	N_0	N_1	N_2	N_3	N_4	$S\bar{d}$	CD (P=0.05)
Root N uptake													
P	0.06	0.06	0.06	0.06	-	-	0.06	0.06	0.06	0.06	0.06	-	-
ET	1.63	1.69	1.87	1.60	0.20	NS	1.67	1.96	1.49	1.98	0.38	0.14	0.28
MT	3.91	4.22	5.22	4.53	0.43	1.06	2.86	4.38	4.72	5.67	4.86	0.25	0.51
PI	4.77	5.11	5.42	5.53	0.39	NS	3.73	5.05	6.10	6.21	4.95	0.17	0.35
B	7.93	8.80	7.40	8.20	0.42	NS	6.14	7.13	8.36	10.43	8.67	0.16	0.32
M	5.60	6.08	5.44	6.15	0.35	NS	4.40	5.64	5.63	7.18	6.40	0.38	0.78
Stem N uptake													
P	0.12	0.12	0.12	0.12	-	-	0.12	0.12	0.12	0.12	0.12	-	-
ET	2.53	2.87	2.44	2.68	0.18	NS	1.89	3.46	2.14	3.64	2.23	0.22	0.44
MT	8.18	7.76	8.12	8.50	0.41	NS	4.30	10.13	8.90	9.67	8.29	0.12	0.25
PI	10.97	10.94	10.72	12.72	0.98	NS	6.60	13.67	11.24	14.92	11.30	0.15	0.30
B	34.10	32.10	34.80	33.50	1.50	NS	20.30	33.30	37.20	42.24	37.07	0.70	1.42
M	11.53	12.70	12.68	11.48	0.61	NS	4.80	9.82	16.13	18.09	14.52	0.23	0.47

Table 39 (Contd.)

Crop growth stages	Green manures						N timings						
	G_0	G_1	G_2	G_3	$S\bar{d}$	CD (P=0.05)	N_0	N_1	N_2	N_3	N_4	$S\bar{d}$	CD (P=0.05)
Total leaf N uptake													
P	0.36	0.36	0.36	0.36	-	-	0.36	0.36	0.36	0.36	0.36	-	-
ET	4.68	7.59	5.82	6.31	1.82	NS	4.15	8.21	4.84	8.22	5.38	0.30	0.62
MT	13.49	16.75	14.05	17.03	1,58	NS	7.31	16.27	17.20	20.24	16.77	0.51	1.05
PI	16.17	20.75	17.55	17.95	2.15	NS	11.46	22.77	16.87	23.20	17.27	0.59	1.21
H	31.36	37.49	32.35	34.38	3.18	NS	14.48	34.06	35.72	44.02	46.57	0.65	1.32
M	11.33	14.43	12.92	11.94	1.85	NS	5.23	10.81	15.78	17.08	16.49	0.22	0.45
Panicle N uptake													
M	56.10	54.02	54.06	60.26	2.25	NS	32.12	53.57	67.82	76.78	55.13	2.90	6.00
Total N uptake													
P	0.54	0.54	0.54	0.54	-	-	0.54	0.54	0.54	0.54	0.54	-	-
ET	8.84	12.15	10.13	10.59	1.62	NS	7.71	13.63	8.47	13.84	8.99	0.30	0.61
MT	25.58	28.73	27.39	30.06	1.95	NS	14.47	30.78	30.82	35.58	29.92	0.35	0.71
PI	31.91	36.80	3.69	36.20	2.15	NS	21.79	41.49	34.21	44.33	33.52	0.59	1.22
H	73.39	78.39	74.55	76.08	3.41	NS	40.92	74.50	81.28	96.69	92.31	0.91	1.85
M	84.56	87.23	85.10	89.83	3.05	NS	46.55	79.84	105.36	119.13	92.54	3.28	6.70

Table 40. Nitrogen uptake (kg ha^{-1}) at different growth stages of rice as influenced by green manures and N timings - *kharif* '95

Crop growth stages	Green manures						N timings						
	G_0	G_1	G_2	G_3	$S\bar{d}$	CD (P=0.05)	N_0	N_1	N_2	N_3	N_4	$S\bar{d}$	CD (P=0.05)
Root N uptake													
P	0.12	0.12	0.12	0.12	-	-	0.12	0.12	0.12	0.12	0.12	-	-
ET	1.91	2.21	2.15	2.26	0.41	NS	1.90	2.62	1.84	2.48	1.87	0.09	0.18
MT	5.10	5.89	5.40	6.29	0.52	NS	4.28	6.29	5.78	6.74	5.20	0.23	0.47
PI	7.20	8.90	7.38	8.64	0.82	NS	6.04	9.03	7.24	10.30	7.45	0.27	0.55
B	9.35	11.75	9.55	9.88	1.15	NS	7.94	10.09	9.91	12.45	10.33	0.21	0.43
M	5.80	6.69	6.50	6.18	0.85	NS	4.61	6.36	6.17	7.61	6.72	0.28	0.57
Stem N uptake													
P	0.21	0.21	0.21	0.21	-	-	0.21	0.21	0.21	0.21	0.21	-	-
ET	2.08	2.49	2.69	2.07	0.32	NS	1.95	3.03	2.06	2.85	1.86	0.12	0.24
MT	8.85	11.12	10.51	11.91	1.35	NS	6.40	10.62	10.89	13.61	11.66	0.35	0.72
PI	13.93	20.00	19.58	17.87	1.74	4.25	10.06	22.15	15.26	23.93	17.82	0.26	0.54
B	47.37	54.97	50.20	48.31	2.13	5.21	32.90	53.53	53.99	54.77	57.10	0.39	0.79
M	18.97	21.00	23.92	22.78	2.85	NS	13.05	20.11	24.54	25.71	25.27	0.25	0.51

Table 40 (Contd.)

Crop growth stages	Green manures						N timings						
	G_0	G_1	G_2	G_3	$S\bar{d}$	CD (P=0.05)	N_0	N_1	N_2	N_3	N_4	$S\bar{d}$	CD (P=0.05)
Total leaf N uptake													
P	0.41	0.41	0.41	0.41	-	-	0.41	0.41	0.41	0.41	0.41	-	-
ET	4.27	4.41	4.56	4.33	0.35	NS	2.84	5.99	4.00	5.77	3.70	0.15	0.31
MT	15.96	20.19	22.61	21.06	1.72	4.20	11.61	20.20	22.67	25.01	21.41	0.23	0.47
PI	30.98	45.04	34.37	34.89	3.50	8.56	18.35	45.72	35.70	47.95	36.24	0.52	1.06
H	48.19	59.04	57.89	49.91	3.02	7.38	22.53	66.57	62.88	54.88	67.59	0.65	1.32
M	16.16	23.58	23.60	24.70	1.19	2.91	8.49	24.48	27.39	27.05	23.69	0.32	0.65
Panicle N uptake													
M	71.11	81.83	77.90	74.27	1.23	3.02	43.54	82.26	96.14	98.04	67.17	1.60	3.26
Total N uptake													
P	0.74	0.74	0.74	0.74	-	-	0.74	0.74	0.74	0.74	0.74	-	-
ET	8.26	9.11	9.40	8.66	0.62	NS	6.69	11.64	7.90	11.10	7.43	0.28	0.58
MT	29.91	37.20	38.52	39.26	4.02	NS	22.29	37.11	39.34	45.36	38.27	1.23	2.51
PI	52.11	73.94	61.33	61.40	5.66	13.86	34.45	76.90	58.20	82.18	61.51	1.54	3.15
H	104.91	125.76	117.64	108.10	3.36	NS	63.37	130.19	126.78	122.10	135.00	2.08	4.25
M	112.04	133.11	131.92	127.93	3.11	NS	69.69	133.21	154.24	158.41	122.85	2.62	5.35

Table 41. Nitrogen uptake (kg ha^{-1}) at different growth stages of rice as influenced by green manures and N timings - *rabi* '95-96

Crop growth stages	Green manures						N timings						
	G_0	G_1	G_2	G_3	$S\bar{d}$	CD (P=0.05)	N_c	N_1	N_2	N_3	N_4	$S\bar{d}$	CD (P=0.05)
Root N uptake													
P	0.10	0.10	0.10	0.10	-	-	0.10	0.10	0.10	0.10	0.10	-	-
ET	1.52	2.45	2.18	1.78	0.18	NS	1.54	2.70	1.51	2.73	1.55	0.17	0.35
MT	3.27	4.20	3.69	4.20	0.45	NS	3.19	3.73	3.99	4.37	3.93	0.40	0.81
PI	5.06	5.19	5.36	5.25	0.18	NS	4.15	5.52	5.28	5.82	5.33	0.56	1.15
H	8.19	8.90	8.84	8.66	0.35	NS	6.47	8.77	9.23	10.22	8.74	0.75	1.52
M	6.64	7.48	7.53	6.73	0.42	NS	5.42	7.16	7.51	7.82	7.62	0.59	1.21
Stem N uptake													
P	0.23	0.23	0.23	0.23	-	-	0.23	0.23	0.23	0.23	0.23	-	-
ET	3.07	3.07	3.08	2.78	0.21	NS	2.28	4.54	2.35	3.96	2.24	0.31	0.64
MT	7.25	8.97	8.81	6.78	0.95	NS	4.00	9.10	8.60	10.54	8.34	0.54	1.10
PI	13.15	15.13	15.14	14.50	0.92	NS	9.15	17.50	13.65	20.11	13.01	0.69	1.41
H	43.81	47.58	43.06	44.74	1.95	NS	21.55	43.77	46.76	51.08	66.50	1.59	3.23
M	10.76	12.52	11.92	11.53	0.88	NS	3.49	10.84	15.91	18.07	13.57	0.42	0.85

Table 41 (Contd.)

Crop growth stages	Green manures						N timings						
	G_0	G_1	G_2	G_3	$S\bar{d}$	CD (P=0.05)	N_0	N_1	N_2	N_3	N_4	$S\bar{d}$	CD (P=0.05)
Total leaf N uptake													
P	0.54	0.54	0.54	0.54	-	-	0.54	0.54	0.54	0.54	0.54	-	-
ET	6.97	7.01	6.60	8.03	0.49	1.2	6.19	10.34	4.77	10.08	5.26	0.84	1.71
MT	14.48	15.70	17.63	15.38	0.58	1.42	9.39	16.13	16.86	20.61	16.85	1.45	2.95
PI	26.28	27.33	24.84	26.06	1.30	NS	14.13	28.13	23.45	42.40	26.19	2.09	4.26
H	43.05	50.81	52.27	46.10	1.51	3.7	21.25	47.45	56.67	57.33	61.04	2.62	5.35
M	13.39	13.70	14.45	13.97	1.30	NS	5.42	12.33	19.00	19.23	16.38	0.70	1.42
Panicle N uptake													
M	67.38	69.38	67.67	65.20	3.35	NS	38.39	70.47	79.60	90.08	63.78	2.84	5.80
Total N uptake													
P	0.87	0.87	0.87	0.87	-	-	0.87	0.87	0.87	0.87	0.87	-	-
ET	11.56	12.53	11.86	12.59	0.56	NS	10.01	17.58	8.63	16.77	9.05	0.84	1.72
MT	25.00	28.87	30.13	26.36	1.72	4.20	16.58	28.96	29.45	35.52	29.12	1.54	3.15
PI	44.49	47.69	45.34	45.81	1.62	NS	27.43	51.15	42.38	68.33	44.53	2.31	4.72
H	95.05	107.29	104.17	99.50	3.35	8.20	49.27	99.99	112.66	118.63	136.28	3.55	7.24
M	97.17	103.38	101.57	97.43	5.20	NS	52.72	100.80	122.02	135.20	101.35	4.17	8.50

superior to all other treatments, while between N_2 and N_4 the difference was not consistent over the seasons. At MT stage also N_3 gave significantly highest values and the difference between N_1, N_2 and N_4 got narrowed down. As in the case of N content in plant parts, total N uptake also did not differ consistently between N_2, N_3 and N_4 at heading stage, while N_1 recorded significantly lower values in all seasons. It is quite clear from that data that N_3 and N_2 timings favourably maintained the crop N uptake up to maturity stage compare to other timings.

Interaction effect

The interaction effect of green manures and N timings on crop N removal was significant in *kharif* seasons in both years. In *kharif* '94 it was evident only at H stage (Table 42) whereas in the subsequent year it was at PI stage only (Table 43). The trend was similar in both cases. At each N timings, G_1 was significantly superior to the remaining green manure treatments. Irrespective of green manure applied, N_3 timing increased its uptake than other N timings. The trend of interaction of N timings at a given green manure was not consistent over seasons and crop growth stages.

4.6.6 Rate of N uptake

The per day uptake of N in stem and leaf; and the whole plant (including root) during various growth periods viz.

Table 42. **Total N uptake (g kg^{-1}) at H stage as influenced by the interaction between green manures and N timings - *kharif* '94**

N timings	Green manures				
	G_0	G_1	G_2	G_3	Mean
N_0	44.40	51.80	49.96	48.02	48.55
N_1	83.16	95.85	93.57	89.94	90.63
N_2	94.16	108.52	105.94	101.83	102.61
N_3	106.26	122.47	119.56	114.92	115.80
N_4	100.94	116.34	113.57	109.17	110.01
Mean	85.70	98.99	96.52	92.78	

For comparison between		$S\bar{d}$	CD(P=0.05)
Subplot means at the same main plot	:	4.62	10.85
Main plot means at the same or different subplots	:	3.82	9.25

Table 43. **Total N uptake (kg ha^{-1}) at PI stage as influenced by the interaction between green manures and N timings - *kharif* '95**

N timings	Green manures				
	G_0	G_1	G_2	G_3	Mean
N_0	28.66	40.67	33.73	33.77	34.21
N_1	63.98	90.78	75.30	75.39	76.36
N_2	48.42	68.71	56.99	57.06	57.80
N_3	68.37	97.02	80.47	80.56	81.61
N_4	51.18	72.62	60.23	60.30	61.10
Mean	52.12	73.96	61.34	61.42	

For comparison between		$S\bar{d}$	CD(P=0.05)
Sub plot means at the same main plot treatment	:	3.37	7.50
Main plot means at the same or different sub plot treatments	:	4.20	10.20

P-ET, ET-PI, PI-H and H-M phases are presented in Tables 44 to 47. The data were derived from the mean values on N uptake and hence not statistically analysed. The influence of N timings alone are presented, since that of green manures was not appreciable.

Maximum N uptake rate in stem and leaf was observed at heading stage, while total N uptake in the plant was maximum at maturity. The rate of growth in stem and leaf was positive upto heading and negative thereafter while for the whole plant it was positive always.

The fastest N uptake rate was observed during P-ET stage in N_3 both for stem (0.12 to 0.24 kg ha^{-1} day^{-1}) and leaf (0.28 to 0.41 kg ha^{-1} day^{-1}) followed by N_1. The rate of total N uptake was highest either in N_1 or N_3 over the seasons. The same trend repeated during ET-PI stage also with high values for N_3 in general, particularly in the case of stem N uptake rate. The difference between other N treatments (N_2 and N_4) was not significant upto PI stage.

During PI-H stage, though the difference in N uptake rate between N_2, N_3 and N_4 was not definite over seasons either in stem, leaf or the plant as a whole, in N_1 it was substantially low.

Table 44. **N uptake rate (kg ha^{-1} day^{-1}) as influenced by N timings - *kharif* '94**

Crop growth periods	N_0	N_1	N_2	N_3	N_4
Stem N uptake					
P-ET	0.13	0.24	0.14	0.18	0.14
ET-PI	0.19	0.49	0.39	0.59	0.35
PI-H	0.74	1.09	2.35	1.83	1.86
H-M	-0.21	-0.42	-0.78	-0.54	-0.69
Leaf N uptake					
P-ET	0.26	0.41	0.29	0.34	0.29
ET-PI	0.29	1.01	0.66	0.87	0.44
PI-H	0.54	0.86	1.97	1.61	1.87
H-M	-0.39	-0.88	-1.13	-1.02	-1.07
Total N uptake					
P-ET	0.48	0.75	0.52	0.62	0.51
ET-PI	0.55	1.67	1.20	1.66	1.14
PI-H	1.47	2.26	3.62	3.73	4.07
H-M	0.26	0.26	0.46	0.45	-0.03

Table 45. **N uptake rate (kg ha^{-1} day^{-1}) as influenced by N timings - *rabi* '94-95**

Crop growth periods	N_0	N_1	N_2	N_3	N_4
Stem N uptake					
P-ET	0.06	0.12	0.07	0.13	0.08
ET-PI	0.23	0.51	0.46	0.56	0.45
PI-H	0.65	0.93	1.24	1.30	1.23
H-M	-0.41	-0.62	-0.55	-0.64	-0.59
Leaf N uptake					
P-ET	0.14	0.28	0.16	0.28	0.18
ET-PI	0.37	0.23	0.60	0.75	0.59
PI-H	0.14	0.54	0.90	0.99	1.40
H-M	-0.24	-0.61	-0.52	-0.71	-0.79
Total N uptake					
P-ET	0.26	0.47	0.28	0.48	0.30
ET-PI	0.70	1.39	1.29	1.52	1.23
PI-H	0.91	1.57	2.24	2.49	2.80
H-M	0.15	0.14	0.63	0.59	0.01

Table 46. **N uptake rate (kg ha^{-1} day^{-1}) as influenced by N timings - *kharif* '95**

Crop growth periods	N_0	N_1	N_2	N_3	N_4
Stem N uptake					
P-ET	0.10	0.17	0.11	0.16	0.10
ET-PI	0.35	0.83	0.57	0.92	0.69
PI-H	1.76	2.41	2.98	2.37	3.02
H-M	-0.53	-0.90	-0.80	-0.79	-0.86
Leaf N uptake					
P-ET	0.14	0.33	0.21	0.32	0.19
ET-PI	0.67	1.73	1.38	1.83	1.41
PI-H	0.32	1.60	2.09	0.53	2.41
H-M	-0.38	-1.14	-0.96	-0.75	-1.19
Total N uptake					
P-ET	0.35	0.64	0.42	0.61	0.39
ET-PI	1.21	2.84	2.19	3.09	2.35
PI-H	2.22	4.10	5.28	3.07	5.65
H-M	0.17	0.08	0.74	0.98	-0.32

Table 47. **N uptake rate (kg ha^{-1} day^{-1}) as influenced by N timings** - *rabi* '95-96

Crop growth periods	N_0	N_1	N_2	N_3	N_4
Stem N uptake					
P-ET	0.09	0.18	0.09	0.16	0.08
ET-PI	0.36	0.68	0.59	0.85	0.57
PI-H	0.65	1.38	1.74	1.63	2.82
H-M	-0.43	-0.78	-0.73	-0.79	-1.26
Leaf N uptake					
P-ET	0.24	0.41	0.18	0.40	0.20
ET-PI	0.42	0.94	0.98	1.70	1.10
PI-H	0.37	1.02	1.75	0.79	1.83
H-M	-0.38	-0.84	-0.90	-0.91	-1.06
Total N uptake					
P-ET	0.38	0.70	0.32	0.66	0.34
ET-PI	0.92	1.77	1.78	2.71	0.81
PI-H	1.15	2.57	3.70	2.65	4.83
H-M	0.08	0.02	0.22	0.39	-0.83

After heading stage the rate of N uptake in stem and leaf depicted a negative trend in all treatments though the difference between treatments was not definite.

It was interesting to observe the total N uptake rate during H-M stage (Fig.16) during which the highest rate was in N_3 (0.39 to 0.98 kg ha^{-1} day^{-1}) followed by N_2 (0.22 to 0.74 kg ha^{-1} day^{-1}), whereas it was considerably low in other treatments, even with negative values in N_4 treatments. Both increase (upto heading) or decrease (afterwards) was of low magnitude in N_0 in the case of stem and leaf. Similarly the rate of total N uptake was also lowest in N_0 plots throughout the crop growth period.

4.7 Remobilization of N

The difference between N uptake in root, stem or leaf at heading (maximum values) and that at maturity is referred to as 'remobilized N' and is considered as the contribution to grain. The data (Table 48) reveal that the N remobilization was high from leaf than that from stem. The pattern and amount of N remobilized from stem or leaf was inconsistent between treatments. However, the total amount of N remobilized was lowest in N_0 plots (24.5 to 37.18 kg ha^{-1}) and highest in N_4 plots (54.92 to 98.71 kg ha^{-1}) on an average. The total N remobilization was 75.39 kg in N_4 and 30.79 kg in N_0, whereas in other treatments it ranged from 62.92 to 64.26 kg N ha^{-1}.

Table 48. N remobilization from plant parts to the grain (kg ha^{-1}) in rice as influenced by N timings

Seasons	N remobilization to grain from			
	Root	Stem	Leaf	Total
Kharif '94				
N_0	2.20	7.70	14.60	24.50
N_1	3.69	18.20	32.60	54.49
N_2	3.69	28.80	41.90	74.39
N_3	3.58	20.00	37.70	61.28
N_4	3.49	25.60	39.50	68.59
Rabi '94-95				
N_0	1.74	15.50	9.30	26.54
N_1	1.49	23.48	23.30	48.27
N_2	2.73	21.07	19.90	43.70
N_3	3.25	24.15	26.90	54.30
N_4	2.27	22.55	30.10	54.92
Kharif '95				
N_0	3.33	19.85	14.00	37.18
N_1	3.73	33.42	42.10	79.25
N_2	3.74	29.45	35.50	68.69
N_3	4.84	29.10	27.80	61.74
N_4	3.61	31.83	43.90	79.34
Rabi '95-96				
N_0	1.05	18.06	15.83	34.94
N_1	1.61	32.93	35.12	69.66
N_2	1.72	30.85	37.67	70.24
N_3	2.40	33.01	38.10	73.51
N_4	1.12	52.93	44.66	98.71

4.8 N-15 studies

Studies on uptake and recovery of ^{15}N labelled urea was conducted in *kharif* '94 only.

4.8.1 Uptake of total N and fertilizer ^{15}N in plant

Both total N and fertilizer ^{15}N uptake in the plants at heading and at maturity were found to considerably vary with green manures and N timings (Table 49).

At heading stage, total N uptake was lowest in non-green manure plots (102.5 kg ha^{-1}). Among green manures, parthenium (G_3) gave the lowest N uptake value. A similar trend was observed at maturity also. However, the difference between G_1 and G_2 was narrow.

Among N timings, higher but comparable uptake values with N_2 and N_3 was obtained both at H and at M, compared to other two N timings.

Uptake of ^{15}N

Accumulation of ^{15}N in plant at H was highest in sesbania (49.7 kg ha^{-1}) and lowest in non-green manure plot (42.1 kg). Incorporation of sesbania (G_1) or cowpea (G_2) significantly (significance decided as suggested by Beverly and Hallmark, 1992) increased ^{15}N uptake from fertilizer (18 and 14%

respectively) over control plots. However, at M there was not much difference between these green manure treatments.

Significant effect of N timings on ^{15}N uptake could be observed both at heading and maturity though the trend of influence was slightly different with the stages. At H lower ^{15}N uptake was observed in N_1 (41.0 kg ha^{-1}) and N_1 (43.8 kg ha^{-1}) as against 51.1 kg ha^{-1} and 48.9 kg ha^{-1} in N_4 and N_2, respectively.

At maturity highest ^{15}N uptake was observed in N_2 (53.1 kg) followed by N_3 (50.3 kg). Substantially low ^{15}N uptake was obtained in N_1 and N_4 (39.1 vs 33.9 kg ha^{-1} respectively) at this stage. The increase in ^{15}N uptake at maturity in N_2 was by 35.8 and 56.6 per cent and 28.6 and 48.4 per cent in N_3 respectively over N_1 and N_4. There was no difference in the trend of ^{15}N uptake between straw and grain.

Time course change in total N and fertilizer ^{15}N uptake

Total N in plant tended to increase from heading to maturity (Fig.19). The increase was more pronounced for N timings than for green manures. The increase was substantial in N_2 and N_3 (from 122.6 to 141.0 kg in N_2 and from 115.4 to 147.7 kg in N_3). After H stage, fertilizer ^{15}N was found declining in N_1 and N_4, and it was rapid in the latter one. On the contrary, in N_2 and N_3 timings which received ^{15}N at H stage also, showed an increase in ^{15}N uptake at maturity.

Table 49. Total N (soil N + fertiliser - N) and fertilizer ^{15}N uptake of rice as influenced by green manures and timings of fertilizer ^{15}N application

Treatments	Total N (kg ha^{-1})					Fertilizer - ^{15}N (kg ha^{-1})				
	Heading (whole plant)	Maturity				Heading (whole plant)	Maturity			
		Root	Straw	Grain	Total		Root	Straw	Grain	Total
Green manures										
G_0	102.5	9.8	50.4	60.5	120.7	42.1	3.31	16.9	22.4	42.6
G_1	121.1	9.9	51.4	70.7	132.0	49.7	3.33	17.3	26.0	46.6
G_2	116.7	9.8	50.5	70.9	131.2	47.9	3.29	17.0	26.0	46.3
G_3	110.3	10.0	49.0	68.5	127.5	45.3	3.36	16.5	21.2	41.0
N timings										
N_1	104.2	9.6	37.1	63.3	110.0	41.0	3.40	13.1	22.7	39.1
N_2	122.6	10.2	58.7	72.1	141.0	48.9	3.75	21.6	27.8	53.1
N_3	115.4	10.0	62.5	74.5	147.0	43.8	3.34	20.9	26.1	50.3
N_4	108.3	9.8	43.0	60.7	113.5	51.1	2.79	12.2	18.9	33.9

4.8.2 Recovery of ^{15}N

Estimates of ^{15}N recovery in the plant from applied ^{15}N urea (Table 50) did not reveal significant influence of green manures over non-green manure at maturity. However at H, increased ^{15}N recovery of 7.7 per cent was observed in sesbania (G_1) treated plots over control plot (G_0).

The ^{15}N recovery both at H and M was very much influenced by N timings, though the trend of influence was somewhat different with stages. Both at H and M, the highest recovery was in N_2 (48.9% vs 35.46%). The lowest recovery at heading was in N_1 timing (27.3%), but at maturity it was in N_4 (22.57%). The difference between N_2 and N_3 on ^{15}N recovery by the plant at maturity was very small, but were considerably higher than other N timings. The ^{15}N recovery by the plant decreased as it approached maturity (Fig.18), the decrease being drastic in N_4 (34.10 to 22.57%). The trend of influence by N timings was similar in straw also.

4.8.3 Soil ^{15}N recovery and unrecovered ^{15}N

The data on soil ^{15}N recovery (Table 50) show that considerable amount of applied ^{15}N - labelled urea remained in the soil after harvest of the rice crop. It ranged from 20.30 per cent to 30.70 per cent in parthenium (G_3) and sesbania (G_1) incorporated soil respectively. The ^{15}N recovery in soil was influenced by N timing also. The residual ^{15}N found in soil was

Table 50. Recovery of fertilizer ^{15}N (percentage of ^{15}N applied) in soil-plant (rice) system

Treatments	Rice-heading stage (whole plant)	Rice-maturity stage				Post harvest soil ^{15}N	Unrecovered ^{15}N
		Root	Straw	Grain	Total plant		
Green manures							
G_0	32.10	2.21	11.29	14.33	27.83	28.30	43.87
G_1	39.80	2.22	11.53	16.60	30.35	30.70	38.95
G_2	38.60	2.20	11.32	16.60	30.12	27.40	42.48
G_3	36.40	2.24	10.96	16.10	29.30	20.30	50.40
N timings							
N_1	27.30	2.27	8.71	15.10	26.08	18.70	55.22
N_2	48.90	2.50	14.36	18.60	35.46	26.00	38.54
N_3	35.10	2.23	13.90	17.40	33.53	34.90	31.57
N_4	34.10	1.86	8.11	12.60	22.57	27.10	50.33

highest in N_3 timing (34.90%) and it was lowest in N_1 (18.70%). The ^{15}N balance in soil under N_2 and N_4 treatments were almost similar (26.00 vs 27.10%).

Both green manures and N timings influenced the unrecovered ^{15}N. It was highest in G_3 (50.40%) and lowest in G_1 (38.95%). In G_2 and G_0 it was identical (around 43%). Regarding N timings, the unrecovered ^{15}N was highest in N_1 (55.22%) followed by N_4 (50.33%) whereas in N_2 and N_3 it was substantially low.

4.9 Uptake of P and K by crop

The P and K uptake by the plant estimated at maturity are given in Table 51.

The beneficial effect of green manures on P uptake was significant in *kharif* '95 only. Uptake of P in G_0 was significantly lower (18.2 kg) compared to green manured plots (20.4 to 21.8 kg). Between green manures there was no difference in uptake by crop.

Uptake of P and K was significantly influenced by N timings in all the seasons of study. Significantly highest K uptake was obtained in N_3 during the first year, while it was at par with N_2 in the second year. In the case of K uptake also N_3 registered its superiority, nevertheless at par with N_2 or N_4

Table 51. Total P and K uptake (kg ha^{-1}) at maturity of rice as influenced by green manures and N timings

Treatments	P uptake (kg ha^{-1})				K uptake (kg ha^{-1})			
	K 94	R 94	K 95	R 95	K 94	R 94	K 95	R 95
Green manures								
G_0	19.2	12.4	18.2	12.5	193	118	177	120
G_1	20.3	12.4	21.8	13.3	195	122	195	128
G_2	20.2	12.8	21.1	13.1	203	122	193	131
G_3	19.7	13.1	20.4	13.5	194	123	189	131
$S\bar{d}$	0.62	0.91	1.19	0.95	5.2	2.6	8.2	6.2
CD (0.05)	NS	NS	2.90	NS	NS	NS	NS	NS
N timings								
N_0	13.4	8.3	15.5	9.5	131	74	140	95
N_1	19.8	11.9	20.2	12.3	193	109	192	115
N_2	21.8	13.9	22.6	15.1	215	135	193	140
N_3	23.7	16.1	24.1	17.4	240	142	214	152
N_4	20.7	13.1	19.5	11.2	210	137	203	135
$S\bar{d}$	0.47	0.88	1.76	1.18	5.9	4.7	5.5	5.3
CD (0.05)	0.95	1.80	3.60	2.40	12.0	9.5	11.3	10.8

K = kharif R = rabi

and the difference between these three treatments was not wide over the seasons.

The interaction effect between green manures and N timings (Table 52) was significant for P uptake in *kharif* '95. The highest P uptake (25.8 kg ha^{-1}) was observed in G_1N_3 combination, superior to all other combinations. At N_2, N_3 and N_4 timings the performance of G_0 was significantly lower in sesbania (G_1) and cowpea (G_2) while parthenium (G_3) did not differ conspicuously from other green manures or non-green manure.

Table 52. Total P uptake (kg ha^{-1}) at maturity of rice as influenced by the interaction between green manures and N timings - *kharif* '95

N timings	Green manures				
	G_0	G_1	G_2	G_3	Mean
N_0	13.9	16.6	16.1	15.1	15.4
N_1	18.1	21.6	21.0	20.3	20.3
N_2	20.2	24.2	23.5	22.7	22.7
N_3	21.6	25.8	25.0	24.2	24.2
N_4	17.4	20.9	20.2	19.6	19.5
Mean	18.2	21.8	21.2	20.4	

For comparison between		$\bar{Sd}$	CD(P=0.05)
Sub plot means at the same main plot	:	1.73	4.20
Main plot means at the same or different sub plot	:	1.53	3.70

4.10 Yield components

The summary of data collected on various yield attributes are given in Tables 53 to 56.

On comparison between *kharif* and *rabi* seasons, it could be observed that the number of panicles m^{-2} was substantially lower in *rabi* than *kharif* season, the average number of panicle being 573-580 m^{-2} *kharif* and 402-478 in *rabi*. The number of filled grains was also less in *rabi* seasons compared to *kharif* seasons. But in the case of unfilled spikelets and length of panicle a reverse trend was noticed. With regard to panicle weight and 1000 grain weight such a difference between seasons was not observed.

Effect of green manures

Incorporation of green manures resulted in significant variation in the number of panicles m^{-2}, weight of panicle and number of filled grains per panicles in *kharif* '95. In other seasons the influence was not significant although the number and quality of panicles in non-green manure plots were generally poor than green manured plots.

In *kharif* '95 the significantly more number of panicles were observed in cowpea plots (613 m^{-2}) which was at par with other green manures. All green manures produced significantly more panicles compared to G_0 (513 m^{-2}). While considering the panicle weight, incorporation of sesbania (G_1) favourably influenced the panicle weight (1.77 g) which was superior to all other treatments. Similar trend was observed in the number of filled grains also, producing maximum grains in G_1 (73) significantly superior to other treatments. The second rank was held by G_3 which was significantly superior to G_0 but at par with G_2. However G_2 was at par with G_0.

Effect of N timings

All the yield components studied were substantially influenced by N timings across the seasons. Number of panicles per m^{-2} was always highest in N_3 timing (708 to 712 in *kharif* and 480 to 574 in *rabi*) followed by N_2 with 635 to 650 panicles in *kharif* and 465 to 525 in *rabi*) both significantly different except in *rabi* '95-96 and superior to other treatments in all seasons. In N_3 timing, it was found that the number of panicles got increased around 32 per cent over N_1 or N_4 in *kharif* season; and in *rabi* it was by 23 per cent over N_1 and 18 to 33 per cent over N_4. The difference between N_1 and N_4 was inconsistent over the seasons. Unfertilized crop invariably produced lowest number of panicles m^{-2}. The trend was almost similar with respect to the panicle qualities also, except with the percentage of unfilled grains. With regard to the percentage of unfilled grains in a panicle, it was invariably more in N_4 timing (35-42%), while the difference between other treatments including N_0 did not vary

Table 53. **Yield attributes of rice as influenced by green manures and N timings - *kharif* '94 and *rabi* '94-95**

Treatments	Kharif '94				Rabi '94-95			
	Pm^{-2}	FG	US%	1000 grain wt. (g)	Pm^{-2}	FG	US%	1000 grain wt. (g)
Green manures								
G_0	541	80	26	20.6	467	71	26	20.0
G_1	581	85	26	20.1	493	75	28	20.2
G_2	601	86	26	20.1	479	76	27	20.1
G_3	567	87	26	19.9	471	72	30	19.9
$S\bar{d}$	29	3.1	2.5	0.52	21	2.8	3.1	0.32
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
N timings								
N_0	462	75	19	19.9	335	62	24	18.9
N_1	536	83	28	20.1	468	71	32	20.2
N_2	635	88	24	20.2	525	79	24	20.6
N_3	708	97	24	20.1	574	85	21	21.4
N_4	521	79	35	19.8	487	69	39	19.1
$S\bar{d}$	29	2.5	2.0	0.63	14	1.5	1.1	0.25
CD (P=0.05)	60	5.2	4.1	NS	29	3.1	2.2	0.51

Pm^{-2} = number of panicles m^{-2}; FG = number of filled grains $panicle^{-1}$; US% = percentage of unfilled grains $panicle^{-1}$

Table 54. Yield attributes of rice as influenced by green manures and N timings - *kharif* '95 and *rabi* '95-96

Treatments	Kharif '95				Rabi '95-96			
	Pm^{-2}	FG	US%	1000 grain wt. (g)	Pm^{-2}	FG	US%	1000 grain wt.(g)
Green manures								
G_0	513	65	29	20.7	390	61	31	18.9
G_1	612	73	30	20.4	410	64	32	19.5
G_2	613	67	27	20.3	412	63	33	19.2
G_3	589	68	30	20.6	395	65	32	18.9
$S\bar{d}$	12	1.0	1.8	0.21	10	1.8	2.5	0.39
CD (P=0.05)	30	2.4	NS	NS	NS	NS	NS	NS
N timings								
N_0	457	60	25	20.0	310	60	24	18.5
N_1	542	67	31	21.0	395	62	32	20.1
N_2	650	74	25	21.0	465	65	23	20.9
N_3	712	77	26	21.0	480	70	21	21.2
N_4	546	63	37	20.0	360	60	42	19.8
$S\bar{d}$	16	1.9	1.6	0.17	9	1.2	2.0	0.25
CD (P=0.05)	32	3.9	3.2	0.35	19	2.5	4.1	0.52

Table 55. Panicle length (cm) and weight (g) as influenced by green manures and N timings - *kharif* '94 and *rabi* '94-95

Treatments	Kharif '94		Rabi '94	
	Length (cm) panicle^{-1}	Weight (g) panicle^{-1}	Length (cm) panicle^{-1}	Weight (g) panicle^{-1}
Green manures				
G_0	17.95	1.59	19.65	1.52
G_1	18.21	1.72	21.25	1.73
G_2	18.26	1.69	21.95	1.71
G_3	18.39	1.74	21.42	1.72
$S\bar{d}$	0.35	0.08	1.02	0.96
CD (P=0.05)	NS	NS	NS	NS
N timings				
N_0	16.85	1.42	18.00	1.32
N_1	17.23	1.67	20.25	1.59
N_2	18.95	1.82	22.85	1.90
N_3	19.73	1.95	23.96	1.93
N_4	18.25	1.56	20.28	1.61
$S\bar{d}$	0.30	0.05	0.38	0.08
CD (0.05)	0.61	0.11	0.78	0.17

Table 56. Panicle length (cm) and weight (g) as influenced by green manures and N timings - *kharif* '95 and *rabi* '95-96

Treatments	Kharif '95		Rabi '95	
	Length (cm) panicle^{-1}	Weight (g) panicle^{-1}	Length (cm) panicle^{-1}	Weight (g) panicle^{-1}
Green manures				
G_0	18.30	1.55	20.86	1.58
G_1	19.09	1.77	22.54	1.61
G_2	19.27	1.61	22.00	1.61
G_3	18.59	1.62	20.62	1.63
$S\bar{d}$	0.61	0.03	0.95	0.15
CD (P=0.05)	NS	0.07	NS	NS
N timings				
N_0	17.54	1.45	19.60	1.28
N_1	18.92	1.60	21.30	1.52
N_2	19.18	1.72	22.40	1.80
N_3	19.73	1.84	23.20	1.95
N_4	18.67	1.59	21.10	1.49
$S\bar{d}$	0.28	0.25	0.45	0.06
CD (P=0.05)	0.58	0.10	0.91	0.12

significantly, but definitely low (19-32%) in N_0 plots over the seasons.

Interaction effect

In *kharif* '95 alone, the interaction effect of green manures and N timings could be observed on number of panicles (Table 57) length of panicle (Table 58) weight of panicle (Table 59) and filled grains (Table 60).

Highest number of panicles m^{-2} was resulted by the interaction effect of G_1N_3 (749). Such a promotery effect on this yield component was also seen with G_2 or G_1 under N_3 timing. In general, G_1 and G_2 influenced the panicle production favourably compared to other green manures and non green manure at any N timings. Evidently lowest p m^{-2} (403) was observed in G_0N_0.

The perusal of data on the interaction effect of treatments on length of panicle (Table 58) revealed a similar trend. However, the effect of green manure at N timings was not consistent.

Again, interaction between G_1 and N_3 profoundly enhanced the weight of panicle (2.08 g). All other combinations resulted in significantly lower panicle weight.

Table 57. Number of panicles m^{-2} as influenced by the interaction between green manures and N timings - *kharif* '95

N timings	Green manures				
	G_0	G_1	G_2	G_3	Mean
N_0	403	481	482	463	457
N_1	478	570	572	549	542
N_2	573	683	685	658	650
N_3	628	749	751	721	712
N_4	481	574	575	553	546
Mean	513	611	613	589	

For comparison between		$S\bar{d}$	CD(P=0.05)
Subplot means at the same main plot	:	22	52
Main plot means at the same or different subplots	:	27	62

Table 58. Length of panicle (cm) as influenced by the interaction between green manures and N timings - *kharif* '95

N timings	Green manures				
	G_0	G_1	G_2	G_3	Mean
N_0	16.40	18.10	18.20	17.47	17.54
N_1	18.54	19.33	18.87	18.96	18.93
N_2	19.37	18.47	19.60	19.30	19.19
N_3	19.50	19.67	20.50	19.27	19.74
N_4	17.67	19.87	19.20	17.93	18.67
Mean	18.30	19.09	19.27	18.59	

For comparison between		$S\bar{d}$	CD(P=0.05)
Subplot means at the same main plot	:	0.22	0.53
Main plot means at the same or different subplots	:	0.37	0.89

Table 59. **Weight of panicle (g) as influenced by the interaction between green manures and N timings - *kharif* '95**

N timings	Green manures				
	G_0	G_1	G_2	G_3	Mean
N_0	1.30	1.73	1.47	1.30	1.45
N_1	1.60	1.61	1.44	1.74	1.60
N_2	1.67	1.75	1.81	1.63	1.72
N_3	1.69	2.08	1.72	1.86	1.84
N_4	1.49	1.69	1.60	1.59	1.59
Mean	1.55	1.77	1.61	1.62	

For comparison between	$S\bar{d}$	CD(P=0.05)
Subplot means at the same main plot	: 0.06	0.14
Main plot means at the same or different subplots	: 0.07	0.15

Table 60. **Number of filled grains panicle^{-1} as influenced by the interaction between green manures and N timings - *kharif* '95**

N timings	Green manures				
	G_0	G_1	G_2	G_3	Mean
N_0	56	64	59	60	60
N_1	64	71	66	66	67
N_2	70	79	72	75	74
N_3	73	82	75	78	77
N_4	60	67	62	62	63
Mean	65	73	67	68	

For comparison between	$S\bar{d}$	CD(P=0.05)
Subplot means at the same main plot	: 3.2	7.7
Main plot means at the same or different subplots	: 3.1	7.3

The filled grains per panicle failed to respond to the interaction effect of green manures at N_1 and N_4 timings. Clear advantage of G_2 combined with N_3 or N_2 timings was evident with higher number of filled grains (82 and 79 respectively). The combination of G_3N_3 was also equally effective. The effect of *green manures over non-green manure* was evident from significantly higher number of panicles with better qualities in green manured plots.

4.11 Grain and straw yield

The data on grain and straw yield over the seasons are presented in Table 61 and 66, respectively. The grain yield over the seasons are depicted in Fig.20.

Effect of green manures

The influence of green manures on grain yield was evident only in the second *kharif* season ('95). Incorporation of sesbania (G_1) significantly increased grain yield (6.39 t ha^{-1}) over all other treatments. The grain yield with other green manures viz. cowpea (G_2) and parthenium (G_3) though significantly lower than G_1, they produced significantly higher grain yields (6.08 and 6.04 t ha^{-1}) compared to non-green manure plot (5.73 t ha^{-1}).

The yield reduction due to non-green manuring (G_0) treatments ranged from 5 to 10 per cent. In other seasons also the yield in non-green manure plot G_0 was lowest though not significantly differed from green manured plots. A similar influence was observed on straw yield also.

Effect of N timings

Application of N significantly increased the grain yield over control plots. Similarly, the strategy of N timing also resulted in significant variation in grain yield over seasons.

The treatment N_3 (150 kg N in six splits from planting upto heading) resulted in the highest grain yield followed by N_2, (50 kg N ha^{-1} each at ET, PI and H stages) both significantly different except in the first season; and superior to other treatments over all seasons. The yield with N_1 (75 kg N ha^{-1} at P and 37.5 kg N ha^{-1} each at MT and PI stages) and N_4 (50 kg N ha^{-1} at ET and 100 kg N ha^{-1} at PI stage) was always lower than N_3 and N_2 but higher than N_0 plot. An yield increase of 15 to 33 per cent over N_4 and N_1 was observed in N_3, while in N_2 it ranged from 11 to 28 per cent. The yield reduction in N_0 ranged from 37 to 45 per cent over N_3 and 34 to 38 per cent over N_2 over the seasons.

With regard to straw yield (Table 66) as influenced by N timings, no clear variation could be observed between N_2, N_3 or N_4. As in the case of grain, straw yield was always lowest in unfertilized plot.

Table 61. Grain yield of rice (t ha^{-1}) as influenced by green manures and N timings

Treatments	Kharif '94	Rabi '94-95	Kharif '95	Rabi '95-96
Green manures				
G_0	5.29	4.11	5.73	4.47
G_1	5.65	4.19	6.39	4.69
G_2	5.65	4.22	6.08	4.71
G_3	5.45	4.48	6.04	4.62
$S\bar{d}$	0.21	0.25	0.09	0.17
CD (P=0.05)	NS	NS	0.21	NS
N timings				
N_0	3.91	3.04	4.69	3.24
N_1	5.54	4.09	5.90	4.46
N_2	6.17	4.67	7.11	5.20
N_3	6.40	5.37	7.39	5.84
N_4	5.55	4.09	5.21	4.38
$S\bar{d}$	0.19	0.20	0.10	0.13
CD (P=0.05)	0.39	0.41	0.20	0.27

Interaction effect

Significant influence of the interaction effect between green manures and N timings on grain field could be observed in *kharif* '95, whereas in other seasons the interaction effects were not significant.

In *kharif* '95 (Table 64) maximum grain yield (8.48 t ha^{-1}) was obtained in N_3 timing (six splits) applied with sesbania (G_1) and it was significantly superior to all other combinations. The performance of green manures varied with N timings. At N_1 timing, parthenium (G_3) recorded the highest yield (6.44 t ha^{-1}) which was significantly superior to G_0, G_1 and G_2. Sesbania (G_1) was superior to G_0 but did not differ from G_2. At N_2 and N_3 timings, G_1 recorded significantly higher grain yield compared to other green manure treatments. In unfertilized plots (N_0), the yield in non-green manure treatments (G_0) was significantly lower than green manure applied plots.

Though the effect of interaction between green manures and N timings was not significant in other seasons, comparatively higher grain yield was observed with the combinations of green manures with N_2 (50 kg N ha^{-1} each at ET, PI and H stages) and N_3 (six splits) timings. Similarly the performance of all green manures was better than non-green manure even in N_0 plots. In *kharif* '94 (Table 62) maximum grain yield was with N_3 timing by cowpea (G_2) incorporation (6.82 t ha^{-1}) followed by sesbania

(G_1) incorporation (6.59 t ha^{-1}). The performance of N_2 was better with sesbania (6.70 t ha^{-1}) followed by parthenium (6.15 t ha^{-1}) and cowpea (6.10 t ha^{-1}). In non-green manure plots much a definite trend could not be observed.

In *rabi* '94-95 (Table 63) the green manure treatments performed better with N_3 timings, whereas such an effect could not be observed with N_2 timings. The maximum grain yield was with G_3N_3 combination (5.80 t ha^{-1}) followed by G_1N_3 combination (5.47 t ha^{-1}). Unlike in *rabi* '94-95, in the subsequent *rabi* season (Table 65) both N_2 and N_3 timings performed better under different green manure treatments than other N timings.

Harvest index

The ratio of grain yield to the biological yield (Harvest Index: HI) (Table 67) was not influenced by green manure treatments in any season. With regard to the N timing treatments, generally a low HI in N_4 (0.46 to 0.48 over the seasons) could be observed. Between other N timing treatments the values (ranging from 0.49 to 0.59 over the seasons) did not differ appreciably in any season.

4.12 Relationship between N concentration, N uptake, yield and yield components

The linear relationship of panicle characteristics with yield, total N uptake and leaf and stem N concentrations were

Table 62. Grain yield of rice (t ha^{-1}) as influenced by the interaction between green manures and N timings - *kharif* '94

N timings	Green manures				
	G_0	G_1	G_2	G_3	Mean
N_0	3.52	3.71	4.14	4.27	3.91
N_1	5.46	5.86	5.55	5.28	5.54
N_2	5.72	6.70	6.10	6.15	6.17
N_3	5.92	6.59	6.82	6.27	6.40
N_4	5.82	5.40	5.66	5.30	5.55
Mean	5.29	5.65	5.65	5.45	

For comparison between	$S\bar{d}$	CD(P=0.05)
Subplot means at the same main plot	0.59	NS
Main plot means at the same or different sub plots	1.91	NS

Table 63. Grain yield of rice (t ha^{-1}) as influenced by the interaction between green manures and N timings - *rabi* '94-95

N timings	Green manures				
	G_0	G_1	G_2	G_3	Mean
N_0	2.98	2.83	2.93	3.40	3.04
N_1	3.56	4.52	4.04	4.25	4.09
N_2	4.90	4.35	4.90	4.51	4.67
N_3	4.96	5.47	5.27	5.80	5.37
N_4	4.17	3.78	3.96	4.43	4.09
Mean	4.11	4.19	4.22	4.48	

For comparison between	$S\bar{d}$	CD(P=0.05)
Subplot means at the same main plot	0.53	NS
Main plot means at the same or different sub plots	1.62	NS

Table 64. Grain yield of rice (t ha^{-1}) as influenced by the interaction between green manures and N timings - *kharif* '95

N timings	Green manures (G)				
	G_0	G_1	G_2	G_3	Mean
N_0	3.70	5.35	5.20	4.52	4.69
N_1	5.51	5.98	5.66	6.44	5.90
N_2	7.16	7.47	6.80	7.01	7.11
N_3	7.31	8.48	6.86	6.91	7.39
N_4	4.96	4.68	5.86	5.33	5.21
Mean	5.73	6.39	6.08	6.04	

For comparison between	$S\bar{d}$	CD (P=0.05)
Subplot means at the same main plot	: 0.17	0.40
Main plot means at the same or different subplots	: 0.18	0.41

Table 65. Grain yield of rice (t ha^{-1}) as influenced by the interaction between green manures and N timings - *rabi* '95-96

N timings	Green manures				
	G_0	G_1	G_2	G_3	Mean
N_0	3.13	3.29	3.30	3.24	3.24
N_1	4.31	4.52	4.54	4.46	4.46
N_2	5.03	5.27	5.30	5.20	5.20
N_3	5.65	5.92	5.95	5.83	5.84
N_4	4.23	4.44	4.46	4.38	4.38
Mean	4.47	4.69	4.71	4.62	

For comparison between	$S\bar{d}$	CD (P=0.05)
Subplot means at the same main plot	0.35	NS
Main plot means at the same or different sub plots	1.45	NS

Table 66. **Straw yield of rice (t ha^{-1}) as influenced by green manures and N timings**

Treatments	Kharif '94	Rabi '94-95	Kharif '95	Rabi '95-96
Green manures				
G_0	5.75	4.15	4.66	4.32
G_1	5.88	4.29	5.10	4.45
G_2	5.84	4.30	5.07	4.60
G_3	5.91	4.24	5.02	4.48
$S\bar{d}$	0.28	0.19	0.17	0.21
CD (P=0.05)	NS	NS	0.41	NS
N timings				
N_0	3.93	2.55	3.65	2.58
N_1	5.67	3.77	5.11	4.27
N_2	6.35	4.81	5.02	5.05
N_3	6.73	5.22	5.50	5.17
N_4	6.55	4.88	5.53	5.21
$S\bar{d}$	0.21	0.25	0.19	0.15
CD (P=0.05)	0.42	0.51	0.38	0.31

Table 67. Harvest index of rice as influenced by green manures and N timings

Treatments	Kharif '94	Rabi '94-95	Kharif '95	Rabi '95-96
Green manures				
G_0	0.48	0.50	0.55	0.50
G_1	0.49	0.49	0.56	0.51
G_2	0.49	0.50	0.55	0.51
G_3	0.48	0.51	0.55	0.51
$S\bar{d}$	0.04	0.03	0.04	0.03
CD (P=0.05)	NS	NS	NS	NS
N timings				
N_0	0.49	0.54	0.56	0.56
N_1	0.49	0.52	0.54	0.51
N_2	0.49	0.49	0.59	0.51
N_3	0.49	0.51	0.57	0.53
N_4	0.46	0.46	0.48	0.46
$S\bar{d}$	0.02	0.02	0.03	0.02
CD (P=0.05)	0.05	0.04	0.06	0.03

worked out; and the correlation values ('r') are given in Table 68.

The grain yield had high significant correlation with total tillers, number of panicles and their length and weight and the number of filled grains per panicle with 'r' values ranging from 0.70 to 0.90. The relationships of number of filled grains (r=0.90) and panicle weight (r=0.84) with yield was more stronger than that with other parameters. The total N uptake in plant at maturity was found to be significantly related with yield attributes.

The leaf N concentration at PI stage influenced the panicle characteristics significantly but not the total tillers or number of panicles. However, leaf N concentration at heading had considerable relationship with total tiller (r=0.49), panicle length (r=0.53) and panicle weight (r=0.43) but not with number of panicles or number of filled grains.

The relationship of stem N concentration at PI stage was more strong with panicle length (r=0.63) and panicle weight (r=0.62) than with other parameters, though the relationship was significant and positive. The panicle weight or filled grain number was not related with stem N concentration at H, but other parameters were related. Stem N concentration at mid maturity had significant relationship with tiller number and panicle characteristics. Leaf N concentration at maturity was having

Table 68. Co-efficients of correlation (r) between N uptake, growth parameters, yield components and the yield of rice

		Plant height	Total tillers $hill^{-1}$	Panicle m^{-2}	Panicle length	Panicle weight	Filled grains $panicle^{-1}$	Grain yield
i	Grain yield	0.68**	0.72**	0.77**	0.70**	0.84**	0.90**	-
ii	Total N uptake	0.80**	0.80**	0.79**	0.75**	0.89**	0.83**	0.84**
iii	Stem N concn. PI	0.54**	0.51*	0.47*	0.63**	0.62**	0.51*	0.68**
iv	Leaf N concn. PI	0.51*	0.26	0.35	0.55**	0.51*	0.44*	0.45*
v	Stem N concn. H	0.37	0.60**	0.50*	0.59*	0.42	0.26	0.65*
vi	Leaf N concn. H	0.49**	0.49**	0.31	0.53*	0.43*	0.23	0.45*
vii	Stem N concn. MM	0.58**	0.67**	0.49*	0.48*	0.60**	0.47*	0.20
viii	Leaf N concn. MM	0.47*	0.66**	0.51*	0.40	0.53*	0.42	0.78**

* Significant at P (0.05)
* Significant at P (0.01)

better relationship with total tillers, number of panicles and panicle weight but not with panicle length or number of filled grains.

Total N uptake in the plant had strong relationship with grain yield (r=0.84). Similarly the leaf N concentration at mid maturity stage significantly correlated with grain yield (r=0.78) whereas leaf N concentration at PI and heading (r=0.45) had comparatively less strong relationship. Stem N concentration at PI stage was having better relationship with yield (r=0.68) than by stem N concentration at heading (r=0.65). Mid maturity stage stem N concentration was having only very poor relationship with yield.

The N uptake at maturity was regressed linearly with grain yield and panicle characteristics; and the regression equations developed are given in Table 69.

Table 69. Linear relationships of N uptake at maturity with panicle characteristics and grain yield of rice

Cause (x)	Effect (y)	Coefficient of correlation (r)	Regression equation
Maturity N uptake	Number of panicles m^{-2}	0.77	y =197.2 + 2.337 x
"	Panicle length (cm)	0.75	y =15.96 + 0.022 x
"	Panicle weight (g)	0.89	y = 9.50 + 0.051 x
"	Grain yield (t ha^{-1})	0.84	y = 2.02 + 0.030 x

4.13 Apparent N recovery (ANR)

Apparent N recovery (ANR) at heading stage was calculated as the percentage recovery of N applied before that stage and is referred to as 'ANRH', and in the same manner, recovery at maturity was also calculated based on total N applied and is referred to as 'ANRM'.

ANR recovery from green manures

Green manure-N recovery was computed only for *kharif* seasons (Table 70) since it was not applied in *rabi* seasons. The difference in N recovery from green manures between heading and maturity stage was inconsistent over the seasons. In both years, highest N recovery was obtained from sesbania (G_1) (24.2 and 38.6%) followed by cowpea (G_2) (19.8 and 23.6%) and the lowest with in G_3 (5.9 and 12.9%). On the other hand, N recovery at maturity was highest in cowpea (10.5%) in *kharif* '94 and from sesbania (39.0%) in *kharif* '95. As at heading, N recovery was lowest in parthenium at maturity also.

ANR from fertilizer

The difference between N timings on N recovery both at heading and at maturity was large (Table 70). At both stages the recovery was considerably more in N_3 or N_2 compared to N_4 and N_1. The N recovery in N_3 and N_2 timings ranged from 40.4 to

64 per cent at heading and 39.2 to 59.1 per cent at maturity, whereas in other treatments it was considerably low. Over the stages heading and maturity, the recovery was almost similar in N_1 timing and inconsistent in N_2 and N_3 timing. But in N_4 there was considerable decrease at maturity over heading stage. Over the seasons, a general decrease in apparent N recovery was observed in *rabi* season compared to *kharif* season both at heading and at maturity.

4.14 N use efficiency

The data on N use efficiency in terms of both agronomic efficiency (AE) and physiological efficiency (PE) as influenced by green manures (in *kharif* only) and N timings are given in Table 71. The grain production efficiency of applied N (AE) was lower than the efficiency of absorbed N by the plant (PE).

Effect of green manures

The AE of applied green manure-N ranged from 3.0 to 12.2 kg grain kg^{-1} N with highest efficiency from sesbania (G_1), followed by cowpea (G_2) and the lowest from parthenium (G_3). The PE of applied green manures varied with seasons with considerably higher values for sesbania in both years over other green manures. Not much difference between cowpea and parthenium was present over years.

Table 70. **Apparent N recovery (percentage of N applied) byrice as influenced by green manures and N timings**

Treatments	K '94		R '94-95		K '95		R '95-96	
	ANRH	ANRM	ANRH	ANRM	ANRH	ANRM	ANRH	ANRM
Green manures								
G_1	24.2	8.4			38.6	39.0		
G_2	19.8	10.5			23.6	36.8		
G_3	12.9	7.4			5.9	29.4		
N timings								
N_1	28.1	28.1	22.3	22.2	44.5	42.3	34.0	32.0
N_2	54.2	40.9	40.4	39.2	63.4	56.4	64.0	46.0
N_3	54.0	49.5	44.6	48.4	47.0	59.1	55.0	55.0
N_4	41.0	33.9	34.3	30.7	47.8	35.4	58.0	32.0

K = kharif R = rabi
ANRH = ANR at heading ANRM = ANR at maturity

Table 71. **Nitrogen use efficiency of rice as influenced by green manures and N timings**

	Agronomic efficiency (kg grain kg^{-1} N)				Physiological efficiency (kg grain kg^{-1} N uptake)			
	K 94	R 94	K 95	R 95	K 94	R 94	K 95	R 95
Green manures								
G_1	6.7		12.2		78.9		31.3	
G_2	6.7		6.5		63.0		17.6	
G_3	3.0		5.7		40.1		19.5	
N timings								
N_1	10.9	7.0	8.1	8.1	38.6	31.5	19.0	25.4
N_2	15.0	10.8	16.1	13.1	36.7	27.5	28.6	28.3
N_3	16.6	15.5	18.0	17.3	33.5	32.1	30.4	31.5
N_4	10.9	6.9	3.4	7.6	32.2	22.6	9.6	23.4

K = kharif R = rabi

Effect of N timings

The trend in AE of different N timing treatments was of similar nature in all seasons with highest efficiency in N_3 timing (15.5 to 18.0 kg) followed by N_2 (10.8 to 16.1 kg), whereas in N_1 and N_4 it was considerably low (3.4 to 10.9 kg). Similarly the physiological efficiency was also highest in N_3 (30.4 to 33.5 kg) except in *kharif* '94 and the second position was held by N_2 (27.5 to 36.7 kg) except in *rabi* '94. Invariably the lowest efficiency was observed in N_4 timing.

4.15 Post-harvest soil analyses

4.15.1 Organic carbon

The organic carbon (OC) content in the post-harvest soil was not influenced by N timings in any season whereas the influence of green manures was evident in *kharif* '95 (Table 72).

In *kharif* '95 parthenium (G_3) incorporation resulted in significantly higher OC content (0.88%) over non-green manure treatments (G_0). However it was on par with cowpea (G_2: 0.85%) and sesbania (G_1:0.83%) which in turn were on par with non-green manure treatment. Invariably, in all seasons lowest OC was observed in non-green manure plots (0.76 to 0.96%).

Table 72. Organic carbon content (%) of post-harvest soil

Treatments	Kharif '94	Rabi '94	Kharif '95	Rabi '95
Greenmanures				
G_0	0.76	0.96	0.78	0.85
G_1	0.85	0.94	0.83	0.99
G_2	0.86	0.99	0.85	1.03
G_3	0.84	0.92	0.88	1.05
$S\bar{d}$	0.06	0.07	0.04	0.09
CD (0.05)	NS	NS	0.09	NS
N timings				
N_0	0.79	0.94	0.84	0.93
N_1	0.82	0.94	0.84	1.02
N_2	0.84	0.95	0.83	0.97
N_3	0.85	0.96	0.83	0.99
N_4	0.84	0.98	0.83	1.01
$S\bar{d}$	0.04	0.06	0.04	0.06
CD (0.05)	NS	NS	NS	NS

4.15.2 Total N and available N

The analyses of soil after the fourth crop (*rabi* '95-96) (Table 73) revealed that the content of both total N and available N got declined with continuous rice cropping without green manuring or N fertilization. Total N was highest in parthenium applied plots (G_3: 2188 kg ha^{-1}) which did not differ significantly from other green manures. In all green manure plots, the total N was significantly higher than that in non-green manure plot. In the case of available N also, the trend was same as that of total N. The available N content in all green manure plots (114 to 129 kg ha^{-1}) were significantly higher than that in non-green manure plot (91 kg ha^{-1}).

The influence of N application on total N and available N was significant over unfertilized treatments. Both total N and available N was lowest in N_0 treatment (1810 kg vs 85 kg) which was significantly lower than N applied treatments. The total N in the post-harvest soil in N timing treatments ranged from 2115 to 2195 kg ha^{-1} and the available N ranged from 115 to 125 kg ha^{-1}.

Build up of N

The effect of green manuring and N fertilizer application is more clear from the data on N build up over the initial status (Table 73). The initial total N content (2040 kg ha^{-1})

Table 73. Soil N content (kg ha^{-1}) after the fourth crop (*rabi* '95-96) and the N build up over initial status

Treatments	Total N (kg ha^{-1})	Build up of toal N (kg ha^{-1})	Available N (kg ha^{-1})	Build up of available N (kg ha^{-1})
Green manures				
G_0	1862	-178	91	-19
G_1	2122	82	118	8
G_2	2158	118	114	4
G_3	2188	148	129	19
$S\bar{d}$	65	-	7	-
CD (P=0.05)	158	-	18	-
N timings				
N_0	1810	-230	85	-25
N_1	2175	135	115	5
N_2	2115	75	118	8
N_3	2120	80	122	12
N_4	2195	155	125	15
$S\bar{d}$	111	-	12	-
CD (P=0.05)	228	-	25	-

Initial status Total N : 2040 kg ha^{-1}
Available N : 110 kg ha^{-1}

got decreased to 1862 kg in G_0 and to 1810 kg in No, resulting in a reduction of 178 kg and 230 kg ha^{-1}, respectively. The build up of total N ranged from 82 to 148 kg ha^{-1} by green manure incorporation and from 75 to 155 kg ha^{-1} by N fertilization over a period of two years. The trend was similar in available N also. The reduction in available N over a period of two years was by 19 kg ha^{-1} in non-green manure plot and by 25 kg in unfertilized plot. The increase due to green manure incorporation ranged from 4 to 19 kg ha^{-1} and from 5 to 15 kg ha^{-1} by N application. The N build up was maximum by parthenium (G_3) incorporation among the green manures and by N_4 timing among the N timing treatments.

4.16 Economics of green mauring and N timings

The net income and B:C ratio of rice cultivation with green manuring and N timings are given in Tables 74 and 75. The details of computations are presented in Appendices V to IX.

The influence of green manures on net income was evident in all seasons. However appreciable increase in net income could be observed only with sesbania in *kharif* '95. The net income was lowest in non-green manure plots (G_0) in all seasons; and highest in sesbania incorporated plots (G_1) in *kharif* seasons (Rs.17417/- in *kharif* '94 and Rs.20434/- in *kharif* '95). In *rabi* '94-95 highest net income was obtained by parthenium

(Rs.12354/-) and in *rabi* '95-96 from cowpea plots (Rs.13540/-). In general, the net income was higher in *kharif* seasons compared to *rabi* seasons.

Incorporation of green manures did not change the B:C ratios appreciably, especially in the *kharif* seasons during which it was applied. However, in *kharif* '95 sesbania incorporation gave marginally higher B:C ratio (2.97) over non-green manure treatment (2.89). The same trend has been reflected in the mean B:C ratio for *kharif* seasons as well. In *rabi* seasons the B:C ratio was found to be slightly higher in plots in which green manures were applied (in *kharif* seasons) (2.15 to 2.41) than non-green manure plots (2.11 to 2.29).

The N application strategies greatly influenced the net income as well as B:C ratios. Highest net income was always associated with N_3 timing (Rs.16502/- to Rs.25054/-) followed by N_2 timing (Rs.13202/0 to Rs.23663/- and lowest in unfertilized plot (Rs.6149/- to Rs.13422/-) over the seasons. There was no appreciable difference in the net income between N_1 and N_4 timings but both were lower than N_3 and N_2. In N_3, the net income increased by 32-42 per cent in *kharif* and 55-57 per cent in *rabi* over N_1 and N_4, over the years. In N_2 the corresponding increases were 24-34 per cent in *kharif* and 28 to 30 per cent in

Table 74. Net income and B:C ratio of rice cultivation as influenced by green manures and N timings - *Kharif* seasons

Treatments	Net income (Rs.ha^{-1})			B:C ratio		
	Kharif '94	Kharif '95	Mean	Kharif '94	Kharif '95	Mean
Green manures						
G_0	16604	18146	17375	2.73	2.89	2.81
G_1	17417	20434	18926	2.66	2.97	2.82
G_2	17403	18994	18199	2.67	2.83	2.75
G_3	16670	18959	17815	2.62	2.84	2.73
N timings						
N_0	10012	13422	11717	2.09	2.46	2.28
N_1	16847	18243	17545	2.63	2.77	2.70
N_2	19954	23663	21809	2.93	3.29	3.11
N_3	21091	25054	23073	3.03	3.42	3.23
N_4	17212	15285	16249	2.67	2.48	2.58

Table 75. **Net income and B:C ratio of rice cultivation as influenced by green manures and N timings - *Rabi* seasons**

Treatments	Net income (Rs.ha^{-1})			B:C ratio		
	Rabi '94-95	Rabi '95-96	Mean	Rabi '94-95	Rabi '95-96	Mean
Green manures						
G_0	10680	12347	11514	2.11	2.29	2.20
G_1	11079	13381	12230	2.15	2.40	2.28
G_2	11222	13540	12381	2.17	2.41	2.29
G_3	12354	13096	12725	2.29	2.37	2.33
N timings						
N_0	6149	7083	6616	1.72	1.83	1.78
N_1	10217	12053	11135	2.05	2.24	2.15
N_2	13202	15707	14455	2.36	2.62	2.49
N_3	16502	18563	17533	2.69	2.90	2.80
N_4	10600	12049	11325	2.09	2.24	2.17

rabi. The B:C ratio also followed the similar trend with the highest value in N_3, followed by N_2.

The favourable effect of combination of N_3 or N_2 timings with green manures was evident in all seasons. In *kharif* '94, the combination of N_3 timing with cowpea (G_2 N_3) gave the highest net income and B:C ratio followed by G_1N_2 combination whereas in the subsequent *kharif* season these parameters were highest in G_1N_3 combination (Rs.29770/- and 3.80) (Appendix-VIII). In *rabi* seasons also combination of N_3 with parthenium (G_3) (*rabi* '94-95) or cowpea (*rabi* '95-96) gave the highest net income and B:C ratio.

DISCUSSION

Chapter V

DISCUSSION

The present investigation was undertaken to study the effects of green manures and N application strategies on N assimilation and yield of lowland rice. The salient findings obtained from the investigation are discussed in this chapter.

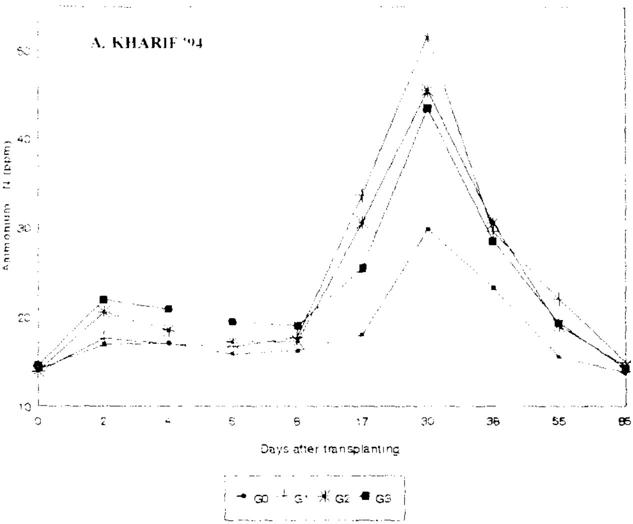
5.1 Ammonium (NH_4^+-N) release pattern

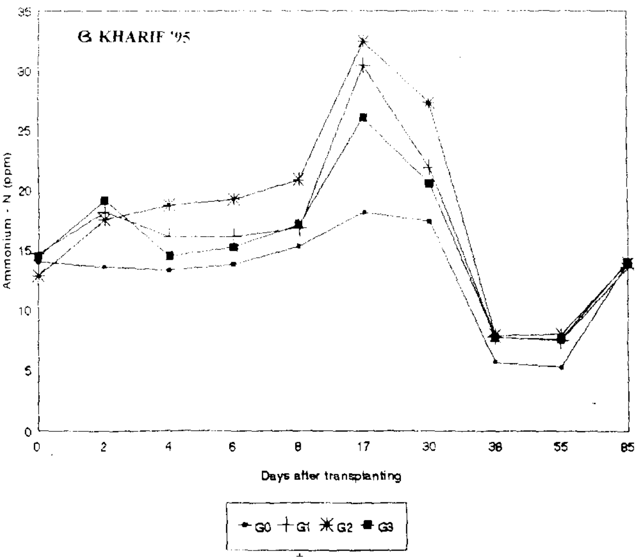
Green manure must undergo mineralization before its N becomes available to the crops. Microbial decomposition constitutes the major process of N release from organic materials into the soil for absorption by plants. During decomposition of green manures, carbon is returned to the atmosphere as CO_2, while organic-N is converted into NH_4^+-N and NO_3^--N through the process of mineralization.

The time course behaviour of NH_4^+-N release from green manures (Tables 20 to 22; Fig.3) shows that the soil NH_4^+-N content gradually increased with time after rice planting, reaching a peak between the second and fourth week and declined thereafter. The gradual increase in soil NH_4^+-N content in the initial stages may be probably due to the gradual decline in C:N ratio due to the release of CO_2 (Palm *et al.*, 1988) and the later decline may be due to the crop uptake (Roechan and

Makarim, 1994) and loss of released N by different soil loss mechanisms (Bharadwaj and Dev, 1985; and Singh *et al.*, 1992).

It was noted that even in non-green manure plots the NH_4^+-N content in soil increased with time with a peak between the second and fourth week as that in green manures. This might be due to the possible build up of soil organic matter (SOM) that originates primarily from decomposing weeds and rice remains during the preceding summer fallow period and subsequent release of NH_4^+-N on flooding the field (Palm and deSilva, 1987). The low NH_4^+-N content under non-green manure treatments may be probably due to that, SOM was the only source for N mineralization in these plots. In green manure treatments both *SOM and the added green manures contributed to the* NH_4^+*-N* release and hence the higher content, as suggested by Buresh *et al.* (1993a). The high NH_4^+-N content in soil by green manure addition, during tillering stages has reflected in the yield as well. A part of the NH_4^+-N released would have been utilized by the crop. The data in Table 13 reveals the effect of green manure in increasing crop biomass from MT to maturity; and the data in Table 40 shows increased crop N uptake from PI to maturity, in *kharif* '95. This can be attributed to the substantially high soil NH_4^+-N content in the green manured plots during the active vegetative growth stages.


A. KHARIF '94
Ammonium - N (ppm)
Days after transplanting
G0 G1 G2 G3


B. KHARIF '95
Ammonium - N (ppm)
Days after transplanting
G0 G1 G2 G3

Though there existed variation in NH_4^+-N release among green manures, pronounced difference in the soil NH_4^+-N content between different green manures was evident only when the soil NH_4^+-N was at a higher level (between second and fourth week). According to Singh *et al.* (1992) decomposition and N mineralization of green manures are dependent not only on the C:N ratio but the N content also. The C:N ratio of parthenium, cowpea and sesbania were 29, 14 and 11, respectively. Though the C:N ratio of parthenium used was high, the N content (0.75%) was almost equal to sesbania (0.87%) and cowpea (0.61%) (Table 4). Further, from the C:N ratio alone one cannot predict the release of NH_4^+-N from green manures as the quality of the substrate (lignin, polyphenols, cellulose etc.) also affect the metabolic efficiency of the microbial decomposers that determines the NH_4^+-N release pattern (Rosswall, 1981).

The overall results of the present study have clearly brought out the significant increase in NH_4^+-N by N fertilizer application. The influence was more pronounced in the early stages of crop growth. Whenever estimation succeeded N application, there was a spurt in the NH_4^+-N content (Tables 20 to 22; Fig.4). This observation is in accordance with that reported by John *et al.* (1989c). Though N timings affected NH_4^+-N, the level of N applied at any stage was found not having a prolonged effect when it was estimated at the succeeding crop growth stage. Application of N @ 75 kg ha^{-1} (N_1) or 25 kg ha^{-1}

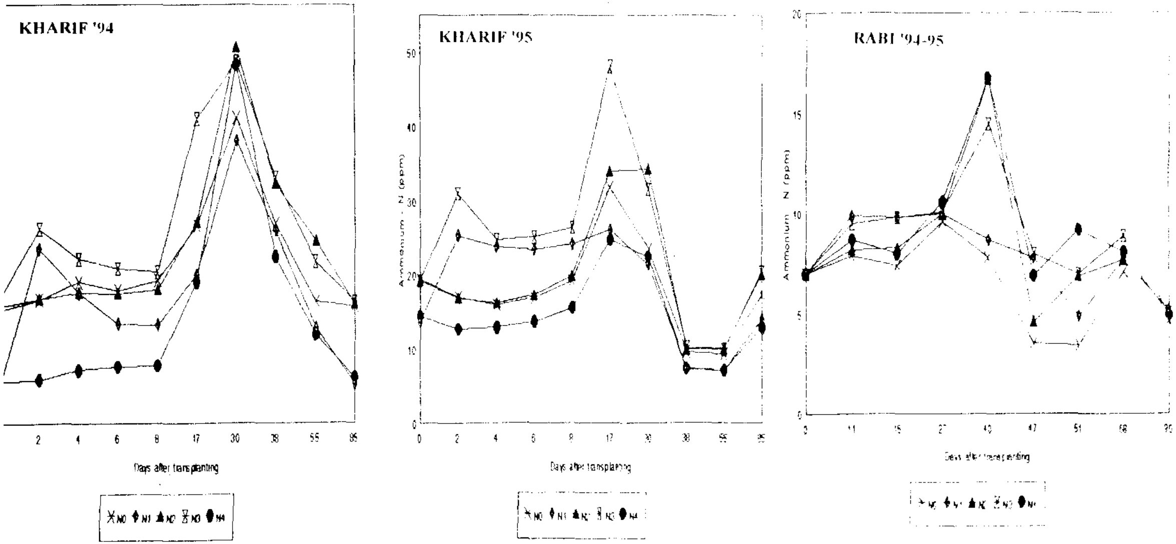


Fig. 4. Time course NH_4^+-N release under N timings

(N_3) at planting did not make any difference in soil NH_4^+-N content after one or two weeks. This indicates considerable losses from higher doses of N fertilizer if applied at early stage when the foraging capacity of the crop was limited. Similarly, application of 100 kg (N_4) or 25 kg (N_3) at PI stage did not cause any difference in soil NH_4^+-N content at heading stage. Nitrogen applied of N at later stages, particularly at heading as done in N_2 and N_3 in this experiment have been well utilized by the crop as evidenced from both higher N uptake (Tables 38 to 41) and N uptake rates (Tables 44 to 47; Fig.16) during the H-M period.

The N timing strategy of six splits each @ 25 N ha^{-1} spreading from P to H stage (N_3) maintained the soil NH_4^+-N content at a rather high or equal level to the treatments which received 50 kg or 100 kg at any stage (N_1 or N_4), throughout the crop growth period. In N_2 also the NH_4^+-N content was more than N_1 or N_4 during the active vegetative and reproductive stages. The strategy of N application from ET to H stages followed in N_2 treatment has maintained the NH_4^+-N content in soil sufficient enough to meet the crop demand. This has resulted in higher nL, biomass and N uptake from ET upto maturity and consequently higher yield, though less than N_3. The low NH_4^+-N content in unfertilized plots (N_0) throughout the crop growth was naturally due to the absence of N application. As a result, N_0 plots recorded the lowest yield in all seasons.

The low NH_4^+-N content in *rabi* season may be one of the reason for low yield, compared to *kharif* season. *Rabi*, being monsoon season, continuous percolation of water through the soil might have leached out considerable amount of the mineralized N. Moreover a major portion of the mineralized N from SOM as well as added green manure would have been absorbed by the *kharif* rice experiencing favourable climatic conditions. Moreover, in *rabi* fertilizer was the major source of N for the crop. Further, the losses of N from applied fertilizer would be high in *rabi* season (Cao *et al.*, 1983).

Prediction models for NH_4^+-N release pattern

Mathematical models for NH_4^+-N release pattern from different green manures and non-green manure treatments were evolved. The best fitting models were selected based on the prediction ability and 'r^2' values and are given below. These models allow prediction of soil NH_4^+-N content at any stage after planting rice.

The models allow prediction of the probable period of maximum NH_4^+-N content in soil after transplanting rice.

Prediction models for NH_4^+-N content in soil - *kharif* '94

Treatments	Prediction model	r^2	Estimated parameter values
Non-green manure (G_0)	$\ln NR = \frac{a+cD+eD^2}{1+bD+dD^2+fD^3}$	0.97	a = 2.7537 b = -0.0562 c = -0.1503 d = 0.0009 e = 0.0024 f = 2.2677 e-07
Sesbania (G_1)	$NR = a+b \exp\left(-\exp\left(-\left(\frac{D-c}{d}\right)\right)-\left(\frac{D-c}{d}\right)+1\right)$	0.98	a = 16.8771 b = 45.5662 c = 24.4672 d = 6.5477
Cowpea (G_2)	$NR^{0.5} = \frac{a+cD+eD^2}{1+bD+dD^2+fD^3}$	0.97	a = 4.1123 b = -0.0683 c = -0.2665 d = 0.0013 e = 0.0059 f = 2.6339 e-06
Parthenium (G_3)	$NR = a + \frac{b}{1+\left(\frac{D-c}{d}\right)^2}$	0.95	a = 15.4039 b = 28.8151 c = 28.5456 d = 8.9320

Prediction models for NH_4^+-N content in soil - *kharif* '95

Treatments	Prediction model	r^2	Estimated parameter values
Non-green manure (G_0)	$NR^{-1} = a + bD^2 + cD^{2.5}$	0.88	a = 0.0742 b = -0.0003 c = 4.7086 e-0.05
Sesbania (G_1)	$NR = a + \frac{b}{1 + \left(\frac{D-c}{d}\right)^2}$	0.86	a = 5.4056 b = 27.8553 c = 17.7526 d = 10.2435
Cowpea (G_2)	$\ln NR = \frac{a + cD + eD^2}{1 + bD + dD^2 + fD^3}$	0.98	a = 2.6729 b = -0.0669 c = -0.1321 d = 0.0016 e = 0.0019 f = -9.9103 e-06
Parthenium (G_3)	$NR = a + \frac{b}{1 + \left(\frac{D-c}{d}\right)^2}$	0.79	a = 4.1969 b = 22.4585 c = 17.2872 d = 13.4166

D = days after transplanting
NR = NH_4^+-N (ppm)

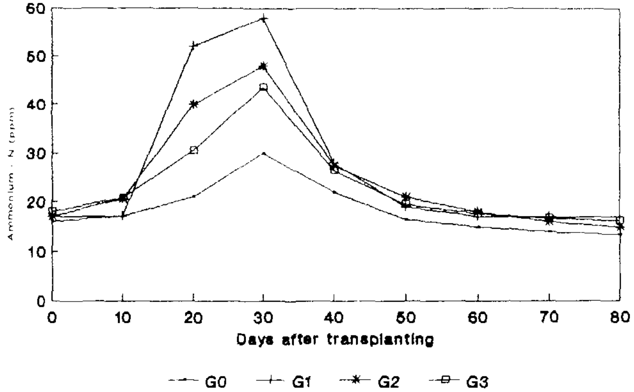


Fig. 5. Prediction of NH_4-N release by green manures - kharif '94

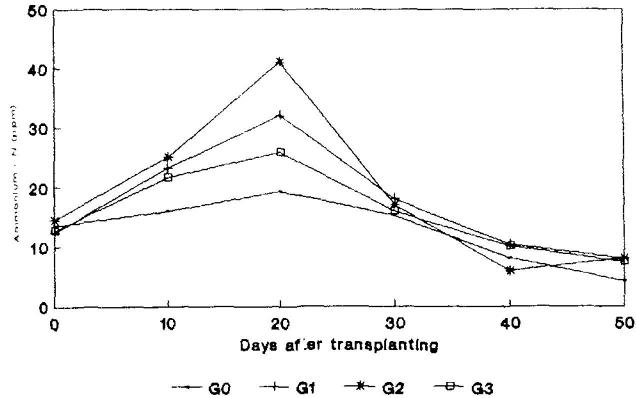


Fig. 6. Prediction of NH_4^+-N release by green manures - kharif '95

Predicted values of soil NH_4^+-N content (ppm) as influenced by green manures

Treatment	Maximum		Minimum	
	DT	NH_4^+-N	DT	NH_4^+-N
Kharif '94				
No green manure (G_0)	32	30.03	80	13.50
Sesbania (G_1)	27	58.12	80	17.00
Cowpea (G_2)	26	50.70	80	15.00
Parthenium (G_3)	29	45.58	80	16.20
Kharif '95				
No green manure (G_0)	21	19.30	50	4.20
Sesbania (G_1)	18	33.25	50	8.00
Cowpea (G_2)	21	41.08	45	6.69
Parthenium (G_3)	17	26.65	50	7.43

DT = days after transplanting

As per the prediction, in *kharif* '94 (Fig.5) the highest NH_4^+-N release from sesbania (G_1), cowpea (G_2) and parthenium (G_3) occurred around 27, 26 and 29 DT, respectively. The corresponding values of NH_4^+-N were 58.12, 50.71 and 45.58 ppm, respectively. In the case of non-green manure treatment, the maximum NH_4^+-N content (30.03 ppm) was predicted to be on 32 DT.

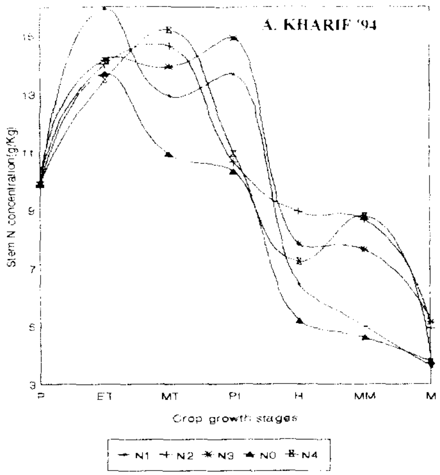
During *kharif* '95 (Fig.6) the highest NH_4^+-N content in soil occurred earlier than the previous *kharif*. As predicted from the mathematical models for *kharif* '94, in the succeeding *kharif* also the amount of NH_4^+-N contribution by green manure treatments were substantial over non-green manure treatment.

5.2 N concentration in plant parts

Application of N fertilizer caused substantial increase of N concentration in stem and leaf of rice. This effect was more conspicuous from ET stage onwards. Similarly, the effect of N timings was also more prominent from ET stage onwards and it prolonged upto PI stage in stem (Tables and 24 to 27) and upto MM stage in leaf (Tables 28 to 31). During the crop establishment period i.e: from transplanting to the initiation of first tiller, the growth and N uptake in crop was slow. Hence the demand of N during this period also was comparatively low. In case, soil could supply the required N due to the mineralization of SOM, external N supply can be avoided as suggested by Thiyagarajan *et al.* (1994a). In the present study, the N concentration in stem or leaf at ET stage was not much varied whether or not N fertilizer was applied at transplanting. So it was clear that the required N to meet the crop demand during the initial stage of crop growth could be made good from the N mineralized from SOM itself.

The gaps between the N concentration curves for different N timing treatments for both stem (Fig.7) and leaf (Fig.8) were wider from ET to PI stage after which the difference got narrowed. The width of curves during the crop growth periods was possibly influenced by the timing of N fertilizer as reported by Daradjat *et al.* (1994).

Towards the late reproductive phase, the position of curves particularly that of nL was mostly decided by N application at H stage. Application of 25 kg N (N_3) or 50 kg N (N_2) at H stage enabled the crop to maintain the leaf N concentration steadily without any drastic deflection from the previous stages. The strategy of applying small splits from planting to heading as done in N_3 enabled the plant to maintain its leaf N concentration throughout the crop growth period at a higher level. Similarly, postponing the first dose of N application till ET stage and subsequent two splits upto heading stage (N_2) gave higher leaf N concentration during the active vegetative phases and also reproductive phases and made up the earlier loss. Nitrogen being a substrate for the biosynthesis of organic-N compounds - proteins - which are constituents of protoplasm and chloroplasts increased the leaf N content and the rate of photosynthesis which ultimately increased the yield (Penning de Vries *et al.*, 1990; Kropff *et al.*, 1992) as evident from higher leaf N uptake by N fertilization in this experiment and consequent yield in N_3 and N_2 timings.



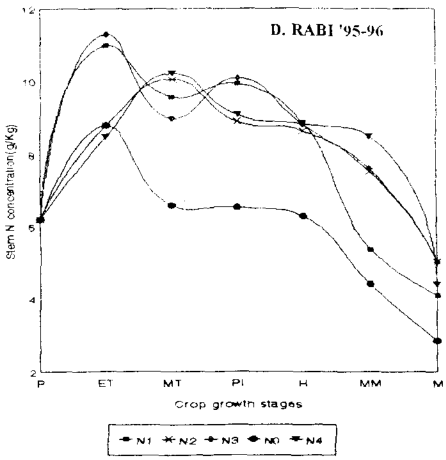
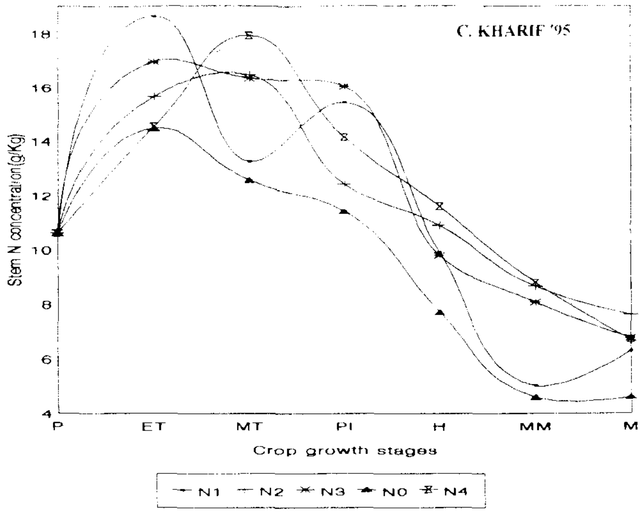
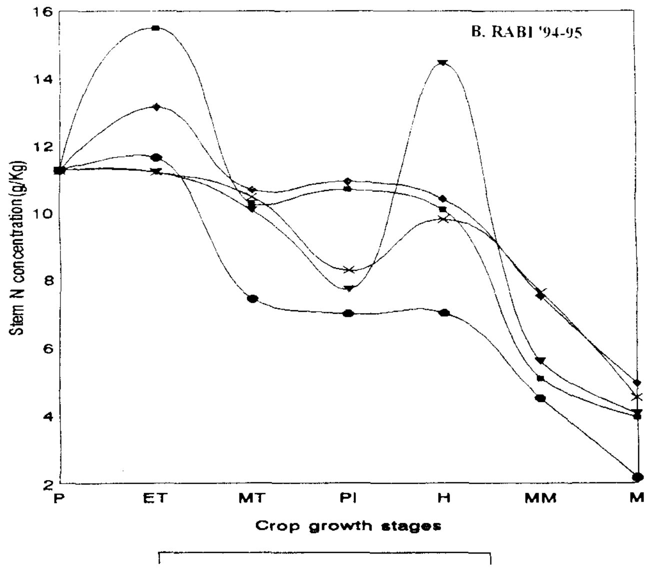


Fig. 7. Time course stem N concentration under N timings

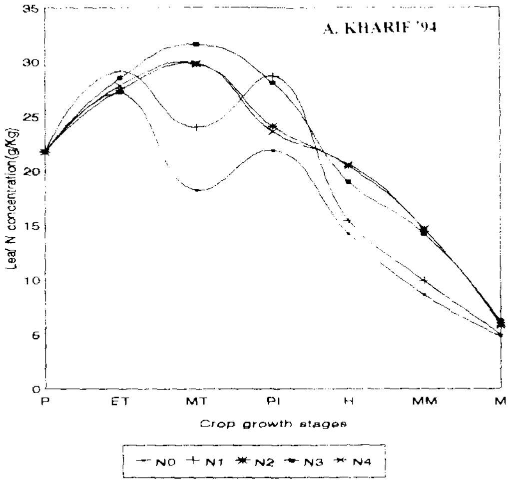

C. KHARIF '95
Stem N concentration (g/Kg)
18
16
14
12
10
8
6
4
P
ET
MT
PI
H
MM
M
Crop growth stages
N1
N2
N3
N0
N4

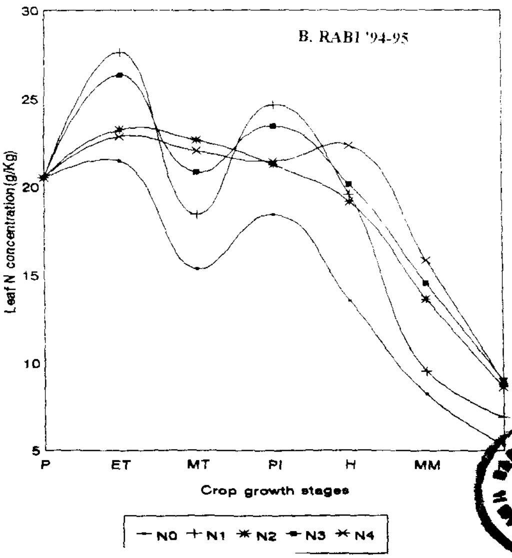

B. RABI '94-95
Stem N concentration (g/Kg)
16
14
12
10
8
6
4
2
P
ET
MT
PI
H
MM
M
Crop growth stages

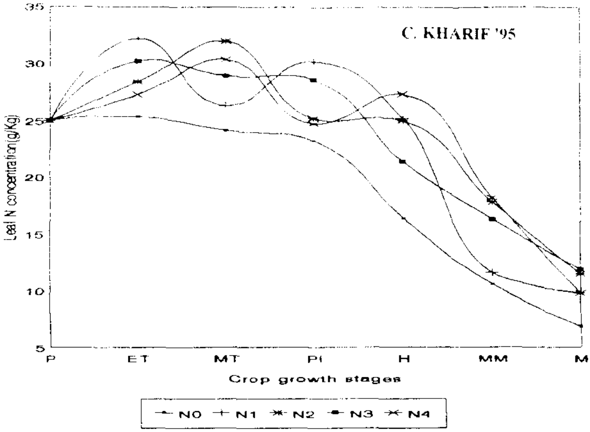
Optimum leaf N throughout the crop growth could be maintained by N_3 timings and that during active vegetative and reproductive phases could be maintained by N_2 timing. The deflection of nL in N_1 timing in which the N application was stopped by PI stage, was drastic after H stage. On the otherhand, application of 100 kg N at PI (N_4) did not increase the nL appreciably over N_2 or N_3 after H stage. According to Thiyagarajan *et al.* (1991) the leaf N concentration cannot be maintained at a higher level with heavy dose of N application in a single split.

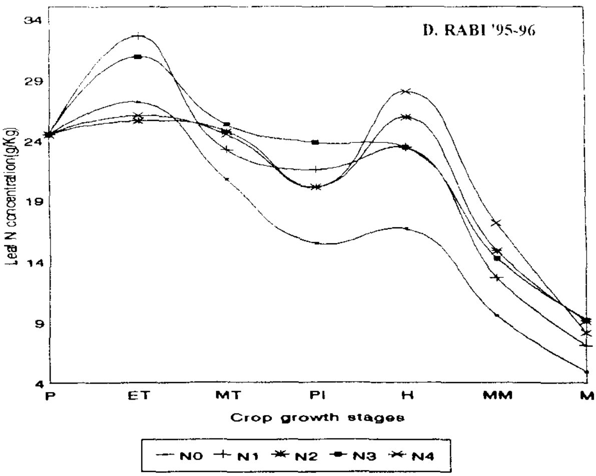
The importance of N application at heading for maintenance of sufficient leaf N concentration during the H-M period was more evident from the results of flag leaf N concentration (Table 32; Fig.10) and the total N in flag leaf (Table 33; Fig.11). The strategy of applying 150 kg N in six equal splits from P to H (N_3) or three splits from ET to H (N_2) favoured maintenance of N concentration as well as total N content in the flag leaf which ultimately resulted in higher yield. The higher SPAD values (Tables 34 and 35; Fig.9) which is an indirect way of measuring chlorophyll or N content in leaf supports the suggestion towards increased photosynthesis by increased leaf N concentration.

In all treatments the stem and leaf N concentration declined gradually upto heading stage after which it was rather drastic upto maturity stage. The decline of N concentration


A. KHARIF '94
35
30
25
20
15
10
5
0
Leaf N concentration(g/Kg)
P
ET
MT
PI
H
MM
M
Crop growth stages
N0
N1
N2
N3
N4


B. RABI '94-95
30
25
20
15
10
5
Leaf N concentration(g/Kg)
P
ET
MT
PI
H
MM
Crop growth stages
N0
N1
N2
N3
N4


C. KHARIF '95
35
30
25
20
15
10
5
Leaf N concentration(g/Kg)
P
ET
MT
PI
H
MM
M
Crop growth stages
N0 N1 N2 N3 N4


D. RABI '95-96
34
29
24
19
14
9
4
Leaf N concentration(g/Kg)
P
ET
MT
PI
H
MM
M
Crop growth stages
N0 N1 N2 N3 N4

during the pre-anthesis period could be attributed to the expansion of dry matter in the plant parts (Matsushima, 1976). The reduction of N concentration in stem and leaf during the post-anthesis period was possibly due to the translocation of N from these plant parts to the grains. Losses of N from crop is also suggested by Wetselaar and Farquhar (1980). Maintenance of N concentration particularly nL at the desired level during the post-anthesis period by N application at heading (N_3 and N_2) ensured the presence of sufficient green leaves and continued carbon assimilation for better grain filling and high yields (Thiyagarajan *et al.*, 1994a). However, raising nL above the optimum level (nL as in N_3) as happened in N_4 around PI stage did not result in yield increase over N_3 or N_2. This finding is in conformity with that of Thiyagarajan *et al.* (1994b). Possibly a high proportion of N was sequestered into the storage pools as amides (Marschner, 1986).

The results indicates that to achieve higher yields it is imperative to maintain optimum leaf N concentration throughout the crop growth, especially from MT to MM stages which would be possible by split application of N from P or ET and continued upto H stage as done in N_3 and N_2 treatments respectively, in this experiment. Though the native soil N supply maintained the desired nL upto ET stage, variation in the crop N status after ET upto flowering or mid maturity stage fully controlled the yield variation (Wopereis *et al.*, 1994). The difference in

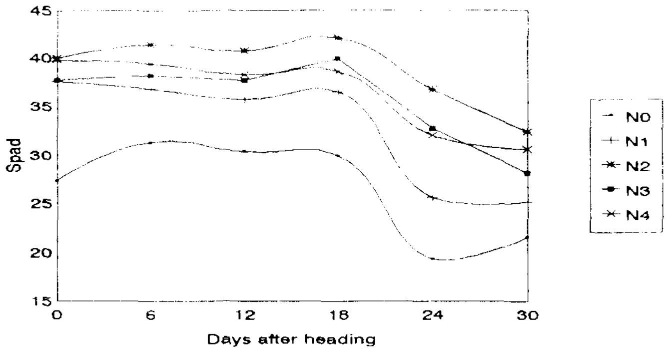


Fig. 9. Time course SPAD values in flag leaf

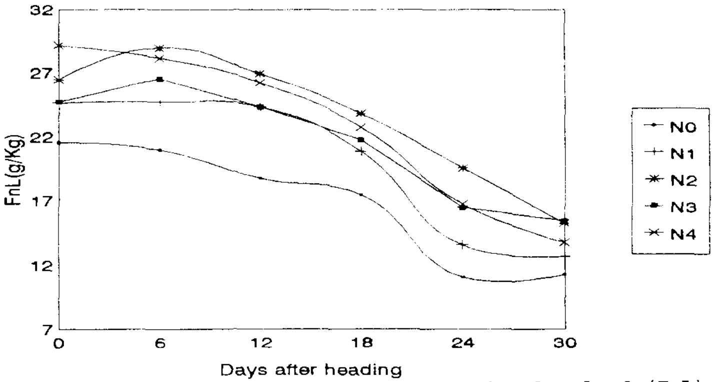


Fig. 10. Time course N concentration in flag leaf (FnL)

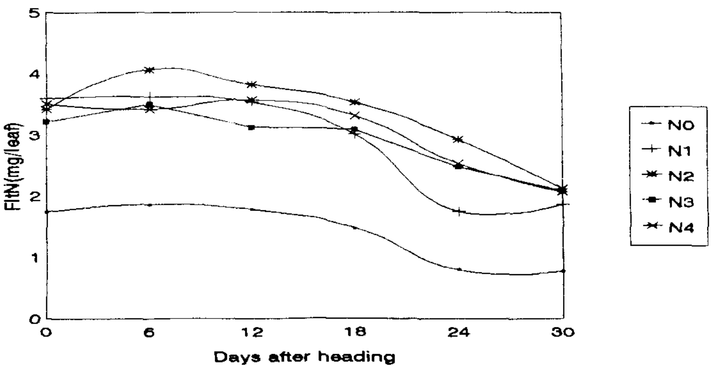


Fig. 11. Time course total N in flag leaf (FltN)

N concentration between N timings got narrowed by H stage, which has reflected in the biomass accumulation as well as N uptake at that stage. The increase in N concentration after H stage was possible by the continued uptake capacity of the crop and the non-limitation of soil N supply (Cassman and Samson, 1994). Higher nL in N_3 and N_2 increased radiation efficiency and photosynthetic activity (Yoshida, 1981) consequently higher biomass accumulation and grain yield. An excess of N around H stage observed under N_4 timing had resulted in low percentage of ripened grains associated with high percentage of unfilled grains (Matsushima, 1976). Further, the sustenance of tillers for panicle bearing was also considerably less in N_4 unlike in N_3 and N_2 and resulted in low yield.

Prediction models for leaf N concentration

The N concentration in leaf at different growth stages of rice pooled over the same seasons were regressed upon days after transplanting to develop mathematical models. The best fitted models based on the prediction ability and r^2 values have been selected for predicting the leaf N concentration at any growth stage under specific N application strategies. These models provide a chance for assessing mathematically the plant N status to decide time of N side-dressing. The models are presented below.

Prediction models for leaf N concentration under different N timing strategies - *kharif* season

Treatments	Mathematical model	r^2	Estimated parameter values
N_c	$nL = a+bD+cD^{1.5}+dD^{0.5}+ee^{-D}$	0.95	a = 53.3435 b = 0.9593 c = -0.0550 d = -9.1138 e = -32.2435
N_1	$nL = a+bD+cD^{1.5}+dD^{2}+eD^{2.5}$	0.91	a = 21.1898 b = 1.1855 c = -0.1387 d = -0.0129 e = 0.0013
N_2	$nL = a+bD+cD^{2}+dD^{2.5}+eD^{3}$	0.95	a = 20.9538 b = 1.1398 c = -0.0789 d = 0.0118 e = -0.0005
N_3	$nL = a+bD+cD^{1.5}+dD^{0.5}+ee^{D}$	0.98	a = 20.9991 b = 0.9669 c = -0.0370 d = 0.0027 e = -3.6334 e-41
N_4	$nL = a+bD+cD^{2}+dD^{2.5}+eD^{3}$	0.94	a = 21.0213 b = 0.9183 c = -0.0598 d = 0.0089 e = -0.0004

D = days after transplanting
nL = leaf N ($g\ kg^{-1}$)

Prediction models for leaf N concentration under different N timing strategies - *rabi* season

Treatments	Mathematical model	r^2	Estimated parameter values
N_0	$nL = a+bD+cD^{1.5}+dD^2+eD^{2.5}$	0.93	a = 22.9178 b = 3.1219 c = -1.1850 d = 0.1425 e = -0.0057
N_1	$nL = a+bD+cD^{1.5}+dD^2+eD^{2.5}$	0.88	a = 22.9674 b = 3.7242 c = -1.3241 d = 0.1564 e = -0.0063
N_2	$nL = a+bD+cD^{1.5}+dD^2+eD^{2.5}$	0.95	a = 22.8933 b = 0.9518 c = -0.3603 d = 0.0469 e = -0.0022
N_3	$nL = a+bD+cD^{1.5}+dD^{2.5}+eD^3$	0.93	a = 22.9460 b = 1.8060 c = -0.4196 d = 0.0056 e = -0.0003
N_4	$nL = a+bD+cD^{1.5}+dD^2+eD^{2.5}$	0.87	a = 22.9110 b = 1.7677 c = -0.7392 d = 0.1029 e = -0.0048

D = days after transplanting
nL = leaf N ($g\ kg^{-1}$)

The predicted time course behaviour of leaf N concentration under different N timing strategies are depicted in Fig.12 and 13. The models and the movement of curves for N timing treatments are almost similar in both seasons though the models are slightly different in their coefficients and exponents.

In control plot (N_0) and in plots which received half of the N at planting (N_1), after the initial increase during tillering stage (within a week in N_0 and with 11 to 21 days in N_1) the regression line deflected downwards almost linearly reaching the lowest values at maturity. As in the 'natural curve', the predicted curve also showed high leaf N concentration during the vegetative growth stage upto heading in N_4 timing, after which it moved down sharply.

In N_2 and N_3 timings almost steady values were maintained by the model during most part of the crop growth period. Though highest values were observed at tillering stages as in other treatments, the rate of increase or decrease was very small maintaining steady values throughout the growth period, particularly upto mid maturity stages.

On comparison of the 'observed curves' and the 'prediction curves' it could be concluded that the 'leaf N concentration models' corroborate well with the natural time course behaviour

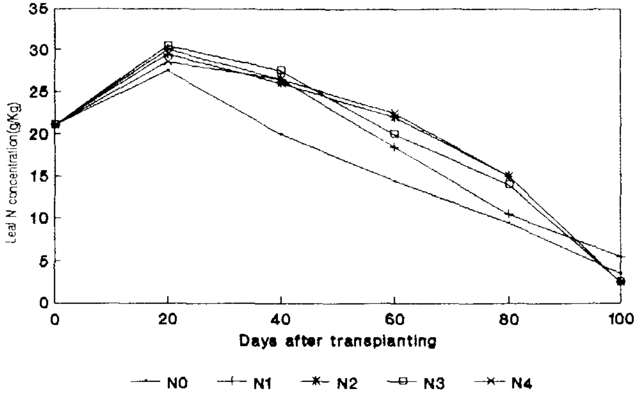


Fig. 12. Prediction of leaf N under N timings - kharif season

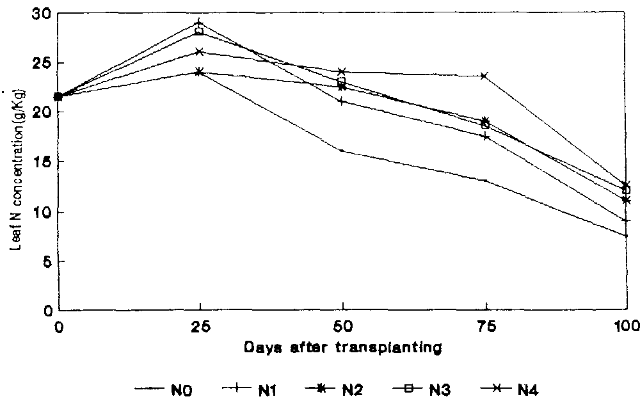


Fig. 13. Prediction of leaf N under N timings - Rabi season

of plant under different N timing strategies. The models allow prediction of plant N status at a given stage of crop growth.

5.3 Use of chlorophyll meter (SPAD) for N side-dressing

Use of a SPAD meter for in-season N management would be possible only by establishing a consistent relationship between leaf N concentration (nL) and SPAD values for specific situations. in the present study a strong correlation between nL and SPAD values (Table 36) was observed from PI stage upto 30 days after heading (pooled *r*=0.75). This indicates the possibility of using SPAD meter values to predict the plant N status reasonably well at any growth stage, particularly after PI stage.

On finding out the strong relationship between nL and SPAD values, an attempt was made to establish the relationship by a mathematical model. It was found that the Lorentzian model (Fig.14) was the best one for the prediction of nL from the observed SPAD values, considering the prediction ability and 'r^2' values. The model is of the form

$$nL = a + \frac{b}{1 + \left(\frac{S-c}{d}\right)^2} \qquad (r^2 = 0.91)$$

where nL = leaf N concentration (g kg^{-1}); and

S = SPAD units

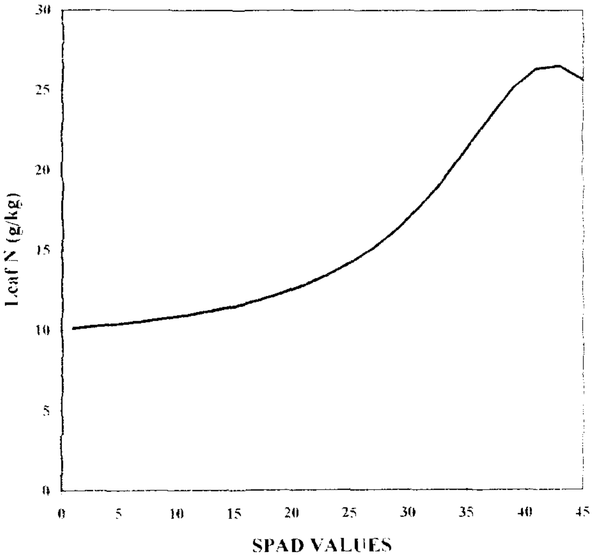


Fig. 14. Prediction of leaf N from SPAD values

The above Lorentzian model was estimated by the method of least squares. The estimated parameter values are: a=8.88; b=17.66; c=42.33; and d=11.31. The model allows the prediction of nL when the SPAD values ranges from 15.30 to 42.33. The corresponding values of nL range from 11.52 to 26.55 g kg^{-1}.

The usefulness of the model for prediction of leaf N concentration based on SPAD values could be confirmed on comparing the predicted nL with the observed nL in this experiment. An example is illustrated below:

Simulated and observed values of nL

Parameter	Crop growth stage			
	H	12 dH	18 dH	24 dH
SPAD values observed in N_3 (Table 35)	37.70	37.70	40.03	32.78
nL observed in N_3 (Table 32)	24.83	24.43	21.79	16.52
Predicted nL	24.00	24.00	25.84	19.19

The comparison between observed nL and predicted nL shows that the model over estimates the nL after 12 dH. This indicates the limitation of the model for its use after that stage. Probably, the senescence of leaves would have been started by this stage and the translocation of N from leaves to the grains almost at a peak rate. This may be the reason for the over estimation of nL by the model after 12 dH. Further, the use of SPAD metre after heading stage for N side-dressing is not warranted since N application beyond heading is not advised by researchers till date.

The evolved SPAD-nL model can be used for assessing the nL based on SPAD values. If the optimum nL during different growth stages of rice could be worked out, the predicted nL can be compared with the optimum nL and decide for N side-dressing as illustrated in the following examples (the SPAD units and optimum nL are assumed values only).

Deciding N side-dressing based on SPAD values

Examples	SPAD values	Optimum nL required	Predicted nL	Decision on N side dressing
1.	35.00	20.50	21.32	not required
2.	25.00	20.50	14.16	required

The usefulness of SPAD meter for assessing the leaf N concentration have been reported by earlier workers also. The chlorophyll meter (SPAD) readings are significantly related to the extractable chlorophyll content (Marquard and Tipton, 1987) which in turn is related to the N status of the plant (Greenwood *et al.*, 1991). The use of SPAD meter for deciding N side-dressing in rice has been suggested by Turner and Jund (1991) and Peng *et al.* (1995). Better relationship of SPAD values with yield in this experiment further confirmed the usefulness of SPAD meter in assessing the leaf N status of rice and deciding the time of N side-dressing (Peng and Cassman, 1995).

5.4 Biomass accumulation

The effect of green manures on biomass accumulation in plant parts and the total DMP of crop was evident in *kharif* '95 season only (Table 13). The total DMP in green manure plots ranged from 12.23 to 12.76 t ha^{-1}. The lack of response in the first season of application (*kharif* '94) was probably due to the low quantity of N (54 kg N ha^{-1}) supplied through green manures. However, the cumulative effect of added green manure combined with favourable soil and climatic conditions in *kharif* '95 season favoured uptake of more nutrients thereby increased the growth and yield. In this season, the effect of green manures on increasing the leaf N concentration was evident for a prolonged period ie; from PI to maturity, which may be one of the reasons for better growth, higher N uptake and yield attributes and consequent higher yield. In other seasons such an influence was not evident either in yield contributing parameters or the yield. In the earlier reports also the effect of green manures was evident only by a continued application (Ventura and Watanabe, 1991) especially when the quantity of N added through green manure was low (Bouldin, 1988).

The importance of adequate supply of N in accumulation of sufficient biomass in rice for better growth and yield could be further emphasized by the severely retarded plant growth in fertilized plot (Tables 11 to 14). Nitrogen being the most important factor for growth, its content in leaf is very well related to photosynthetic rate (Yoshida, 1981).

The better root growth in N applied plots during the early stages of plant growth may be due to the root elongation favoured with N supply as suggested by Kawata *et al.* (1977). However, at later stages the root growth was found to be unrelated to the N supply.

The dose of N (150 kg or less) applied prior to heading did not result in any significant difference in TDMP at heading. The growth of crop during post-anthesis period was found to be dependent on N application at heading stage. The N application strategy of staggered splits from planting upto heading (N_3) ensured a steady N supply throughout the growth period and hence resulted in higher amount of 'biological yield' as well as 'economic yield'. Delaying the first N application upto ET stage and subsequent doses at PI and H stages as in N_2 timing caused rapid increase in total biomass and also maintained at a higher level than N_0, N_1 and N_4. The data in Tables 16 to 19 and also the Fig.15 clearly reveals that the per day accumulation of biomass during H-M stage was invariably more with N_3 and N_2 timings. The N uptake rate (Fig.16) during this period was also high in these two treatments. The slow growth in N_2 timing in the early stage was made up by higher growth rate from PI to maturity through heading stage. The results reveal that 'economic yield' could be better even if a crop was maintained with a low N status in the early stages of growth, provided a continued N supply during active vegetative and reproductive phases was maintained. Similar results have been reported by Thiyagarajan *et al.* (1994a). A general increase in dry matter production in response to N application has been reported by Mae and Ohira (1981) and Moore *et al.* (1981). However, application of N in heavy dose of 100 kg at PI (N_4) did not result in appreciable change in growth as has observed by Wopereis *et al.* (1994).

The quadratic fitness of biomass of vegetative tissues (stem and leaf) and linear function of TDMP of crop indicates accumulation of carbohydrates in the vegetative tissues upto panicle emergence and translocation of carbohydrates to the panicle thereafter (Makarim *et al.*, 1994). During the PI-H period, the rate of accumulation of biomass in stem was very much faster than that in leaf. Similarly, during H-M period the rate of decrease was also higher in stem than in leaf. Comparison of the N timing treatments indicates that the highest rate of stem and leaf biomass accumulation during PI-H period was in N_3 and N_2 treatments. The timing strategy of six splits upto heading (N_3) or three splits upto heading (N_2) enabled steady N supply during the active growth phases and reproductive phases. This has resulted in higher growth rate of stem and leaf during PI-H period and high CGR during H-M period. Such a positive effect on growth components increased the grain yield with these treatments. In contrast, in N_1, low quantity and rate of biomass accumulation resulted in lower yield. The increase of biomass in stem is attributed to the accumulation of starch and sugars (Ramasamy *et al.*, 1994). The drastic reduction in stem biomass after heading is attributed to the rapid remobilization of carbohydrates to the grains (Yoshida, 1981). The higher rate of CGR during H-M phase in N_3 and N_2 was the result of N supply at heading and the resultant increased rate of mineralisation of native N and thus nutrient uptake by the plant during post-anthesis period. Hauck and Bremner (1976) observed such increased mineralization of native soil N by addition of N fertilizer due to 'priming effect'. Higher total biomass at heading but low panicle dry matter in N_4 suggests that much of the stem reserves in N_4 were not effectively used for g-ain filling (Angus *et al.*, 1990; and Drenth and Berge, 1993).

5.5 Uptake of N

The data on N uptake by the crop (Tables 38 to 41) shows that the effect of green manures on increasing the N uptake was evident in *kharif* '95 season only. This was possibly the effect of increased biomass and the prolonged high leaf N concentration from PI to maturity by the influence of green manures. The increased N uptake had resulted in better growth and yield attributes such as number of panicles; length and weight of panicle and number of filled grains. The strong relationship of N uptake with growth and yield attributes (Table 68) reveals the importance of N on improving these parameters and consequently the yield.

The results shows that larger dose of N in limited splits substantially decreased the DMP as well as N uptake. This was clearly evident in N_1 timing where the N application was stopped by PI stage. Early season application of 75 kg N at planting, though increased the soil NH_4^+-N content substantially immediately after application it was not sustained later (Tables 20 to 22). Since the rice roots exhibited limited ability to absorb and assimilate N during the early establishment stage (Meelu and Gupta, 1980), larger basal dressing was found to be not necessary. Reduction in N uptake by the plant which received more N at planting has been reported by Singh *et al.* (1991) also.

The N uptake in different N timing treatments did not show considerable variation at H stage. It was interesting to note that the N uptake beyond heading stage was more dependent on the N application at heading stage. The total N uptake at maturity was highest in N_3 treatment which received six equal splits of N from P to H and it was closely followed by N_2 which received N from ET to H. The data on leaf N concentration (Tables 28 to 31) and biomass (Tables 11 to 14) reveals that, in N_3 there was a sustained maintenance of leaf N concentration and biomass in crop throughout the growth period. In N_2, these parameters were low during the early growth stage but it was made up subsequently. After H stage, the N absorption was very much high in N_3 and N_2 treatments due to N application at heading (Table 44 to 47). In other N timings the N absorption during this period was at a reduced rate since N application was withheld at heading stage. The sustained absorption of N throughout the growth period particularly from ET stage onwards, might have enabled the crop under N_3 and N_2 timings to attain highest N uptake and resulted in better growth and yield as observed by Thiyagarajan *et al.* (1994b). Similar findings have been reported by Bacon (1985) and De Datta *et al.* (1987b).

As in dry matter production, in the case of stem and leaf N uptake also a quadratic fitness was observed, whereas in the case of total crop N uptake it was of linear function (Tables 38 to 41). The decrease of N uptake in vegetative tissues during grain filling stage occurred as the accumulated N has been translocated to the grains (Groot and Spiertz, 1988). The increase in N uptake upto maturity was possibly due to the continued absorption of N from the soil by the plant. Though there occurred continued uptake of N by the crop upto maturity in general, the rate of N uptake very much depended on the N application strategy at heading (Tables 44 to 47). As emphasized in earlier discussions, during H-M stage the rate of N uptake by the crop was substantial with N_3 and N_2 timings, due to application of N at heading stage. In N_3 and N_2, uptake of N in stem and leaves during PI-H stage and the total crop N uptake during H-M period was higher than that in other timings (Fig.16). This was possible by N application starting either from planting or ET and spreading upto heading stage. Increased N uptake in N_3 and N_2 during the reproductive stage enabled the sustenance of more productive tillers and production of better panicles which resulted in higher yield. The increase in N uptake with N_3 and N_2 timings is in consonance with the high growth and biological yield. The less than proportionate increase in N uptake with other N timings might be due to the higher losses associated with untimely application. This observation is in conformity with the reports of Dash *et al.* (1994) and Makarim *et al.* (1994). The increased N uptake rate in N_3 and N_2 treatments during H-M stage can be attributed to the N fertilization at heading stage (Wopereis *et al.*, 1994); and also due to the priming effect of

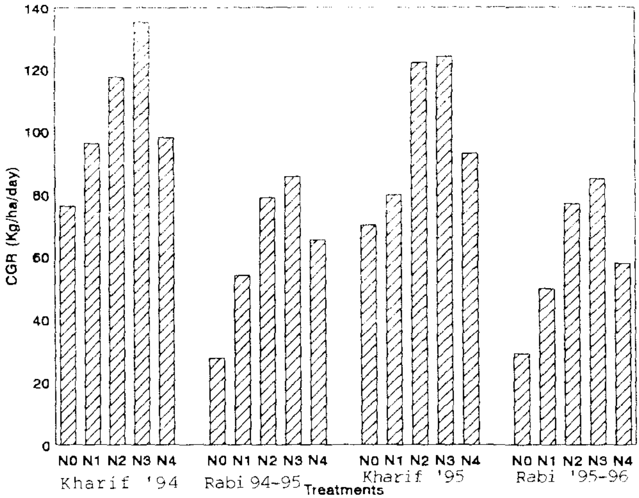
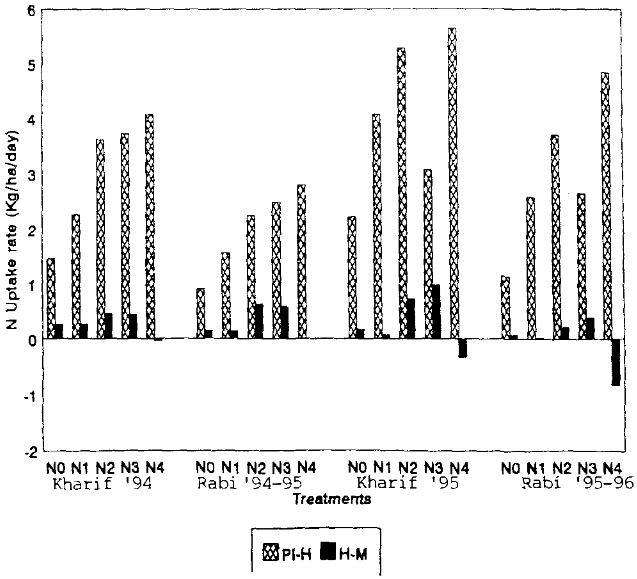


Fig. 15. CGR during H-M period under N timings



added N fertilizer (Hauck and Bremner, 1976). Increased losses of N from plants with higher N uptake around heading stage have been reported y Wetselaar and Farquhar (1980) which was true with N_4 timing of this experiment.

The remobilization pattern (Table 48; Fig.17) shows that the total amount of N translocated to the grains from vegetative tissues was more in N_3 and N_2 treatments compared to N_0 and N_1, but less than N_4. The N uptake data (Tables 38 to 41) reveals that the total crop N uptake during H-M stage was also higher in N_3 and N_2 but it was lowest in N_4 with even reduction after heading. These results indicate that in N_3 and N_2 timings where a part of N was supplied at heading stage also, enabled both better translocation of N from the stem and leaf to grain and also increased N uptake from soil after heading. The increased N uptake during this stage was possibly by the increased rate of uptake as already discussed. Uptake of N after flowering has been reported by Wopereis *et al.* (1994). Yanagisawa and Takahashi (1964) reported that rice derived 60-80 per cent of total N uptake from the soil during the late growth stages. Lack of soil-N supply limited the crop N uptake and yield (Cassman and Samson, 1994). This warrants the need of appropriate timing of N to maintain the soil-N for better uptake and higher crop yields. In this experiment, increased translocation of N from vegetative tissues to the grains as well as increased absorption of N during grain filling stage in N_3 and N_2 by N application at heading resulted in higher yields.

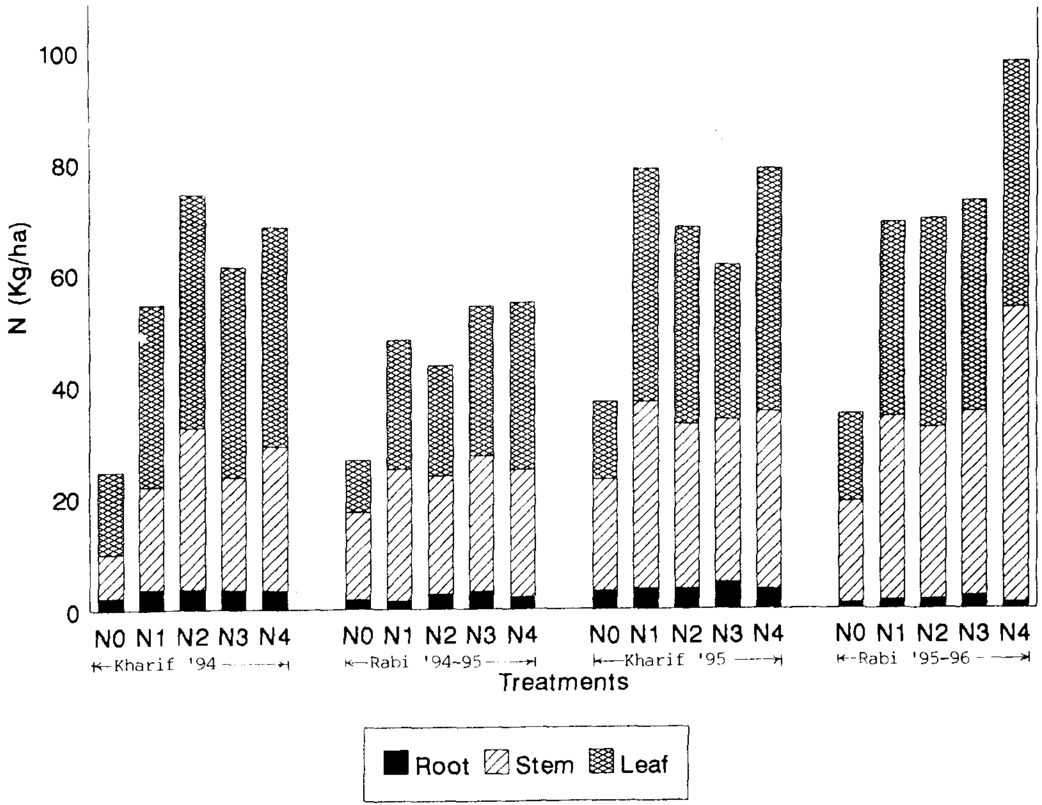


Fig. 17. Remobilization of N from plant parts to grain under N timings

In N_1 timing where N application was stopped by PI stage the translocation of N and uptake of N after heading was limited and resulted in lower yield. In N_4 timing which received very high dose of N (100 kg) at PI stage the assimilates in the sink had come mainly from the vegetative tissues (Norman *et al.*, 1992a) as evident from high values of N remobilization. The reduction in total N uptake after heading in this treatment indicates losses of N from the crop during and ripening phases (Wetselaar and Farquhar, 1980). The limitation in N uptake after heading and also the occurrence of crop N losses in N_4 resulted in less number of productive tillers, decrease in panicle length and weight and increased percentage of unfilled grains. All these resulted in low yield in this treatment.

5.6 ^{15}N isotope studies

It is clear that the uptake of total N (soil N + fertilizer ^{15}N) and fertilizer ^{15}N was high with green manure treatments than that with non-green manure treatments, at heading and at maturity (Table 49). The increase in total N uptake could be attributed to the higher NH_4^+-N release from green manures during the tillering stages. The increase in uptake of fertilizer ^{15}N may be due to the reduction in N losses from soil when it was applied along with green manures. Reduction in N losses from ^{15}N labelled urea applied with green manures has been reported by several workers (Diekmann *et al.*, 1993; and Rekhi and Bajwa, 1993).

The treatmental variation between N timings in ^{15}N uptake (Fig.19) was conspicuous both at heading and maturity. Larger dressing of fertilizer ^{15}N before ET stage (N_1) resulted in low ^{15}N uptake at heading stage. This reveals greater losses of applied N in the early stage of crop growth as the nutrient foraging capacity of the crop was limited (Beyrouty *et al.*, 1987; and Diekmann *et al.*, 1993). Postponing the first split (50 kg N) to ET in N_2 resulted in higher ^{15}N uptake at heading stage. This was due to the increased ^{15}N uptake by the crop during the active vegetative growth periods (Wilson *et al.*, 1989).

Application of a part of N at H stage (N_3 and N_2) helped the crop to maintain a high concentration of ^{15}N, possibly by the better uptake and utilization of ^{15}N during H-M period. Addition of ^{15}N in N_3 (25 kg) and in N_2 (50 kg) at heading possibly delayed leaf senescence, prolonged the photosynthesis and continued the uptake of N (Tanaka, 1976) due to the continued root activity (Cassman and Samson, 1994).

The recovery of applied ^{15}N (Table 50; Fig.18) by the crop at maturity was also high in the treatments which received ^{15}N at heading (N_3 and N_2). This indicates a high recovery proportion of N applied during later stages as a result of increased N absorption by the crop and reduction in N losses from soil. The increase in biomass, higher leaf N concentration and higher N uptake by N fertilization at heading would have resulted in better recovery of the ^{15}N applied. Application of very high dose of ^{15}N fertilizer at planting (N_1) or PI stage (N_4) resulted in lower recovery of ^{15}N at maturity. In N_1, a major portion of ^{15}N applied at planting would have been lost from the soil. On the other hand, the lower recovery in N_4 may be due to both N losses from soil as well as from the crop as suggested by Buresh *et al.* (1989) and Guindo *et al.* (1994).

On comparing the N uptake between heading and maturity (Fig.19) it is clear that the total N uptake increased from heading to maturity in all treatments. But the uptake of ^{15}N got declined from heading to maturity in N_1 and N_4 timings and increased in N_3 and N_2 timings. The increase in total N uptake from heading to maturity give clear indications of continued uptake of soil N by the crop even after heading. The increase in ^{15}N uptake in N_3 and N_2 timings was possibly due to the uptake of ^{15}N applied at heading stage and also due to the 'priming effect' (Jansson and Persson, 1982) or the 'added nitrogen interaction' (Jenkinson *et al.*, 1985). The reduction in ^{15}N uptake in N_1 (N application was over by PI stage) and N_4 (received 50 kg at ET and 100 kg at PI) may be probably due to the losses of ^{15}N from the plant between the late reproductive and maturity stage. The loss of N from the crop might have been occurred by volatilization of NH_3 during transport of

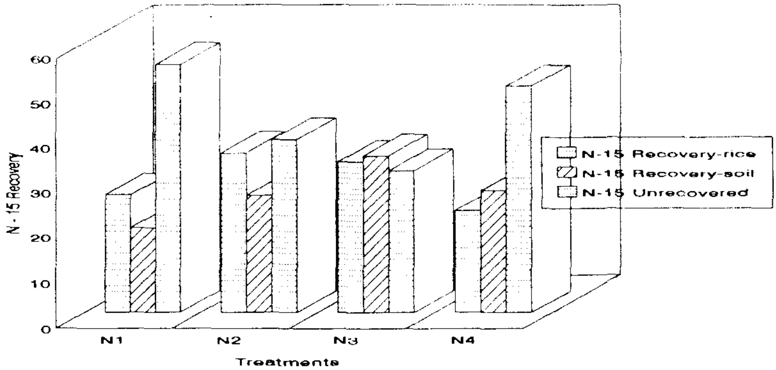


Fig. 18. ^{15}N - crop recovery and soil balance under N timings

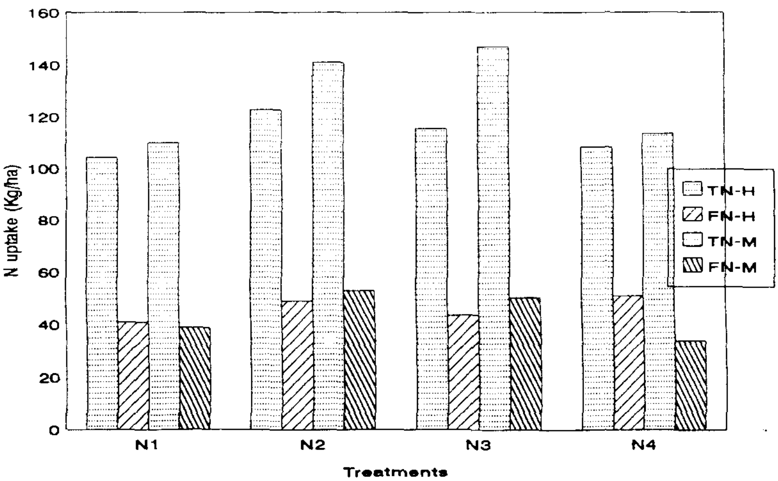


Fig. 19. Total N (TN) and ^{15}N (FN) uptake at heading (H) and maturity (M)

amides resulting from the break down of proteins in the leaf and stem in the phloem vessels (Morgan and Parton, 1989). However, the different loss mechanisms of N from the plant have not been clearly understood (Wetselaar and Farquhar, 1980). The results obtained in this experiment are in agreement with the findings of Norman *et al.* (1992a) and Guindo *et al.* (1994).

The overall results of ^{15}N studies reveals that the uptake and recovery of N fertilizer in rice could be increased by postponing the first application of N upto ET stage and spreading the subsequent splits upto heading stage. The continued N uptake capacity of roots as suggested earlier by Cassman and Samson (1994) is further confirmed by the present investigation. Further, the enhanced mineralisation of native soil-N by addition of N fertilizer (priming effect) was evident from higher ^{15}N uptake and recovery in N_3 and N_2. The loss of N from the rice crop (Wetselaar and Farquhar, 1980) is also proved from the ^{15}N studies.

The 'unrecovered ^{15}N' represents the losses of applied-N from the soil-plant system. Continuing the splits of N upto heading reduced the 'unrecovered ^{15}N' as observed in N_2 and N_3 (38.54% and 31.57%) probably due to less losses of N from the soil. Applying 75 kg N at planting or 100 kg N at PI stage increased the losses of N (50.33 to 55.22%). Increased losses of N if more fertilizers are applied at a time has been reported by Craswell and Vlek (1979). The ^{15}N balances of

18.7 per cent to 34.9 per cent observed in the present study are in accordance with the reports of other workers also (John *et al.*, 1989a and Diekmann *et al.*, 1993).

5.7 Uptake of P and K

The P and K uptake estimated at maturity stage of rice varied with addition of green manure compared to control (Table 51) and the variation was significant in the case P uptake in *kharif* '95 though the difference was not significant between green manures. Since nutrient uptake is a function of both DMP and the nutrient concentration, the high DMP under green manure treatments increased the uptake of these nutrients.

Nitrogen timings resulted in greater uptake of both P and K. As discussed earlier, appropriate N timing strategies stimulated vegetative growth. The resultant foraging capacity of the roots (Diekmann *et al.*, 1993) might have led to increased uptake of these nutrients. The data indicate that the N application timings that continued upto heading (N_3 and N_2) increased the P and K uptake significantly over other N timings. Similar observations have been reported by Cassman and Samson (1994).

5.8 Grain yield

Nitrogen raises grain production since it is a substrate for synthesis of organic-N compounds which constitute protoplasm and chloroplasts (Yoshida and Oritani, 1974; and Beringer, 1980). In the present study also it was seen that the leaf N content got increased with the strategy of N (150 kg N ha^{-1}) application in six equal splits starting from planting spreading upto heading (N_3); or application of same dose in three equal splits from ET upto heading (N_2). Studies have shown that N and chlorophyll content of rice leaves are so closely related (Greenwood *et al.*, 1991), that a deficiency of N may bring about a sharp decline in the photosynthetic activity of the leaves (Barker, 1979; and Maskina *et al.*, 1992).

The amount of leaf N, that is to say, the amount of photosynthetic enzymes often become limiting factor for the photosynthetic process to proceed (Tsuhoda, 1979) under unfavourable N timing strategy as occurred in early N application (N_1) in this experiment. Under the continued N split strategy from planting to heading (N_3) or from ET to heading (N_2), this limiting factor was eliminated as evident from optimum leaf N concentration throughout the growth period (Tables 28 to 31). In N_2 timing the early N demand of the crop was met from the native N as evident from comparable leaf N concentration in unfertilized and fertilized plots during the early tillering stage.

From the foregoing discussion it is clear that N supply in line with the crop demand (N_3 and N_2 timings) resulted in increased net photosynthesis which produced favourable effect on various growth and yield parameters (Tables 53 to 56) culminating in higher grain yield (Table 61; Fig.20). The yields under the six split strategy (5.37 to 7.39 t ha^{-1}) and three split strategy (4.67 to 7.11 t ha^{-1}) were substantially higher than other N timings as a result of N fertilization at heading stage. Corroborative results were obtained by Singh and Bhattacharjee (1988), Dash *et al.* (1994) and Rao *et al.* (1994) also.

Averaged over experiments, rice yields increased from 3.91-4.69 t ha^{-1} with unfertilized plot (N_0) to 6.40-7.39 t ha^{-1} with N_3 timing in *kharif* season whereas such an increase was limited in *rabi* seasons. In this season, the yield in N_3 timing ranged from 5.37 to 5.84 t ha^{-1} whereas in N_0 it was from 3.04 to 3.24 t ha^{-1} over the years. Reduction in yield and dry matter was found to be associated with decrease in tiller number, phytomass yield; and panicle number and panicle length in relation to N timings (Table 53 to 56). Similar observations have been reported by Makarim *et al.* (1994) and Thiyagarajan *et al.* (1994a).

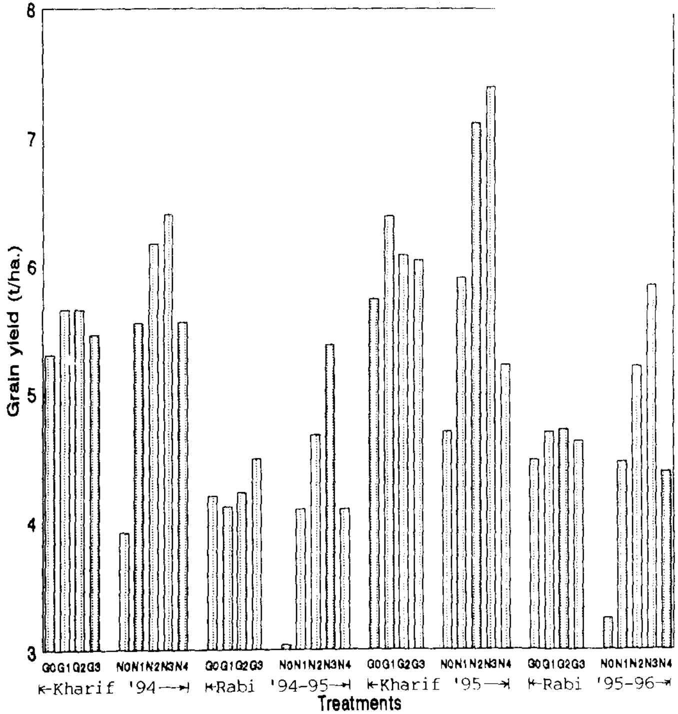


Fig. 20. Grain yield by green manures and N timings

Though green manures increased the growth and yield, the difference in yield due to different green manures was significant only in *kharif* '95 season (Table 61). The results underscore the superiority of short-term application of green manures. The yield capacity of rice is due to panicle number, spikelet number and size of hull (Singh and Bhattacharjee, 1988). Grain yield in this experiment was significantly correlated with number of panicles, length and weight of panicle, and number of filled grains per panicle as evident from the strong relationship between these parameters (Table 68; Fig.23). The N uptake by the plant was also strongly related with these yield components and consequent yield (Fig.24). The yield components such as panicle number; and length and weight of panicle showed substantial increase in sesbania green manure (G_1) treatment (Table 54 and 56). The various growth parameters such as dry matter yield, plant height and tiller number also showed an increase. The yield increase obtained in the sesbania (G_1) treatment, therefore is the culminative effect of all these increases.

The straw yield was highest in N_4 timing compared to other N timings. It was possibly due to the excess vegetative growth by application of 100 kg N at PI stage and thus the continued vegetative growth till maturity inconcomitant to the grain yield. In other treatments the inherent nature of rice in grain yield-straw yield ratio (1:1) was evident.

The advantage of green manures in increasing rice yield was evident from the interaction effects. Even in plots where no fertilizer-N was applied the yield was improved by application of green manures, over non-green manure treatment. The combined effect of green manures with N timings was evident in *kharif* '95 only, where the combination of N_3 timing with sesbania incorporation resulted in the highest yield (8.48 t ha^{-1}). In this season, the NH_4^+-N release from sesbania was at a higher rate especially during the tillering stage. This NH_4^+-N would have been effectively utilized by the crop. Further, the continuous N supply through more splits in N_3 timing helped for the steady maintenance of all growth factors. The green manure incorporation also would have resulted in reduced losses of applied N as has been reported by Diekmann *et al.* (1993). The combined effect of green manure with better N timing strategies confirm the suggestion that the effect of N application could be improved much if combined with green manures. The better performance of green manures over non-green manure in unfertilized plots indicates the nutritional and non-nutritional benefits of green manures.

The data on apparent N recovery (Table 70; Fig.22) and N use efficiency (Table 71; Fig.21) shows the seasonal variations in the recovery of the applied fertilizer-N by the crop as well as in the efficiency of the recovered N for grain production (Agronomic efficiency). Both these parameters were better in *kharif* seasons compared to *rabi* seasons. Comparatively limited rainfall during *kharif* season might have restricted the leaching losses of applied N, enabling higher recovery by the crop. This has resulted in better crop growth and yield in *kharif* season. Because of the better growth with adequate 'source' and 'sink capacity' in the crop, the recovered N would have been effectively utilized for grain production which resulted in higher agronomic efficiency in *kharif* season. The *kharif* season was not only favourable for the recovery of applied N, but also effecting substantial difference in N recovery and agronoic efficiency (AE) of green manures. Sesbania being rich in N content, early decomposition leading to quick release of NH_4^+-N, enhanced the crop N recovery and yield and the resultant agronomic efficiency.

The N application strategy of six splits from planting spreading to heading (N_3) and three splits from ET to heading (N_2) resulted in higher recovery of N at maturity (Fig.22) and agronomic efficiency of the recovered N (Fig.21) by the plant. The ANR was highest with N_3 timing (48.4 to 59.1%) followed by N_2 (39.2 to 56.4%) whereas in N_1 and N_4 it was much reduced. Similarly the AE was also highest in N_3 (15.5 to 18.0 kg grain kg N^{-1}) followed by N_2 (10.8 to 16.1 kg grain kg N^{-1}). The N_3 timing of N application favoured a steady maintenance of soil NH_4^+-N throughout the crop growth, and at least during the active vegetative and reproductive phases with N_2 timing to

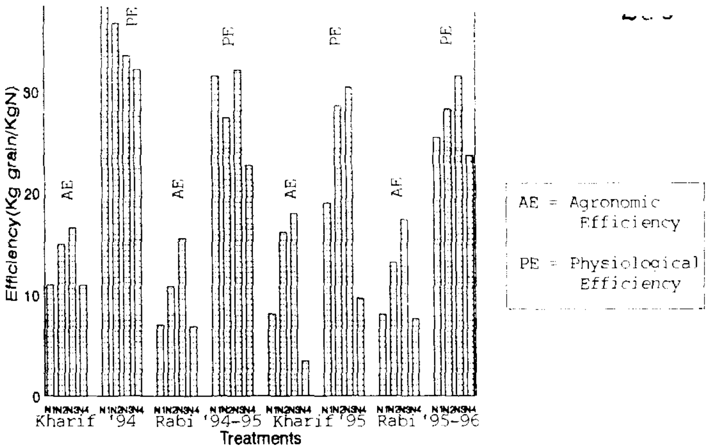


Fig. 21. N use efficiency under N timings

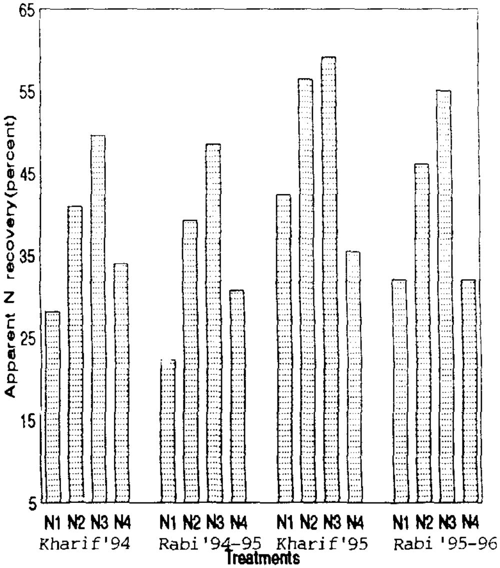


Fig. 22. Apparent N recovery under N timings

cope up with higher the N demand enabled the crop for high N uptake these stages (Palm *et al.*, 1988). Further, in these treatments the 'priming effect' by applied N at heading was evident from the higher N uptake during H-M period. The cumulative effects of all these factors resulted in higher recovery of the added fertilizer in N_3 and N_2, compared to N_1 and N_4. In N_1 and N_4, application of the entire dose of fertilizer was over by PI stage. The losses of applied N in the initial stages would have been more due to low crop N demand and uptake capacity (Meelu and Gupta, 1980). As the availability of N was less in the treatments N uptake during H-M stage was also low and resulted in limited recovery of the applied N and consequent yields. The two major source of N accumulation in grain are by translocation from the vegetative tissues and absorption by the plant during grain filling stage (Ingram *et al.*, 1991). The translocation of recovered N from the vegetative tissues to the grain (Table 48) and N uptake during H-M stage was at a higher rate in N_3 and N_2 treatments. As such in these treatments better crop growth with increased number of tillers provided adequate 'source' capacity. Higher number of productive tillers with more number of spikelets provided sufficient 'sink' for the N accumulation. In N_3 and N_2 timings the number of filled grain was substantially higher than other N treatments. The higher amount of translocated N combined with late season absorbed N enabled the crop to equip

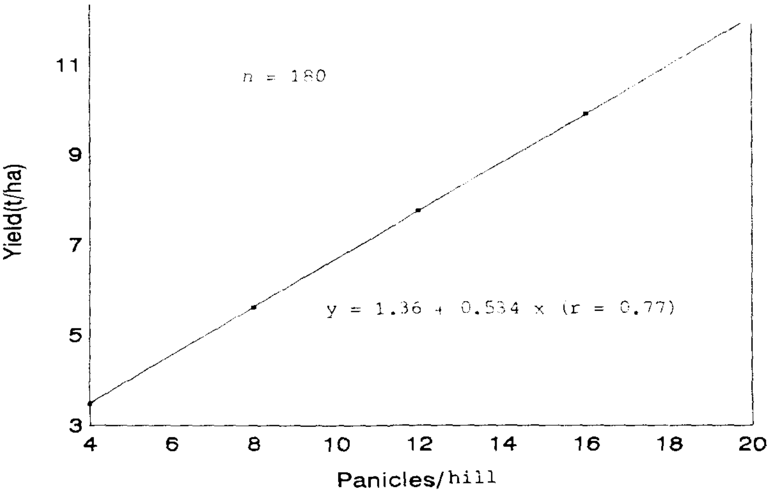


Fig. 23. Grain yield as a function of panicle number

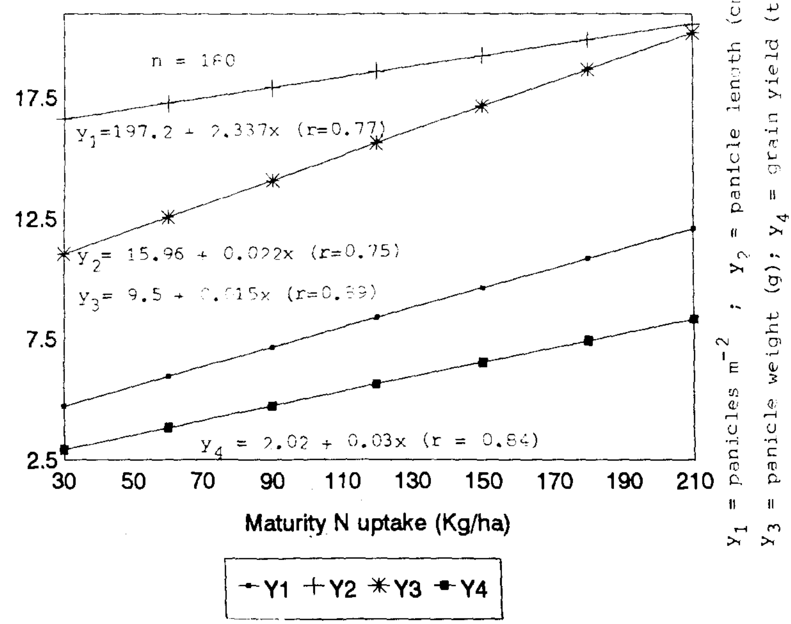


Fig. 24. Grain yield and yield characteristics

with more number of filled spikelets and consequent increase in yield and AE with N_3 and N_2 timings.

It is important in the sense that N assimilation consists of uptake and translocation in plant. On an average there was 43.70 to 74.39 kg N translocated from plant parts to grain in N_3 and N_2 whereas in N_0 and N_1 it ranged from 24.50 to 79.25 kg ha^{-1}. Substantial variation in N assimilation existed with N timings. In N_4, the high N translocation did not result in high yield due to poor sink. This can be interpreted in terms of the fact that the level N_3 and N_2 is clearly related to the N supply during the particular growth stage of the crop. Increased recovery and agronomic efficiency of N applied at later stages of crop growth has been earlier reported by Patnaik and Broadbent (1967); and Reddy and Patrick (1978). The N recovery and agronomic efficiency observed in this experiment are comparable to the values reported by Sivasamy *et al.* (1994) and Thiyagarajan *et al.* (1994a) in similar type of soils.

The harvest index (HI) of the crop (Table 67) was not much influenced by the seasonal effect or by green manure effect, though in general higher grain yield was observed in *kharif* seasons. The data (Table 61 and 66) shows that the grain yield increased concomitantly with biological yield. It may be recalled that the conditions favourable for growth parameters favoured the yield parameters and effected greater translocation of 'source' to the 'sink'. This resulted in a grain yield in almost equal proportion to the biological yield. Since the growth and development of crop was of similar trend for both 'economic' and 'biological' yield, their ratio (HI) was not much altered by seasonal effects. The same was true with the effect of green manures also.

Various N timing treatments also did not cause a conspicuous difference in HI, except that in the timing which received 50 kg N at ET and 100 kg N at PI stage this parameter was generally low (around 0.46). As already discussed, since HI of rice is mostly an inherent character (Yoshida, 1981) it could not be altered much with the management strategy (Matsushima, 1976). Application of 100 kg N at PI stage allowed rapid increase in the vegetative tissues around the heading stage. But limitation of N supply during the grain development stage reduced the 'sink' capacity. As a result the translocated 'source' was not effectively accumulated in the 'sink' which resulted in low grain yield. Higher vegetative growth without a concomitent increase in grain yield resulted in lower HI as reported by Dash *et al.* (1994).

5.9 Post-harvest soil nutrient analyses

The status of organic carbon (OC) in soil (Table 72) showed small increase in OC after second season green manure application. The total N and available N (Table 73) was also found substantially increased by green manure incorporation. The lack of significant increase in OC by green manure incorporation in the first *kharif* season was probably due to the fast mineralisation of added green manures that too in less quantity, due to their chemical nature and the high temperature prevailed in the tropical region (Alexander, 1977). However, application of green manures for the second seasons permitted a gradual build up of organic carbon resulting in significant increase in the second *kharif* season. This was possibly due to the cumulative effect of added green manure (Bremner, 1965; and Bouldin, 1988). Continuous addition of green manure for more seasons resulted in increase in total and available N also as has been earlier reported by Bharadwaj and Dev (1985). The cumulative effect of green manure incorporation reflected in increased yield in the second *kharif* in green manure treatments. Further, there was a general yield increase in green manure plots in the second year compared to the first year. This indicates that incorporation of green manures resulted in gradual build up of organic carbon and soil N status (total N 82-148 kg and available 4-19 kg) over the seasons which resulted in improved soil fertility and crop yield. The beneficial effect of organic matter on soil fertility besides yield has been already established by several workers (Hernandez, 1963; and Magabanua *et al.*, 1985).

Application of N fertilizer resulted in a build of total N (75-155 kg) and available and N (5-15 kg) over the seasons whereas with holding N, resulted in a depletion of N status. This indicates that continuous rice cropping without N fertilization would result in a decline of soil fertility as reported by several workers (DeDatta *et al.*, 1988; and Hegde and Diwedi, 1993). Comparing N timings, the difference in N status was not evident indicating that the N timing strategy did not affect the soil N content.

5.10 Economics of rice cultivation with various green manures and N timing strategy

The economic indices viz. net income and B:C ratio (Tables 74 and 75) were high in *kharif* seasons compared to *rabi* seasons. On an average, the net return in *kharif* was Rs.18112/- while in *rabi* it was Rs.12213/-. Similarly the B:C ratio was also high in *kharif* (2.83) compared to *rabi* (2.32). Higher economic yields obtained in *kharif* seasons had its due share in enhancing the economic indices. The higher recovery of applied fertilizer and agronomic efficiency of the recovered N resulted in effective utilization of applied inputs and resulted in higher net returns and B:C ratios.

Application of green manures marginally increased the net return and B:C ratios especially in the second year. The net income (Rs.20434/-) and B:C ratio (2.97) by sesbania incorporation was substantially higher than other green manures. The grain yield pattern associated with green manure incorporation explains that the yield increase due to green manuring was comparatively higher in the second year. This had resulted in higher net income and B:C ratio.

As in all other parameters such as ANR, AE, HI etc., the influence of N timings on net income and B:C ratios was also highly conspicuous. The timing of N application from planting spreading to heading in six small splits (N_3) gave the highest net return (Rs.21091/- to Rs.25054/- in *kharif* and Rs.16502/- to Rs.18563/- in *rabi*) and B:C ratio (3.03 to 3.42 in *kharif* and 2.69 to 2.90 in *rabi*). This was followed by N_2 timing which received N from ET spreading upto heading. The details of cost of cultivation (Appendix V to IX) shows that it was not much altered by changing the strategy of N application. But better N timings as in N_3 and N_2 gave significant yield increase over other N timings. The higher grain yield in these treatments due to higher recovery and efficiency of the applied N reflected in the advantageous economic indices. Poor utilization of inputs associated with poor growth and yield in other treatments adversely affected the economic returns and B:C ratios.

The favourable interaction effects of better N timings (N_3 and N_2) combined with green manures was evident from higher net income and B:C ratios, compared to other combinations. The practice of sesbania (G_1) green manuring combined with six split N application (N_3) gave the highest net income (Rs.29770/-) and B:C ratio (3.80). This indicatesthat higher economic returns and profitability could be achieved by the combined application of green manures with proper N management strategy to attain maximum yields.

SUMMARY

Chapter VI

SUMMARY AND CONCLUSION

Field experiments were conducted at Tamil Nadu Agricultural University, Coimbatore during the *kharif* and *rabi* seasons of 1994-'96, to study the interactive effects of green manures and timings of N fertilizer application on the changes in crop N relationships, growth and productivity; and uptake, recovery and efficiency of applied N in lowland transplanted rice. The main-plot treatments consisted of three green manures applied to supply 54 kg N ha^{-1} viz., sesbania (*Sesbania rostrata*), cowpea *(Vigna unguiculata)* and parthenium *(Parthenium hysterophorus)* and one non-green manure treatment. Application of 150 kg N ha^{-1} at varying quantities at different growth stages of the crop along with one control (no N) (total five treatments) were the sub-plot treatments. The soil NH_4^+-N flux, time course behaviour of N concentration, biomass accumulation and N uptake in the crop; uptake and recovery of isotope (^{15}N) and non-isotope N; leaf chlorophyll-N relationships; efficiency of applied N; and growth and yield of rice were closely monitored.

A summary of the findings from the results of the present investigations is presented in this chapter.

6.1 Growth and yield

The grain yields of rice were higher in *kharif* seasons, than in *rabi* seasons due to better growth, biomass accumulation; and uptake, recovery and efficiency of the applied N. The net income and B:C ratios were also high in *kharif* seasons.

The favourable effect of green manures on growth (plant height, tiller number and biomass) and yield attributes (number of panicles; and panicle length and weight) and on grain and straw yields was evident in the second season of green manure addition. Though the influence of green manures on these parameters was inconsistent over seasons the parameters showed an increasing trend with green manure addition compared to non-green manure plots.

Nitrogen exerted significant effect on grain yield. The difference in the effect of early application of N (150 kg or less) on growth parameters got narrowed down at heading stage. After heading stage the growth and yield components behaved more or less as a function of N application at heading. Biomass accumulation as well as growth rate (CGR) got increased by N supply at heading. Therefore, it could be concluded that the strategy of applying 150 kg N ha^{-1} in six staggered splits from planting spreading to heading or delaying the first N application upto ET (50 kg N) stage and subsequent two splits at PI and heading stages (50 kg N each) were found to be advantageous in increasing the yield and economics of rice irrespective of the season of cropping. These N timings resulted in an yield increase of 11 to 33 per cent over other N timings.

The time course behaviour of crop biomass accumulation was of quadratic model in the case of stem and leaf and of linear model in the case of crop total biomass. Accumulation of photosynthates in stem and leaf upto panicle emergence resulted in attaining maximum biomass in these parts at heading and translocation photosynthates to the grain from stem and leaf caused a decline of biomass after heading. Application of N at heading caused an increase in the amount as well as rate of accumulation during grain filling stage due to adequate N availability from the applied N and primed out native soil N which ultimately resulted in higher yields.

6.2 NH_4^+-N release pattern

Incorporation of green manures increased soil NH_4^+-N content and the effect was pronounced during the peak period of soil NH_4^+-N content. The peak period of soil NH_4^+-N content occurred between the second and fourth week after transplanting rice. During the peak period of soil NH_4^+-N content, in green manure plots it was 7.90 to 21.89 ppm higher than that in non-green manure plots.

Application of N fertilizer resulted in an immediate spurt in soil NH_4^+-N, but it declined within a few days. Due to faster N uptake by the crop, the decline was rapid during late growth stages. Continued splits (150 kg N ha^{-1} in six equal splits) ensured a steady NH_4^+-N supply to the crop throughout the growth period. Similarly, skipping of basal N and application of 150 kg N in three equal splits starting from early tillering stage onwards also sufficiently met the crop N demand for high yield since the demand for N at early stage was low and could be met from the native soil N.

The mathematical models developed from the data predicted a similar NH_4^+-N release pattern as observed in these experiments.

6.3 N concentration and translocation

Incorporation of green manures did not cause a marked increase in plant-N concentration whereas application of fertilizer-N brought out appreciable increase in this parameter. Application of N in six staggered splits from planting to heading or in three splits from early tillering to heading sustained the leaf N concentration at optimum levels for higher grain yields. Early N application but limitation of N supply at later stages decreased the plant N concentration during grain filling stage and reduced the grain yield.

The N need for grain filling was partially met from the translocated N from leaf and stem and partially from the N absorbed by the plant during heading-maturity period. Leaf contributed more N than stem for the translocation pool of N in the crop. Application of N at heading increased the translocation of N from stem (20.00-33.01 kg) and leaf (19.9-41.9 kg) to grains and also increased the post-anthesis N uptake by the crop.

If N application was stopped by PI stage, both N translocation from vegetative tissues to the grain and N absorption by the plant during post-anthesis period were reduced and resulted in low yields. Excessive N application at PI stage saturated the crop with adequate N before heading stage permitting more remobilization of N, but the limitation of 'sink' resulted in crop-N losses. Further, the post-anthesis N uptake was also limited and resulted in low yields.

The mathematical models developed to predict the time cause behaviour of leaf-N concentration in rice under different N timing strategies corroborated well with the observed values of leaf N concentration in these experiments.

6.4 Leaf chlorophyll (SPAD) - N relationship

The results of strong relationship between chlorophyll meter (SPAD) readings and leaf-N concentration (r=0.75); and between SPAD readings and grain yield (r=0.72) observed in the experiment allows prediction of plant-N status based on SPAD readings. The Lorentzian model was found to be the best fitting one for the prediction of leaf N from the observed SPAD values. The model predicted the leaf N, which was reasonably well correlated with the observed leaf N upto 12 days after heading. It could be concluded that the SPAD meter can be used to diagnose the rice leaf-N status and to decide appropriate time of N top dressing if the time course optimum leaf N in rice was worked out. It is quick, simple and non-destructive method of N estimation unlike the N analyses based on Kjeldahl's procedure.

6.5 Uptake and recovery of N

The uptake of N in the plant parts (stem and leaf) and the total N uptake by the crop followed a similar trend to that of biomass accumulation. Larger doses of N in limited splits substantially decreased the N uptake by the crop due to the increased losses of N from the soil as well as from the crop. The difference in N uptake between N timings became marginal by heading stage. The N uptake after heading was increased by N application at heading. Similarly the rate of N uptake was also increased. The crop which received fertilizer-N at heading accumulated N at a rate around 0.56 kg ha^{-1} day^{-1}. Due to the higher amount and rate of N uptake during between SPAD readings and grain yield (r=0.72) observed in the experiment allows prediction of plant-N status based on SPAD readings. The Lorentzian model was found to be the best fitting one for the prediction of leaf N from the observed SPAD values. The model predicted the leaf N, which was reasonably well correlated with the observed leaf N upto 12 days after heading. It could be concluded that the SPAD meter can be used to diagnose the rice leaf-N status and to decide appropriate time of N top dressing if the time course optimum leaf N in rice was worked out. It is quick, simple and non-destructive method of N estimation unlike the N analyses based on Kjeldahl's procedure.

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The ANR from green manure-N ranged from 7.4 to 39.0 per cent and that from fertilizer-N ranged from 22.2 to 59.1 per cent. The N application strategy of six splits from planting to heading or from early tillering to heading gave higher recovery of the applied N (39.2 to 59.1%).

6.6 ^{15}N studies

Addition of green manure resulted in increased uptake of total N (soil N + fertilizer ^{15}N) and fertilizer ^{15}N. Larger dressing of fertilizer-^{15}N at planting or PI stage decreased the ^{15}N uptake and ^{15}N recovery by the crop. Application of a part of ^{15}N at heading increased the ^{15}N uptake (50.3-53.1 kg ha^{-1}) and recovery (33.53-35.46%) at maturity stage by better utilization of ^{15}N during the post-anthesis period.

Total N uptake increased with crop age upto maturity. The fertilizer-N uptake declined from heading to maturity if ^{15}N was not applied at heading. This indicates continued uptake of soil N by the crop even after heading and enhancement of N uptake after heading by late N supply.

6.7 N use efficiency

In general, in *kharif* season, agronomic efficiency of applied N was higher, compared to *rabi* season. Sesbania incorporation resulted in higher agronomic efficiency (6.7 to 12.2 kg grain kg N^{-1}). The agronomic efficiency of green manure-N ranged from 3.0 to 12.2 kg and that of fertilizer-N ranged from 3.4 to 18.0 kg.

Application of 150 kg N ha^{-1} in six splits @ 25 kg each from planting spreading upto heading gave the highest agronomic efficiency (15.5-18.0 kg). Skipping basal N and applying 150 kg N in 3 splits from early tillering upto heading stage gave the agronomic efficiency comparable to the six split strategy (10.8-16.1 kg). Applying larger doses of N at planting or panicle initiation stage decreased the agronomic efficiency (3.4-10.9 kg).

6.8 Harvest index

The harvest index in rice did not vary much by the seasonal effect, green manure incorporation or by N management strategies. However, application of 100 kg N at PI stage caused excessive vegetative growth around heading stage inconcomitent to the grain yield and resulted in low harvest index (0.46-0.48) compared to other treatments (0.49-0.59).

6.9 Economics

Both net income and B:C ratios were increased by green manure incorporation and the increase was pronounced in the second year. The net income (Rs.20434/-) and B:C ratio (2.97) by sesbania incorporation was substantially higher than other green manures.

Cost of cultivation was not much varied by changing the N timing strategies. But the appreciable yield increase by better N timings starting from planting and continued upto heading; or starting from early tillering but continued upto heading increased the net income and B:C ratios compared to inefficient N timings. The average net income in these treatments ranged from Rs.21809/- to 23073/- in *kharif* and and Rs.14455/- to 17533/- in *rabi*. The B:C ratios ranged from 3.11 to 3.23 in *kharif* and from 2.49 to 2.80 in *rabi*. The incorporation of sesbania combined with six split N timings gave the highest net income (Rs.29770/-) and B:C ratio (3.80).

6.10. Soil fertility

Green manuring and N fertilization increased the organic carbon; and available and total N in soil. Rice cropping without green manure application or N fertilizers resulted in decline of soil fertility. The increase in available N over the initial status after the fourth crop of rice ranged from

4 to 19 kg and that of total N from 82 to 148 kg by green manure addition.

From the overall results it could be concluded that, for improving the soil fertility and rice productivity green manure incorporation is necessary. The beneficial effect of green manures would be evident only by continuous addition. Timing of N application plays a key role in enhancing the growth and yield of rice. The strategy of applying 150 kg N ha^{-1} from planting to heading in six equal splits was found to be the best N top dressing technology to maximize grain yield and economic returns. Even postponement of the first application upto early tillering and spreading the application upto heading stage in three equal splits could be recommended. The SPAD meter can be used to diagnose rice-N status to decide appropriate timing of N side-dressing.

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Chapter VII

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APPENDICES

Appendix - I

Weather parameters during the cropping period - *Kharif* '94

:and-:d ›ek	Period	Mean maximum temper-ature (°C)	Mean minimum temper-ature (°C)	Mean RH (%) 07.22	Mean RH (%) 14.22	Total rain-fall (mm)	Rainy day (no.)	Mean sun-shine hours	Mean Evap. (mm)	Wind velo-city (Kmph)	Solar radiation (Cal cm^{-2} day^{-1})
4	June 11-17	30.4	24.0	71	52	2.1	-	2.5	5.9	24.2	343
5	18-24	32.7	23.8	67	42	-	-	3.5	8.7	21.5	478
6	25-1	31.4	23.8	66	50	10.9	1	3.1	6.7	23.8	398
7	July 2-8	30.7	22.4	77	52	2.5	1	4.3	6.0	14.6	349
8	9-15	28.8	22.8	77	67	112.7	5	1.3	4.1	24.1	239
9	16-22	29.7	23.2	68	54	-	-	3.6	6.9	23.5	361
0	23-29	30.3	23.0	78	58	1.7	-	1.5	4.6	17.7	295
1	30-5	29.3	22.7	79	53	7.5	1	2.8	5.2	16.9	282
2	Aug. 6-12	32.2	21.8	84	49	-	-	6.1	6.0	9.8	391
3	13-19	31.5	22.2	81	49	-	-	3.9	5.8	11.7	334
4	20-26	32.4	21.8	83	51	-	-	2.8	5.3	12.4	325
5	27-2	30.3	23.1	71	59	5.0	1	3.2	5.5	26.4	348
6	Sept 3-9	31.4	22.9	78	55	12.2	1	6.6	6.7	17.6	390
7	10-16	32.1	20.9	84	52	-	-	7.6	6.0	8.4	422
8	17-23	33.8	20.8	80	48	-	-	9.8	7.1	13.3	440

Appendix - II

Weather parameters during the cropping period - *Rabi* '94-95

tand- rd eek	Period		Mean maximum temper- ature (°C)	Mean minimum temper- ature (°C)	Mean RH (%) 07.22	Mean RH (%) 14.22	Total rain- fall (mm)	Rainy day (no.)	Mean sun- shine hours	Mean Evap. (mm)	Wind velo- city (Kmph)	Solar radiation (Cal cm^{-2} day^{-1})
3	Oct.	22-28	28.9	21.8	90	69	161.1	6	4.7	2.0	8.2	295
4		29-4	28.9	21.8	90	73	120.0	6	4.3	2.4	3.4	341
5	Nov.	5-11	26.7	21.0	78	74	48.7	4	2.1	2.4	7.5	295
6		12-18	27.6	21.3	75	70	20.0	2	4.8	2.4	3.0	353
7		19-25	28.9	20.4	85	61	1.6	-	5.9	3.8	6.0	396
8		26-2	29.8	17.8	89	61	-	-	8.2	3.3	3.4	433
9	Dec.	3-9	28.6	15.6	89	54	-	-	9.4	3.4	4.4	506
50		10-16	28.7	18.5	86	57	-	-	9.1	3.6	5.2	468
51		17-23	28.7	16.9	84	60	1.6	-	5.0	3.4	8.5	325
52		24-31	28.7	21.3	86	56	-	-	7.1	3.7	7.2	413
1995 1	Jan.	1-7	28.2	16.8	89	53	1.0	-	5.6	3.4	5.6	368
2		8-14	30.5	21.1	87	57	1.8	-	7.0	2.3	4.7	399
3		15-21	29.0	20.5	87	66	1.0	-	5.8	4.2	9.2	331
4		22-28	30.4	17.9	86	38	-	-	8.5	4.6	7.0	470
5		29-4	30.0	21.0	83	46	-	-	7.7	5.1	7.3	393
6	Feb.	5-11	31.1	19.2	85	45	-	-	8.9	4.8	8.3	444

Appendix - III

Weather parameters during the cropping period - *Kharif* '95

tand- rd eek	Period		Mean maximum temper- ature (°C)	Mean minimum temper- ature (°C)	Mean RH (%) 07.22	Mean RH (%) 14.22	Total rain- fall (mm)	Rainy day (no.)	Mean sun- shine hours	Mean Evap. (mm)	Wind velo- city (Kmph)	Solar radiation (Cal cm^{-2} day^{-1})
995												
1	May	21-27	34.0	23.0	82	61	13.0	1	9.3	5.6	6.2	427
2		28-3	34.3	23.9	84	56	-	-	8.1	5.7	7.0	432
:3	June	4-10	34.1	23.9	78	51	-	-	7.9	7.1	11.8	448
:4		11-17	30.8	23.1	77	57	7.0	-	5.4	5.9	16.5	382
:5		18-24	32.1	23.0	81	57	-	-	6.6	5.4	10.5	388
:6		25-1	31.8	23.4	75	62	2.5	-	5.6	5.5	13.6	373
:7	July	2-8	32.6	22.4	78	53	3.2	-	6.8	7.1	15.7	430
:8		9-15	30.7	24.4	77	60	12.5	2	3.4	6.3	18.0	330
:9		16-22	30.0	23.1	74	66	17.0	2	3.1	5.4	19.8	311
30		23-29	31.0	22.0	89	66	2.5	-	4.1	4.5	8.0	318
31		30-5	31.8	25.5	79	53	-	-	7.6	6.7	13.2	404
32	Aug.	6-12	31.5	22.9	84	54	30.4	2	7.2	5.0	9.8	395
33		13-19	32.2	22.1	83	59	-	-	7.2	6.0	9.0	397
34		20-26	32.5	23.1	76	52	4.8	-	5.6	5.3	7.3	360
35		27-2	29.4	23.0	78	75	14.5	1	2.8	5.1	22.9	308

Appendix - IV

Weather parameters during the cropping period - *Rabi* '95-96

tand-rd eek	Period	Mean maximum temper-ature (°C)	Mean minimum temper-ature (°C)	Mean RH (%) 07.22	Mean RH (%) 14.22	Total rain-fall (mm)	Rainy day (no.)	Mean sun-shine hours	Mean Evap. (mm)	Wind velo-city (Kmph)	Solar radiation (Cal cm^{-2} day^{-1})
9	Sept. 24-30	32.6	21.1	86	51	8.0	1	8.3	5.4	6.1	389
0	Oct. 1-7	32.8	22.4	91	59	17.5	2	5.2	4.3	4.3	323
1	8-14	31.7	21.9	80	52	2.0	-	7.9	5.5	5.5	384
2	15-21	32.7	21.9	84	58	14.5	1	7.6	5.3	6.4	401
3	22-28	30.5	22.2	88	66	66.0	7	7.7	3.7	7.0	381
4	29-4	30.9	22.4	90	64	36.4	3	6.0	3.3	4.2	365
15	Nov. 5-11	29.0	22.3	91	74	45.0	2	4.0	2.4	3.0	318
16	12-18	30.0	20.2	89	61	26.5	2	7.0	2.6	2.7	402
17	19-25	30.9	21.5	86	64	-	-	7.7	3.3	2.9	431
18	26-2	30.8	18.8	88	62	-	-	8.1	3.4	3.5	435
19	Dec. 3-9	29.6	16.9	89	58	-	-	9.2	3.5	4.5	495
50	10-16	29.7	19.2	86	58	-	-	9.1	3.7	5.1	475
51	17-23	29.7	16.9	85	60	-	-	8.0	3.5	7.9	342
52	24-31	29.7	21.3	86	55	-	-	7.5	3.7	7.2	422
1	Jan. 1-7	28.2	20.5	85	57	-	-	7.9	3.6	7.3	425

Appendix-V

Details of cost of cultivation of rice

Sl. No.	Particulars	Inputs	Rate (Rs.)	Total cost (Rs. ha^{-1})
General cost of cultivation				
1.	Preparatory cultivation			
	i. Tractor ploughing twice	1 tractor for 4 hours	90 hr^{-1}	720.00
	ii. Levelling the field	1 tractor for 4 hours	90 hr^{-1}	360.00
2.	Seeds and sowing			
	i. Cost of seed	80 kg	9.00 kg^{-1}	720.00
	ii. Nursery preparation and sowing	1 man day	40.00 day^{-1}	40.00
		2 womendays	35.00 day^{-1}	70.00
3.	Pulling out nursery and transplanting	30 womendays	35.00 day^{-1}	1050.00
4.	P and K fertilizers			
	i. Cost	50 kg P_2O_5 ha^{-1}	15.00 kg^{-1}	750.00
		50 kg K_2O ha^{-1}	8.50 kg^{-1}	425.00
	ii. Application charges	1 man day	40.00 day^{-1}	40.00

5.	Hand weeding twice	35 womendays	35.00 day^{-1}	1225.00
6.	Irrigation	5 mendays	40.00 day^{-1}	200.00
7.	Plant protection			
	i. Cost of chemicals	Hinosan-500 ml	344.00	344.00
		Ekalux 1000 ml	220.00	220.00
	ii. Application charges	1 manday	40.00 day^{-1}	40.00
8.	Harvesting, threshing and cleaning	20 mendays	40.00 day^{-1}	800.00
		35 womendays	35.00 day^{-1}	1225.00
9.	Land rent for one season		300.00	300.00
	Total			8529.00

Production cost of sesbania

1.	Preparatory cultivation			
	i. Tractor ploughing once	1 tractor for 4 hours	90.00 hr^{-1}	360.00
	ii. Clods breaking and levelling	1 tractor for 4 hours	90.00 hr^{-1}	360.00
2.	Seeds and sowing			
	i. Cost of seed	20 kg	15.00 day^{-1}	300.00
	ii. Sowing	1 manday	40.00 day^{-1}	40.00

3. Irrigation	3 mendays	40.00 day^{-1}	120.00
4. Cutting	8 womendays	35.00 day^{-1}	280.00
Total cost of production (estimated yield: 20 t ha^{-1}			1460.00
i. Cost of production of 6.25 t			456.00
ii. Transportation and tranplanting	12 women days	35.00 day^{-1}	420.00
Total cost of sesbania incorporation			876.00

Production cost of cowpea

1. Preparatory cultivation			
i. Tractor ploughing once	1 tractor for 4 hours	90.00 hr^{-1}	360.00
ii. Clods breaking and levelling	1 tractor for 4 hours	90.00 hr^{-1}	360.00
2. Seeds and sowing			
i. Cost of seed	20 kg	16.00 kg^{-1}	320.00
ii. Sowing	1 manday	40.00 day^{-1}	40.00
3. Irrigation	3 mendays	40.00 day^{-1}	120.00

4.	Cutting	8 womendays	35.00 day^{-1}	280.00
	Total cost of production (estimated yield : 20 t ha^{-1})			1480.00
	i. Cost of production of 6.25 t			463.00
	ii. Transportation and trampling	12 women days	35.00 day^{-1}	420.00
	Total cost of cowpea incorporation			883.00

Cost of parthenium

1.	Collection of parthenium (6.25 t)	1 woman day t^{-1}	35.00 day^{-1}	219.00
2.	Transportation and trampling	15 womendays	35.00 day^{-1}	525.00
	Total			744.00

Cost of applied nitrogen

Cost of fertilizers	150 kg N ha^{-1}	7.50 kg^{-1}	1125.00

Appendix-VI

Details of economics of rice cultivation - *Kharif* '94

Treatments	Total cost (Rs ha^{-1})	Yield (t ha^{-1}) Grain	Yield (t ha^{-1}) Straw	Gross income (Rs.ha^{-1})	Net income (Rs.ha^{-1})	Benefit cost ratio
G_0 N_0	8529	3.52	3.87	17388	8859	2.04
G_0 N_1	9714	5.46	5.58	26802	17088	2.76
G_0 N_2	9714	5.72	6.25	28240	18526	2.91
G_0 N_3	9774	5.92	6.62	29288	19514	3.00
G_0 N_4	9734	5.82	6.44	28766	19032	2.96
G_1 N_0	9405	3.71	3.95	18275	8870	1.94
G_1 N_1	10590	5.86	5.70	28650	18060	2.71
G_1 N_2	10590	6.70	6.39	32706	22116	3.09
G_1 N_3	10650	6.59	6.77	32363	21713	3.04
G_1 N_4	10610	5.40	6.59	26936	16326	2.54
G_2 N_0	9412	4.14	3.93	20202	10790	2.15
G_2 N_1	10597	5.55	5.67	27243	16646	2.57
G_2 N_2	10597	6.10	6.34	29986	19389	2.83
G_2 N_3	10657	6.82	6.72	33378	22721	3.13
G_2 N_4	10617	5.66	6.54	28086	17456	2.65
G_3 N_0	9273	4.27	3.97	20803	11530	2.24
G_3 N_1	10458	5.28	5.73	26052	15594	2.49
G_3 N_2	10458	6.15	6.42	30243	19785	2.89
G_3 N_3	10518	6.27	6.80	30935	20417	2.94
G_3 N_4	10478	5.30	6.62	26498	16020	2.53

Appendix-VII

Details of economics of rice cultivation - *Rabi* '94-95

Treatments	Total cost (Rs.ha^{-1})	Yield (t ha^{-1}) Grain	Yield (t ha^{-1}) Straw	Gross income (Rs.ha^{-1})	Net income (Rs.ha^{-1})	Benefit cost ratio
G_0 N_0	8529	2.98	2.49	14406	5877	1.69
G_0 N_1	9714	3.56	3.69	17496	7782	1.80
G_0 N_2	9714	4.90	4.70	23930	14216	2.46
G_0 N_3	9774	4.96	5.10	24360	14586	2.49
G_0 N_4	9734	4.17	4.77	20673	10939	2.12
G_1 N_0	8529	2.83	2.58	13767	5238	1.61
G_1 N_1	9714	4.52	3.81	21864	12150	2.25
G_1 N_2	9714	4.35	4.86	21519	11805	2.22
G_1 N_3	9774	5.47	5.28	26727	16953	2.73
G_1 N_4	9734	3.78	4.93	18982	9248	1.95
G_2 N_0	8529	2.93	2.58	14217	5688	1.67
G_2 N_1	9714	4.04	3.88	19732	10018	2.03
G_2 N_2	9714	4.90	4.87	23998	14284	2.47
G_2 N_3	9774	5.27	5.29	25831	16057	2.64
G_2 N_4	9734	3.96	4.94	19796	10062	2.03
G_3 N_0	8529	3.40	2.55	16320	7791	1.91
G_3 N_1	9714	4.25	3.77	20633	10919	2.12
G_3 N_2	9714	4.51	4.80	22215	12501	2.29
G_3 N_3	9774	5.80	5.21	28184	18410	2.88
G_3 N_4	9734	4.43	4.87	21883	12149	2.25

Appendix-VIII

Details of economics of rice cultivation - *Kharif* '95

Treatments	Total cost (Rs.ha^{-1})	Yield (t ha^{-1}) Grain	Straw	Gross income (Rs.ha^{-1})	Net income (Rs.ha^{-1})	Benefit cost ratio
G_0 N_0	8529	3.70	3.43	18022	9493	2.11
G_0 N_1	9714	5.51	4.80	26715	17001	2.75
G_0 N_2	9714	7.16	4.71	34104	24390	3.51
G_0 N_3	9774	7.31	5.16	34959	25185	3.58
G_0 N_4	9734	4.96	5.19	24396	14662	2.51
G_1 N_0	9405	5.35	3.75	25575	16170	2.72
G_1 N_1	10590	5.98	5.25	29010	18420	2.74
G_1 N_2	10590	7.47	5.16	35679	25089	3.37
G_1 N_3	10650	8.48	5.65	40420	29770	3.80
G_1 N_4	10610	4.68	5.68	23332	12722	2.20
G_2 N_0	9412	5.20	3.73	24892	15480	2.64
G_2 N_1	10597	5.66	5.22	27558	16961	2.60
G_2 N_2	10597	6.80	5.13	32652	22055	3.08
G_2 N_3	10657	6.86	5.62	33118	22461	3.11
G_2 N_4	10617	5.86	5.65	28630	18013	2.70
G_3 N_0	9273	4.52	3.69	21816	12543	2.35
G_3 N_1	10458	6.44	5.17	31048	20590	2.97
G_3 N_2	10458	7.01	5.08	33577	23119	3.21
G_3 N_3	10518	6.91	5.56	33319	22801	3.17
G_3 N_4	10478	5.33	5.59	26221	15743	2.50

Appendix-IX

Details of economics of rice cultivation - *Rabi* '95-96

Treatments	Total cost (Rs.ha^{-1})	Yield (t ha^{-1})		Gross income (Rs.ha^{-1})	Net income (Rs.ha^{-1})	Benefit cost ratio
		Grain	Straw			
G_0 N_0	8529	3.13	2.50	15085	6556	1.77
G_0 N_1	9714	4.31	4.13	21047	11333	2.17
G_0 N_2	9714	5.03	4.89	24591	14877	2.53
G_0 N_3	9774	5.65	5.00	27425	17651	2.81
G_0 N_4	9734	4.23	5.04	21051	11317	2.16
G_1 N_0	8529	3.29	2.57	15833	7304	1.86
G_1 N_1	9714	4.52	4.26	22044	12330	2.27
G_1 N_2	9714	5.27	5.04	25731	16017	2.65
G_1 N_3	9774	5.92	5.16	28704	18930	2.94
G_1 N_4	9734	4.44	5.20	22060	12326	2.27
G_2 N_0	8529	3.30	2.66	15914	7385	1.87
G_2 N_1	9714	4.54	4.40	22190	12476	2.28
G_2 N_2	9714	5.30	5.21	25934	16220	2.67
G_2 N_3	9774	5.95	5.33	28907	19133	2.96
G_2 N_4	9734	4.46	5.37	22218	12484	2.28
G_3 N_0	8529	3.24	2.59	15616	7087	1.83
G_3 N_1	9714	4.46	4.29	21786	12072	2.24
G_3 N_2	9714	5.20	5.07	25428	15714	2.62
G_3 N_3	9774	5.83	5.19	28311	18537	2.90
G_3 N_4	9734	4.38	5.23	21802	12068	2.24