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The potential of Tithonia diversifolia and other species as green manures for highly productive farming systems in the Nepalese Terai

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THE POTENTIAL OF *Tithonia diversifolia* AND OTHER SPECIES AS GREEN MANURES FOR HIGHLY PRODUCTIVE FARMING SYSTEMS IN THE NEPALESE TERAI

A thesis submitted in candidature for the degree of Philosophiae Doctor

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DEDICATION

This thesis is dedicated to my mother
Karima Devi

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Abstract

This thesis presents the results of field experiments conducted in the highly productive farming system of the Nepalese Terai. The main objective of the research was to investigate the value of *Tithonia diversifolia* (tithonia) as a green manure to increase productivity of the rice crop and improve soil fertility.

Field experiment results indicated that tithonia can be propagated either through seeds or stem cuttings from April to May under the Nepalese Terai environmental conditions. Seed propagation after May is not successful.

The growth rate of tithonia is slower than the commonly used green manure species sesbania (*Sesbania cannabina*). One to one and half tonnes of tithonia dry matter can be harvested from one hectare of land when tithonia is grown for 70-80 days. On average one tonne of tithonia dry matter will supply 31.5 kg N, 4.05 kg P and 10.4 kg K.

A litterbag technique was used to compare the decomposition and nutrient releasing characteristics of tithonia along with the common green manures asuro (*Adhotoda vasica*) and bakaino (*Melia azedarchta*) under three incorporation treatments. At an early stage tithonia decomposed faster than asuro and bakaino but later on there was no difference. Under surface mulching all three green manures decomposed more slowly, than when ploughed into paddy and irrigated. Bakaino released N faster whilst asuro released P faster. Tithonia was intermediate between asuro and bakaino in mass loss and nutrient releasing.

Field experiments were conducted for two cropping seasons on a sandy loam and slightly acidic soil under rice-wheat-fallow and rice-vegetables-maize/green manure or fallow cropping systems. Tithonia was tested for its potential value as a green manure to improve rice productivity, using biomass transfer. A comparable grain yield of rice was obtained from chemical fertilizer applied at a rate of 75:10:30 kg N: P: K ha^{-1} and from tithonia biomass when applied at a rate of 2.5 t ha^{-1} (dry matter basis). Productivity was further improved when half the P was supplied from single super phosphate fertilizer and half from tithonia biomass. The application of sesbania as a green manure did not result in a larger rice yield than with tithonia.

Tithonia can supply more than one essential plant nutrient to the soil and nutrients are released immediately after incorporation into the soils. The release of all three major nutrients was higher at early stage (10-15 days after incorporation) and declined gradually. Under flooded conditions NH_4^+-N dominated the N pool but as the crop reached maturity, NO_3^--N dominated as the soil gradually dried. Soil phosphorus concentrations measured using both the Olsen-P and iron oxide filter paper method did not differ significantly whether P was supplied from chemical fertilizer or tithonia. K was significantly higher in soil and in rice plants when tithonia biomass was applied compared to the treatments without tithonia and the concentrations of K was comparable with K in soil and plants treated with artificial fertiliser K.

For *in situ* green manuring tithonia can be fitted into the crop rotation after the wheat harvest and before the transplanting of main season rice. However, biomass production was dependent upon seasonal variation and the number of days the plant was grown in the field. Growing tithonia and sesbania together was not found to be feasible because of different planting times. The dynamics of soil N and P under *in situ* conditions and biomass transfer were similar. However, the field results conducted in the two seasons were inconsistent. Both tithonia and sesbania affected the main companion crop maize under a relay system but tithonia reduced the maize yield more heavily.

A participatory survey of farmers from two districts showed that farmers thought that green manure technology could potentially improve crop productivity of rice and enhance the fertility level of soils that are under intensive cultivation. Farmers liked rice bean, sunn-hemp and sesbania due to their fast growth, quick decomposition and positive effect on rice yield. However, there are some constraints associated with the promotion of green manure technology in the study area. The main constraints as indicated by the farmers are the unavailability of seeds for green manure crops, lack of irrigation and limited access to tractors to incorporate the green manure into the soil.

In conclusion tithonia may be a potential green manure for improving rice productivity under a biomass transfer system but for *in situ* green manuring there is a need for more field research before recommending it to farmers. The results have indicated that at least 2.5 t ha^{-1} dry matter is required to get a satisfactory crop yield whereas the production of tithonia biomass under normal condition is only 1.5 t ha^{-1}, since under an intensive farming system the fallow period is quite short. There is an issue of sustainability under both biomass transfer and *in situ* systems because of nutrient mining in the former system and in latter system an external supply of plant nutrients is still required. However, tithonia could be a very promising plant for the areas of the lower hills where it could be grown in hedgerows in the sloping terraces and used for multiple purposes.

TABLE OF CONTENTS

CHAPTER 5

CHPATER 6

THE POTENTIAL OF RELAY CROPPING TITHONIA AND SESBANIA WITH MAIZE AND THEIR IMPACT ON SUBSEQUENT RICE CROP YIELD

CHAPTER 8

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH AND PROMOTIONAL ACTIVITIES

LIST OF TABLES AND FIGURES

CHAPTER 1

CHAPTER 2

CHAPTER 4

CHAPTER 5

CHAPTER 6

CHAPTER 7

LIST OF FIGURES

CHAPTER 1

CHAPTER 2

CHAPTER 3

CHAPTER 4

CHAPTER 5

CHAPTER 6

PLATES

APPENDICES

CHAPTER 2

CHAPTER 3

CHAPTER 4

CHAPTER 5

CHAPTER 6

CHAPTER 7

Acronyms and abbreviations

ADF	Acid Detergent Fibre
AIC	Agricultural Inputs Corporation
ANOVA	Analysis of Variance
APP	Agriculture Perspective Plan
ARS	Agricultural Research Station
ATS	Agriculture Technology Service
CAZS	Centre for Arid Zone Studies
CBS	Central Bureau of Statistics
CEH	Centre for Ecology and Hydrology
CIMMYT	International Maize and Wheat Improvement Centre
CV	Coefficient of Variance
DADO	District Agricultural Development Office
DAP	Di-ammnonium phosphate
DF	Degree of freedom
DFID	Department for International Development
DSS	Division of Soil Science
EC	Eastern Chitwan
FAMPAR	Farmer managed participatory research
FAO	Food and Agriculture Organisation
FGD	Focus Group Discussion
FP	Farmers practice
FW	Farm Walk
FYM	Farmyard manure
GDP	Gross Domestic Product
HARP	Hill Agriculture Research Project
ICIMOD	International Centre for Integrated Mountain Development
IRD	Informal Research and Development
IRRI	International Rice Research Institute
LI-BIRD	Local Initiative for Bio-diversity, Research and Development
LSD	Leas Significant Difference
LRMP	Land Resource Mapping Project
K	Potassium
MoP	Muriate of Potash
NARC	Nepal Agricultural Research Council
NESS	Nepal Environment Scientific Services
NS	Non-significant
NRRP	National Rice Research Programme
NWRP	National Wheat Research Programme
N	Nitrogen
PAC	Pakhribas Agricultural Centre

PCI	Participatory Crop Improvement
PSRP	Plant Science Research Programme
PVS	Participatory Varietal Selection
P	Phosphorus
PSI	Phosphorus Sorption Isotherm
SAFS	School of Agriculture and Forest Sciences
Sed	Standard error of difference
Se	Standard error of mean
SSP	Single Super Phosphate
TSBF	Tropical Soil Biology and Fertility
TSP	Triple Super phosphate
UWB	University of Wales, Bangor
WC	Western Chitwan
VDC	Village Development Committee
Yr	Year

CHAPTER 1

GENERAL INTRODUCTION

1.1 INTRODUCTION

This chapter describes the background to the present research and its social and scientific context. A brief background of the high production potential system in the Terai[1] region of Nepal is given together with an outline of current soil fertility management issues including the present and potential role of green manure in the Nepalese farming system. This provides the context in which the main objectives for this research were set and the structure of the thesis are set out together with an account of the procedure employed for site selection and descriptions of the sites used for the controlled field experiments.

1.2 Background and context

1.2.1 Farming systems in the high production potential area of Nepal

The flat land of the Terai, the inner valleys of the Siwalik region of Nepal and the irrigated valleys of the lower hills have high potential for intensive agriculture because of a warm temperature, availability of irrigation and reasonable infrastructure. Therefore, farmers are intensifying their farming systems from the traditional rice-fallow system to rice-wheat, rice-vegetables, rice-rice-fallow and maize-mustard or vegetable cropping systems. The dominant cropping pattern in these areas is now rice-wheat-fallow. This system occupies 600 000 ha (Regmi, 1998) and is considered to be very important for grain production. Recently farmers have started growing vegetables such as potato and tomato, vegetable root crops during winter and leafy vegetables after the main season rice harvest.

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[1] .The Terai region is one of the five physiographic regions of Nepal. The Terai represents flat land with alluvium deposits, that is moderately fertile and well suited for production of a range of crops. As a result of infrastructural development such as roads, irrigation and market opportunities, the cropping intensity has been increased in this region compared to other parts of Nepal.

1.2.2 Importance of rice in the Nepalese economy

Rice (*Oryza sativa* L.) is the most important staple food crop in the world today (Sthapit, 1994; NRRP, 1997). In Asia rice is the principal staple food crop with more than 250 million farm households dependent upon it and it is the most important source of employment and income for rural people (NRRP, 1997; Joshi, 2001).

In Nepal, rice is also the most important staple crop and occupies about 1.5 million ha of land with an annual production of 3.6 million t. The productivity, however, is only 2.46 t ha^{-1}. The flat land (Terai) and lower hills of Nepal have the greatest potential for intensive cultivation. The Terai contains 73% of the rice crop area and produces 75% of total production. This is equal to 56% of the total food grain production of the country and amounts to 20% of the agricultural sector's contribution to GDP (NRRP, 1997).

1.3 Soil fertility depletion and soil management issues

1.3.1 Soil fertility depletion problems under a high production system

Nutrient depletion is a major concern under intensive farming systems. With intensive farming two or more crops per year are grown and plant nutrients are removed from the soil with the harvesting of straw and gains. This continuous practice creates a negative nutrient balance of macro and micronutrients being over-exploited.

One solution would be the application of fertilisers. In Nepal the consumption of chemical fertiliser including nitrogenous, phosphate and potassium compounds rose from 46 160 to 90 263 t between 1988/89 and 1997/98, of which phosphate fertiliser consumption rose from 13 124 to 24 300 t (CBS, 1999). Nevertheless Nepal still has the lowest consumption of chemical fertiliser in the world both per unit of land and crop production because fertiliser need to be imported and such imports are constrained by a shortage of foreign currency. The use of farmyard manure (FYM) is an alternative but animal dung tends to be used for fuel in the Terai. As it is, the amount of manure produced is steadily declining because of declining animal numbers, which are themselves a result of the pressure on forest resources that have traditionally provided fodder, particularly in the dry winter season (Thapa *et al.*, 1997).

In general farmers who apply nitrogenous fertilisers do so in the form of urea top dressing and tiny amounts of phosphate and potassium fertilisers are applied to the major crops. Carson (1992) has reported that the level of phosphorus in tropical soils is invariably low and after nitrogen, phosphorus is becoming the major nutrient most restricting plant growth. Fairhurst *et al.*'s (1999) world map of P deficient soil shows Nepal with P deficient soil. As innovations in crop production increase harvested grain and soils are threatened with becoming deficient in phosphorus, in the Terai region they should be supplied with P from external sources otherwise phosphorus levels in soil will decline to a level such that profitable agriculture is no longer possible. Sherchan and Gurung (1998) reported that under normal farmer management, wheat and rice remove N 138 kg ha^{-1}, P 64 kg ha^{-1} and K 161 kg ha^{-1} in one cropping cycle and there is a negative balance of both N and P, and the P deficit is large. Tripathi (1996) reported that the loss of P was at a rate of 24 kg ha^{-1} yr^{-1} when N only (at 100 kg ha^{-1}) was applied to rice and wheat crops. However, the loss of P was negligible when FYM (10 t ha^{-1}) and P (13 kg ha^{-1} and 18 kg ha^{-1}) along with N 100 kg ha^{-1} was applied to rice and wheat crops.

A long term soil fertility trial conducted at the Nepal Agricultural Research Council (NARC) Research Station at Bhairawa has indicated that yields of rice and wheat under continuous cropping are primarily controlled by phosphorus fertiliser, and then by potassium (Regmi, 1997a and 1997b). In contrast maize responds to increasing amounts of all major nutrients (N, P and K) in the Chitwan valley (Srivastava and Neupane, 1998). Shah and Schreier (1991) also expressed concern over soil acidity and the phosphorus availability problem on red and acidic soils in the middle hills of Nepal. Brown *et al.* (1999) reported that, under a double and triple cropping system in the middle hills of Nepal, nitrogen and phosphorus are in deficit when maize is incorporated into the rotation. A CIMMYT/IRRI diagnostic survey conducted in 1989 in the Rupendehi district in the Terai region identified phosphorus deficiency restricting rice and wheat yields as a priority problem (Harrington *et al.*, 1993). Furthermore the survey identified that there was potential for introducing green manure crops and a recommendation was made for research to be undertaken on the screening and testing of green manuring species and to determine the extent to which incorporating green manure might be beneficial.

The Nepal Agricultural Perspective Plan 1995 (APP, 1995) has identified soil fertility and the limited availability of fertilisers as key constraints to increased crop productivity. The Ninth Plan in 1998 of His Majesty's Government of Nepal has also emphasised the need to implement the Agricultural Perspective Plan and has stressed the importance of increasing inputs of manure and fertiliser for improving soil fertility (Mathema *et al.*, 1999).

1.3.2 Potential options for the improvement of soil fertility

To overcome the problem of declining soil fertility, the application of organic manure is an alternative option but, as already stated, farmyard manure is increasingly in short supply and the majority of farmers do not have access to expensive chemical fertiliser. The application of chemical fertiliser may also be of limited value due to fixation by soil colloids and losses through leaching. A number of research findings have emphasised that the use of green manure either alone or in combination with chemical fertiliser improves the availability and efficiency of these applied nutrients and eventually improves soil fertility (Abrol and Palaniappan, 1988; Yadvinder-Singh *et al.*, 1991). Green manure technology has been proved a cost-effective technology and has both short term and long term benefit (Mann and Garrity 1994). The application of green manure substantially reduces the inorganic N inputs to the rice crop. Since most green manure crops are leguminous and they have ability to fix the atmospheric nitrogen and make available to the accompany crop or to the succeeding crops. It has also been well recognised that the use of green manuring practice help to recycle the essential plant nutrients by capturing nutrients from the deep soil profile and make access to the succeeding crops.. In general the cereal crops cannot utilise nutrients from the deep soil profile due to shallow root system. Green manure crops also make utilise the non-labile nutrients to crops. Therefore nutrient cycling could be a sustainable approach for maintaining soil fertility. However this depends upon the environmental factors (Van Noordwijk, 1999). It has also been emphasised that there is a need to improve the nutrient recycling system. Since nitrogen is the most versatile nutrient that under goes into transformation and likely to be lost in most cases if not utilised efficiently. A study has been carried out to unitise the nitrate nitrogen during the fallow period under an intensive cropping systems through a catch crop otherwise it is subjected to be lost through various path ways (Tripathi *et al.*, 1997).

1.3.3. The value of tithonia as a fertiliser

Tithonia diversifolia is a perennial shrub, belonging to the family Asteraceae, and is widespread in the tropics. It produces large quantities of leaf biomass with a high nutrient content and can tolerate regular pruning. It has long been recognised as an effective green manure for lowland rice (Nagarajah and Nizar, 1982). Adoya *et al.* (1997) reported that tithonia improves soil fertility, gives increased rice yield and also protects against termites.

Recent research in the highlands of western Kenya by ICRAF and TSBF into the use of tithonia biomass as an organic fertiliser raised expectations (Niang *et al.*, 1996). Foliar biomass imported onto fields was found to be an effective source of nutrients for maize, supplying N, P and K. Buresh and Niang (1997) reported that tithonia applied at 2 t ha^{-1} on a dry weight basis contains about 60 kg N ha^{-1}, 5 kg P ha^{-1} and 60 kg K ha^{-1}. In some cases maize yields were higher with tithonia than with inorganic fertilisers although the reason for this is not known (Gachengo, 1999). A higher maize yield can also be obtained when tithonia and triple super phosphate (TSP) or diammonium phosphate (DAP) are applied together (Jama *et al.*, 2000). It has been reported that 5 t ha^{-1} of tithonia dry matter will produce a response in maize yield equivalent to 60 kg N ha^{-1} and 50 kg P_2O_5 ha^{-1} (Jama *et al.*, 2000). Tithonia has also been found to be an effective source of nutrients for vegetables. Farmers in Kenya prefer to use it on these higher value crops rather than on maize (ICRAF, 1996; Buresh and Niang, 1997).

Release of P from tithonia foliar biomass is rapid and the supply of plant available P is at least as effective as from a soluble fertiliser. Labile soil P determined by the anion exchange resin technique and that from the Olsen-P method were very similar after green biomass of tithonia or phosphate fertiliser was added at equal P rates to an acid soil (Nziguheba *et al.*, 1998). Application of tithonia was also associated with slightly reduced P adsorption in the soil and increased soil biological activity (Nziguheba *et al.*, 1998). This may enhance the availability of P and other nutrients by greater cycling through labile soil organic pools.

A number of fields' experiment on the use of N-fixing leguminous plants as a source of plant nutrients for lowland rice production have been carried out. These plants have proved to be beneficial in terms of crop yield and soil fertility (Beri *et al.*, 1989a and 1989b; Bharwdwaj and Datt, 1995; Bhardwaj and Dev, 1985; Yadvinder-Singh *et al.*, 1991). In addition, the synchronisation of N-release with plant demand has received considerable research attention but the factors controlling release of P from decomposing green manures are less well understood (Myers *et al.*, 1994). In the case of N mineralisation the initial quality of biomass such as the C:N ratio, N%, and lignin+polyphenol:N ratios have been considered important parameters (Palm and Sanchez, 1991; Handayanto *et al.*, 1997). But there is lack of adequate research in the case of P mineralisation and the factors controlling the mineralisation processes. However, there is some evidence that N: P ratios, C:P ratios and the initial content of P may be important in controlling the release of P. But the long-term effect on the P store in the soil and availability of P will depend on the presence of Fe and Al oxides, calcium and soil texture due to adsorption behaviour of soil colloids. The amount of green manure added and management method and timing of incorporating the organic matter in the soil will also have an effect on P release and distribution (Huffman *et. al.*, 1996). It has been suggested that availability of P from organic residues may be greater than from inorganic fertiliser and that P may remain within the soil system in a more accessible form (Egball *et al.*, 1996; Vig *et. al.*, 1997).

1.3.4 Green manuring in the context of the Nepalese farming system

More than thirty plant species are used for green manuring purposes in the hills of Nepal (Bhattarai *et al.*, 1987; Sthapit, 1990; Subedi, 1997; Moss, 2000). However, in the Terai region there is very limited use of green manure species. Widely used green manures in the hills are asuro (*Adhatoda vasica*), titepati (*Artemisia vulgare*), siris (*Albizia lebbek*), khirra (*Sapium insigne*), banmara (*Eupatorium adenophora*), siplican

(*Crataeva unilocularis*), bakaino (*Melia azedarchta*), dhaincha (*Sesbania cannabina*), sunn-hemp (*Crotolaria juncea*) and ankhetare (*Walsura trijuga*). They are mainly leguminous shrubs and trees, and some leguminous annuals such as sunn hemp and various types of beans. In the hills of Nepal the cut and carry system of green manuring, involving biomass and hence nutrient transfer from one site to another, is the most common (Moss, 2000). The practice of *in situ* production of green manure biomass is slowly becoming popular in the wetlands of the Terai region (Bhattarai *et al.*, 1987). This practice is successful because there is adequate moisture at the time of planting and warm temperatures and because sufficient time is available between the two successive crops. However, despite the high potential of green manuring practices the application of green manure is still very limited in the Terai (K. D. Joshi, personal communication). The major constraint with the green manure technology is that it requires an extra labour to collect from the forest and apply into the fields. The requirement in terms of amount is also quite high to get a desirable response from the green manures. It has also been envisaged that this practice will mine the soil fertility of a site from where the biomass is transferred to another fields in the long term.

In the context of Nepalese farming, tithonia is a novel plant for use as a green manure. It is naturalised and widely distributed in the country below 1400 to 1500 m altitude and either classed as a weed or used mostly as a fodder and fuel wood in the lower hills of Nepal. Unlike some other green manure plants tithonia is rich in plant nutrients, like P and K as well as N and many micronutrients and it also possesses insecticide properties (Buresh and Niag, 1997). It is, therefore, likely that tithonia would make a good green manure by increasing the crop yield response when grown in a mixture with leguminous species. Benefits could be expected when two different types of green manure crops with different rooting systems are grown together which would exploit different above and below ground niches and thus make full use of the available solar radiation, nutrients and water (Gathumbi, 2000). Tithonia may contribute to sustainability by increasing the size of the pool of P that is recycled, making application of only a modest amount of P from external sources necessary, which may be organic or inorganic.

On the whole P from organic sources is preferable to P from inorganic sources. Both acidic and alkaline soil has P fixing characteristics and P applied from an inorganic source is more likely to be locked up (Yadvinder-Singh *et al.*, 1988; Yashpal *et al.*, 1993; Yashpal *et al.*, 1995). Despite beneficial effect of green manures there are a number of potential issues concerning the sustainability of the green manure practices both from socio-economic and scientific point of view such as the nutrient mining or long term effect and cost effectiveness.

1.4 Research structure

1.4.1 Purpose of the study

The main purpose of this research was to expand knowledge of soil fertility management and incorporate this into agronomic practices as appropriate in the Terai region of Nepal. It was envisaged that this might be done by promoting the technology of green manuring with tithonia either alone or together with other green manures if appropriate, to improve the productivity of major cereal crops. The specific objectives were as follows.

- To investigate the growth habit and potential biomass production of tithonia in the Nepalese Terai environment.
- To investigate characteristics of decomposition of tithonia along with other popular green manure crops.
- To develop an integrated nutrient management practice that increases nutrient cycling and availability to crops and therefore increases and sustains crop productivity in areas of high production potential in Nepal.
- To understand farmers' perceptions regarding green manure crops and the practice of green manuring in high production potential areas so that adoption rates can be improved.

1.5 Research approach and thesis outline

The research activities in the field were designed in a logical sequence. Tithonia is already becoming popular as a green manuring plant mostly for the upland environment in Africa (Gachengo *et al.*, 1999). But in the South East Asian region green manure and rice cultivation go together and tithonia fallows are common in some areas (van Noordwijk *et al.*, 1999). Therefore, the emphasis is on the efficacy of tithonia as a green manure under wetland cultivation field conditions. Attempts have been made to understand both the agronomic practice and the potential role of tithonia to improve soil fertility in the high potential production system in Nepal.

The first activity was a comparative study on the decomposition and major plant nutrient releasing behaviour of tithonia to establish whether it was of potential interest in the present context.

The second activity was to investigate the growth habitat of tithonia, its production potential and the appropriate times for planting and propagation under the warm humid conditions of the Terai. .

The third activity involved field trials to investigate the value of tithonia as an organic fertiliser and its efficiency when used in conjunction with chemical fertiliser or other sources of organic fertiliser in a biomass transfer system for lowland rice cultivation.

The fourth activity was similar to the third but here tithonia was tested as an *in situ* green manure either alone or in combination with other green manure species. The main aim was to investigate whether tithonia fits into the rice-wheat crop rotation or not and its green manure value when grown *in situ*.

The fifth activity was to find out the potential of relay cropping tithonia and sesbania with maize and their impact on subsequent rice crop yield. Farmers' preference for green manure is to relay it with early maize and use the biomass for the main season rice crop.

The last activity was on-farm participatory green manure trials that aimed to capture some understanding of farmers' perceptions regarding novel as well as the traditional green manure crops and to determine their selection criteria for green manure species. This is critical information required to design appropriate interventions with green manure technology and promotes them.

1.6 Field site selection

1.6.1 Selection and description of the site

The Chitwan district of the Terai was selected because it represents a high production potential system. An on-farm survey on the use of green manuring had been completed by Andreas Brede, a postgraduate student of the University of Wales, Bangor in 1998 (Brede, 1998). Several visits were made to the Chitwan valley to select an appropriate site and to identify participating farmers. The site selected lies in Radhapur village in Chitwan district. The geographical location is 84^0.22' E and 27^0.36' N (Map 1). The altitude is 187 m above sea level. The site is most representative and lies in the intermediate terrace. The area is one of the three clusters where the Participatory Crop Improvement (PCI) project is currently running. This is a collaborative project involving the Centre for Arid Zone Studies, University of Wales, Bangor, UK and LI-BIRD.

The site represents an area where a rice-wheat-fallow cropping pattern is the dominant one. The area is one with high production potential, with intensive cropping (three crops in a year), access to irrigation and to markets. In addition, green maturing practices using three species *Sesbania cannabina*, *S. rostrata* and *Sesamum indica* are also quite popular in the area. For these reasons it was thought that farmers in this area might be interested in developing and utilizing green manure technology.

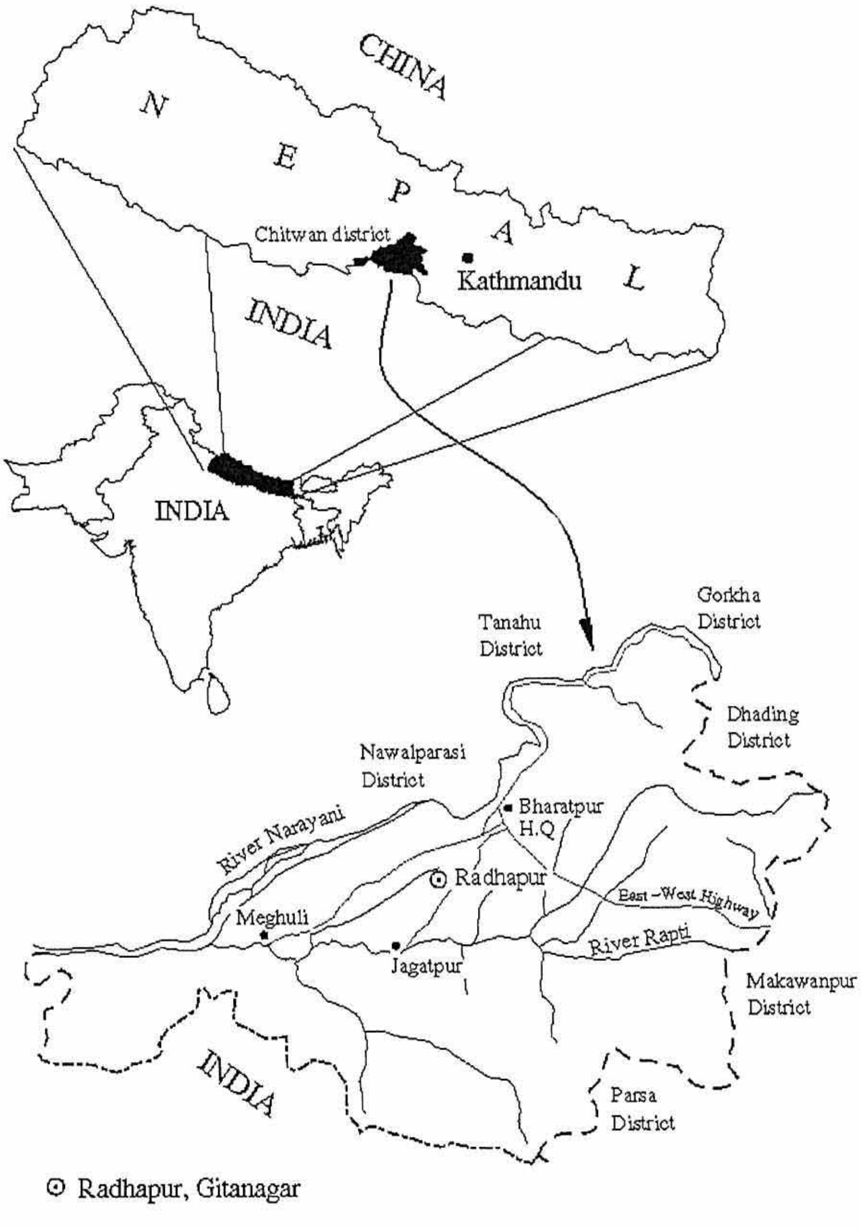
Modern green manuring practices are fairly recent in the valley. Dhaincha (*Sesbania* spp.) is the most popular green manure species and was introduced by Rampur Research Station, part of the Nepal Agricultural Research Council, then the Department of Agriculture, in the early 1960's (S L Maskey, 1999, personal communication). Green manuring crops are mostly grown on irrigated (*Khet*) lands. Approximately 50 to 60 days are required to get adequate biomass prior to incorporation into the soil before rice transplanting. Besides sesbania, sesame (*Sesamum indica*)(an oil seed crop) and sun-hemp are also found growing in the area. Sunn-hemp (*Crotolaria juncea*) is mostly grown on welldrained land. However, the crop is not very popular among farmers yet. The use of asuro (*Adhatoda vasica*) as a green manure is traditional in the hills. The immigrant communities in the valley are from the hills and they have transferred the use of this plant from the hill to the valley. The use of asuro is found only near to the forest areas since this vegetation is not grown on cultivated land but is collected from forest and applied to land in a form of biomass and nutrient transfer.

1.7 Land selection for field trial

1.7.1 Land selection and soil type

One half hectare of irrigated land (*Khet* land) was rented to accommodate field trials in Radhapur, Chitwan district. The soils were sandy loam, brown, deep and of moderate fertility. The soil is classified as **Dystrochrept**, a great group according to the United State Department of Agriculture (USDA) soil taxonomy system. The land was in an area under two to three crops within an annual rotation and generally fertilised with organic manure and occasionally with chemical fertilisers. Year round irrigation facilities existed. During the dry period water from a deep tube well was used to irrigate the land but during the wet summer and the rainy season irrigation from a nearby canal was available. A limited amount of chemical fertiliser had been applied in the past, mostly urea, DAP, muriate of potash (MoP) and complex salt. Organic manures such as farmyard manure, compost, dhaincha (green manure), poultry manure and biogas slurry (occasionally) is also commonly used in the area.

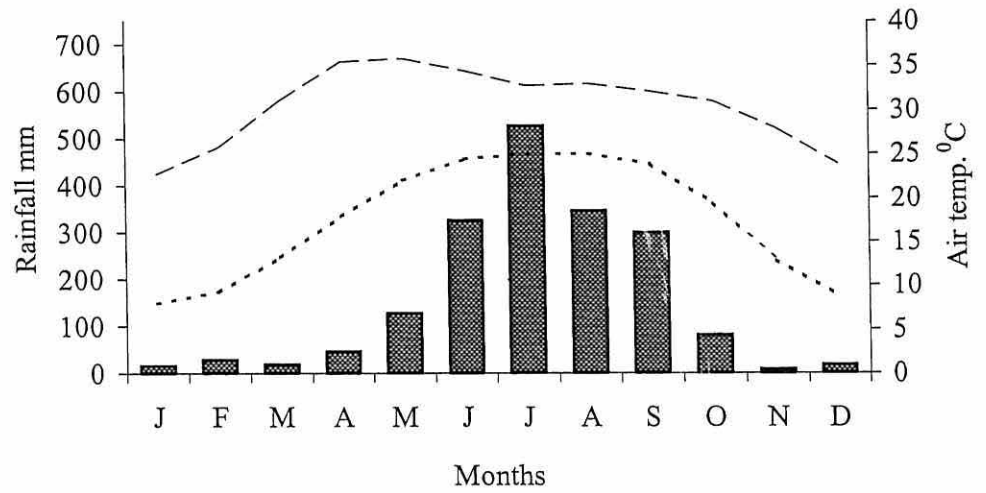
Location of the experimental site
Radhapur, Gitanagar,Chitwan district, NEPAL



Map_1

1.7.2 Climate

The Chitwan valley has a subtropical climate with a very hot and humid summer, wet monsoon and a short cold winter season. In the valley, summer is very dry before the monsoon and the air temperature reaches 35.5°C on average but under extreme weather conditions the air temperature can reach more than 40 °C and very dry winds or storms are also experienced (Figure 1.1). The rainy season which starts in June lasts for about 4 months.



Legend: Rainfall mm ( ), maximum air temperature °C (--- ---) and minimum air temperature °C (-----).

Figure 1.1: Mean monthly maximum and minimum air temperature and rainfall (Source: Rampur Agriculture Research Station, Chitwan, (1971 to 1999)

In this time more than 80% of total annual rainfall occurs (total 1600 to 1800 mm). The rainy season is very humid and warm.

The winter is cold and dry and the mean air temperature is around 15 to 18°. The minimum air temperature is 7.9 °C (monthly mean) in January.

1.7.3 Land and soil types

The Chitwan valley is a tectonic depression and the Churia or Siwalik range lies to the north and south. In the north steep to very steep hills are made up of sandstone and limestone. The foothills are gentle slopes made up of young coarse sediment and boulders. Rapti and Narayani are the two major rivers.

The valley consists of a number of terraces. The lowest terrace is known by different names as the *ghol* or *khal* or *jarhaniya,* literally meaning "lowland" and the uppermost terrace is the *tandi* or upland. Between these upland and lowland terraces, there are a number of terraces in an intermediate position, occupying the largest area. The local term for the intermediate terrace is *oshania.* In addition there are active flood plain terraces adjacent to the rivers. The young flood plains are coarse sand and silt deposits and flooding during summer is common. In the foothills very coarse, young alluvial fans are found and in some places boulders and stones.

The valley soils are developed on alluvial material as the result of deposition at different times (LRMP, 1986). The upland soils are deep and well drained. The dominant textural class is sandy loam to loamy sand according to FAO system. The pH is acidic in the upland. Soils of the lowland are heavy in texture and rich in organic matter and these soils are alkaline with around 8.3 pH. Drainage is very poor in the lowland. The soils near to the river terrace are shallow and of coarse texture. On the intermediate terraces soils are dark greyish brown loamy sand to sandy loam and the soil pH ranges from 5.5 to 6.2. These soils are moderately well drained. This type of soil occupies the major part of the valley. The forest soils are acidic, pH 5.4. The carbon content ranges from 0.18 to 0.34%. The dominant textural class is sandy loam (Maskey, 1982). However, the forest soils on flat land are very deep and have a high organic matter content.

A typical soil profile description from the experimental site is given below

Soil depth cm	Horizon	Description
0 - 13	Ap1	Very dark greyish brown (10YR 3/2), sandy loam, non- sticky and non-plastic, massive, clear smooth boundary,

13 – 21	Ap2	Very dark greyish brown (10YR 3/2), sandy loam, non- sticky and non-plastic, slight hard pan, 25% yellowish red mottles, clear boundary.
21- 43	B2	Dark greyish brown (10YR4/2), sandy loam, friable, non-sticky, fine to medium sub-angular blocky structure, clear smooth boundary.
43 - 67	B3	Yellowish brown (10YR 5/4), loamy sand, very friable and non-sticky, medium sub-angular blocky structure, gradual smooth boundary.

67 – 115 C Brownish yellow (10YR 6/8), sandy loam, slightly sticky, friable, very weakly developed sub-angular blocky structure.

Chemical properties of soil profile are given in Table 1.1 and Table 1.2

Table 1.1: Soil chemical properties.

Depth cm	Horizon	Total N (%)	P (kg ha^{-1})	K (kg ha^{-1})	Exchangeable cations ($cmol/kg^{-1}$)				C.E.C. ($cmol/kg^{-1}$)
					Ca	Mg	Na	K	
0-13	Ap1	0.21	57.68	108	2.8	1.32	0.64	0.79	18.50
13-21	Ap2	0.15	25.48	68	3.8	1.2	0.48	0.35	12.50
21-43	B2	0.09	16.48	68	3.9	1.3	0.60	0.35	12.70
43-67	B3	0.07	8.24	44	3.85	1.29	0.06	0.50	10.20
67-115	C	0.04	8.24	40	3.8	1.4	0.52	0.42	8.54

Table 1. 2: Soil textural class, pH and organic carbon content (O.C.) of the soil profile

Horizon	PH	OC%	Particle size distribution			Textural Class
			Sand (%)	Silt (%)	Clay (%)	
AP1	5.80	1.99	53.3	31.7	13	Sandy loam
Ap2	6.25	1.55	59.3	31.7	9	Sandy loam
B2	6.50	0.94	59.3	29.7	11	Sandy loam
B3	6.55	0.54	53.3	27.7	19	Sandy loam
C	6.70	0.24	57.3	19.7	23	Sandy clay loam

1.7.4 Cropping pattern

Rice and maize based cropping patterns are predominant in the Chitwan district. In general this means that rice is grown on irrigated land (*Khet*) and maize is grown on non-irrigated or partially irrigated upland. However in practice the picture is more complex. Rana *et al.* (1996) have reported that under the rice based system more than 115 cropping patterns are practised while under the maize based system around 50 different cropping patterns are found.

The drainage associated with the landform is also one of the factors taken into account in selecting the cropping pattern. Socio-economic factors and market price also play a role. In the lowland, or *ghol,* early rice (*Chaite dhan*) followed by main season rice is the dominant cropping pattern, although locally winter maize is also grown. In the intermediate terrace a variety of cropping patterns is practised of which rice followed by wheat is popular. However, this is influenced by market price and availability of chemical fertilisers. Other cropping patterns are main season rice then winter vegetables, mustard or fallow. Rice-vegetables/potato-green manuring and rice-spring maize-fallow are also popular. The intermediate terraces are the areas where the practice of green manuring is most popular.

On the upper terraces summer maize followed by mustard or winter vegetables is widespread. The maize based cropping pattern is dominant on upper terraces since the production constraint in the uplands is moisture or lack of irrigation. Some of the popular cropping patterns are maize-fallow, maize-maize-fallow, maize-millet-fallow, maize-sesame-fallow. In a limited area the Narayani irrigation scheme allows main season rice to be grown. Choice of rice variety is determined by land type since moisture availability influences the planting time, and consequently a wide range of rice varieties are grown in the valley.

1.8 Ecological distribution of tithonia in Nepal

Tithonia is found from the eastern region (Dhankuta) to the western region (Gulmi) at an altitude range from 450 m to 1550 m above sea level. Tithonia is found on a wide range of soil types, but mainly on soils brown to red in colour and sandy loam to clay loam in texture. However, tithonia is also found on steep rocky slopes and even in very degraded land, and on steep limestone rock. Tithonia has been observed in natural forests in the eastern region near Dharan bazaar.

Tithonia is a multipurpose plant. It can be used for fuel, fodder and live fencing around the farm boundary. Tithonia is a good fodder for sheep, goats and cattle before flowering (till November).

The plant is 1 to 3 m tall and it is known by two local name *armanda* and *suryamukhiphul* or *taramandal*. A new flush of growth occurs in April - May with maximum growth attained in June. Propagation is very easy and can be done from root and stem cuttings or from seed. Usually two to three loppings can be made for fodder. Flowering normally occurs from November to January.

The major nutrient content of tithonia samples collected from Dhankuta, Palpa and Shyangja are given below. Samples were analysed at Pakhribas Agricultural Centre (PAC) and Nepal Environmental Scientific Services (NESS) laboratory, Kathmandu. They reveal high but variable contents of N, P and K.

Table 1.3: Nutrient contents of Tithonia samples collected from four locations.

Location	N%	P%	K%	Analysed at
Dhankuta_1 (1300m)	3.70	0.30	4.20	PAC Lab., Dhankuta
Dhankuta_2 (1300 m)	3.76	0.35	3.69	PAC Lab., Dhankuta
Shyangja (850 m)	3.94	0.50	3.67	NESS Lab., Kathmandu
Palpa (1000 m)	3.13	0.76	3.60	NESS Lab., Kathmandu

The research as outlined above (Section 1.5) is reported in the six following chapters and then conclusions are drawn from the body of work as a whole in the last chapter 8.

CHAPTER 2

COMPARATIVE ANALYSIS OF THE DECOMPOSITION OF THREE GREEN MANURE SPECIES

2.1 INTRODUCTION

Application of plant materials as green manure to maintain or improve soil fertility is a common practice in both traditional rice cultivation and intensive modern farming systems in Nepal. Farmers apply leaves, twigs and tender stems of both leguminous and non-leguminous plant materials. The characteristic considered important by farmers is rapid decomposition of the green manure, such that nutrient releasing behaviour matches the fast growth of the crop, which occurs in the wet, warm conditions after the monsoon. Farmers use this property to classify the types of vegetation that are used for green manuring, in particular for rice cultivation, but also rice and millet production and vegetable growing in the hills and terai regions of Nepal.

Decomposition and release of nutrients from the applied biomass is a function of the quality of organic materials, environmental factors such as temperature and moisture, the decomposers present and placement methods (Harmon *et al.*, 1999; Schomber *et al.*, 1994). A number of research findings indicate that quality of vegetation for green manuring purposes can be assessed from N content or C:N ratio. Haynes (1986) reported that material with a C:N ratio less than 15 to 20 decomposes more quickly than low quality residues with C:N ratios higher than this. However, later work showed that material with similar N content and C:N ratio exhibit different decomposition rates (McDonagh *et al.*, 1995). Handayanto *et al.* (1994) suggested that polyphenol:N ratios are good indicators of the decomposition rate of vegetation. Also, Palm and Sanchez (1990) have reported that polyphenolics retard decomposition and N release by binding nitrogen-containing compounds in the plant materials into resistant complexes. Becker *et al.* (1994) have reported that lignin:N ratio is the residue quality parameter most closely correlated with decomposition. Understanding these processes is important so that nutrient availability can be managed by controlling the timing, quantity and quality of organic inputs to achieve a positive effect on crop growth (Myers *et al.*, 1994).

Green manuring is not a new technology in Nepal and farmers have been using vegetative materials in different forms to enrich the fertility of cropland for many years. However, there are opportunities to increase its acceptance by farmers on a larger scale. This may be especially important as it might mean that the requirement for expensive inorganic fertiliser can be reduced. Surface mulching of vegetative materials for winter and summer crops to conserve moisture and maintain soil temperature is a common practice among farmers. There is a major opportunity to improve soil fertility through the use of green manure plants. But there is a lack of scientific studies in Nepal on the decomposition and nutrient release behaviour of these plant materials (tithonia, asuro and bakaino), and the effect of different methods of incorporation into the soil. Such information is needed before a sound technology can be recommended to farmers.

In Nepal, asuro (*Adhatoda vasica* Nees.) is the most commonly used green manure vegetation in the hills and terai (Bhattarai *et al.*, 1987; Sthapit, 1990; Subedi, 1997). Leafy twigs and branches are lopped from asuro shrubs and carried to the fields. Sesbania was not included in the trial because this crop is not grown in the winter season. Bakaino (*Melia azedarachta* L.) is also commonly used as green manure but is also favoured as fodder and timber and has a fairly high concentration of major nutrients. Tithonia (*Tithonia diversifolia* A.Hemst.Grey.), is a naturalised plant in Nepal known locally as *taramanda*l, whose potential as a green manure is the subject of present research. It is thought to have good potential because of the high content of major nutrients in its tissue. This has been recognised in Africa and South East Asia (ICRAF, 1996). However, before recommending tithonia green manuring to farmers in Nepal it is important to understand the decomposition process in the rice system in which it will be used (Gilmour *et al.*, 1998) in comparison with the accepted green manures already used by farmers.

2.2 OBJECTIVES

The main objectives of the study were as follows.

- To investigate the decomposition rates of plant materials that is commonly used for green manuring purposes in Nepal, and compare this to the decomposition rate of tithonia.

- To study the nutrient release pattern of these plant materials.
- To investigate and explain the effect of incorporating green manure into wet and dry soil on decomposition processes.

2.3 MATERIALS AND METHODS

2.3.1 Litterbag experiment

The litterbag method was used to assess the decomposition rate of plant materials and mineralisation of selected nutrients. The litterbag method has been used by numerous researchers because it is simple, and easily replicable (Vanlauwe *et al.*, 1997; McDonagh *et al.*, 1995 and Handayanto *et al.*, 1994). A nylon material with 1 mm mesh size was used to prepare litterbags of 10 cm by 10 cm so that macro-fauna could be excluded. The experiment consisted of four plant materials (three species, asuro, bakaino and tithonia, with two forms of tithonia) and three incorporation methods, and was laid out using a split plot design with four replications. The main plot was incorporation method and the subplot consisted of the different types of vegetation.

The three incorporation methods and their labels were as follows.

Surface mulch (M1): Application of a layer of mulch to experimental plots and non-irrigated. Litterbags laid out in a row of six bags per subplot beneath the mulch of the same species, and held in place with hooks of plastic covered metal.

Ploughed in, incorporation method without irrigation (M2): Application of a layer of mulch and mixing of the mulch into the soil simulating ploughing. Six litterbags per subplot buried at about 5 cm in mixed soil and mulch.

Ploughed in, paddy (irrigation) incorporation method (M3): Puddling of the plot followed by application and mixing of the mulch into the soil and subsequent daily irrigation simulating paddy conditions. Six litterbags per subplot mixed into the soil plus mulch layer.

The plant materials in the litterbags and their labels were:

- tithonia leaves (S1),
- tithonia leaves plus stems in the same dry weight ratio as measured in the plant (S2),
- asuro leaves (S3), and

- bakaino leaves (S4).

The split plot design was laid out in four blocks, each divided into three incorporation strips, and plant materials S1 – 4 allocated at random within the strips (Figure 2.1). Each block was 14 m by 27 m and each plot was 4 m by 5 m and each sub plot was 0.8 m by 0.5 m. A distance of 1.5 m was kept between the blocks and the paddy treatment was separated with galvanised iron sheet in order to prevent water flowing on to the adjacent blocks and plots. Biomass of mulch in all cases was 10 $t.ha^{-1}$, which approximates to farmers practice (Sthapit, 1990).

Figure 2.1: Plan of the lay out of the experiment.

Replication	**Replication-I**			**Replication-II**		
Main plot	M1	M2	M3	M1	M2	M3
Subplot	S1	S4	S2	S3	S1	S3
	S2	S3	S4	S4	S4	S1
	S3	S1	S3	S2	S3	S2
	S4	S2	S1	S1	S2	S4
Replication	**Replication-III**			**Replication-IV**		
Main plot	M1	M2	M3	M3	M2	M1
Subplot	S3	S1	S2	S1	S4	S3
	S2	S4	S4	S3	S2	S4
	S4	S2	S1	S4	S3	S1
	S1	S3	S3	S2	S1	S2

2.3.2 Litterbag preparation

Plant materials were collected from a nearby forest and agricultural field boundary. Materials were mixed well, air dried for two days, and were turned frequently to speed up drying. Air dried material was used in the litterbags to reduce variability in moisture content which would otherwise have occurred with fresh material variably drying during litter bag preparation. The use of oven dry material was rejected on the grounds that it would be too far from actual practice and could affect decomposition and nutrient release patterns. The ratio of leaves to stems for tithonia was estimated from representative branches from growing plants. The ratio between air-dry weight of stem and leaves was approximately 1:2. Samples of all initial material were bulked by litter type and stored for chemical analysis.

Initially 10 g of air-dry material was used in each litterbag except for the tithonia leaves+stems material where 20 g was used otherwise volume of plant material in the bags would have been much smaller than the other treatments. When expressed as dry weight at 60°C, these initial weights corresponded to 7.76 g tithonia leaves, 15.48 g for tithonia leaves + stems, 5.05 g for asuro, and 6.30 g for bakaino.

The field experiment took place from 16th December 1998 to 17th March 1999. One litterbag was retrieved from each subplot on each of six occasions after incorporation; at 2, 5, 10, 30, 60 and 90 days. Care was taken not to disturb the remaining bags. Soil particles attached to the litterbag were carefully removed by washing with distilled water two to three times. The material was then removed from the bags and dried at 40^{0}C for 24 hours, weighed, ground and stored. The samples were retained for nutrient analysis. The results are expressed at 60°C oven dry weight.

2.3.3 Soil moisture and soil temperature:

Soil temperature and moisture content were measured daily from the main block of the experimental plot to have an idea of the main block. Temperature was monitored using a soil thermometer and soil moisture was determined by the gravimetric method of Anderson and Ingram (1993).

2.3.4 Nutrient analysis

Carbon, total nitrogen and total phosphorus were analysed at the Centre for Hydrology and Ecology (CEH) and School of Agricultural and Forest Sciences, University of Wales, Bangor, U.K. Total carbon and total nitrogen content were obtained using a LECO CHN 2000 Elemental analyser and total P by digestion with H_2SO_4 and H_2O_2

mixture in the presence of Se powder (Allen, 1974), followed by analysis using the molybdenum blue colorimetric method on a Skalar auto-analyser.

Lignin and polyphenol content of the initial samples were analysed at the Merlewood Research Station, Centre for Ecology and Hydrology using the acid detergent fibre (ADF) procedure of the Folin Denis method as described in the Tropical Soil Biology and Fertility Handbook (Anderson and Ingram, 1993). The analysis was done by the staff of the Merlewood Research Station.

2.3.5 Estimation of total mass remaining and mass of N and P remaining and their statistical analysis

Remaining total weight (W_r) (%) at each sampling occasion was calculated as:

$W_r = (W_n/W_i)100$ (eqn 1)

Where W_i = initial mass and W_n = mass at the nth sampling time

The mass of N and P remaining at each sampling time was calculated by multiplying the N and P concentration measured at each sampling occasion by W_n. The mass of N and P remaining (%) was then calculated as for total mass in equation 1 but using the appropriate masses for the nutrient in question.

Analysis of variance (ANOVA) on W_r (%), N and P concentration, mass of N and P remaining (%), C/N and C/P ratios were carried out using Genstat version 3.2 statistical software to examine the effect of plant material, method of incorporation and their interactions on the above parameters. The data were tested for the normality probability and the equal variances and found non-significant. Therefore the data were not transformed. The structure of the ANOVA skeleton used for the analysis is given in Appendix 2.1a.

Double negative exponential curves (eqn 2) were fitted to describe the decay of total mass and that of individual nutrients, as suggested by Wieder and Lang (1982) and considered to be one of the most biologically meaningful ways to express the relationship. The regression curves were fitted to mean values of remaining mass for each time point.

$F = f_l^{-klt} + f_r^{-krt}$ (eqn 2)

where f_l and k_l are coefficients corresponding to the % of labile fraction and its decay constant, f_r and k_r the % recalcitrant fraction and its decay constant. F represents either the proportion of total mass remaining (%) or the proportion of the mass of N or P remaining (%) in the litterbags at a specific time (t) in days.

2.4 RESULTS

2.4.1 Soil moisture and soil temperature

Weekly mean (average of seven days) soil temperature is shown in Figure 2.2. Soil temperature was initially 18°C then gradually rose up to first week of February then remained almost constant, ranging from 25 to 30°C. This increase is consistent with increasing air temperature, which is shown in Figure 2.3. As we would expect, soil moisture was consistently higher in the paddy plots (M3) than in the two other treatments. There was no difference between surface mulching (M1) and the ploughed in without irrigation treatment (M2) (Figure 2.4). There was no rainfall during the study, which explains the gradual decrease in soil moisture content in the non-irrigated plots. There was some variation in moisture even in the paddy plots, which were sometimes difficult to maintain fully wetted despite irrigation.

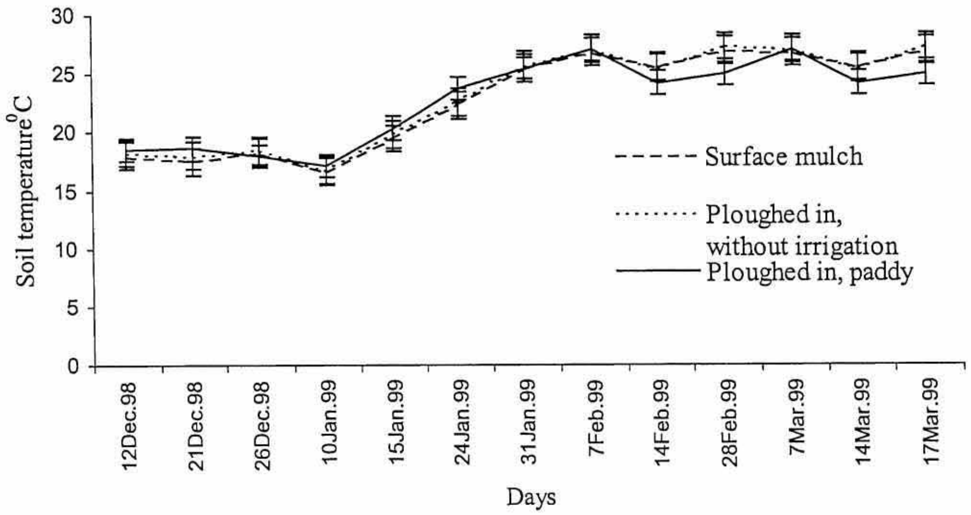


Figure 2.2: Soil temperature at a depth of 10 cm recorded during the decomposition study.

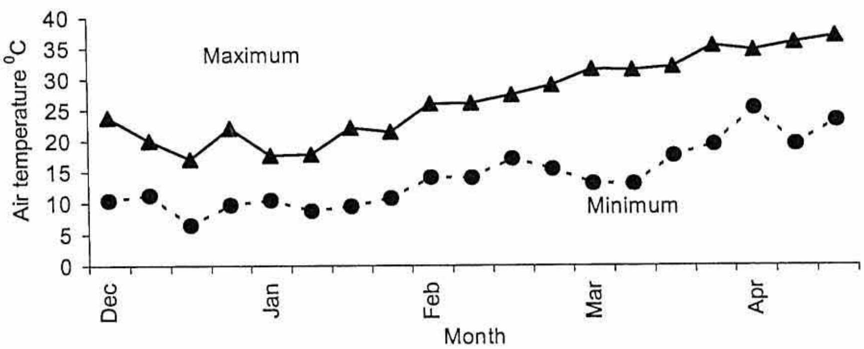


Figure 2.3: Weekly mean of maximum and minimum air temperature recorded during the study period.

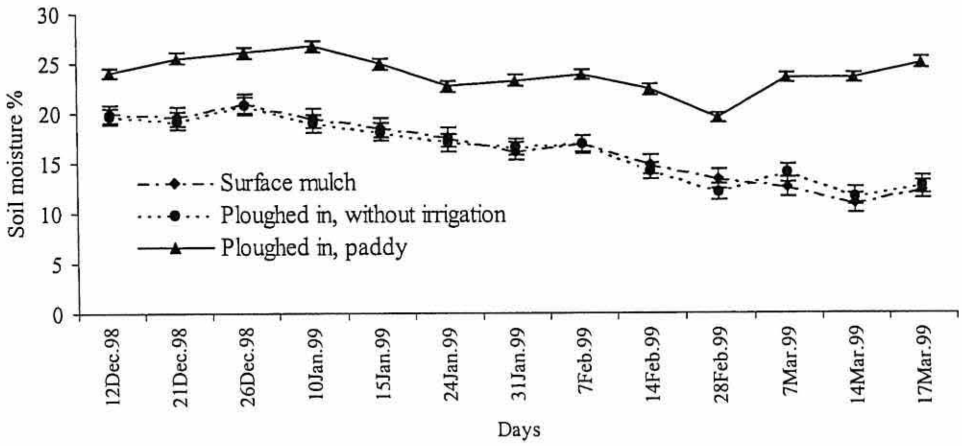


Figure 2.4: Gravimetric soil moisture at 0-15 cm depth recorded during the decomposition study

2.4.2 Litterbag decomposition

2.4.2.1 Quality of vegetation samples

The initial nutrient content and chemical composition of the vegetation in the litterbags are given in Table 2.1.

Table 2.1: N, P, C, lignin (L) and polyphenol (PP) concentrations in the initial vegetation samples

Vegetation type	N (%)	P (%)	C (%)	L (%)	PP (%)	C:N	L:N	L+PP:N
Tithonia leaves	3.62	0.36	39.7	12.0	3.8	10.97	3.32	4.36
Tithonia leaves+ stems	2.70	0.285	38.7	-	-	14.33	-	-
Asuro leaves	4.87	0.34	39.8	5.5	3.2	8.17	1.13	1.78
Bakaino leaves	4.78	0.285	43.0	10.0	2.9	8.99	2.09	2.70

2.4.2.2 Regression model

The double negative exponential regression model was used to describe the decay of total mass of vegetation and the mass of specific nutrients for three methods of incorporation. Weight loss during the initial 10 days of incorporation was very rapid but thereafter was much slower (Figure 2.5). Each curve consisted of two discrete sections corresponding to labile and recalcitrant fractions respectively, which are well described by the double negative exponential model. This pattern was observed irrespective of vegetation type and incorporation method.

The fitted coefficients, r^2 and the F test for each regression are given in Appendices 2.2a, 2.2b, 2.2c and 2.2d. The regressions were highly significant for total mass and mass of N remaining in the litterbags for all vegetation types and incorporation methods, with >90% of the variation in the data explained by the fitted lines in most cases. In contrast, the regressions were not significant for the mass of P remaining in some treatments as discussed below (Section 2.4.7).

2.4.2.3 Effect of incorporation method

Comparison of remaining mass at various times using ANOVA indicated that there were no significant differences in the decomposition rate in the initial period (2 to 5 days) amongst the different incorporation methods (Appendix 2.3). But during the second phase, the incorporation method resulted in a large effect on decomposition rate. The surface mulch generally had lower mass loss from day 10 to day 90 than the two forms of incorporation ($p \leq 0.05$). After 30, 60 and 90 days both incorporation methods showed higher mass loss ($p \leq 0.01$) than surface mulch but were not significantly different from each other (Figure 2.5 and Appendix 2.3).

2.4.2.4 Effect of litter type

The pattern of mass loss in the two tithonia treatments (leaves and the mixture of leaves plus stems) were remarkably different to that in leaves of asuro and bakaino. A highly significant difference ($p \leq 0.01$) was observed when weights remaining in the litterbags were examined for days 5 and 10. The two tithonia treatments (leaves and the mixture of leaves and stems) showed more rapid weight loss than other species at five days after incorporation although after 10 days, while tithonia leaves had decomposed more rapidly than the other materials, the mixture of tithonia leaves and stems was not significantly different from the other species. During the remaining phase of decomposition (30-90 days), however, there were no significant differences between decomposition of the different species (Figure 2.6 and Appendix 2.3).

There was no significant interaction between the type of vegetation and method of incorporation throughout the period, suggesting that method of incorporation and type of vegetation affect decomposition independently (Appendix 2.3).

2.4.3 Nitrogen concentration at each occasion in the vegetation samples

At all litterbag removal dates there was a highly significant difference ($p \leq 0.01$) in N content between types of vegetation (Appendix 2.4). N content generally declined over time. N content did not differ significantly ($p > 0.05$) between bakaino and asuro throughout the period but was lowest in the mixture of stems and leaves of tithonia at all times except after 30 days, when it was not significantly lower than tithonia leaves and asuro (Appendix 2.4). Final concentrations reflected the gradient in initial concentrations of the different species (Appendix 2.4).

The incorporation method had no significant ($p > 0.05$) effect on N content except at the 60^{th} and 90^{th} day of sampling when the irrigated, incorporated treatment (M3) was significantly lower than the others (Appendix 2.4). There was evidence of a significant interaction between incorporation method and type of vegetation only at the first and last time of observation when the N content of bakaino tended to be higher on the surface (M1) than when irrigated and incorporated (M3).

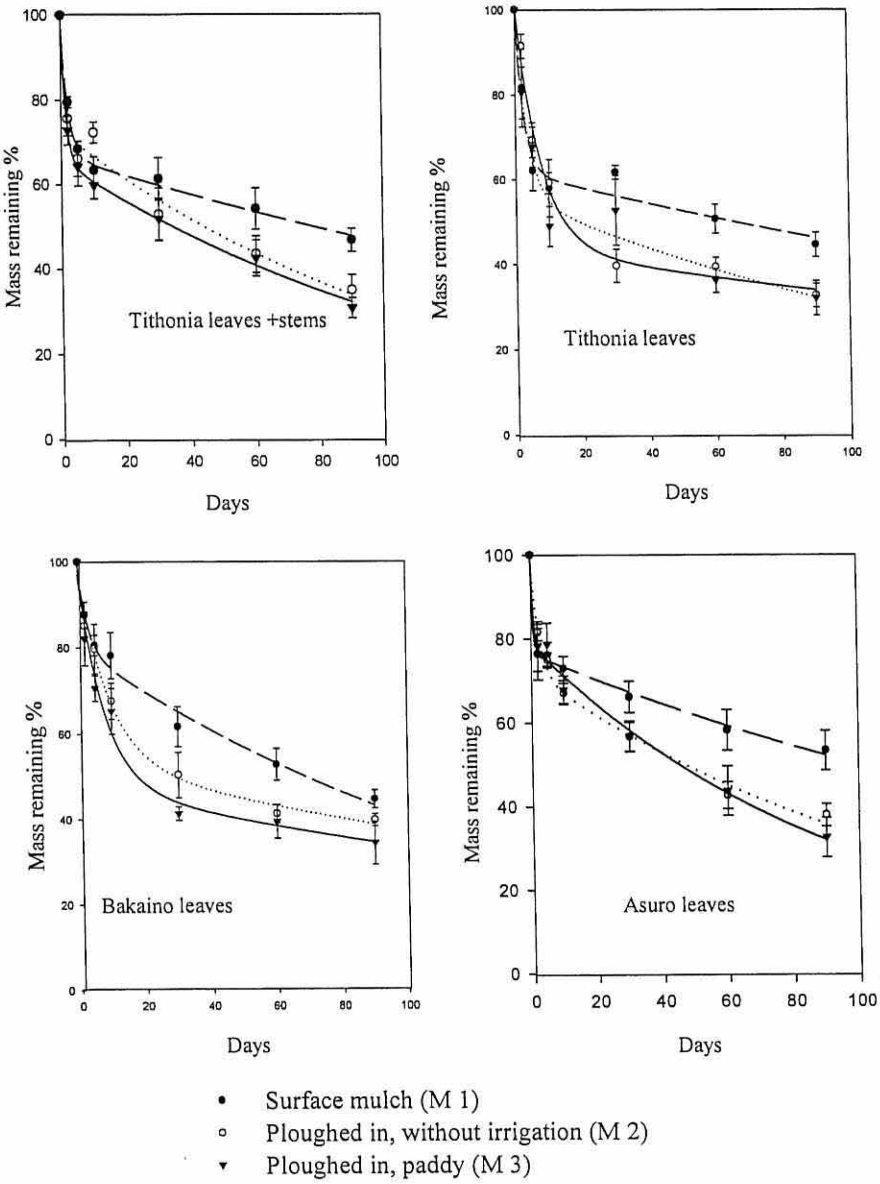


Figure 2.5: Change in total mass of vegetation in litter bags over time (expressed as the percentage of the initial mass remaining). Points are means (n=4)with standard error bars, lines are fitted regressions (Appendix 2.2a).

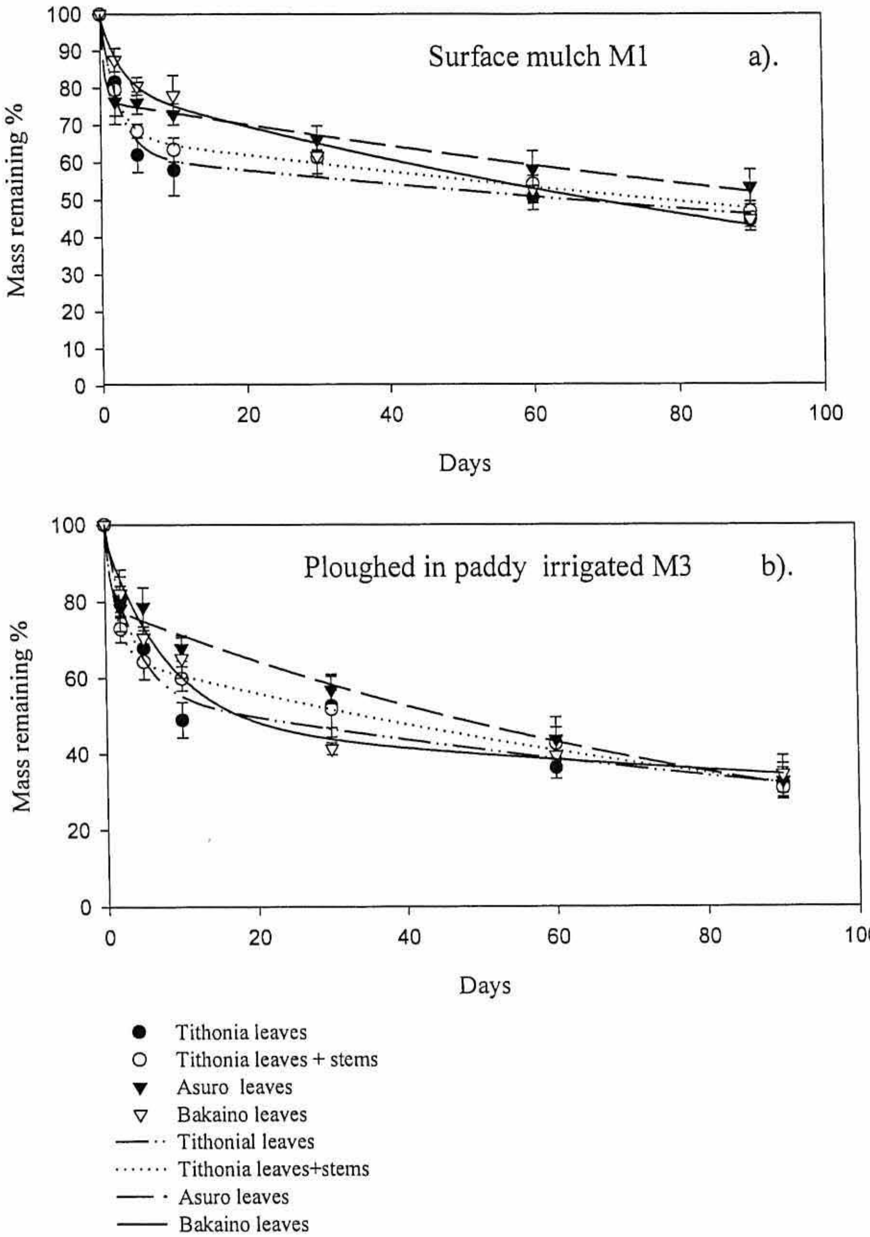


Figure 2.6 (a and b): Changes in total mass of vegetation in litterbags over time (expressed as the percentage of the initial mass remaining). Points are means (n=4) with standard error bars, lines are fitted regressions (Appendix 2.2a) surface mulch (a) and ploughed in paddy (b) treatment.

2.4.4 Mass of nitrogen remaining in litterbags

In the beginning, mass of N remaining was higher in leaves of tithonia than all other vegetation treatments ($p \leq 0.001$). After 10 days, N remaining in the mixture of tithonia leaves and stems was higher than in all other treatments and it remained higher at the later sampling times but was only consistently significantly higher than asuro (Figure 2.7 and Appendix 2.5).

Method of incorporation was found to affect the rate of N loss. During the initial phase of decomposition, paddy incorporation (M3) had lower amounts of N left than with other incorporation methods ($p \leq 0.001$) whereas there was no significant difference between surface mulching (M1) and incorporation without irrigation (M2). By the 90th day, 48.6% of N remained in the surface treatment compared to 33% when incorporated without irrigation (M2) and 23% when incorporated and irrigated (M3) (Figures 2.7 and 2.8a&b, Appendix 2.5).

There was no interaction effect between the method of incorporation and types of vegetation.

2.4.5 C:N

Initial C:N ratios were lower for asuro and bakaino than tithonia, and lower for tithonia leaves only than the mixture of tithonia leaves and stems (Table 2.1). During decomposition there was a significant effect of vegetation type on C:N ratio at all measurement times but there was no consistent trend in how the C:N ratios changed with time across the four vegetation types. (Figure 2.9, Appendix 2.8). There was no consistent effect of incorporation method on C:N ratios.

2.4.6. Phosphorus concentration of the litter at each occasion of sampling

A highly significant difference ($p<0.001$) was observed in P concentration for different types of vegetation throughout the period (Figure 2.10 and Appendix 2.6). Leaves of tithonia contained the highest P concentration at all the sampling but not at 30 days times, ranging from 0.37% to 0.50% (Appendix 2.6). Asuro leaves had the lowest P content at all sampling times varying from 0.20% to 0.29% and were highly significantly different ($p \leq 0.01$) from the rest of the litters. In general P concentration did not differ ($p>0.05$) between leaves of bakaino and the mixture of leaves plus stems of tithonia but at 30 and 60 days was higher in bakaino (Appendix 2.6).

At the initial stage incorporation method had no effect on P concentration but it did after the 10^{th} day. The surface mulch and ploughed in paddy treatments (M1 and M3) had lower P concentrations relative to the ploughed in unirrigated treatment (M2) after 30 days with final concentrations in the order M2 > M1 > M3. An interaction was observed between the vegetation and method of incorporation at the later sampling times (60 and 90 days). Tithonia and bakaino contained a higher P concentration with M2 than the other incorporation methods, whereas asuro had a lower P concentration with M3 compared to other methods (Appendix 2.6).

2.4.7 Amount of P remaining in the litterbags

The double exponential negative regression lines (Section 2.4.2.1) were drawn to see the relationship of the percentage of initial P remaining over time for different litter types. The regressions were significant for most treatments but the double exponential model did not fit well with bakaino in M1 and M2, tithonia leaves + stem with M1 and tithonia leaves with M2 incorporation methods (Figures 2.10 and 2.11, Appendix 2.2c). A single exponential model was similarly unable to describe to the decay, which is complicated by increase as well as decrease in mass of P in the bags over some intervals. This is caused mainly by fluctuation on P concentration, which may reflect contamination of the litter with soil particles and solution, and so these data were not further analysed.

A statistically significant difference was found in the amount of P remaining between litter types at all stages of observations. The amount of P left was highest in bakaino, indicating slower release of P during decomposition, particularly during the initial phase. Both tithonia and asuro lost between 20 and 50% of P mass during the first 10 days whereas bakaino only lost between 5 and 20%. On the 90th day the P left was in the order: bakaino (57.7%) > tithonia leaves (46.4%) > tithonia leaves + stems (42.2%) > asuro (35.5%).

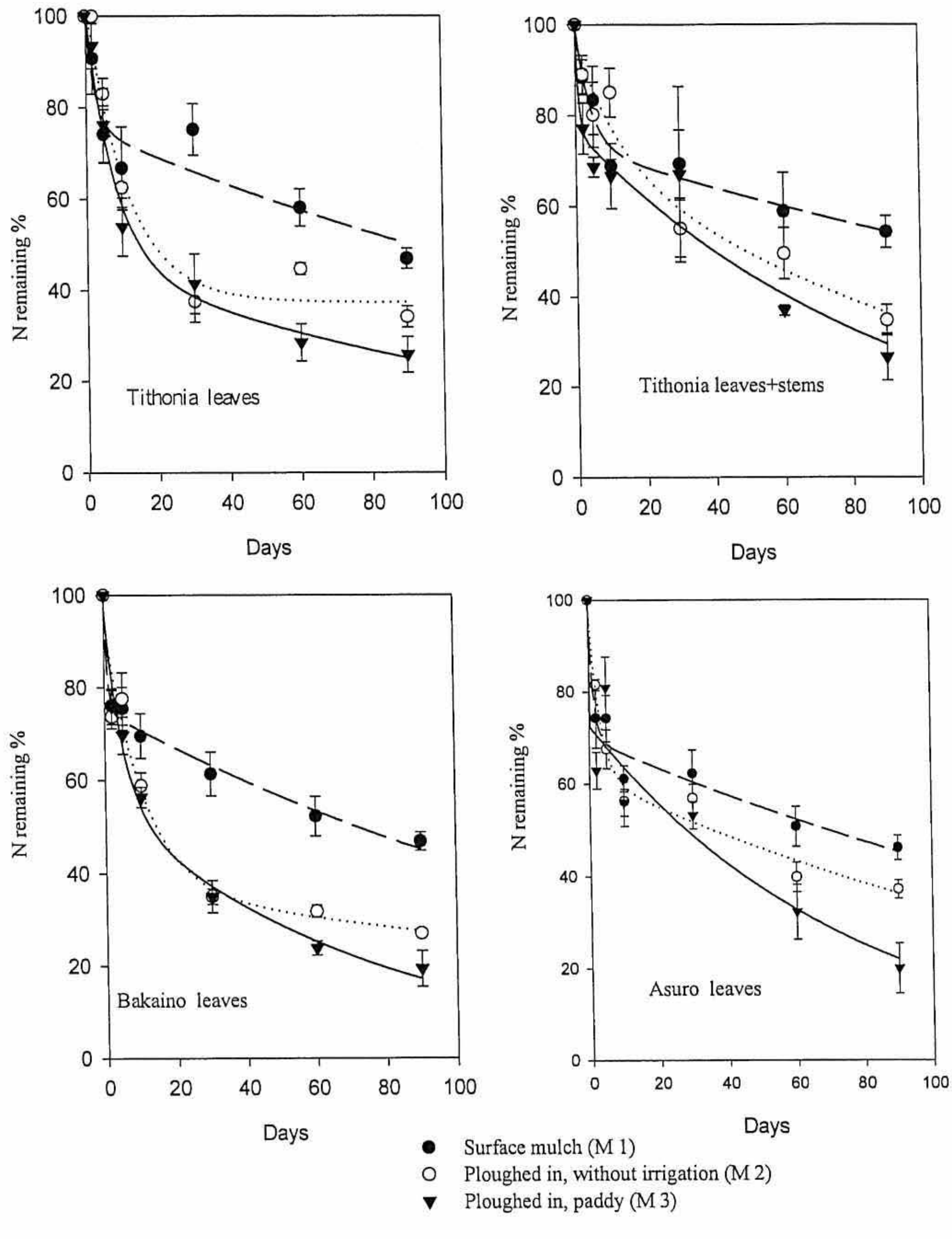


Figure 2.7: Changes in total mass of N of vegetation in litterbags over time (expressed as the percentage of the initial mass of N remaining). Points are means (n=4) with standard error bars, lines are fitted regressions (Appendix 2.2b).

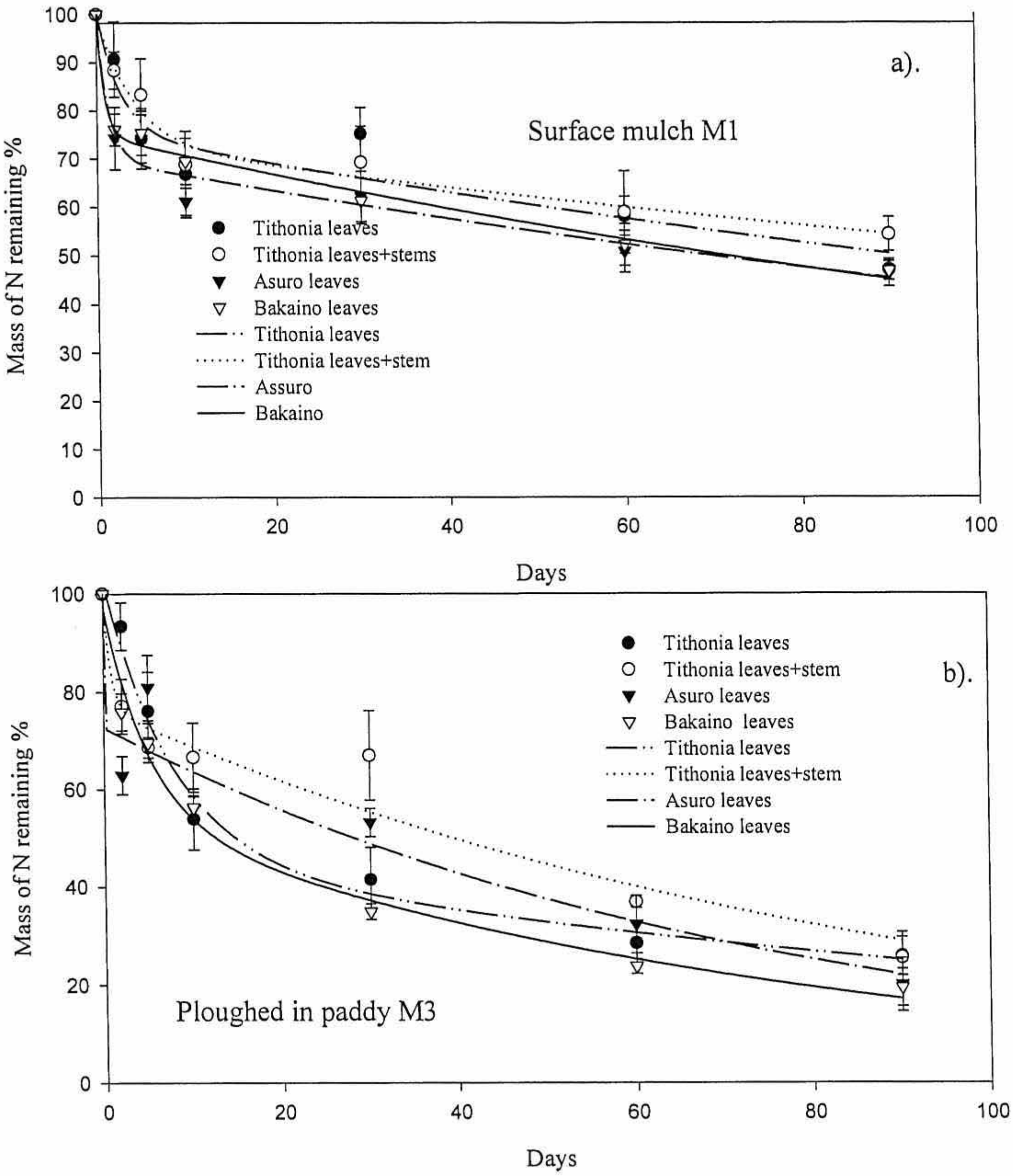


Figure 2.8 (a & b): Changes in total mass of N of vegetation in litterbags over time (expressed as the percentage of the initial mass of N remaining). Points are means (n=4) with standard error bars, lines are fitted regressions (Appendix 2.2b). (a) surface mulch and (b) ploughed in paddy treatment.

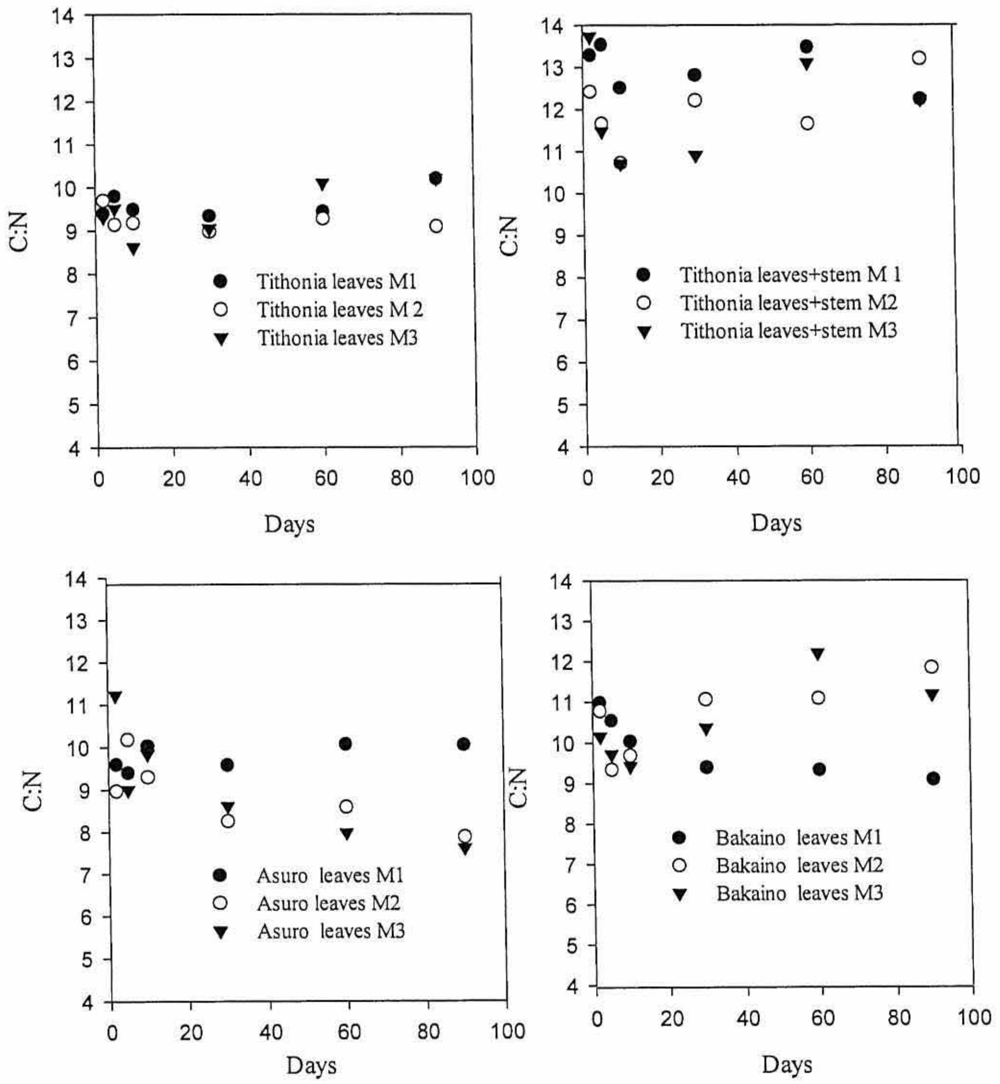


Figure 2.9: C:N of four vegetation types under three incorporation treatments over times. Standard errors are given in the Appendix 2.10.

There was a significant effect of incorporation method on the mass of P remaining throughout the second phase of decomposition (days 30 – 90) but not initially (days 2 - 10) (Appendix 2.7). Loss of P was higher when material was ploughed in and irrigated (M3) than in the two other methods. There was no interaction between litter type and incorporation method, indicating that the types responded similarly to the different incorporation methods. However, in contrast to total mass and N loss rates, phosphorus loss was similar in the surface (M1) and non-irrigated but ploughed in (M2) incorporation methods in tithonia leaves and asuro leaves (Figure 2.10).

2.4.8 C:P ratios

C:P ratio of the vegetation types under different incorporation method has been graphically presented using the double exponential equation (Appendix 2.2d). The model did not fit well for either of the tithonia litter types that, after an initial rapid drop in the C:P ratio, remained almost flat (Figure 2.12). However, the model did produce significant regressions with bakaino and asuro leaves when biomass was incorporated into paddy situation and incorporated without irrigation respectively.

Initial C:P ratios of the litters increased from 110 to 150 in the order tithonia leaves< asuro< tithonia leaves plus stems < bakaino. After 2 days, the C:P ratio of asuro increased to 234 indicating a fast, large release of P relative to C. This was equivalent to 50% of the initial P mass relative to 15-30% from the other vegetation types. After 2 days, there was a decreasing trend in C:P ratios for all litters, indicating a greater loss of C relative to P. Ratios stabilised between 70 and 100 in three of the four vegetation types (Appendix 2.9).

The incorporation method was also found to affect the C:P ratio of vegetation except at 2 and 30th day. Overall higher C:P ratios were found with the surface mulch method followed by ploughed in paddy method, with lowest C:P ratios observed in ploughed in unirrigated method (Figure 2.12).

There was no interaction effect of litter type and incorporation method on C:P ratio up to 30th day of observation. But after this there was a tendency for a lower C:P ratio with leaves of tithonia and bakaino in the ploughed in unirrigated method (M2). Leaves of asuro had the highest C:P ratio (155 to 188) when vegetation was surface mulched (Appendix 2.9).

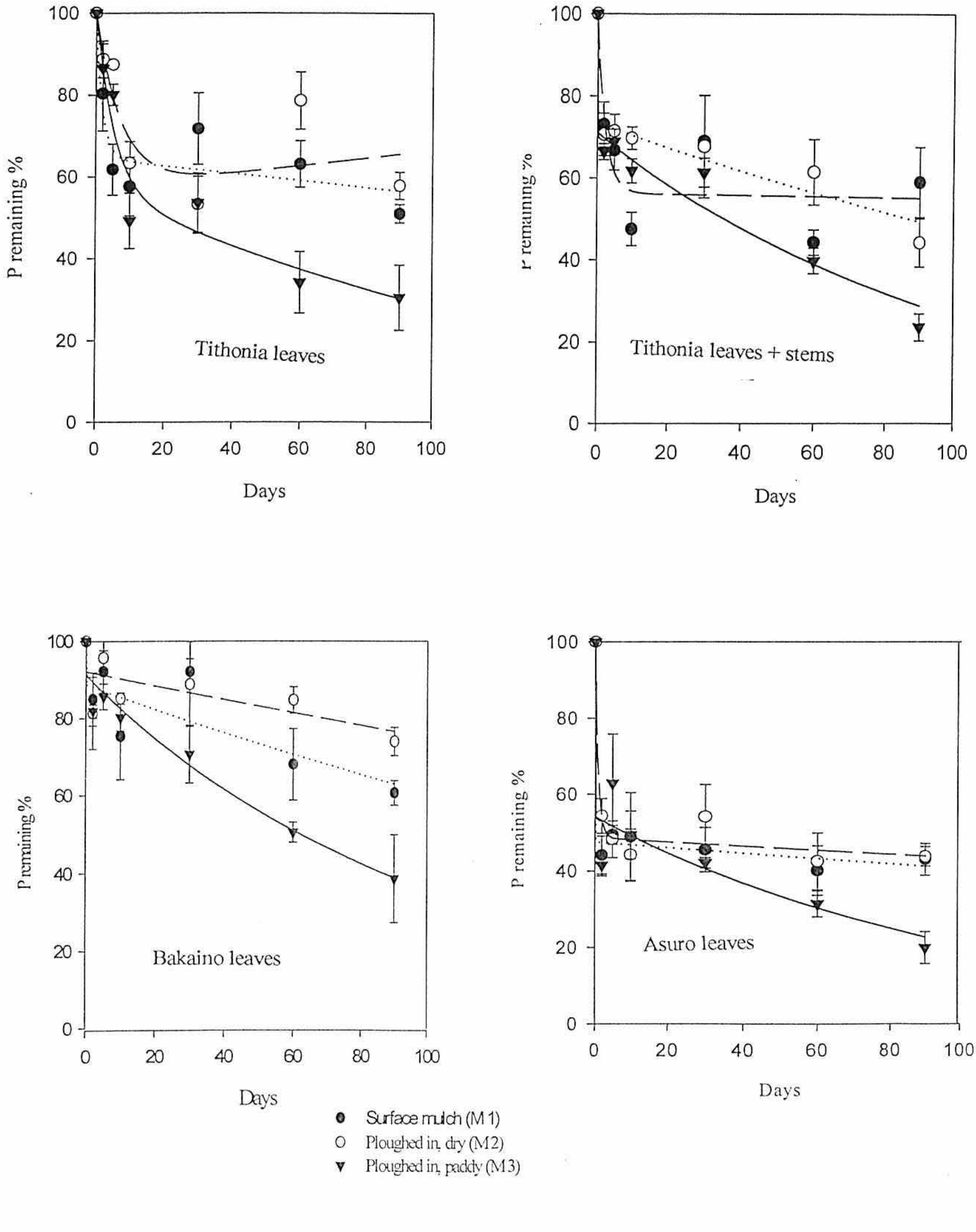


Figure 2.10: Changes in mass of P of vegetation in litterbags over time (expressed remaining as the percentage of the initial mass of P remaining). Points are means (n=4) with standard error fitted regressions (Appendix 2.2c)

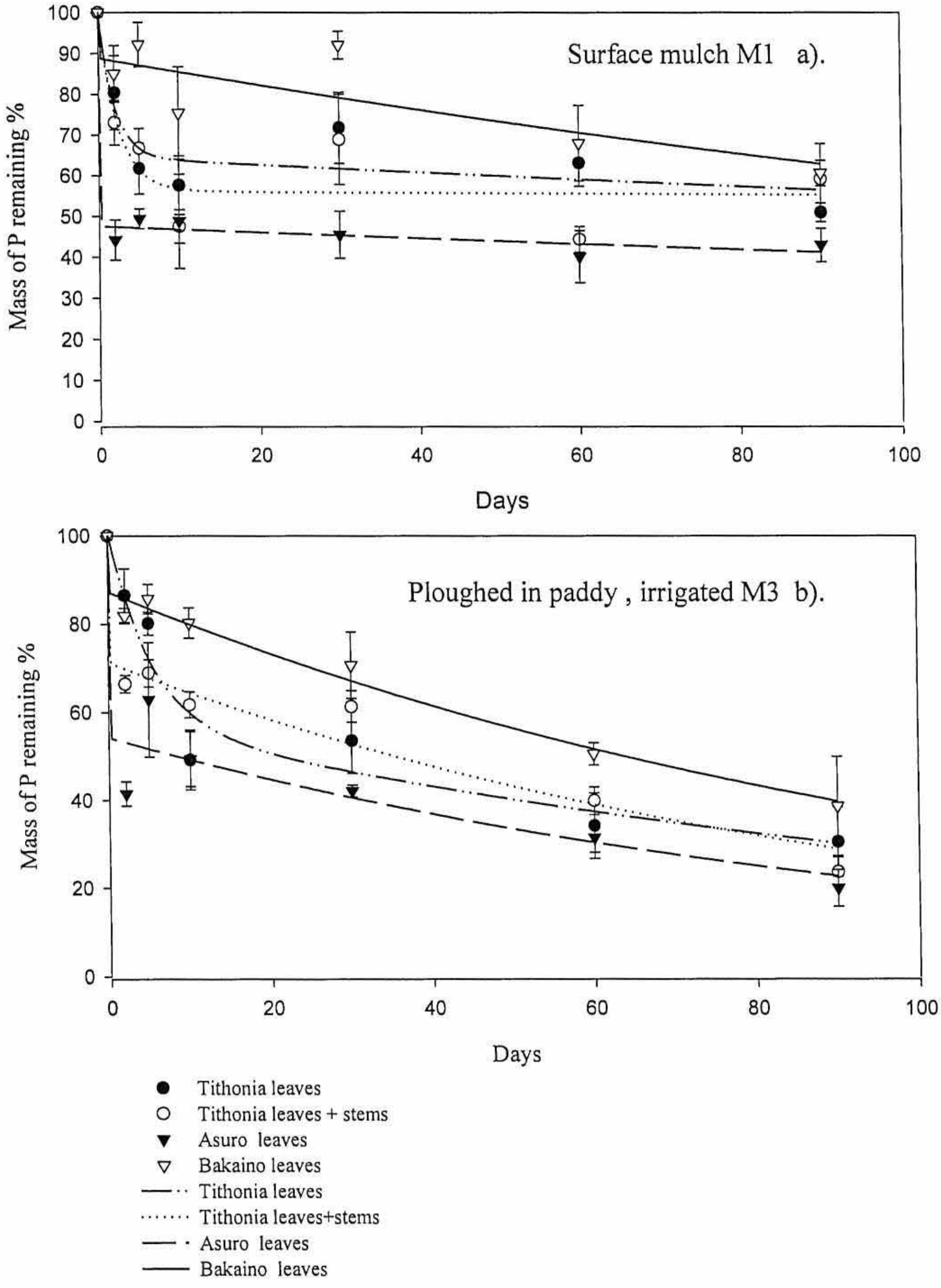


Figure 2.11: Changes in total mass of P vegetation in litterbags over time (expressed as the percentage of the initial mass of P remaining). Points are means (n=4) with statdard error bars, lines are fitted regression (Appendix 2.2c) (a) surface mulch (b) and ploughed in paddy incorporation treatment.

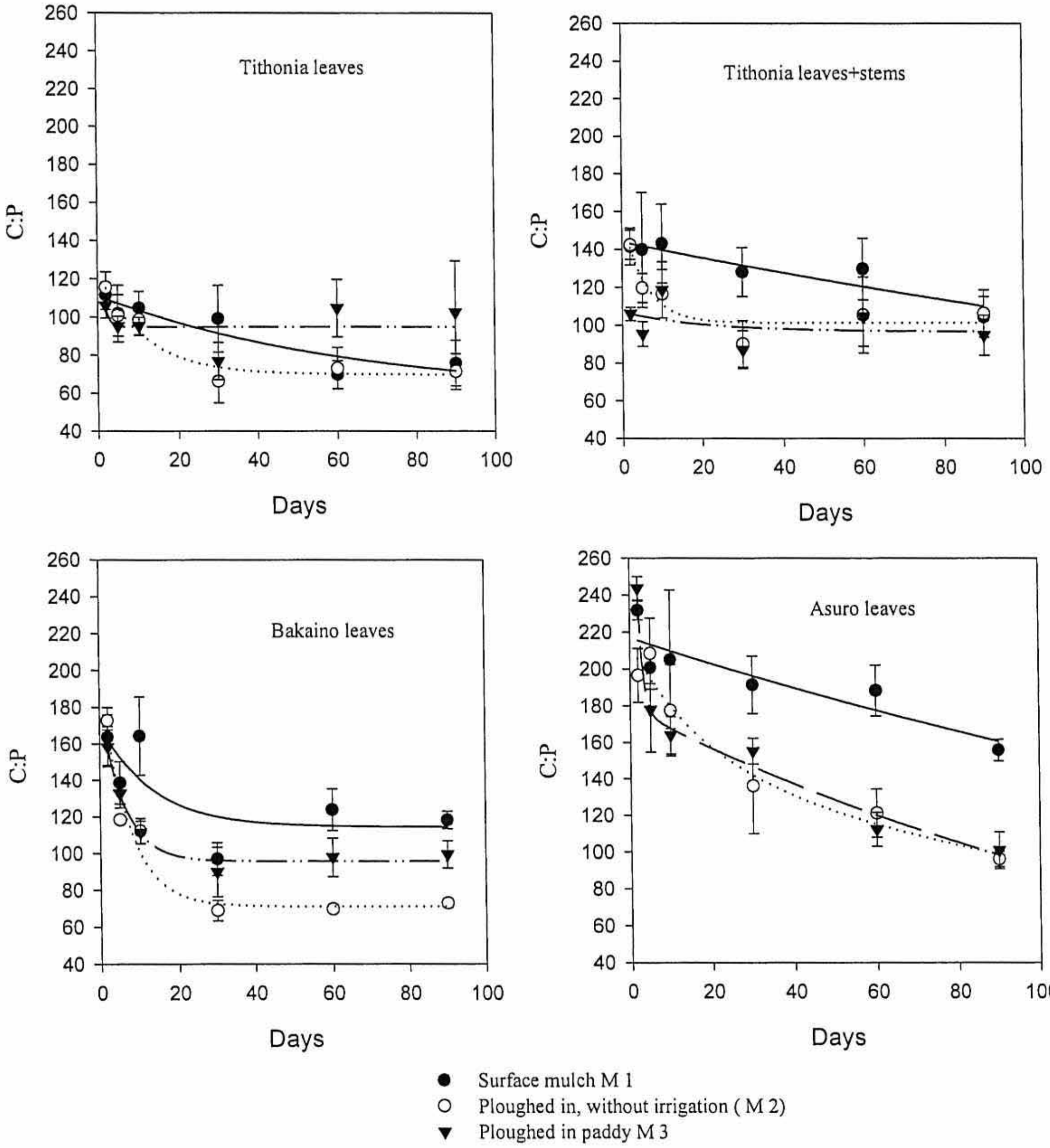


Figure 2.12: C:P ratios of four vegetation type under three incorporation treatments over time.

2.5 DISCUSSION

2.5.1 Pattern of decomposition

The double exponential curves indicate that there are clearly two phases of decomposition (Figures 2.5, 2.7 and 2.8). At the early stage (less than 10 days) the curves are steeper indicating a rapid mass loss. This will represent the labile fraction, the water-soluble compounds, sugar, and other carbohydrates, cellulose or hemicellulose, which are quickly decomposed (Wieder and Lang, 1982 and Harmon *et al.*, 1999). At later stages the curves are less steep, showing a slow steady decay of vegetation. In the second phase more stable compounds such as recalcitrant acid insoluble substances, polysaccharides, lignin and polyphenols are left that are more resistant to decomposition (Saviozzi *et al.*, 1995). Similar results have also been reported by other researchers (Budelman, 1988; Wilson and Raymer, 1992; Tian *et al.*, 1992, Handayanto *et al.*, 1994).

2.5.2 Effect of litter type

In general, the decomposition trend of the vegetation types under study was similar over time. However, in the early stage differences among the litter types were observed. Mass loss from leaves and the mixture of leaves plus stems of tithonia were higher than leaves of asuro and bakaino. After 30 days of burial nearly 50% of original mass was lost compared to 30% for the other two species. De Costa and Atapattu (2001) also found higher percentage of weight loss of leaves of tithonia than gliricidia (*Gliricidia sepium*), flemingia (*Flemingia congesta*) and calliandra (*Calliandra calothyrsus*) after three weeks of incorporation. Decomposition rates have been linked to litter chemistry particularly C:N, lignin and polyphenols:N and lignin+polyphenols:N ratios. In this study there was a significant relationship between percentage mass remaining and lignin+polyphenols:N ratios that explained 99% variation, lignin:N (97%) and polyphenols:N (85%). However, there was no significant relationship between the mass of N and P remaining at 90 days when compared against these parameters.

Unlike mass loss, for both decomposition stages, there were differences among the types of vegetation in their N and P loss. Leaves and the mixture of leaves plus stems of tithonia showed comparatively lower N loss than asuro and bakaino species during both stages. During the labile loss phase, both leaves of tithonia and bakaino showed quick loss of N under irrigated conditions whereas N loss was similar in all vegetation types under surface mulch. The mixture of leaves plus stems of tithonia and leaves of asuro showed a less steep slope than leaves of bakaino and tithonia during the labile phase indicating a slower rate of N release (Figure 2.7). During the recalcitrant phase under all the incorporation methods distinct differences were not seen. However, N loss from tithonia stems plus leaves was always found to be lower than the other vegetation types. The marked difference was only between the incorporation treatments (Figure 2.8). De Costa and Atapattu (2001) also reported that the rate of N release from tithonia stems is slower than from leaves. N release was slowest in tithonia leaves over the first few days. Timing of N release was subsequently similar across the vegetation types.

A higher P loss was found in asuro over 90 days and least from the leaves of bakaino (Table 2.2). These results suggest that whilst mass loss rates do not differ significantly between species over 90 days, the capacity to supply N and P for release differs.

Table 2.2: Total N and P released from vegetation over 90 days (n=12)

Vegetation type	N lost mg g^{-1}	*s.e* N	P lost mg g^{-1}	*s.e* P
1. Tithonia leaves	23.17	1.10	1.93	0.159
2. Asuro	31.92	1.85	2.19	0.131
3. Bakaino	32.93	1.78	1.21	0.164
4. Tithonia leaves+stems	16.59	1.11	1.64	0.182

Note:- *s. e.* – standard error

Over a 90- day period bakaino lost 32.93 mg g^{-1} the greatest amount of N per gram of material whilst asuro supplied 31.92 mg g^{-1} and tithonia leaves supplied 23.17 mg g^{-1}. The tithonia leaves plus stem supplied the lowest amount of N at only 16.59 mg g^{-1}. For phosphorus, the amount supplied decreased in the order of asuro >tithonia leaves>tithonia leaves plus stems > bakaino leaves (Table 2.2).

The timing of release also differed between species with bakaino releasing P at a slow but consistent rate over a 90 day period. This contrasts with tithonia and asuro, which release most freely available P within the first 10 days.

The incorporation method had a great effect on release of both N and P (Table 2.3). The order of N release was M3>M2>M1 and the difference were highly significant. But the effect on P release was significantly higher only from M3 and there was no difference statistically between M2 and M1 over the 90 day observation period.

Table 2.3: The effect of incorporation method on release of N and P over 90 days (n=16)

Method of incorporation	N mg g^{-1}	*s.e.*_N	P mg g^{-1}	*s.e.*_P
M1 Surface mulch	20.79	1.51	1.544	0.113
M2 Ploughed in Non-irrigation	26.72	1.73	1.503	0.134
M3 Ploughed in irrigation	31.05	2.25	2.375	0.142

Note *s. e.* = Standard error

The initial concentrations of C, N, lignin and polyphenolic compounds have been considered to be very important in controlling decomposition and nutrient release (Gilmour *et al.,* 1998, Handayanto *et al.*, 1997 and Budelman, 1988). A higher mass loss of N with leaves of tithonia, asuro and bakaino at the earlier stage could be because of their low C:N ratio compared to the mixture of stem plus leaves of tithonia (Appendix 2.8). It has been suggested that an initial N content of more than 1.73% and C:N ratio of lower than 20 are necessary for immediate N mineralisation (Frankenberger and Abdelmajid, 1985). Singh *et al.* (1996) reported that there was similar release of N in leguminous (*Leucaena leucocephela* Lamb) and non-leguminous plants (*M. azedarachta* L.). They also found that in the first two weeks after incorporation there was larger N release that came from the labile organic pool. Thereafter there was a slow release of N that was partly controlled by a second pool of organic N, which contributed only a small fraction of the total released.

The C:N ratio is well established as an indicator of N release and was found to be below the critical value of 20 for immediate mineralisation in all the vegetation samples. The early understanding of release of N on decomposition of biomass proposed that it was controlled by lignin to N and polyphenols to N ratios. Melillo *et al.* (1982) reported that lignin to N ratio controlled decomposition and mineralisation. Palm and Sanchez (1991), reported that net mineralisation was not correlated to %N or %lignin in the leaf material but was found to be negatively related to the polyphenolic concentration or the polyphenols to N ratio. But Fox *et al.* (1990) found a significant negative correlation between lignin+polyphenols to N ratio and net N mineralisation after 6 weeks. However, they did not find a significant correlation between net N mineralisation and lignin:N ratio. The initial lignin+polyohenol to N ratios of alfalfa (*Medicago sativa* L.) and stylo (*Stylosanthes scabra* Vog., var. Fitzroy). were 1.48 and 5.82 respectively. Handayanto *et al.* (1994) also reported a significant correlation between weight losses and N released and lignin+polyphenols:N ratio in a litterbag and leaching tube experiment. They considered the lignin+polyphenols:N ratio the best indicator of N release because of its higher correlation with the amount of N released and with the rate constant (Handayanto *et al.*, 1994). This relationship was derived using a single exponential model.

Tithonia leaves in the present research had a lignin+polyphenols:N ratio at 4.36, which was much higher than asuro (1.79) and bakaino (2.7). The initial N content of the litter types under test was also higher than the critical level of N (1.73%) required for immediate mineralisation. Vanlauwe *et al.* (1997) reported that a lignin+polyphenols:N ratio larger than 8 or 10 did not cause substantial change in C biomass. But the vegetation studied here such as tithonia, asuro and bakaino had lignin+polyphenols:N ratios from this (1.78-4.36). There was higher mass loss of N under the ploughed in and irrigated conditions than the surface mulch and ploughed in without irrigation. Leaching of water soluble polyphenolic compounds can be expected under irrigated conditions, therefore this might have contributed to more release of N than under surface mulch and non-irrigated condition since these polyphenol compounds have the ability to bind proteins or amino acids (Handayanto *et al.*, 1997). Seneviratne *et al.* (1998) reported that tithonia showed net N mineralisation up to 100% when C was at 39.9% and polyphenolics at 2.32% after 8 weeks at a moisture content of more than 10

$1m^{-2}$. The initial lignin + polyphenol to N ratio of tithonia was measured at 3.35. The tithonia vegetation samples used in the study contained lignin and polyphenols at 12 and 3.8% respectively. But C content in tithonia leaves decreased over time, starting at around 40% in the early stage and later ranging from 33 to 36%. The lower remaining weight in tithonia is likely, therefore, to be largely because of the low C content, since loss of mass is directly related to the low amount of C.

Overall the rate of P loss was found to be slightly slower than N loss, irrespective of type of vegetation. Leaves of bakaino were more resistant to P loss compared other litter types. During the initial phase, P loss was of the same magnitude irrespective of litter type. The ploughed in paddy incorporation method had a strong effect on P loss with loss of P was higher than under the surface mulch and ploughed in without irrigation treatments.

Palm *et al.* (1999) reported that P concentration should be above 0.24% for immediate mineralisation. In general, tithonia contained higher P than asuro and bakaino leaves. Mafongoya *et al.* (2000) observed that with inorganic materials with less than 0.2% total P there would be little or no P mineralisation. All vegetation included in this study contained much higher P contents than this critical level so immobilisation would have been unlikely (Table 2.1). Sharpley and Smith (1989) reported that inorganic P content in plant materials would largely affect the early release pattern of P. However, the double exponential curves indicated that the mass loss of P was slower when the biomass was surface mulched irrespective of the types of litter. But in the ploughed in paddy situation the mass loss rate progressively increased over timeIn the initial period no distinct difference was observed between the incorporation treatments. However, the types of vegetation showed differences with asuro having a lower amount of P left followed by tithonia leaves and the mixture of stem and leaves, whilst bakaino had higher amount of P left than the rest of the vegetation types at both stages.

Budelman (1988) stated that the critical upper value for the C:P ratio is not well defined but immobilisation of P occurs at C:P greater than 100. Nguluu *et al.* (1996) reported that the rate of N mineralisation of residue is related to its P concentration. Neither of these statements is supported by the results obtained in this study.

2.5.3 Effect of method of incorporation on mass and nutrients loss

2.5.3.1 Mass loss

The incorporation method had more influence on decomposition than the type of vegetation. In this study, when biomass was incorporated into soil similar to a paddy transplanting situation and irrigated daily, decomposition rates were greatest over the 90 day period. This was due to a change in the second phase of decomposition, as there were no significant differences during the initial phase. The surface mulch showed least biomass being decomposed over time and the trend was similar with all types of vegetation, while the biomass incorporated into soil but not irrigated was found to be intermediate although not significantly different to the paddy treatment (M3) (Figure 2.6 a & b). Soil temperature was very similar across treatments but soil moisture differed significantly (Figures 2.2, 2.3 and 2.4). Physical mixing and intimate contact with the soil is the most important factor determining mass loss and there was no significant difference between the unirrigated (M2) and paddy (M3) incorporation methods, where in both conditions biomass was incorporated into the soil. Similarly, Holland and Coleman (1987) observed that decomposition of residue was less when it was surface mulched compared to incorporated into the soil. Schomberg *et al.* (1994) also reported that residue decomposition rate was influenced by crop placement and water regime. These authors observed that the amount of dry biomass remaining was higher following surface placement of alfalfa (*Medicago sativa* L.), sorghum (*Sorghum bicolor* L.) and wheat (*Triticum aestivium* L.) than following burial.

2.5.3.2 Mass of N loss

Similar to mass loss there were two distinct phases of N loss. In the initial period mass of N lost was high but later there was a more gradual loss of N (Figures 2.7 and 2.8). When the vegetation was compared under different incorporation regimes it was observed that moisture content of soil affects the mass loss of N. During the initial phase, nitrogen was lost most quickly in the ploughed in, paddy plots (M3). The reason could be adequate moisture available to the microbes for a quick action.

2.5.3.3 Mass of P loss

For phosphorus, only the ploughed in paddy and irrigated method (M3) affected rate of release.

In summary, mass (carbon) loss is affected by ploughing only, nitrogen loss by both ploughing and irrigation and phosphorus loss by irrigation only. This may indicate that most N and a proportion of P is held in a labile, soluble pool in the plant cell whereas carbon and remaining N pools are held in more structural components which are released following mechanical disturbance.

2.5.4 The limitation of the litterbag technique

One of the limitations of using the litterbag technique was that the samples were damaged by the termites during the winter. During the wet season too when the soils dry out then various times of insects but mostly the beetles damage the samples and bags. It was also experienced that the amount of biomass to be sued in the litterbags should not be less than 50 g since the loss of biomass is very high and fast due to submerged condition. Contamination of the samples from fine soil particles is also another problem and at the latter stage the washing of samples is not very satisfactory and there is likely to be lost of very fine particles of samples.

2.6 CONCLUSION

The following conclusions can be drawn from the study:

A double exponential model, with separate rate constants for a rapidly decomposing (labile) fraction and a recalcitrant fraction that decomposes more slowly, was able to explain total mass loss and N release for all the litter types but was not as suitable for modelling P release.

Tithonia biomass initially decomposes faster than the alternative local green manures used by farmers (asuro and bakaino) but rates of mass loss do not differ between species at later stages of decomposition.

Mass loss is not a good indicator of nutrient release. Significant differences in N and P lost were observed between species with bakaino the most N but least P whereas asuro lost P at a faster rate than the other species. The method of incorporation had a larger effect on both mass loss and nutrient loss than the type of litter.

This has demonstrated the importance of the incorporation of litter to achieve rapid nutrient release in these soils, even in paddy conditions. Therefore the results confirm the current practice of incorporation of green manure biomass followed by farmers in the study area. Farmers also prefer vegetation, which has slow releasing characteristics and is rich in major plant nutrients. This allows farmers more flexibility for timing of incorporation of biomass and rice seedlings transplanting. Since tithonia releases nutrients very fast at an early stage this might have a relatively low impact on rice growth because rice seedlings are too young and cannot make use of nutrients for growth at an early stage and secondly because in the submerged conditions under rice systems, plant nutrients, especially nitrogen, could be lost either through leaching or denitrification. An alternative approach could be mixing poor quality vegetation with tithonia so that the nutrients will be released slowly to match the nutrient requirements of crops. This would also help to reduce nutrient losses and improve nutrient uptake by crops. However an adaptive field research study would be useful to see the effect of mixing high and low quality vegetation before recommending this to farmers. However, there might be a negative effect on the young rice seedlings if the amount of biomass was very high.

Farmers in the study area allow 15 to 30 days after mulch application before planting to ensure biomass is well decomposed and has released nutrients that would be available to young rice seedlings. This study has demonstrated that there is no need to wait this long since nutrients are released more quickly than this. Therefore farmers should transplant seedlings soon after (2-5 days) biomass has been incorporated into the field.

CHAPTER 3

SEASIONALITY OF GROWTH IN TITHONIA AND SESBANIA IN THE TERAI AND THEIR POTENTIAL PLACE IN CROPPING SEQUENCES

3.1 INTRODUCTION

Tithonia diversifolia (Helms.) A. Gray belongs to the family Asteraceae, the plant is branched, broad-leaved and perennial (Ayeni *et al.*, 1997). The plant is well known in Southern and Central America and the African continent. Tithonia is found in the hills of Nepal at an altitudinal range of 450 m to 1550 m and is popularly known as *taramandal*. It is found growing in all types of soil. It is mostly observed growing on brown coloured and medium to heavy textured and acidic soils, although in some places tithonia can be found on steep limestone rock. It is used mainly as fuel wood and to feed goats. It is also used as live fencing on farm boundaries.

Tithonia biomass is used for green manure purposes in Africa to improve soil fertility and crop productivity (ICRAF, 1996; Gachengo *et al.*, 1999 and Jama *et al.*, 2000). But information on propagation techniques and the appropriate time for planting under the hot and humid conditions, which occur in the Terai of Nepal, is lacking. Limited field studies have been carried out in Africa and South America. Mustonen (2000) reported that the best vegetative materials for multiplication of tithonia are the woody branches with a thickness greater than 1.5 cm. Upfold and Staden (1990) reported that the embryos of ripe seeds of tithonia are dormant and should be kept for three months before planting to obtain a high germination rate. Ayeni *et al.* (1997) reported that the emergence of tithonia seedlings takes place within 2 to 3 days of planting. A study on seeding depth and emergence of seeds also revealed that at a seeding depth of 0-5 cm there was a germination rate of 84 -100% (Ayeni *et al.*, 1977). There was poor emergence of seeds as the depth of seeding placement increased.

To assess the potential of tithonia as an organic fertiliser in the high production potential areas of the Terai it is important to understand the growth habit of tithonia over the seasons, the best methods to propagate the plant, and the most appropriate time to fit the plant into the prevailing cropping patterns.

The specific objectives of the research reported in this chapter were, therefore to:

- determine the appropriate time for planting tithonia and to quantify the biomass production and nutrient acquisition per unit area and time,
- make a comparison of tithonia with the popular green manure crop sesbania (*Sesbania cannabina*), and
- determine the most appropriate propagation technique for tithonia in the Terai environment of Nepal.

3.2 MATERIALS AND METHODS

3.2.1 Observation study in 1998 rainy season

In the 1998 rainy season a field study on propagation methods was carried out. Matured and semi hard branches and roots were collected in the hills at an altitude of 1400 m and brought to the experimental site (187 m) in the months of August and September. The cuttings were put on a moist jute bag and wrapped carefully and transported. The stems were cut to 152.4 to 203.2 mm in length with 3-4 nodes. The stems were buried in the ground at an angle while roots were just buried and covered with soil. Survival rate was recorded.

3.2.2 Field trial in 1999 dry summer season

An observation field trial was planted out using seeds, stems and rhizomes of tithonia and compared with sesbania (*Sesbania cannabina*). The individual plot size was 1.5 m x 1.5 m. Three rows were planted at 50 cm distance from each other. Seeds of tithonia were planted in a continuous line at an approximate seed rate of 9 kg ha^{-1}. The semi hard stems and root cuttings were buried at an interval of 30 cm. Sesbania seeds were planted in a continuous line at a rate of 40 kg ha^{-1}. The distance between rows for sesbania seeds was the same as that for roots and stem cuttings of tithonia (50 cm). Five batches of tithonia and sesbania seeds were sown at intervals of 20 days each. Stem and root cuttings were propagated on 28^{th} March and 17^{th} April. Measurements of plant height and biomass were recorded.

3.2.2 Field trial in dry summer season 2000

A field trial growing tithonia and sesbania within a randomised complete block design (RCBD) with three replicates was laid out on a sandy loam soil. The seed rate for sesbania and tithonia was 40 kg ha^{-1} and 10 kg ha^{-1} respectively. The experimental plots were 6 m^2. The space between the plots was 50 cm. The row distance was 50 cm. Seeds were planted at intervals of 15 days starting from 1 April. The seeds of tithonia were collected from the experimental site established in 1998.

Measurements of plant height and dry matter were taken on five occasions. The measurements then had to be abandoned because the field was flooded due to heavy monsoon rains and more than 60 - 70 % plants died. Seeds sown after the third planting (May) did not germinate at all which hampered measurements. Therefore only results from three planting dates (April 1, 15 and 24) were analysed and presented here.

Once harvested, plant samples were dried in an oven at 60°C for 24 hours, ground, sealed in a plastic container and stored in the fridge before chemical analysis in order to avoid microbial activity. Since the room temperature was around 35 °C during that period and the humidity was also high. Nitrogen, phosphorus and potassium content in the plant tissue were analysed at the Henfaes Agricultural Station, University of Wales, Bangor. The methodology was changed for the determination of N and P since the Henfaes laboratory was equipped for this methodology. Nitrogen was analysed using a Kjeltec 1030 auto analyser. Plant samples were kept in a furnace at 490°C for 8 - 12 hours for ashing. Ash was then dissolved using 1M HCl and a 100 ml volume was made up and kept for further analysis. The Vanado molybdenum, a yellow colour method, was used for P determination. K concentration in the extract was determined using an Atomic Absorption Spectrophotometer.

3.3 RESULTS

3.3.1 Result of 1998 and 1999 field trials

The observation study conducted in the 1998 rainy season in the months of August and September indicated that both root and stem cutting propagation methods were successful. However, the stem cuttings had a 40 - 50 % success rate whereas root cuttings were 90% successful. The study could not be continued beyond September due to heavy flooding in the experimental site and measurement could not be taken.

The non-replicated trial conducted in 1999 summer season (March - April) could not be completed, again due to flooding. The growth of sesbania was faster than tithonia (Appendix 3.1). There were no significant differences in the growth pattern of tithonia whether propagated by seeds, stems or root cuttings (Appendix 3.1). Production of fresh biomass of tithonia was also recorded comparing different propagation methods. Plants were grown for 90 and 108 days before harvesting (Appendix 3.2). Biomass production was recorded at 42.2 t ha^{-1} when propagated through roots in March (i.e. 108 days) whereas plants propagated in April produced very low biomass because of the shorter growing period (i.e. 90 days). The difference might also have been affected by the different growing periods. There was no difference in biomass production between stem propagation and seeding for the March planting (108 days) but in the April planting (90 days) stem propagation produced nearly 50% more biomass than either seeds or root cuttings (Appendix 3.2).

3.3.2 Results of 2000 summer season

Biomass production of sesbania and tithonia per unit area planted at three dates is presented in Figures 3.1 and 3.2. A highly significant, exponential, positive relationship was observed between dry matter yield and growing time. Biomass production of tithonia per unit time was significantly lower than for sesbania (Figures 3.1 and 3.2).

The relationship between the growing period and dry matter accumulation was highly significant for both the species (Figures 3.1 and 3.2). Early planting of tithonia showed higher dry matter production than the later planting (Figure 3.2). The planting date did not greatly affect the dry matter production of sesbania.

3.3.3 Nutrient accumulation over time

Nitrogen concentrations in the growing tithonia plants were measured. The relationship between the N concentrations in tithonia and growing period was found to be polynomial quadratic and was significant ($p<0.05$) in plants from the April 1 and April 15 plantings. However, the relationship was not significant in plants from the April 24 planting. There was an increment in N concentrations up to 80 - 90 days after planting after which it tended to decrease (Figure 3.3).

A significant negative linear relationship between the length of growing period and N concentrations in sesbania was found at all planting dates (Figure 3.4).

The relationship between length of growing period and P concentration was non significant at April 15 planting dates in tithonia whilst the relationship was significant at the first and last date of planting (Figure 3.5). The relationship between P concentrations and the length of growing period was significant at all planting dates for sesbania (Figure 3.6). The relationship was a polynomial quadratic in both the species (Figure 3.5, Figure 3.6).

A non-significant negative linear relationship in April 1 and 15 plantings was found between the growing period of tithonia and K concentrations (Figure 3.7). For the April 24 planting the relationship was positive but non-significant. A trend towards a polynomial quadratic relationship was found between K concentrations and the growing period of sesbania (Figure 3.8). The relationship was significant sesbania only for the April 24 planting date.

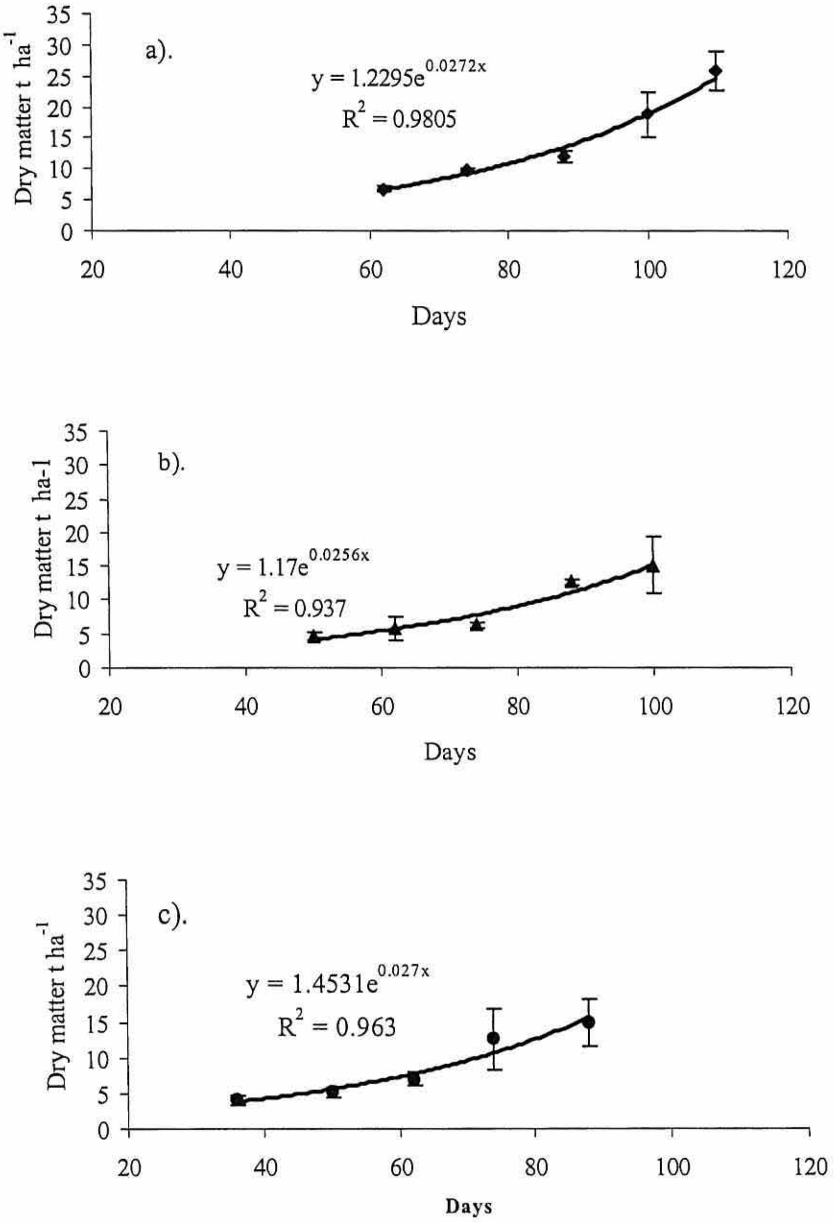


Figure 3.1: Dry matter production of sesbania for three planting dates; a= 1 April, b =15 April and c= April 24, 2000.

Plate 3.1: Biomass production of *Tithonia diversifolia*. This stand is ready for incorporation into the soil for green manuring.

Plate 3.2: *Sesbania cannabina* at seed harvesting stage. *Tithonia diversifolia* is at the flowering stage in the month of November.

Plate 3.3: Rapid growth of *Sesbania cannabina* planted at 15 day intervals.

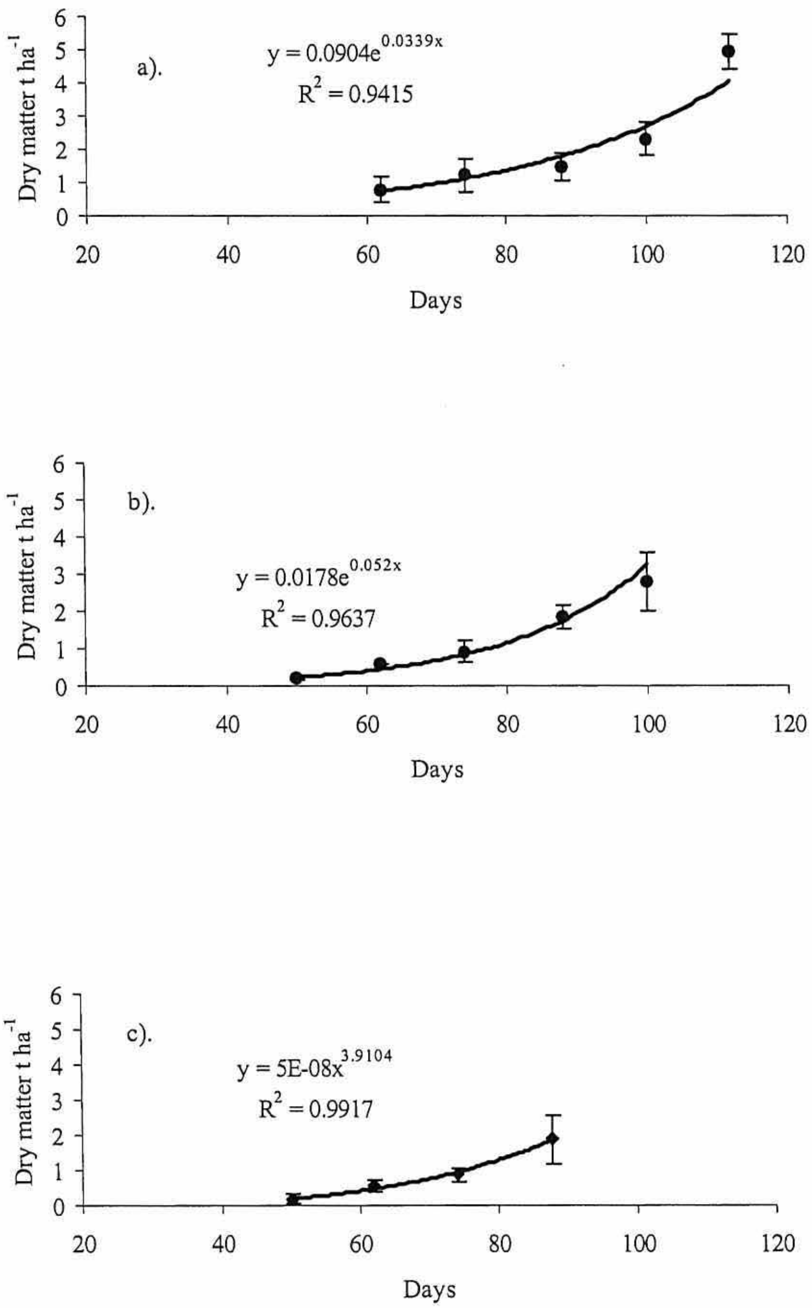


Figure 3.2 : Dry matter production of tithonia for three planting dates; a=1 April, b==15 April and c=April 24, 2000.

3.4 DISCUSSION

3.4.1 Propagation method and planting time

The planting time of leguminous green manure crops in the tropical and sub tropical environment in South Asia varies greatly and is influenced by crop species, crop management and cropping patterns. However, the general planting time starts in April and runs until June/July. Adequate biomass production of sesbania can be achieved after 45 - 60 days. This study has shown that tithonia can also be grown between March and April although it may suffer from low oxygen supply if the monsoon commences early and soils are waterlogged. Both stem and root cuttings and seeding could be recommended to farmers as a means of propagation but it has also been demonstrated that the seeds are no longer viable if sown after May. Even with this limitation, this does leave a sufficient time gap between wheat harvest and main season rice transplanting for a tithonia green manure crop. Ayeni *et al.* (1997) reported that with early establishment in the month of March and April in the western Nigerian environment, plants grew very tall and accumulated adequate biomass compared with those established in the mid-late rainy season from June onwards. However, the same is not true in the Terai environment because of the difference in the climatic conditions.

Both stem and root cuttings are appropriate as a means of propagation. However, propagation from seeds is more complicated and uncertain. Jama *et al.* (2000) cited the work of King'ara (1998) and reported that stem cuttings of 20 to 40 cm length inserted it an angle in soil are better than if buried horizontally. Use of seeds may be a difficult task for farmers as the land preparation, soil types and seeding depth will influence germination (Ayeni *et. al.*, 1997).

3.4.2 Biomass production of tithonia

Yadavinder Singh *et al.* (1994) reported that the most productive green manure crops yielded about 4-5 t ha^{-1} dry biomass in 50-60 days. The production of dry matter of tithonia is quite low compared to sesbania species such as *S. cannabina, S. rostrata* and *S. aculeata.* This study has shown that within 70 to 90 days 1 - 1.5 t ha^{-1} dry matter yield of tithonia could be produced compared to 6-14 t ha^{-1} dry matter of sesbania (*S. cannabina*). Beri *et al.* (1989a, 1989b) reported that 23 t ha^{-1} shoot materials, equivalent to 5 t ha^{-1} of dry matter of sesbania (*S. aculeate)*, can be produced within 60 days and 101 to 104 kg N ha^{-1} can be accumulated. The potential for tithonia production may be greater in different systems. Jama *et al.* (2000) reported that a mean dry weight of 7.5 t ha^{-1} tithonia biomass can be produced when it is grown as hedges and they have reported that biomass production will be higher under fertilised soils. Ayeni *et al.* (1997) reported that 5 kg dry matter per plant could be produced if grown for 9 months.

3.4.3 Nutrient Concentration

The concentrations of N was found to be sensitive to the age of the growing plants for both tithonia and sesbania, whereas P and K concentrations were generally more constant (Figures 3.3, 3.4, 3.5, 3.6, 3.7 and 3.8). N, P and K concentration were measured on plant samples (leaves plus stem) taken from 36 day to 110 days old plants. N, P and K concentrations in tithonia were in the range of 2.5 - 3.8%, 0.376 - 0.442% and 1.13 - 2.6% respectively. Sesbania contained N, P and K in the range of 2.3 - 2.97%, 0.37 - 0.466 % and 0.73 - 1.35% respectively. These results indicate that tithonia has high concentrations of both N and K compared to sesbania. Jama *et al.* (2000) reported that N, P and K concentrations of green leaves of tithonia were in the range of 3.1 - 4.0, 0.24 - 0.56 and 2.7 - 4.8% respectively. These results are in line with the results reported by Jama *et al.* (2000) and Gachengo *et al.* (1999).

Overall N, P and K concentrations were found to decrease with increasing growing time in both tithonia and sesbania. This indicates that the age of green manure plants at harvest time is important for the purpose of manuring, as older plants will have lower concentrations of both N and P. They will have higher C/N and C/P ratios affecting both the decomposition and the mineralisation of nutrients.

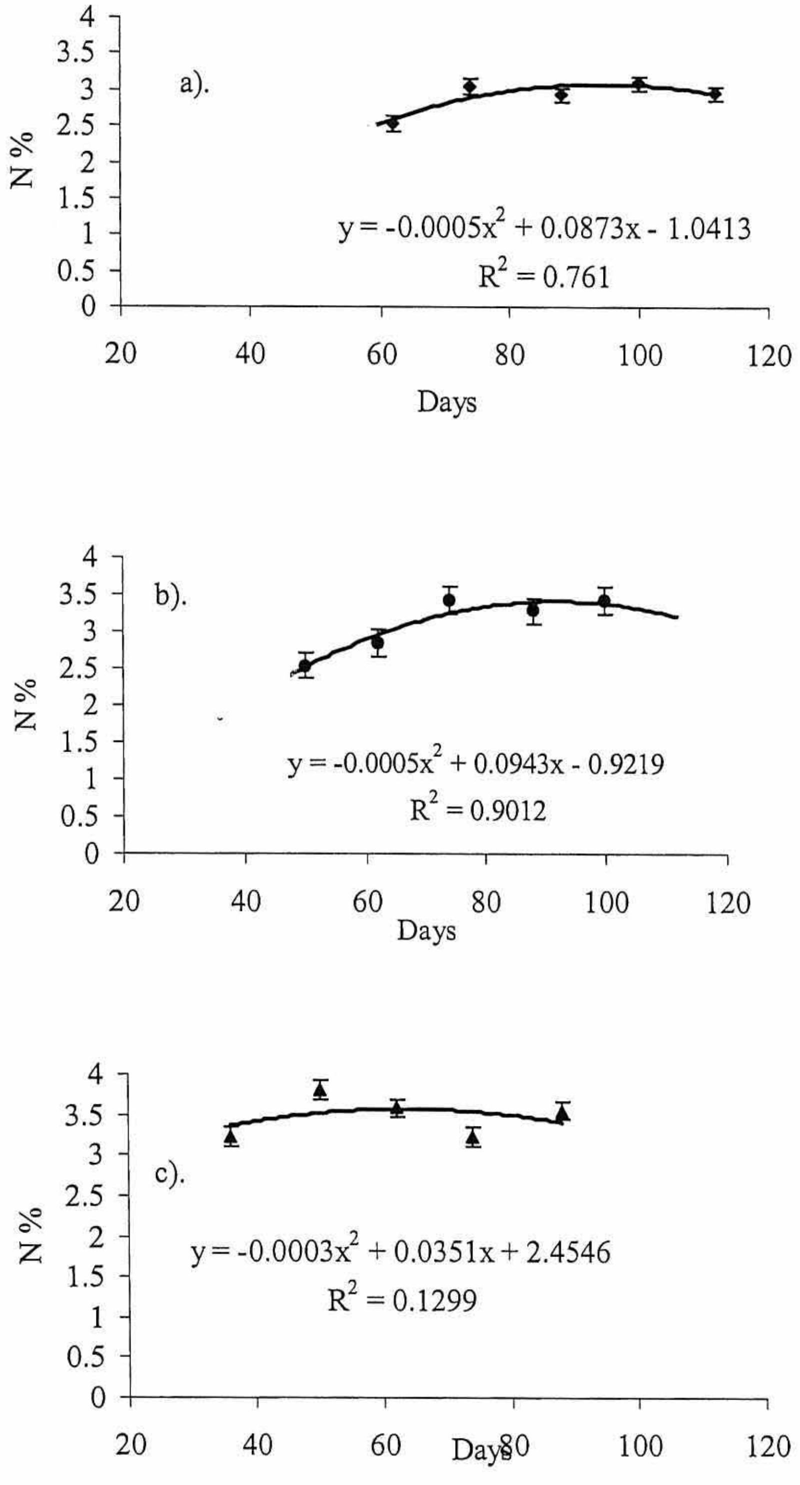


Figure 3.3: Nitrogen concentrations in tithonia plants over the growing period at three planting dates; a = April 1, b = April 15 and c = April 24, 2000.

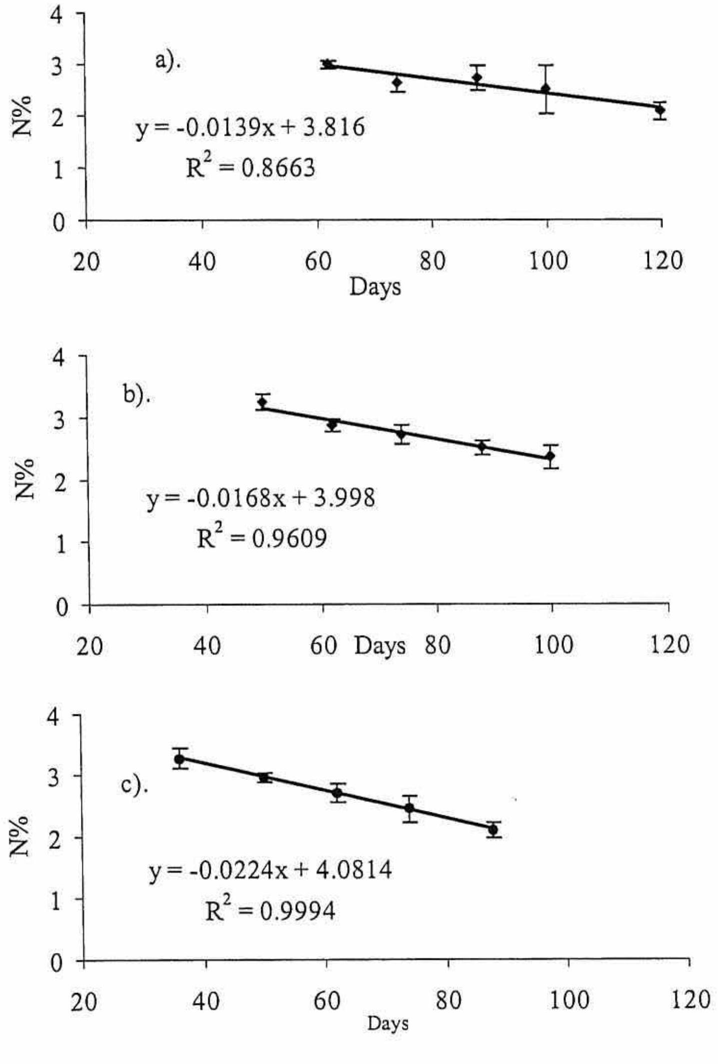


Figure 3.4: N concentrations in sesbania plants over the growing period at three planting dates; a = April 1, b = April 15 and c = April 24, 2000..

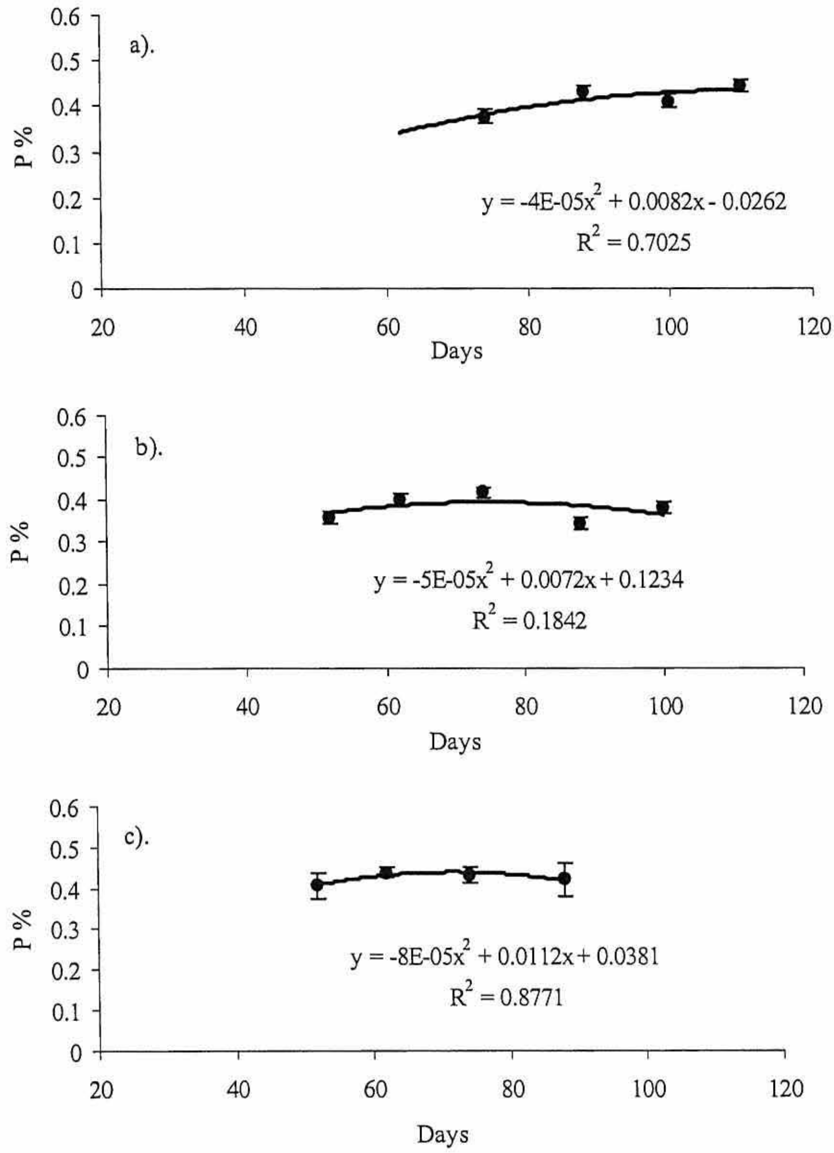


Figure 3.5: Concentrations of P in tithonia plants over the growing period planted at three different dates; a = April 1, b = April 15 and c = April 24, 2000.

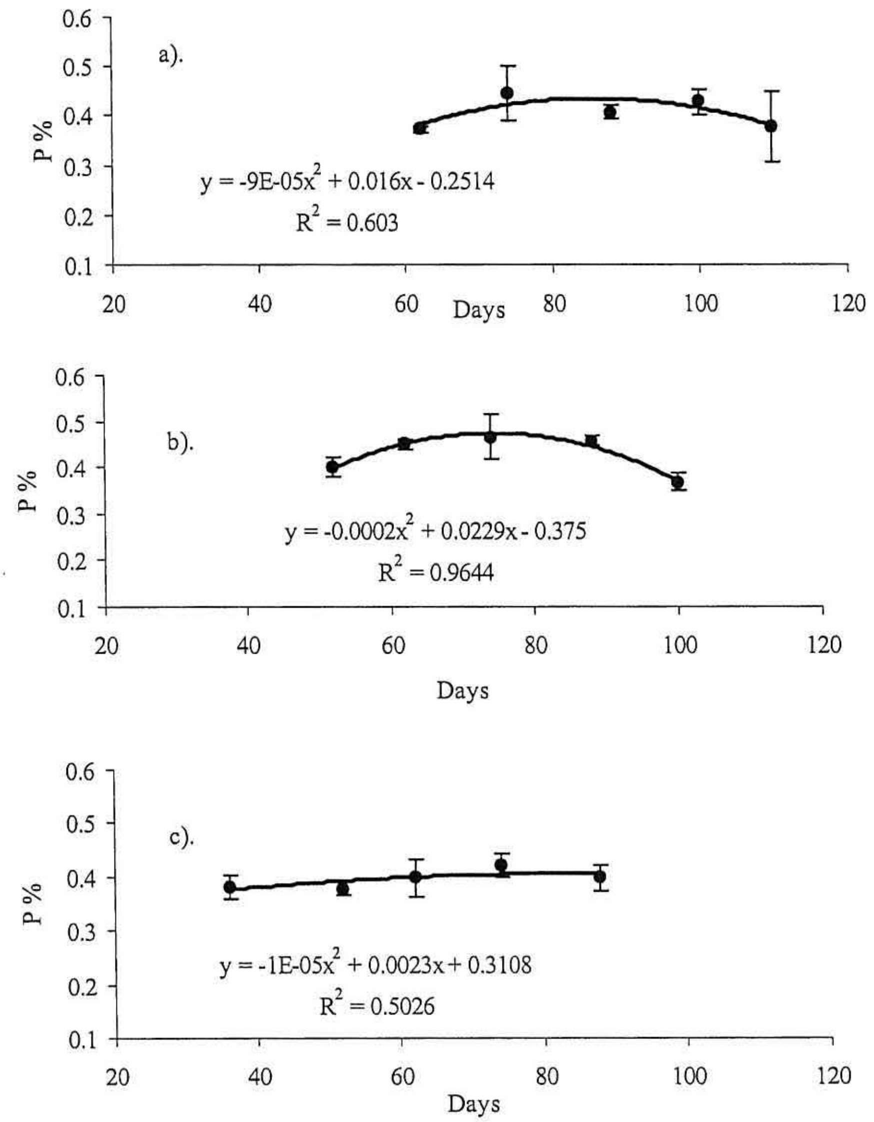


Figure 3.6: P concentrations in sesbania plants over the growing period planted at three dates; a = April 1, b = April 15 and c = April 24, 2000.

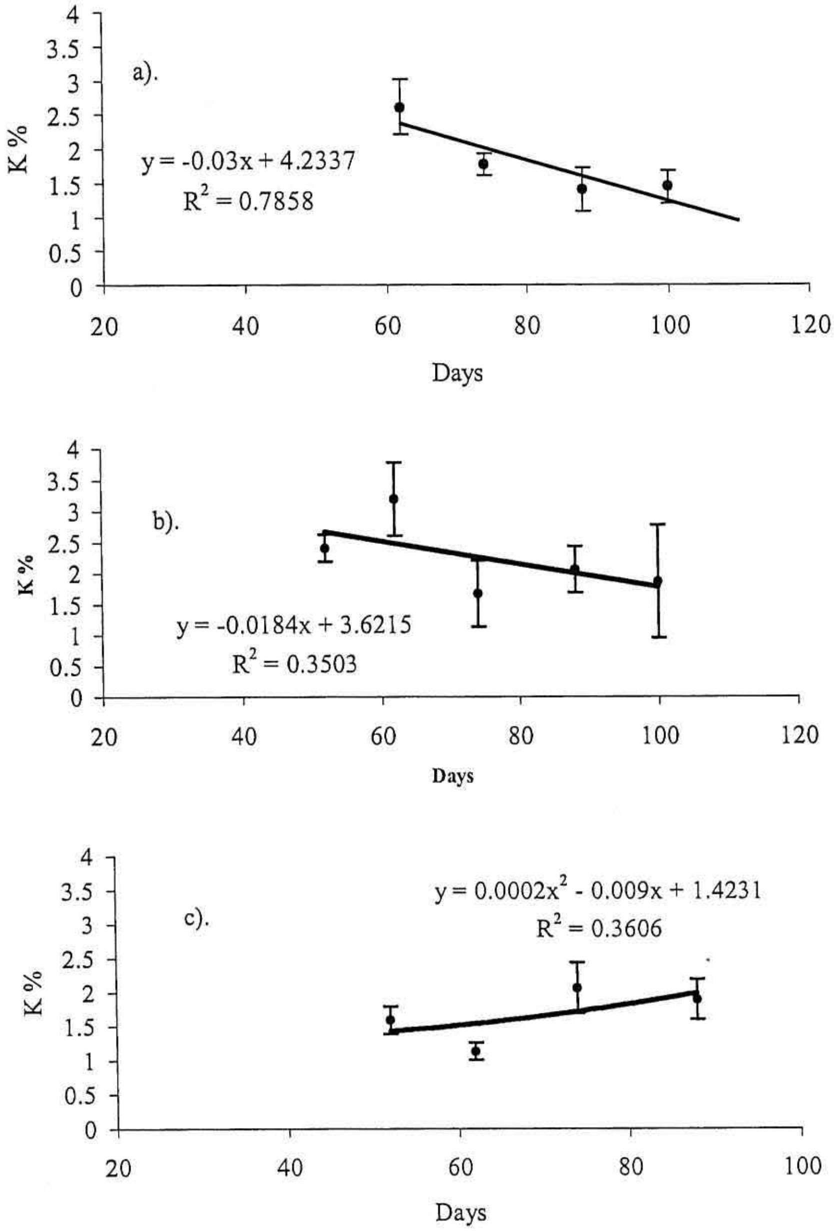


Figure 3.7: Concentrations of K in tithonia plants over the growing plant planted at three dates; a = April 1, b = April 15 and c = April 24, 2000.

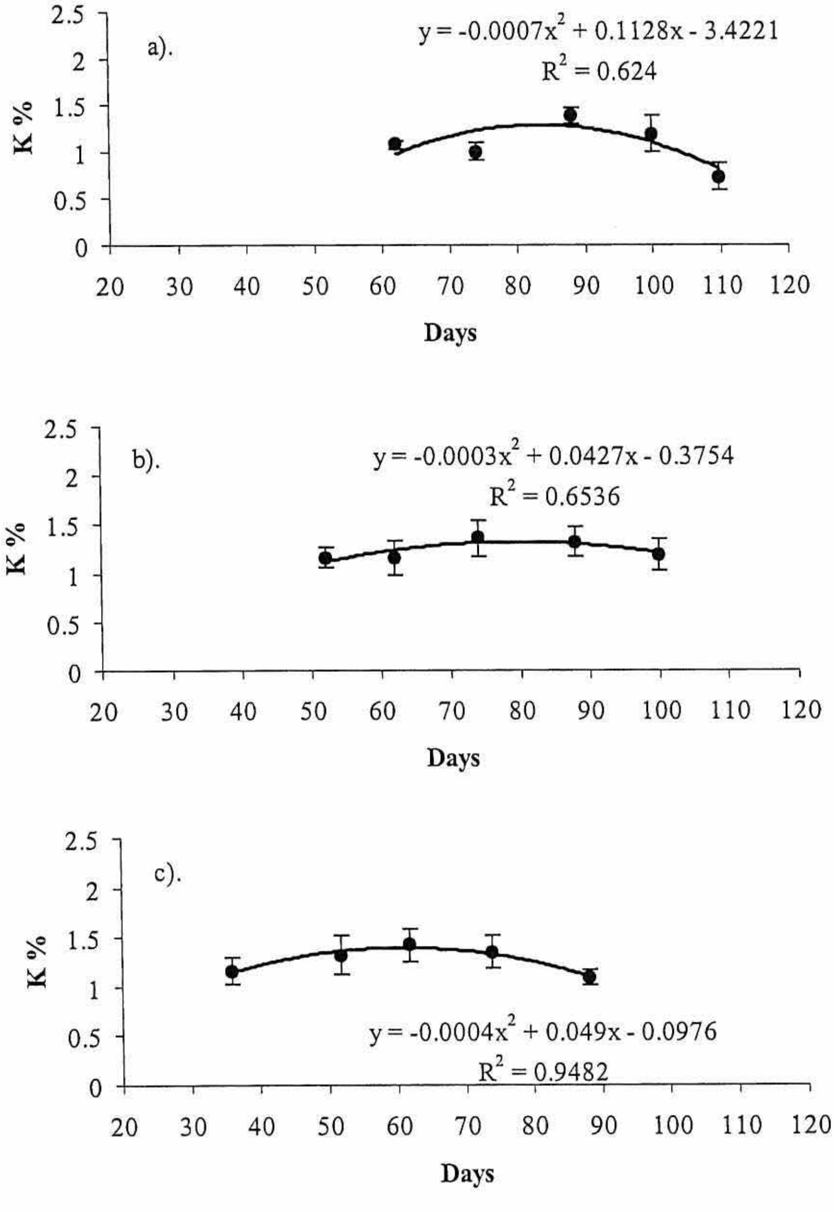


Figure 3.8: Concentration K in sesbania plant over the growing period planted at three dates; a = April 1, b = April 15 and April 24, 2000.

March and April plantings are acceptable because they can fit into either rice-vegetables-maize (relay) or rice-wheat-fallow systems, but under the fallow system farmers can allow more time for biomass production. As both N and P concentrations are important for mineralisation. Therefore the critical period for tithonia harvesting would be around 80 days.

3.5 CONCLUSION

Tithonia could be propagated either through stem-cuttings or root-cuttings during the summer and winter season in the sub tropical, hot and humid environment of Nepal. Establishment by seeds can be done in March and April. Tithonia could be fitted into rice-wheat-fallow or rice-vegetable-maize cropping systems. A specific niche for tithonia in the Terai environment would be on upland terraces. The rise of the water table is slow in these terraces during the monsoon and the land is well drained and unlikely to suffer waterlogging. This will allow more time for adequate biomass production.

Farmers can harvest tithonia between 70 - 80 days for green manuring purposes and 1 - 1.5 t ha^{-1} dry matter can be produced at this time. On average 1 t dry matter will supply 31.5 kg N, 4.05 kg P and 10.40 kg K (N 3.15%, P 0.41% and 1.04% K). Major nutrients N, P and K will start declining when the plants are grown in the field for more than 90 days although this is less severe for P than for N. Compared to the popular sesbania green manure crop the growth rate as well as biomass production of tithonia were found to be low, although concentrations of N and K were greater. The length of growing period of tithonia is also longer than sesbania. Sesbania starts flowering in the month of September while tithonia starts flowering from mid November. Tithonia is still considered to be a wild plant and there is a need to find out ways of adapting it for domestication.

CHAPTER 4

THE VALUE OF TITHONIA BIOMASS AS A FERTILISER, ALONE AND IN CONJUNCTION WITH OTHER ORGANIC AND INORGANIC MATERIALS

4.1 INTRODUCTION

Soil fertility and plant nutrition are key factors for improving productivity of major food grain crops under high production potential systems, because cropping intensity has increased in response to infrastructural development, and wheat and rice varieties, which are very responsive to nitrogen, have been promoted (Doberman *et al.*, 1998). But soil fertility is declining because the soil has inherently low reserves of nutrients, and plant nutrient balance is not being maintained as nutrients are exported with harvested products.

Pandey and Joshy (2000) have recently reviewed chemical fertiliser application and distribution status in Nepal and reported that the application of chemical fertiliser is increasing. However, imports of chemical fertilisers are heavily dependent on external donor support and in general the amount of fertiliser used is small. The average application of chemical fertiliser in terms of total plant nutrients was only 35 kg ha^{-1} in the 1995 fiscal year, which is one of lowest amounts in the world. Applications of the major nutrients as N, P_2O_5 and K_2O were on average 24.8 kg ha^{-1}, 8.1 kg ha^{-1} and 0.6 kg ha^{-1} respectively. The availability of organic sources of plant nutrients is also decreasing due to declining access to vegetation, including fodder, from common property forest resources, and the consequent decrease in production of farmyard manure and compost. Furthermore, in the terai, animal dung is used for fuel (methane gas or dry fuel cakes) decreasing its availability as fertiliser. Therefore there is a need to integrate organic and inorganic sources of plant nutrients (Sherchan and Gurung, 1995) so that farmers can use resources efficiently. The underlying principle of the combined or integrated use of chemical and organic fertiliser is to improve the efficiency with which the nutrients that are applied are used (Hobbs and Adhikari, 1997).

In the high production system of the Indo-Gangatic and South East Asia regions the green manure crop species that are being adopted by farmers for rice production are mainly leguminous and have the ability to fix atmospheric nitrogen. This has proved to be an appropriate technology (Yadvinder-Singh, *et al.*, 1991; Beri *et al.*, 1989a; Bhardwaj and Dev, 1985). *Tithonia diversifolia* (tithonia) has been identified as a potential green manure plant in Africa and South East Asia because it has a high concentration of P in its tissue along with N and other major plant nutrients (ICRAF, 1996). Use of tithonia is attractive since under intensive farming systems both N and P are becoming deficient (Regmi, 1997a). Field studies have also shown that both macro and micro plant nutrients such as N, P, S, B, Mo and Zn are limiting to crop production in Nepalese soils (Khatri-Chhetry, 1982; Pandey, 1985; Regmi, 1997a and 1997b). Under the submerged conditions of the rice paddy, availability of P should not be restricted but despite this, there are reports of rice crops responding to application of phosphorus (Regmi, 1997a; Greenland and De Datta, 1985). There is also an assumption that under wet land cultivation P is not limiting but after rice the dry period commences and succeeding crops such as wheat may suffer P deficiency (Willett, 1991; Kirk *et al.*, 1989). Furthermore the removal of P from soil by improved crop varieties may be much greater than by traditional varieties (Goswami and Banerjee, 1978; De Datta *et al.,* 1990).

Recommendations for fertiliser application are available for Nepal (Joshy and Deo 1976; Pandey, 1991) but these recommendations are purely for chemical fertilisers. Combined use of both inorganic and organic sources of plant nutrients is likely to be beneficial since the chemical fertiliser can supply nutrients in high concentrations for short periods while the organic sources can be expected to have an ecological function in the soil system, as well as supplying nutrients in smaller concentrations over longer periods.

Consequently tithonia could be a useful plant in the high production potential region of Nepal to enhance P supply and improve the efficiency of P fertilisers applied along with other major plant nutrients. Nziguheba *et al.* (1998) reported that application of tithonia biomass either alone or in conjunction with triple super phosphate (TSP) increased resin extractable P, bicarbonate extractable P, microbial-P and sodium hydroxide extractable P in soil. Tithonia also reduced P adsorption by the soil. It has also been shown that legumes have the ability to utilise insoluble P and plant P is mineralised at a faster rate than soil organic P (Vig *et al.*, 1997; Bin, 1983). Therefore, the following hypotheses were tested in field experiments conducted on rice during the summer seasons of 1999 and 2000 in the Chitwan valley of Nepal.

For the experiment carried out in 1999 the hypothesis were that:

1. tithonia biomass is a more effective P fertiliser than inorganic P, for a given amount of P added,
2. tithonia increases the uptake of applied inorganic P by crops,
3. tithonia increases the uptake of P and N applied in other organic forms by crops.

A similar experiment was conducted in the summer season of 2000. The treatments were amended to confirm the results of the 1999 of summer season and also to examine an issue raised by the 1999 season experiment, namely that:

4. tithonia supplies appropriate amounts of many different nutrients and that the K and Zn that it contains may have beneficial effects on crop yield.

4.2 MATERIALS AND METHODS

Field experiments were, therefore, undertaken in the Chitwan valley to assess the effectiveness of a variety of fertiliser treatments on the yield of rice. Yield and nutrient uptake, and nutrient availability in the soil at various stages of the experiment were determined. Throughout the two years of the field trials, minimum and maximum weekly air temperature and weekly rainfall were recorded.

4.2.1 Experiment No 1 (summer season 1999)

4.2.1.1 Experiment layout and treatments

A field experiment was laid out in a randomised complete block design with four replications. The crop was main season rice (*Oryza sativa* L.). Application of 20 to 30 kg P_2O_5 ha^{-1} is normal for most improved rice varieties in the terai region of Nepal (Gami and Sah 1998; Yadav *et al.*, 1998). Therefore we have taken 10 kg P ha^{-1} as an intermediate application rate for our experiment. The amount of fresh tithonia needed to supply 10 kg P ha^{-1} was calculated from its P concentration and this also supplied 75 kg N ha^{-1}. The treatments were as follows.

T1. (Ct) = Control without any chemical and organic fertilisers.

T2. (P) = 10 kg P ha^{-1} supplied from single super phosphate (SSP).

T3. (N) = 75 kg N ha^{-1} supplied from urea (split into two doses, basal dose and top dressing at the time of maximum tillering).

T4. (NP) = 75:10:0 kg NPK ha^{-1} supplied from SSP and urea.

T5. (Ti) = 10 kg P ha^{-1} supplied from tithonia fresh biomass.

T6. (Ti+P) = 5 kg P ha^{-1} from tithonia fresh biomass and 5 kg P ha^{-1} from SSP.

T7.(FYM+P) = 5 kg P ha^{-1} farm yard manure (FYM) and 5 kg P ha^{-1} from SSP.

T8. (Sc+P) = 5 kg P ha^{-1} from sesbania [*Sesbania cannabina* (Retz)] fresh biomass and 5 kg P ha^{-1} from SSP.

T9. (Ti+Sc) = 4.5 kg P ha^{-1} from tithonia fresh biomass and 5.5 kg P ha^{-1} from sesbania fresh biomass.

T10. (FYM) = 10 kg P ha^{-1} from FYM.

All fertilisers, apart from T3 (N) were applied at the start of the experiment. Biomass of tithonia required for the experiment was collected one day before trial planting. The biomass were chopped with sickle. The size was approximately 20 to 30 cm and spread in the respective plot and incorporated into the soil with spade. In order to normalise the amount of nitrogen equal to 75 kg N ha^{-1} additional nitrogen was supplied as urea to the treatments T6 (Ti+P), T7 (F+P), T8 (Sc+P) and T10 (FYM). The layout of the field experiment is given in Table 4.1.

Figure 4.1: Layout plan of 1999 experiment

Block	Treatments								
I	6	2	3	7	1	5	4	9	10	8
II	4	8	7	9	10	1	5	2	6	3
III	9	7	6	1	5	3	10	4	8	2
IV	1	5	8	2	3	10	6	9	4	7

Plots were 5 m by 4 m. The space between plots was 50 cm. Between blocks, the space was 1 m. A bund of 50 cm width and 75 cm height was constructed in each experimental plot to check the water flow from one plot to another plot.

A new terrace was selected which had not previously been used for any experiments. However, to reduce any soil variability in the field or to avoid the residual effect of fertilisers applied to previous crops, a maize crop was grown with a higher seed rate than usual (40 kg ha^{-1}). The maize crop was grown up to the silking stage and then the whole plant harvested. A nursery bed was prepared to produce enough seedlings required for transplanting. The rice variety Sabitri, which is high yielding, of medium height and popular in the area was used. Thirty day old seedlings were transplanted on 20th July 1999 with an inter and intra row spacing of 20 cm. At each planting station three seedlings were transplanted (a common practice in the study area). The outer row in each plot was regarded as a buffer and not used in any of the assessments. The next two rows in from the outer row were assigned to destructive sampling 11, 32, 44, 94 and 112 days after transplanting.

The crop was harvested on 17th November 1999. The grain and straw yield were estimated from the central area of 10.64 m^2 in each plot leaving the two destructive sampling rows and the border row on all four sides. Grain yield was adjusted to 12% moisture level. Rice straw was sun dried for two days then weighed. At the time of crop harvest the important yield attributes such as thousand grain weight, plant height, number of tillers per planting station, panicle length and number of grains per panicle were also recorded and analysed in both the years.

Based on the nutrient content of biomass of tithonia and sesbania and farmyard manure (FYM), the required weights were calculated and applied one day prior to transplanting rice seedlings. Nutrient concentrations are given below in Table 4.1.

Table 4.1: Nutrient content of organic fertiliser materials used in the experiment.

Sample	N%	P%	K%
1. *T. diversifolia*	3.13	0.376	3.60
2. Farmyard manure (FYM)	1.38	0.315	0.50
3. *Sesbania cannabina* Retz.	4.4	0.346	1.6

4.2.1.2 Rice yield, nutrient content and uptake

Rice plant samples from each experimental plot were taken on 5 occasions (11, 32, 44, 94 and 112 days after transplanting from four planting stations from the destructive harvest rows. The stations to harvest were selected at random. Plant samples were first washed with distilled water then placed in the oven for 24 hours at 60^0C and weighed. Samples were then ground and kept in plastic bags, sealed and stored prior to analysis for N, P and K. For nutrient analysis 0.2 g of ground plant sample was digested with 2 ml digestion mixture, which was prepared from H_2SO_4, selenium powder and salicylic acid. After complete digestion in a block digester at 360°C for about two and half hours total time, the tubes were allowed to cool down and made up to 40 ml final volume with distilled water then stored in 50 ml plastic bottles. The procedures were followed as described in the hand book of tropical soil fertility and fertility by Anderson and Ingram (1993). The bottles were stored in the fridge and the samples analysed subsequently as follows.

Total N was analysed using the method described by Anderson and Ingram (1993). Two reagents were prepared. Reagent A is 34 g sodium salicylate, 25 g sodium citrate, 25 g sodium tartrate and 0.12 g sodium nitroprusside mixed and made up to 1 l. Reagent B is 30 g sodium hydroxide and 0.5 g sodium dichloroisocyanurate and made up to 1 l volume. The intensity of colour was read on a Spectrophotometer at 655 nm.

Phosphorus was analysed using the ammonium metavanadate, ammonium molybdate colorimetric method at 440 nm. Potassium was determined directly on a Philips PU9100 Atomic Absorption Spectrophotometer, at 769 nm.

4.2.1.3 Measurement of nutrient availability in soil

The dynamics of N, P and K in soil during the growth of the rice crop were studied by analysis for various forms of N and P, together with K on five occasions during the crop growth. To monitor N *in situ*, ion-exchange resin bags were used to provide estimates of nitrate and ammonium concentration.

Available P in the soil was measured *in situ* using iron-impregnated filter paper strips at five occasions in 1999 and 2000. Soil samples were taken on the same five occasions. The schedule for sampling soils, resin bags and plant samples is given below. These analyses were all undertaken on five occasions during the crop growth phase, as shown in Table 4.2.

Table 4.2: The sampling schedule for 1999 was as follows

Rice growth stage	Seedling establishment	Active tillering stage	50% booting stage	50% flowering and grain filling stage	Maturity and harvesting stage
Date	31st July	19th August	29th September	31st October	17th November

Further investigation of the treatments on soil phosphorus status included estimation of the total, inorganic and organic phosphorus pool at the beginning and end of the experiment, and the P sorption characteristics by estimation of the phosphorus sorption index (Bache and William, 1971) again at the beginning and end of the experiment.

4.2.1.4 Resin bags for monitoring nitrogen dynamics

A mixture of strong basic anion and strong acidic cation resin bags were used to measure NH_4 and NO_3 in the soil solution. These bags were prepared at the Centre for Ecology and Hydrology (CEH) laboratory in the U.K. Bags were sewn from material derived from nylon tights and filled with 20 g of anion resin and 15 g of cation resin (Sibbesen, 1978; Cooperband and Logan, 1994; Somasiri and Edwards, 1992). Then the bags were tied off to close them. The bags were washed with 1M HCl solution for 15 minutes to clean impurities off the resins, then rinsed in a bucket of de-ionised H_2O. Then the bags were washed with $NaHCO_3$ solution for 15 minutes. All bags were stored at 4^0C before sending to Nepal and using in the field.

In the field each resin bag was placed in the experimental plot in the upper 15 cm of soil for 48 hours. One bag was placed in each plot at a time. The bags were removed and washed with distilled H_2O to remove soil particles. The bags were air dried and kept in a cold box and sent to the Centre for Ecology and Hydrology (CEH) laboratory for analysis.

Nitrate and ammonium were extracted from the resin bags using 100 ml of 2M KCl in wide neck conical flasks, shaking for 60 minutes. The extract was filtered through Whatman's No 1 filter papers, which had been pre-washed with 50 ml of the KCl. The resin bags were then shaken again in 100 ml of 2M KCl and the two extracts were combined.

The determination of ammonium-N is based on the modified Berthelot reaction; ammonium is chlorinated to monochloramine, which reacts with salicylate to 5 aminosalicylate. After oxidation and oxidative coupling a green coloured complex is formed which is measured spectrophotometrically at 660 nm.

The determination of nitrate plus nitrite is based on the cadmium reduction method. The sample was passed through a column containing granulated copper-cadmium to reduce the nitrate to nitrite. The nitrite (originally present plus reduced nitrate) was determined by diazotizing with sulphanilamide and coupling with α-naphthyl-ethylene diamine dihydrochloride to form a highly coloured azo dye, which was measured spectrophotometrically at 540 nm.

4.2.1.5 Measurement of soil phosphorus availability

4.2.1.5.1 Use of iron impregnated filter papers

To measure P in soil solution in the flooded rice field iron impregnated filter papers (Menon *et al.*, 1989) were used at four times during the growth of the rice crop. The detailed methodology regarding preparation and application in the field was as follows.

The iron-impregnated filter papers were prepared at the CEH laboratory. Whatman No 541 filter papers were placed in a solution of 30% ferric chloride ($FeCl_3.6H_2O$) overnight. Then they were air-dried followed by soaking in a solution of 2.7M NH_4OH overnight. The filter papers were gently washed with de-ionised water and air-dried.

Then they were cut into strips, 2 cm by 12 cm. A small hole was made in the end of each and a thread tied on to aid extraction. Six filter papers strips were randomly inserted into the soil in a slanting position in each experimental plot and marked with a stick for easy re-location. After 24 hours the strips were retrieved and washed with distilled water to clean off any adhered soil particles. The strips were air-dried and stored prior to extraction of phosphorus.

The six strips from each experimental plot were placed in a 500 ml conical flask and 100 ml of 0.1M H_2SO_4 added. Flasks were shaken on a rotary shaker until the filter papers became white. Normally this took about 3.5 hours at which point it was considered that the adsorbed P was completely dissolved. The extraction time was kept constant for all the samples. The solutions were filtered through Whatman No 541 filter paper and phosphorus was determined by the ascorbic acid colorimetric method on an auto analyser.

4.2.1.5.2 Olsen P (0.5 M $NaHCO_3$ pH 8.5) determination

Available phosphorus was determined using Olsen's method (Olsen *et al.*, 1954). An extracting solution of 0.5M $NaHCO_3$ (pH 8.5) was used. The ratio between the moist soil and extracting solution was 1:20. The conical flask with soil and extracting solution was shaken for 30 minutes and then the suspension filtered through Whatman No 541 filter paper. Then a blue colour was developed with ascorbic acid and the intensity of colour was measured with the help of an autoanalyser at 660 nm wave length.

4.2.1.5.3 Total, inorganic and organic phosphorus

Total, organic and inorganic phosphorus were measured in the soil samples taken just before planting rice and after harvest. Total phosphorus was measured following the method described in the TSBF handbook (Anderson and Ingram, 1993). The difference between the igniting a soil sample at 550°C and non ignited soil sample renders organic phosphours.

The method in detail consisted of weighing 1±0.001 g of ignited and non-ignited sample into 250 ml conical flasks to which 50 ml of 1M H_2SO_4 was added and the flasks were then shaken on a rotary shaker at a speed of 200 rpm overnight. The next morning samples were filtered through Whatman No 541 filter paper. The filtrate was stored in clean plastic bottles until analysis. After preparing an appropriate dilution of the digested samples, phosphorus concentration was determined on a Skalar autoanalyser.

4.2.1.5.4 Phosphorus Sorption Isotherm (PSI)

Phosphate sorption isotherms were determined using the method described by Bache and Williams (1971). In short the procedure is as follows: 5 g of air-dry soil is placed in a 250 ml bottle. 50 ml of 0.01M KH_2PO_4 in 0.01M KCl was poured into the bottle and made up to 100 ml final volume. The bottles were shaken vigorously for 18 h. Then, after the suspensions were filtered through Whatman filter paper No 542 phosphate remaining in the solution was determined by the ascorbic blue colorimetric method in an auto-analyser. This is termed C, the equilibrium concentration of PO_4-P in μ mol l^{-1} and the difference between initial and final concentrations, x, the sorbed phosphate is measured as mg PO_4-P per 100 g. PSI is a ratio between log x and C.

Litterbag method

Litterbags were used to study the decomposition of vegetative materials as described in chapter 2. The amount of fresh vegetation used in litterbags was 10 g which is equivalent to an application rate of 10 t ha^{-1} of biomass that is in line with amounts applied by farmers. Due to a rapid decomposition rate under submerged and warm humid conditions the sampling frequency was narrowed down to 10 day intervals.

4.2.2 Experiment No 2 (summer season 2000)

In the experiment conducted in 2000, additional treatments were incorporated to examine the potential role of K and Zn. There was some evidence from the 1999 experiment that higher K concentrations were found in the rice and soil in the tithonia treatment. Zn was included because there was evidence of lower occurence of Zn deficiency in tithonia treated plots than in other treatments in 1999. Zinc deficiency in rice is a known problem in the area.

4.2.2.1 Experiment layout and treatments

The summer 2000 experiment was a randomised complete block design with four replicates and eleven treatments. The details of the treatments are given below.

T1. (Ct) = Control plot (no chemical fertiliser and no manure)

T2. (N) = 75 kg N ha^{-1} (half dose basal and half top dressed at the time of maximum tillering using urea)

T3. (NP) = 75:10:0 kg NPK ha^{-1} (N half dose basal and remaining top dressed at the time of maximum tillering using urea)

T4. (NK) = 75:0:30 kg NPK ha^{-1} (N half dose basal and remaining top dressed at the time of maximum tillering using urea)

T5. (NPK) = 75:10:30 kg NPK ha^{-1}(N half dose basal and remaining top dressed at the time of maximum tillering using urea)

T6.(NPK+Zn) =75:10:30 kg NPK ha^{-1}(N half dose basal and remaining top dressed at the time of maximum tillering using urea) plus 25 kg ha^{-1} zinc sulphate

T7. (NP+Zn) =75:10:0 kg NPK ha^{-1} (N half dose basal and remaining top dressed at the time of maximum tillering using urea) plus 25 kg ha^{-1} zinc sulphate

T8. (Ti) = 100% from tithonia equivalent to 10 P kg ha^{-1}

T9. (Ti+Zn) = 100% from tithonia equivalent to T8 plus 25 kg ha^{-1} zinc sulphate

T10. (Sc) = 100% from sesbania equivalent to T8

T11. (Sc+Zn) =100% from sesbania equivalent to T8 plus 25 kg ha^{-1} zinc sulphate

The lay out of the field trial was as follows:

Figure 4.2: Lay out plan of the field experiment

BLOCK	TREATMENTS										
Block 1	T3	T9	T1	T10	T5	T7	T2	T6	T8	T11	T4
Block 2	T7	T10	T4	T3	T11	T1	T5	T8	T2	T9	T6
Block 3	T5	T6	T9	T8	T4	T3	T10	T1	T11	T7	T2
Block 4	T8	T3	T7	T2	T10	T5	T1	T4	T9	T6	T11

The experimental plots were 4 m by 4 m and the space between plots and blocks was 50 cm and 1 m respectively. Inter and intra row spacing was 20 cm as in 1999. Thirty-day-old rice seedlings were transplanted on July 8, 2000. The same rice variety used in Experiment 1, Sabitri was chosen for consistency. The crop was harvested on November 8, 2000. The outer three rows from all four sides of the plot were used for destructive sampling and were not included in the final harvest. Border rows were also not included in the final harvest.

A similar range of measurements were made on the crop and soils in this experiment as in experiment 1. The sampling times were 3, 15, 30, 60, 90 and 102 days after seedlings were transplanted but only a few parameters were measured for observations on the first and last sampling occasions.

Table 4.3: Schedule for sampling soil and plant samples, resin and iron impregnated papers.

11 July	23 July	7 August	7 Sept	8 Oct and 20 Oct.
Early seedling establishment	Maximum tillering	Booting	Flowering to grain filling	Maturity and harvest

Plant samples were taken from four planting stations to estimate the dry matter yield and nutrient concentration as in 1999. Nutrient (N, P and K) uptake was estimated at four growth stages only. At harvest the nutrient concentration in grain was not measured as this was already done in the experiment 1 in the 1999. Resin bags and iron strips were placed into the soil for 48 hours. Iron strips and resin bags were prepared at the LI-BIRD laboratory, Nepal. Differences between procedures used in 1999 and those used in 2000 are noted below.

4.2.2.2 Resin bags

In the 1999 season the main aim was to measure only ammonium and nitrate in soil using resin bags. In 2000 we were aiming to measure ammonium, nitrate, P, K and zinc in the resin extract. As in 1999 both strongly acidic (Amberlite 200) and strongly basic resins (Amberlite 200) were used, with each bag containing 20 g of anion resin and 15 g of cation resin.

The resin bags were saturated with Na and Cl. Four buckets with 5 l of 1M HCl and four buckets with 5 l of 1M NaCl were prepared. First, a batch of 50 resin bags were placed into one of the buckets containing HCl for 15 minutes and occasionally stirred with a glass rod. Then the resin bags were washed with distilled water carefully and then immersed in another bucket containing HCl, this was repeated until the bags had been immersed in all four buckets and then the procedure was repeated for the four buckets containing NaCl. Lastly the bags were transferred quickly into a clean bucket and rinsed with distilled water. Then they were stored in the fridge before taking into the field.

The extracting procedure was the same as used in 1999 except that in 2000 we were measuring more plant nutrients including K and so used 1M NaCl as the extracting solution. After extracting the resin the extracts were stored in 50 ml vials and kept in the fridge for future analysis.

Ammonium and nitrate were analysed at the CEH laboratory. K was measured directly on a Toshiba Microprocessor flame photometer in Nepal. Resin extractable Zn and K were measured on an atomic spectrophotometer at the Nepal Environmental Scientific Service (NESS), Kathmandu.

Available K in soil was also measured using 1M ammonium acetate solution at pH 7.0. The ratio between soil to extracting solution was 1:20 and this was shaken for 5 minutes. Then K was read on the extract directly on the flame photometer.

Plant samples were analysed at the Henfaes Agricultural Research Station, University of Wales, UK. Nitrogen was digested using sulphuric acid and digestion tablets. The digestion was distilled and and ammonia was absorbed on boric acid and titrated against HCl for the determination of nitrogen. Plant samples were oven dried at 490^0C for 24 hours in a crucible and dissolved in 1M HCl. Phosphorus was determined using the Vanado-molybdenum colorimetric method and K was directly read on an absorption spectrophotometer.

4.2.3 Statistical analysis

Results from both experiments were examined by analysis of variance (ANOVA), using a general linear model in Minitab version 12.2 and 13.1. This was carried out for grain and straw yields, yield contributing attributes such as thousand grain weight, number of tillers, panicle length, plant height, soil fertility parameters of soil such as available P, available K, available zinc, resin extractable NH_4-N and NO_3-N, total N, P and K nutrient concentrations in rice plant samples and nutrient uptake by crops both in straw and grains. The significance of differences between treatments was tested by the least significant difference (LSD) method or by planned contrast in Genstat. The mean values and standard errors for individual treatments are presented graphically for comparison between the treatments at various stages, with standard error of difference (Sed) shown as a separate bar on each graph.

4.3 RESULTS

4.3.1 Weather information during the experimentation

Seasonal trends in air temperature and rainfall for 1999 and 2000 are shown in Appendix 4.1 together with times of transplanting rice and harvesting. The distribution of rainfall did not vary much between years but there was a higher total rainfall in 1999 than in 2000 and there was a drier spell in the autumn of 1999 than in 2000. In 2000 there was a larger variation between the maximum and minimum air temperature compared to 1999.

4.3.2 Rice grain yield and straw production

In 1999 all treatments had grain yields significantly higher than the control except for sole application of inorganic P (Figure 4.3a and Appendix 4.2). The highest grain yield, from the tithonia plus inorganic P treatment was 60% higher than the control but only significantly different from sole inorganic P, sole N and FYM + inorganic P among the other treatments. The combined inorganic N and P application and the combined biomass of tithonia and sesbania both yielded significantly higher than the sole inorganic P in addition to the control while sole tithonia, sole FYM and sesbania plus inorganic P were significantly higher than the sole inorganic P treatment as well as the control. There was also significantly higher yield (p=.005) from tithonia included treatments than the artificial chemical fertilizer when a contrast analysis was performed.

In 2000 grain yields were of a similar magnitude to those obtained in 1999 with the highest yield in the treatment with inorganic N, P and K application, over 46% above the control (Figure 4.4a). Only selected data are shown in the figures: full data are given in Appendix 4.3. All treatments in 2000 had higher grain yield than the control except the mixture of inorganic N and P, and the mixture of N, P and Zn.

In 1999, there were no significant differences between straw yields (Figure 4.3b, Appendix 4.1) but straw yields were very variable and unusually low, resulting in unrealistically variable and high harvest indices (0.49-0.65). For these reasons straw biomass data were not used further analysis for this year. Straw production generally followed the same pattern as grain yield in 2000 but was substantially higher than in 1999 and harvest index was lower and varied less (0.42 to 0.48) (Figure 4.4b).

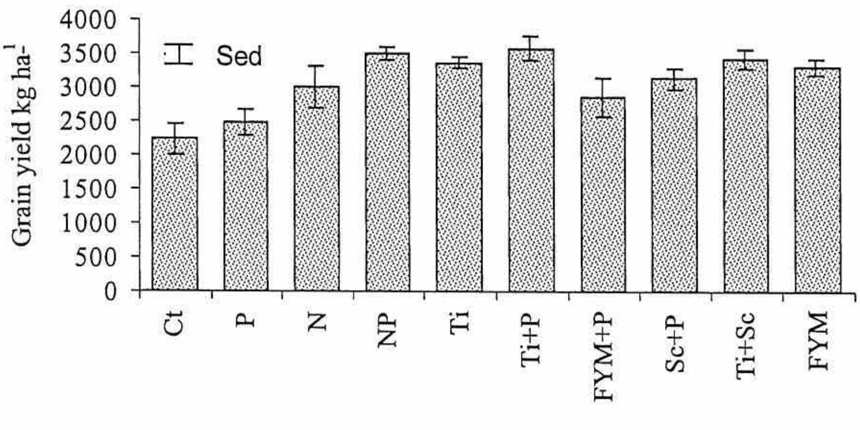


Figure 4.3a: Mean (± standard error) grain yield for rice in 1999. Treatment codes as in the methods section, 4.3.11

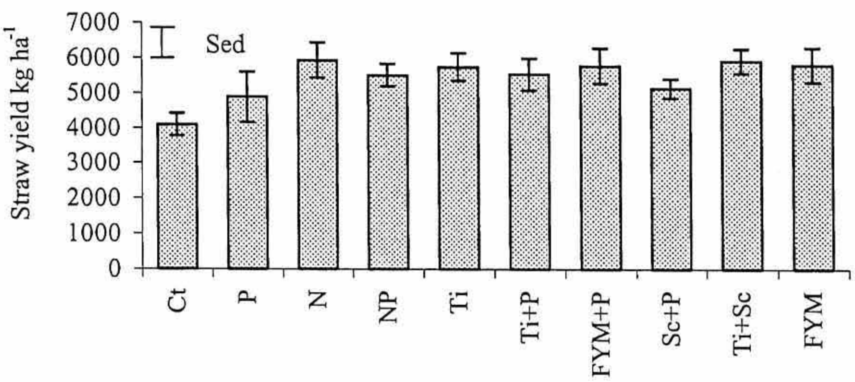


Figure 4.3b: Mean (± standard error) straw yield of rice in 1999

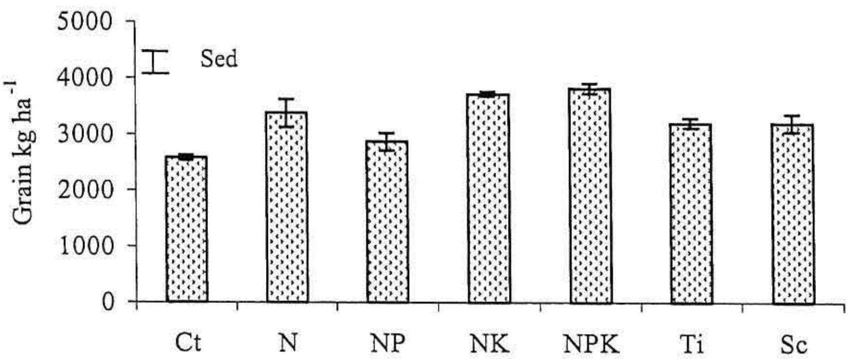


Figure 4.4a: Mean (± standard error) grain yield for rice in 2000. Treatment codes are given in the method section 4.3.2.1.

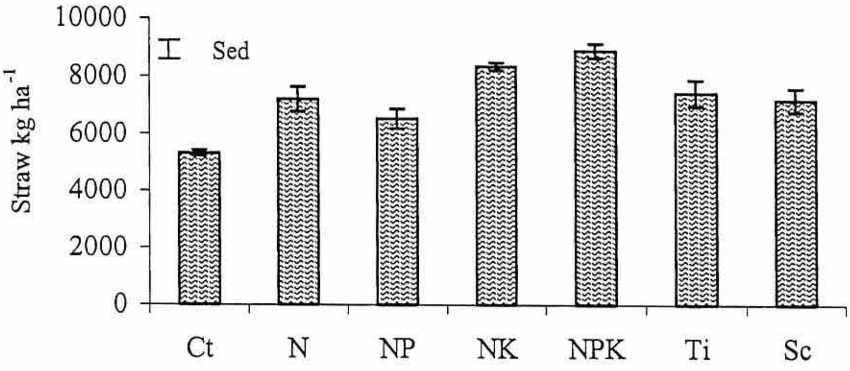


Figure 4.4b: Mean (± standard error) straw yield of rice in 2000

4.3.3 Yield attributes

In 1999 the two highest thousand grain weights were obtained from the mixture of tithonia and sesbania and tithonia alone, being significantly higher ($p<0.05$) than in three treatments receiving only artificial fertiliser (P, N and NP) and 100% FYM. The smallest grains were from FYM alone (Appendix 4.2). The number of tillers per station varied widely between treatments and although significant differences were observed, there was no apparent pattern to these differences. Panicle length was similar in all the treatments and not different at $p<0.05$. The tallest plants were in the tithonia alone treatment and they were significantly taller ($p<0.05$) than the Ct, P and NP treatments. The second tallest plants were in the 100% FYM treatment in 1999.

In 2000 there were no significant differences between treatments in number of tillers per station, panicle length and number of grains per panicle. Thousand grain weight was lowest in the control and tithonia + Zn but similar in the other treatments. Tallest plants were from the NK, NPK treatments and these were significantly different from the control (Ct) NP, NPZn and sesbania treated plots but not from tithonia treated plots (Appendix 4.3).

4.3.4 P concentration in the rice crop

P concentration in plant tissue declined over time in all treatments in both years although the decline was more noticeable in 1999. Very few differences between the treatments were observed, and for most of the experiment results from all treatments were little different to the control.

There were no significant differences ($p>0.05$) between treatments in P concentration in the early, tillering and booting stages in 1999 season. At the flowering stages highest concentrations of P were measured in N, NP, FYM+P and sole FYM treatments. It is notable that the lowest concentrations of P were found in the four treatments Ti, Ti+P, Sc+P and Ti+Sc in which green manure was added. P concentrations in grain was found non significant between treatments (Figure 4.5). In 2000, however, green manure treatments tended to have less P at maturity than chemical fertiliser treatments, but more than in the control (Figure 4.6).

4.3.5 P uptake by the rice crop

Nutrient uptake at each stage in the growth of the rice crop was calculated by multiplying dry matter yield by nutrient concentration data.

In the year 1999, no significant difference ($p>0.05$) was observed between treatments on P uptake by the crop at the early, tillering and booting stages (Figure 4.7). At the flowering stage, NP and FYM+P showed highest P uptake. The tithonia treatments either sole or with P from SSP showed lower P uptake than NP and were not significantly different from the control plot. Overall, P uptake by grain was not significantly affected by treatment (Figure 4.7). But a planned contrast showed that green manure treatments had higher grain P uptake than other treatments ($p=0.02$).

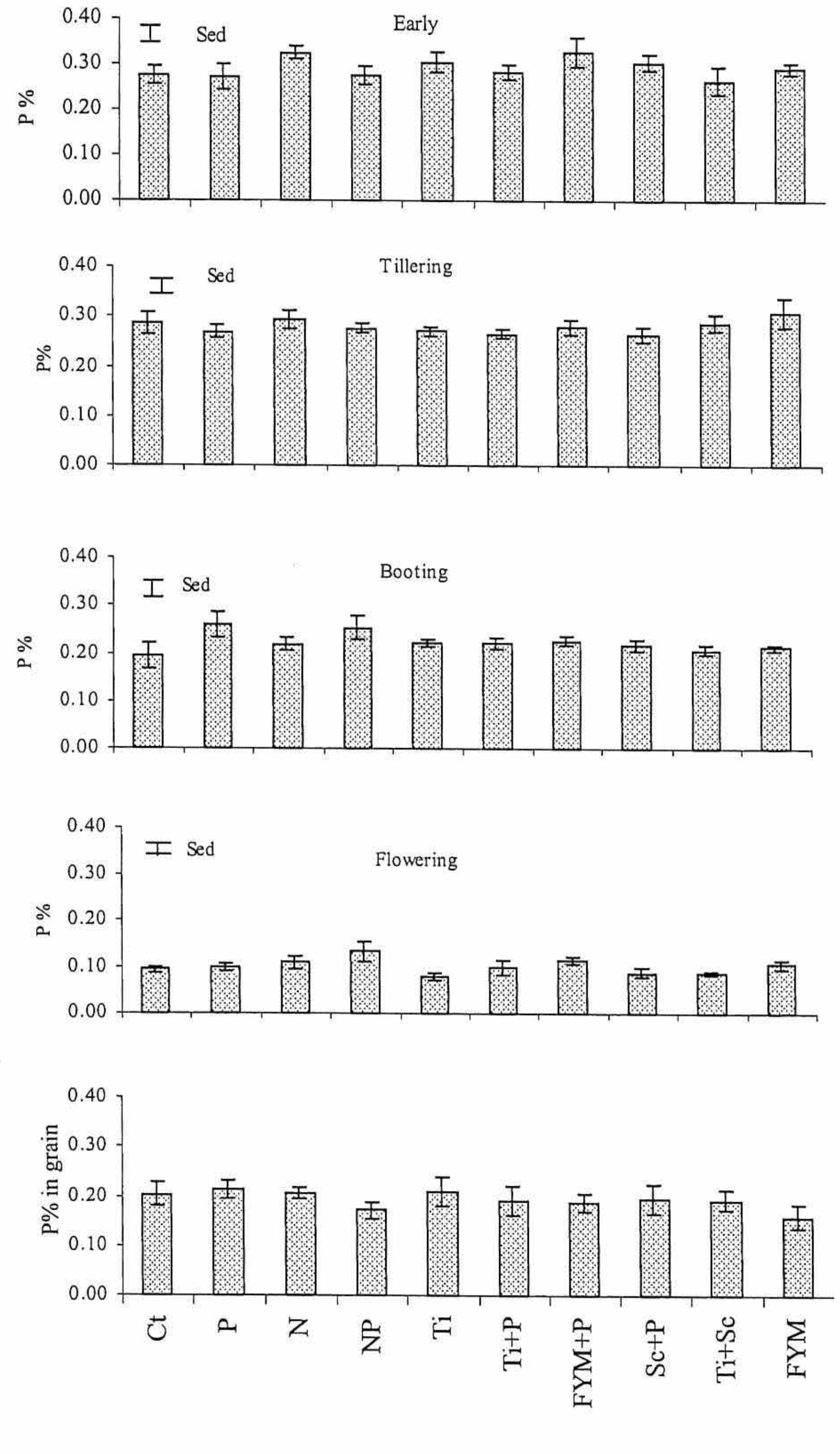


Figure 4.5: Concentration of P in rice plant in 1999. Sed for grain was very small value.

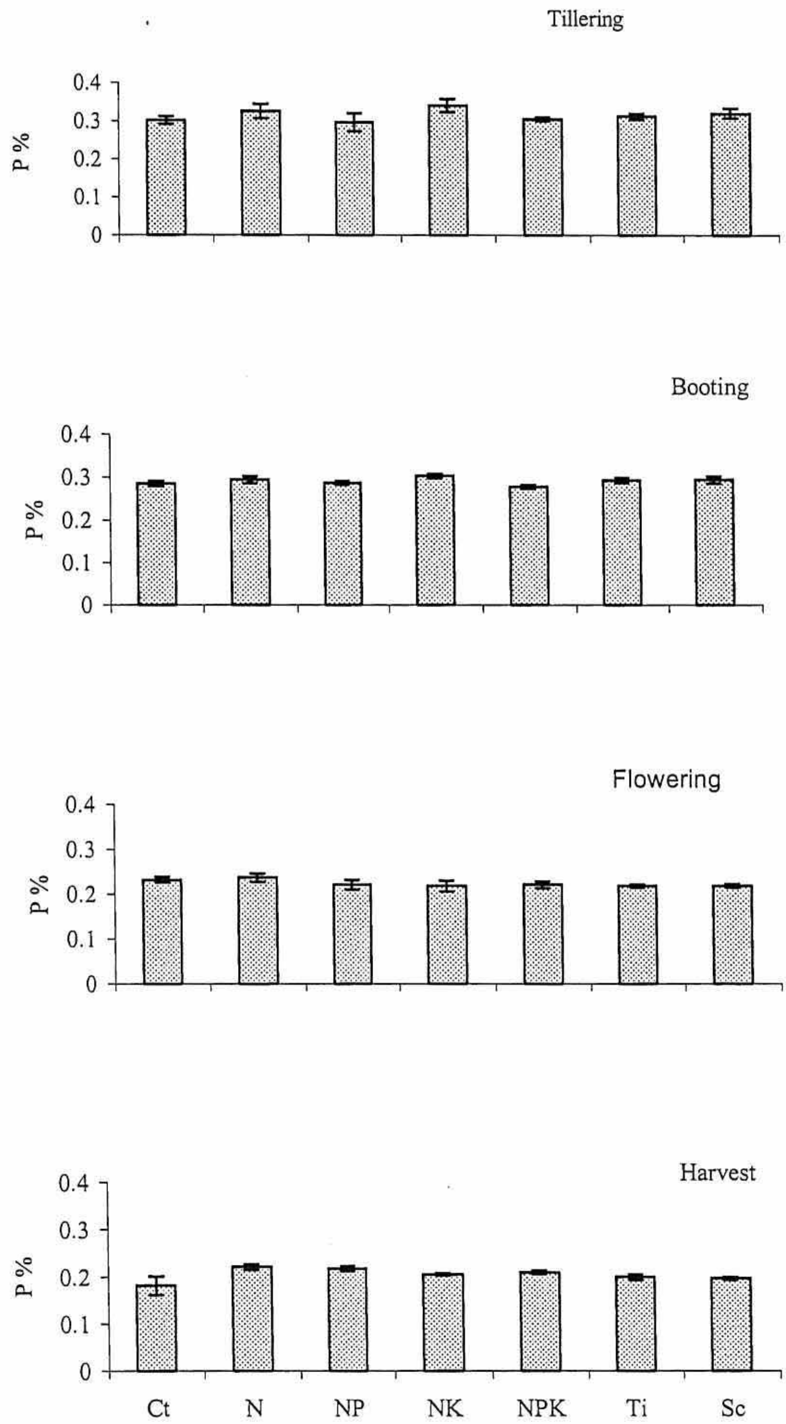


Figure 4.6: Concentrations of P in rice in 2000. Sed is not shown because of very small values.

In 2000, P uptake at harvest was very similar in all treatments receiving only artificial fertiliser and was substantially greater than in the control. Uptake of P at the harvest was somewhat lower in green manure treatments than in those receiving only chemical fertiliser, and in the case of the tithonia treatment (Ti) uptake at harvest was only slightly higher than in the control (Figure 4.8). A variation in P uptake between years could be due to the differing productivity and the fact that the sampling dates were not the same in both years.

4.3.6 P use efficiency

P use efficiency was calculated using the following formula (Sharma and Parmar, 1998):

$$\text{efficiency (\%)} = P_t - P_o/P_a \text{ X } 100 \qquad \text{(eqn. 1)}$$

Where P_t = P uptake in treated plot, P_o = P uptake in control plot (kg ha^{-1}) and P_a = P applied (kg ha^{-1}).

In 1999 highest P use efficiency in grain was in the four treatments in which green manure was applied (Ti, Ti+P Sc+P and Ti+Sc) but especially in the three receiving tithonia (Table 4.4).

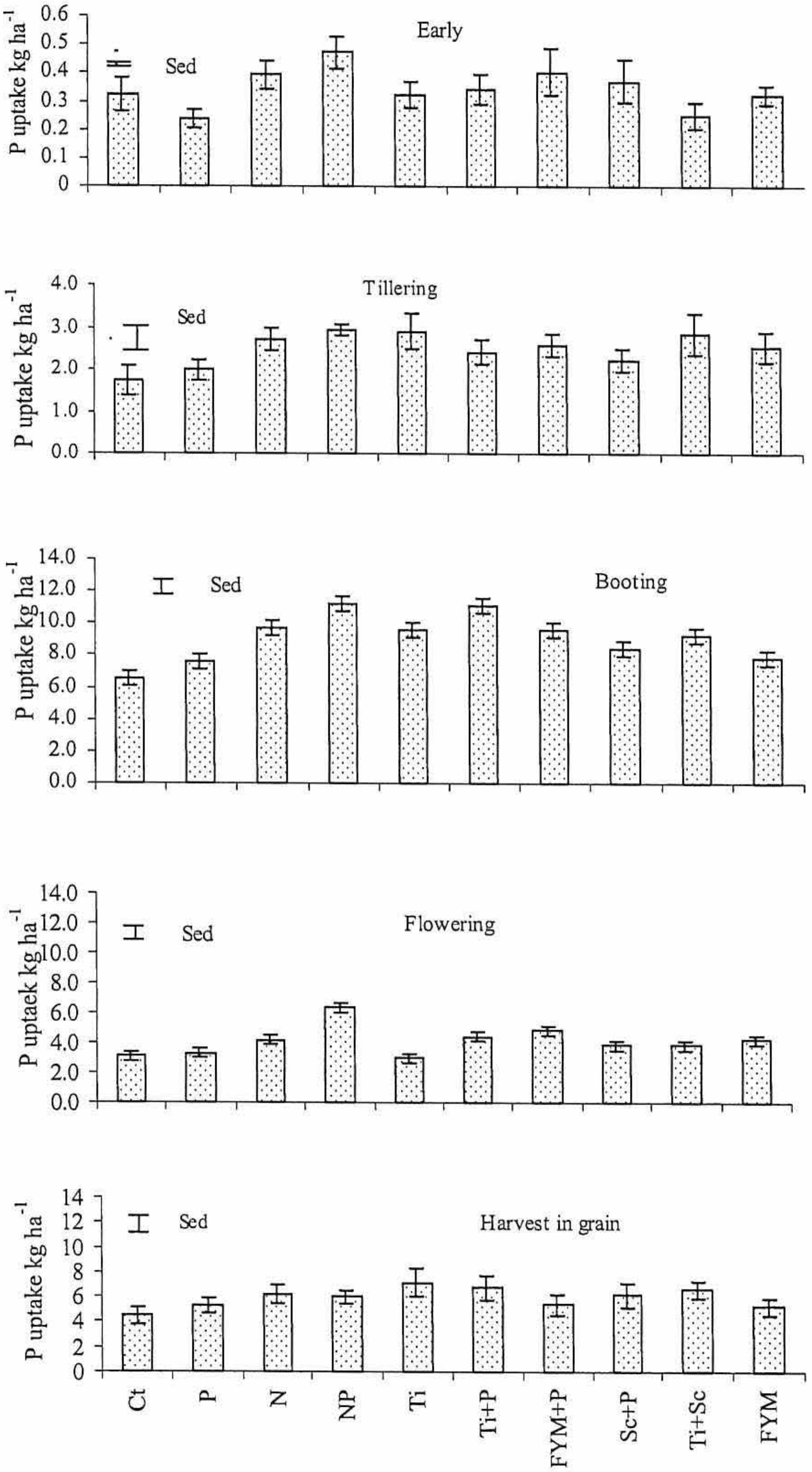


Figure 4.7: P uptake by rice in 1999

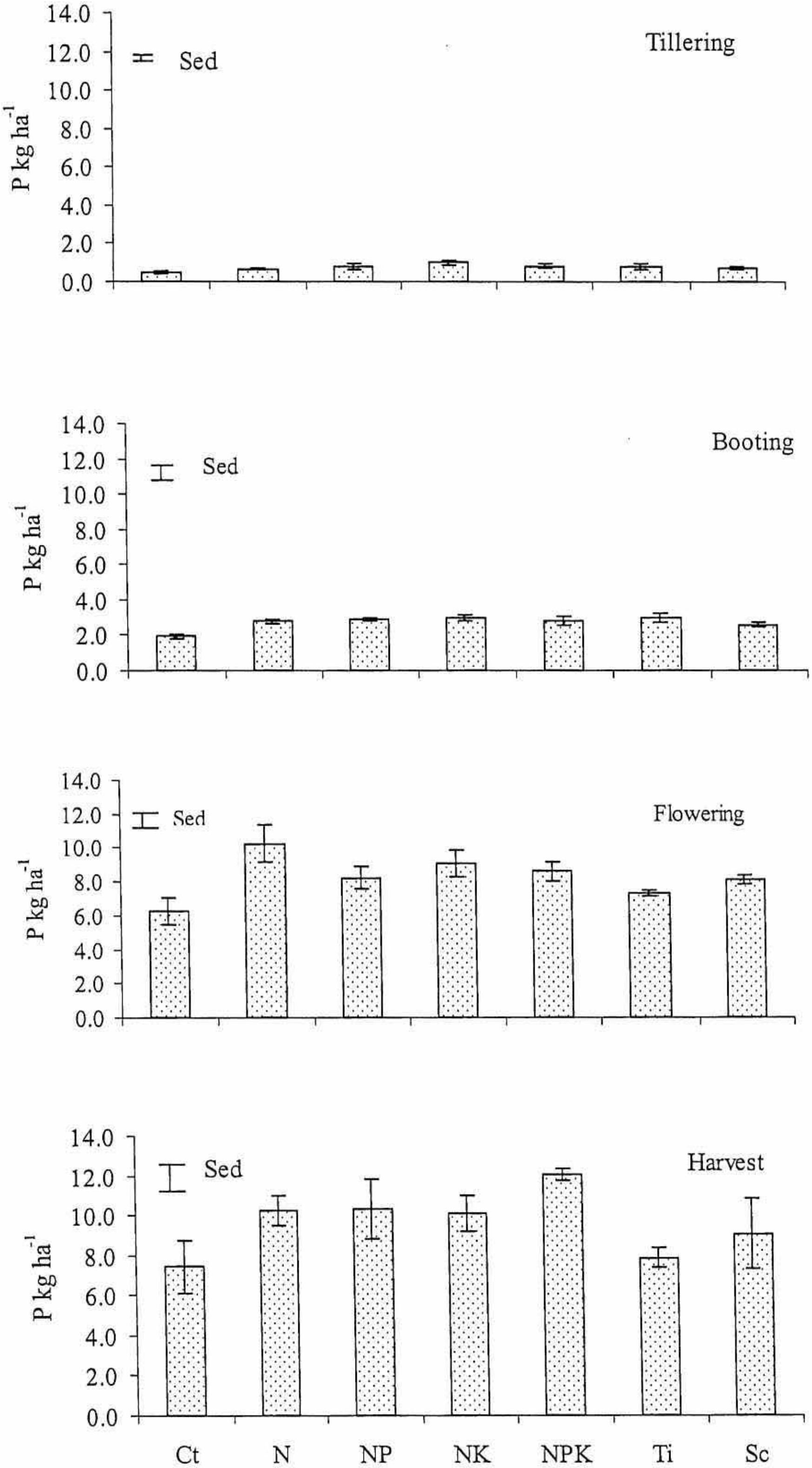


Figure 4.8: P uptake by rice in 2000

Table 4.4: Phosphorus use efficiency by rice for selected treatments in 1999.

Selected treatment	Phosphorus use efficiency %
	Grain
T4. NP	14.8
T5 100% tithonia (Ti)	26.1
T6. 50% tithonia + 50% Single super phosphate (Ti+P)	22.6
T7. 50% FYM + 50% Single super phosphate (FYM+P)	8.8
T8. 50% sesbania + 50% Single super phosphate (Sc+P)	16.6
T9. 45% tithonia + 55% sesbania (Ti+Sc)	21.1

4.3.7 Dynamics of P availability in soil during the growth period of rice

Available P was measured on soil samples collected at intervals during the experiment using the Olsen-P method (Anderson and Ingram, 1993) and *in situ* using the iron oxide impregnated filter paper method (Menon *et al.*, 1988; Menon *et al.*, 1989) in 1999 and 2000. The former method is a common laboratory routine adopted by many soil testing and research laboratories in the world. The second method is not routinely used but because it is an *in situ* method should provide a good estimate of the concentration of P in soil that would be available to the growing plants.

Olsen P varied little between treatments or over time and most values were within the range 0.5 to 1.2 mg 100 g^{-1}. These are within the 'medium' availability range suggested by Landon (1984). There is some evidence of a slight decrease with time in most treatments but this was also observed in the control (Figure 4.9).

Filter paper strips, however, did show some significant differences between treatments. At the initial, flowering and maturity stages the concentrations of P were not significantly different at ($p>0.05$), but differences were found at tillering and booting stages. At tillering highest concentrations of P were found in the FYM+P (43.69 µg strip^{-1}), FYM (40.81µg strip^{-1}), and the NP treatments (39.98 µg strip^{-1}). The tithonia alone (Ti) treatment had only 27.20 µg P strip^{-1}, which was similar to the control (Figure 4.10). At the flowering stage, the treatment which received FYM only had a much higher concentration than the other treatments.

In contrast to the Olsen P data, the results from the filter paper showed substantial changes in availability over time with highest concentration in the tillering and flowering stages, dropping to around one third of the booting concentration in the flowering to maturity phases (Figure 4.10). In year 2000, only the iron oxide filter paper method was used to measure P in soil. No significant differences due to treatment were observed ($p>0.05$). Over time, however, there was a decrease in P with the growing rice crop (Figure 4.11). The larger amount of P measured in 2000 by the filter papers could be due to the longer period left in the soil (48 hours). In year 1999 the filter papers were kept for only 24 hours in the field. The aim was to know whether the time difference does affect or not on P absorption. However the method gives us a qualitative information.

4.3.8 Organic and total P

In year 1999 total P and organic P were determined on soil samples collected before planting and after crop harvest. There were no significant differences ($p>0.05$) between treatments for either. Similarly the phosphorus sorption isotherm (PSI) was determined before crop planting and after crop harvest but again there was no significance difference ($p>0.05$) due to the treatments. The soil at the site had a very low P adsoption capacity. The soil contains very low clay content (10 to 12 %) and also low organic matter and this could be one of the reasons for low phosphorus adsorption. Renaudin (2000) has also studied the soil from the same field for P absorption characteristics and found that the PSI curve is almost flat after a slight rise. This could be because of saturation of the adsorption sites due to repeated use of dia-ammonium phosphate and heavy application of poultry manure by farmers in the past, or it could be because of the low clay content. The latter soil properties is more likely to affect. The results for organic P, total P and PSI are given in the appendix (Appendix. 4.4a and 4.4b).

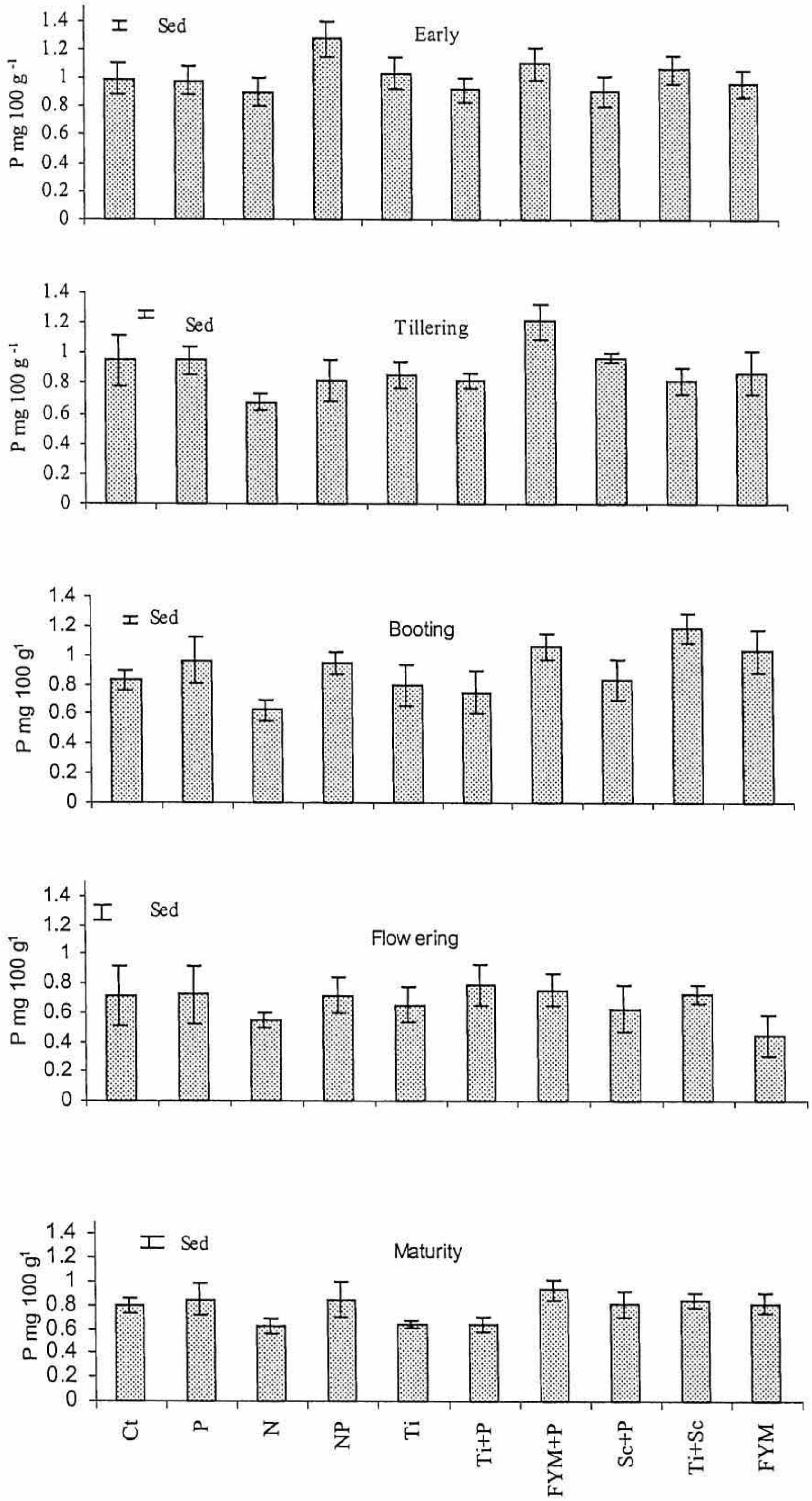


Figure 4.9: Available Olsen -P in soil at various growth stage of rice in 1999.

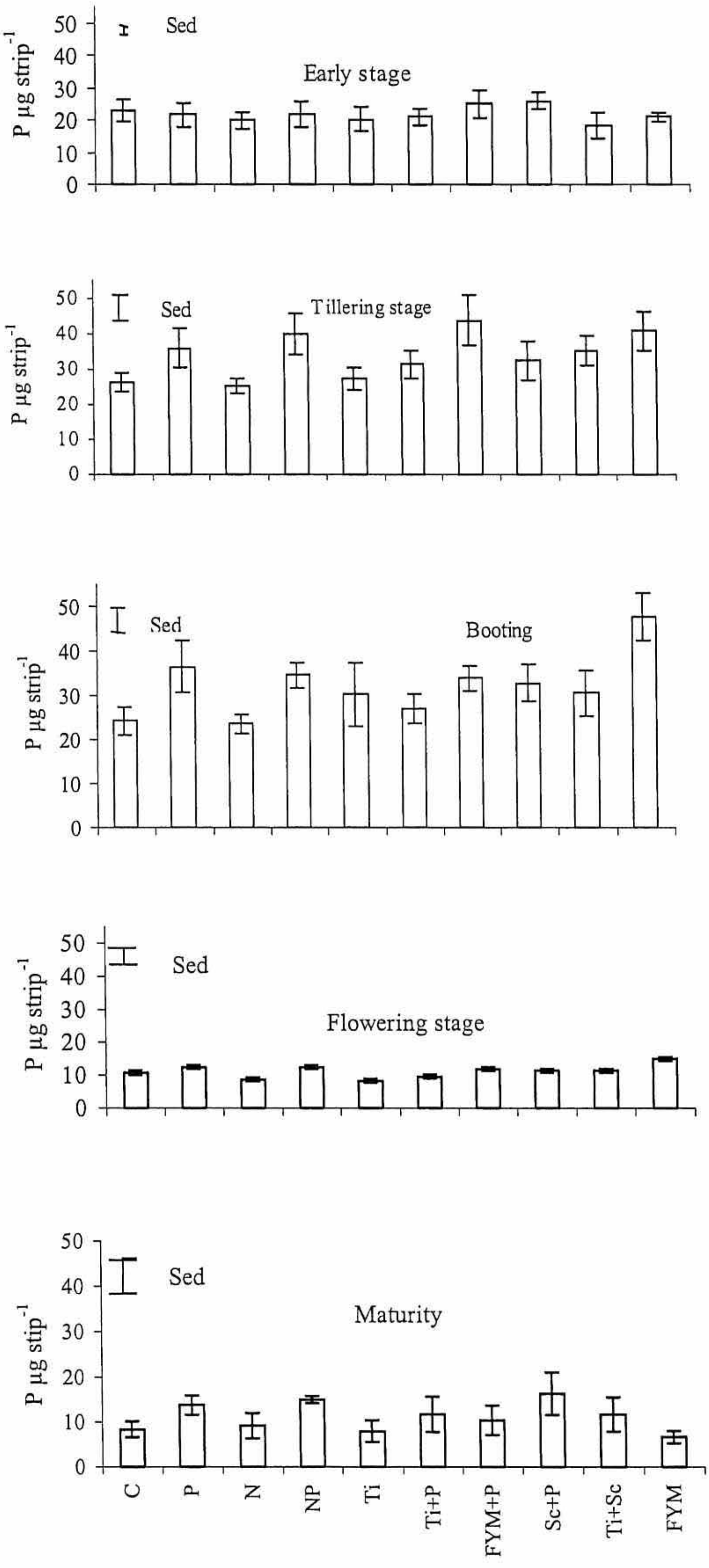


Figure 4.10: Available P in soil measured using iron oxide filter papers at various growth stages of rice in 1999

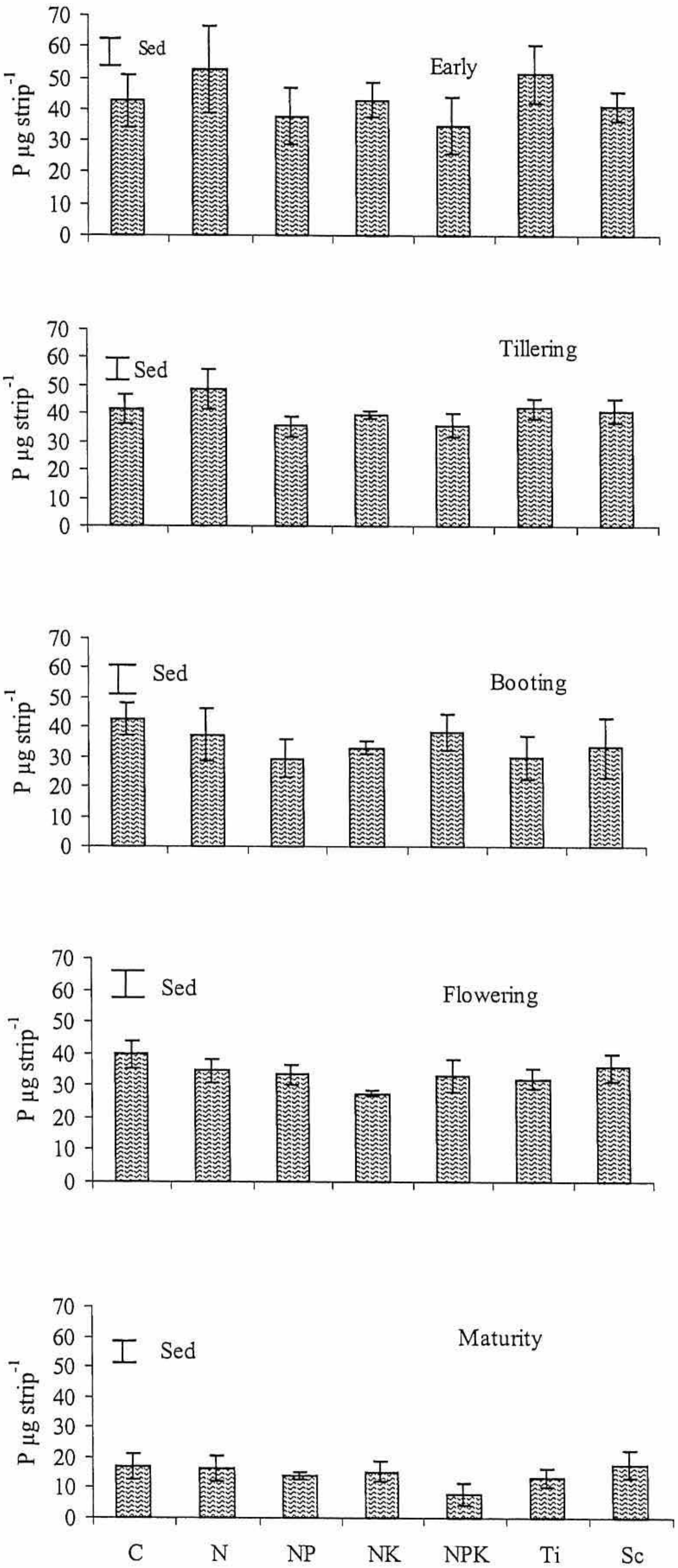


Figure 4.11: Available P in soil measured using iron oxide filter paper at various growth stages of rice in 2000

4.3.9 Mass loss of P from litterbags

Figure 4.12 shows that the loss of P from litterbags at the initial stage was very rapid and then afterward the loss was slow. In general, loss of P from tithonia was faster than from sesbania. A double exponential model was used to express the relationship between mass of P loss again the decomposition time.

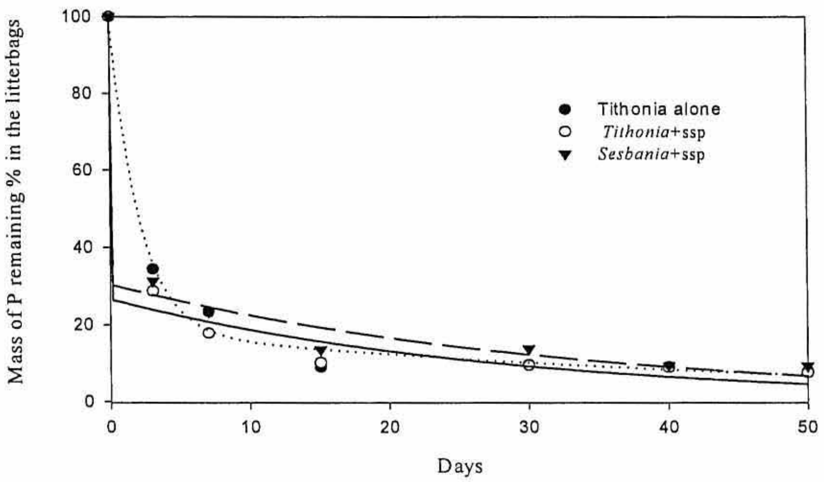


Figure 4.12: Mass of P (% of initial mass) remaining in the litterbags in 1999. Tithonia leaves (•), tithonia + SSP (o) and sesbania + SSP (∇).

4.3.10 N concentrations in the rice crop at various growth stages

In 1999 nitrogen concentrations in rice were initially above 2% in the early and tillering stages, but then declined steadily in all treatments and were well below 1% at flowering. In the early stage the highest concentration of N (2.99%) was found in FYM+P and followed by N, NP, Ti and sole FYM. The lowest concentration was from P (2.20%) and Ct (2.34%) (Figure 4.13).

At booting stage, highest concentrations of N were found in the N (1.53%) and NP (1.59%) treatments and they were significantly higher ($p \leq 0.01$) than tithonia alone (1.04%) and the mixture Ti+Sc (1.036%). When P was supplied 50% from FYM plus

50% SSP (FYM+P), the N concentration was higher than Ti+P, Sc+P and Ti+Sc (Figure 4.13).

At flowering to grain filling stage a significantly higher concentration of N was observed from N (0.96%), NP (0.85%) and FYM+P (0.91%) than in other treatments. At maturity the concentration of N followed same trend as in the flowering stage. N, FYM+P and NP had the highest N concentrations. The sole tithonia treatment (1.25%) had N concentration less than NP (1.6%) but similar to the rest of the treatments (Figure 4.13). Two treatments had the highest N concentration virtually throughout the experiment in plant samples. These were N from artificial fertiliser and 50% FYM and 50% SSP (FYM+P). N concentrations in grain at harvest was found non significantly different from one another.

In 2000 concentration of N in all treatments declined over time from around 2.5 to 3% at tillering to around 1% at harvest. Concentrations of N at various growth stages of rice were significantly different except at the booting stage. At the tillering stage N concentration tended to be higher in the chemical fertiliser treatments irrespective of nutrients supplied, than in the green manure treatments (Figure 4.14). At the flowering to grain filling stages and at maturity N concentration was lowest in the tithonia treatment and sesbania was only a little higher (Figure 4.14). At harvest the rice plants also contained less N in the sole tithonia treatment (Ti) than in the rest of the treatments (Figure 4.14).

4.3.11 N uptake by the rice crop at various stages

In 1999 highest N uptake at most stages was found in the N and NP treatments in which nutrients were supplied from chemical fertiliser. However, these values were not significantly different ($p>0.05$) from the green manure and FYM treatments (Ti, Ti+P, F+P, Sc+P, Ti+Sc and FYM). N uptake in the control (2.83 kg ha^{-1}) and P treatment (1.93 kg ha^{-1}) at the early stage was significantly lower than in NP, Ti and Ti+P.

N uptake by grain was significantly different. Treatments such as NP, sole FYM and mixture of tithonia and sesbania showed N (Figure 4.15) uptake at 55.4, 46.8 and 47.6 kg ha^{-1} respectively. The Ct and P alone were low at N uptake. The rest of the treatments were similar and intermediate.

In 2000 from tillering to flowering and at the grain filling stage highly significant differences in uptake were observed ($p \leq 0.01$). These were mainly between the control and all other treatments. No significant differences were found between the tithonia treatment and the treatments where nutrients were supplied from chemical fertiliser sources up to the flowering stage (Figure 4.16). At the flowering to grain filling stage there was considerable variation in N uptake. But uptake in the control and tithonia treatments was similar, and was significantly lower than in the chemical fertiliser treated plots. N uptake in the sesbania treatment (Sc) had similar uptake to the chemical fertilizer treatments (Figure 4.16).

4.3.12 Nitrogen use efficiency

In 1999 nitrogen use efficiency by grain was highest in the NP treatment (34.8%) whereas the three treatments where tithonia was added had much lower values of around 20%. In treatments FYM+P and Sc+P in which FYM or sesbania were added with SSP, even lower N use efficiency in grain was found.

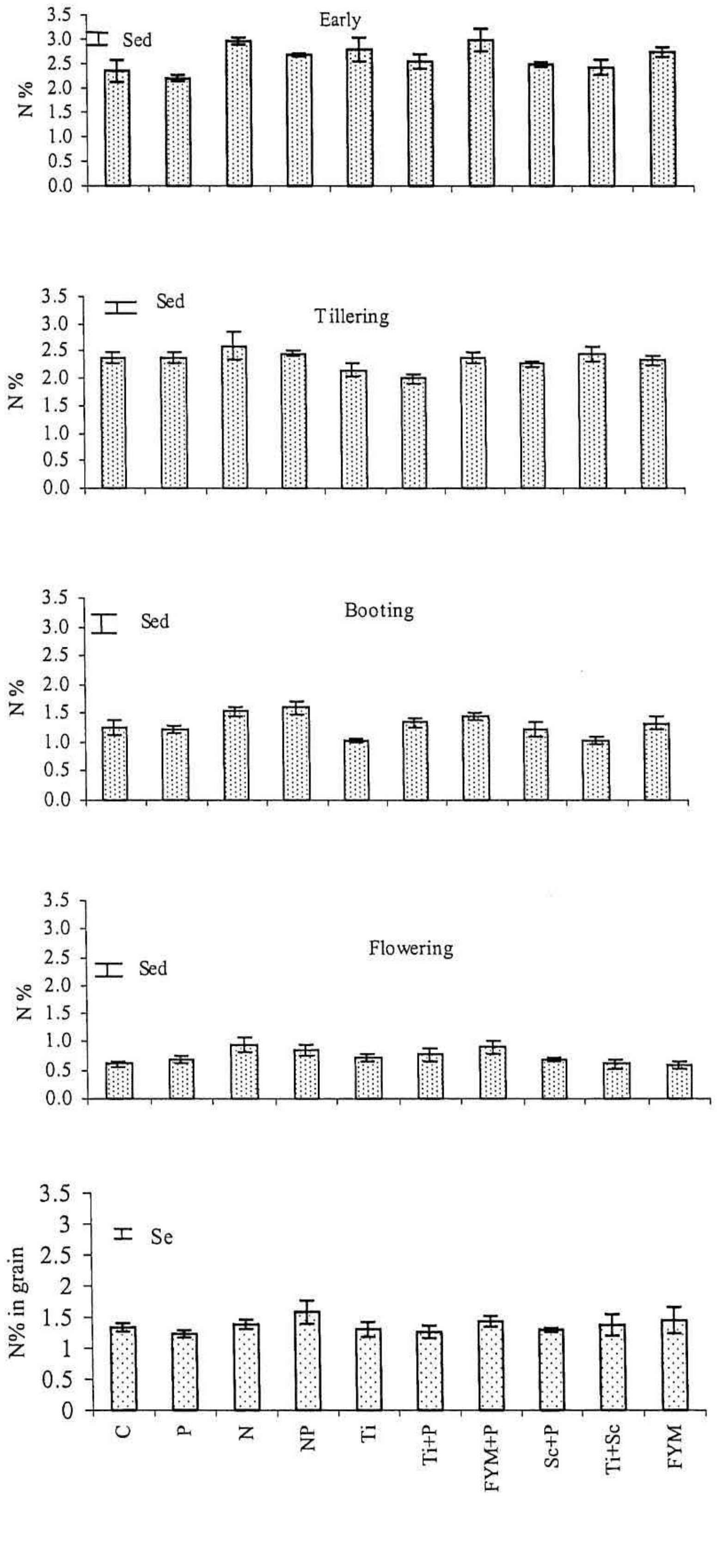


Figure 4.13: Concentrations of N in rice plants at various growth stages in 1999

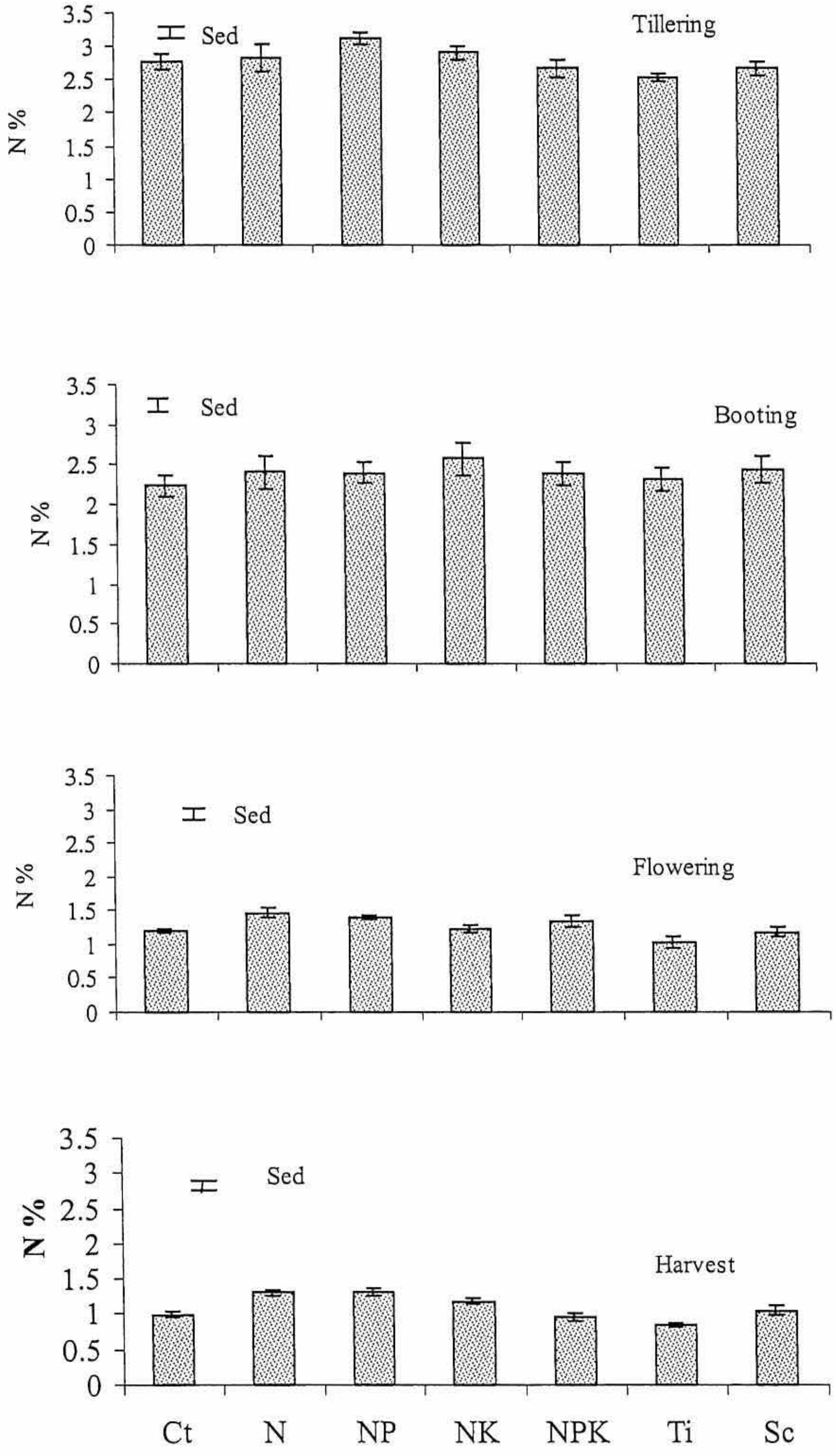


Figure 4.14: Concentrations of N in rice plants at various growth stages in 2000.

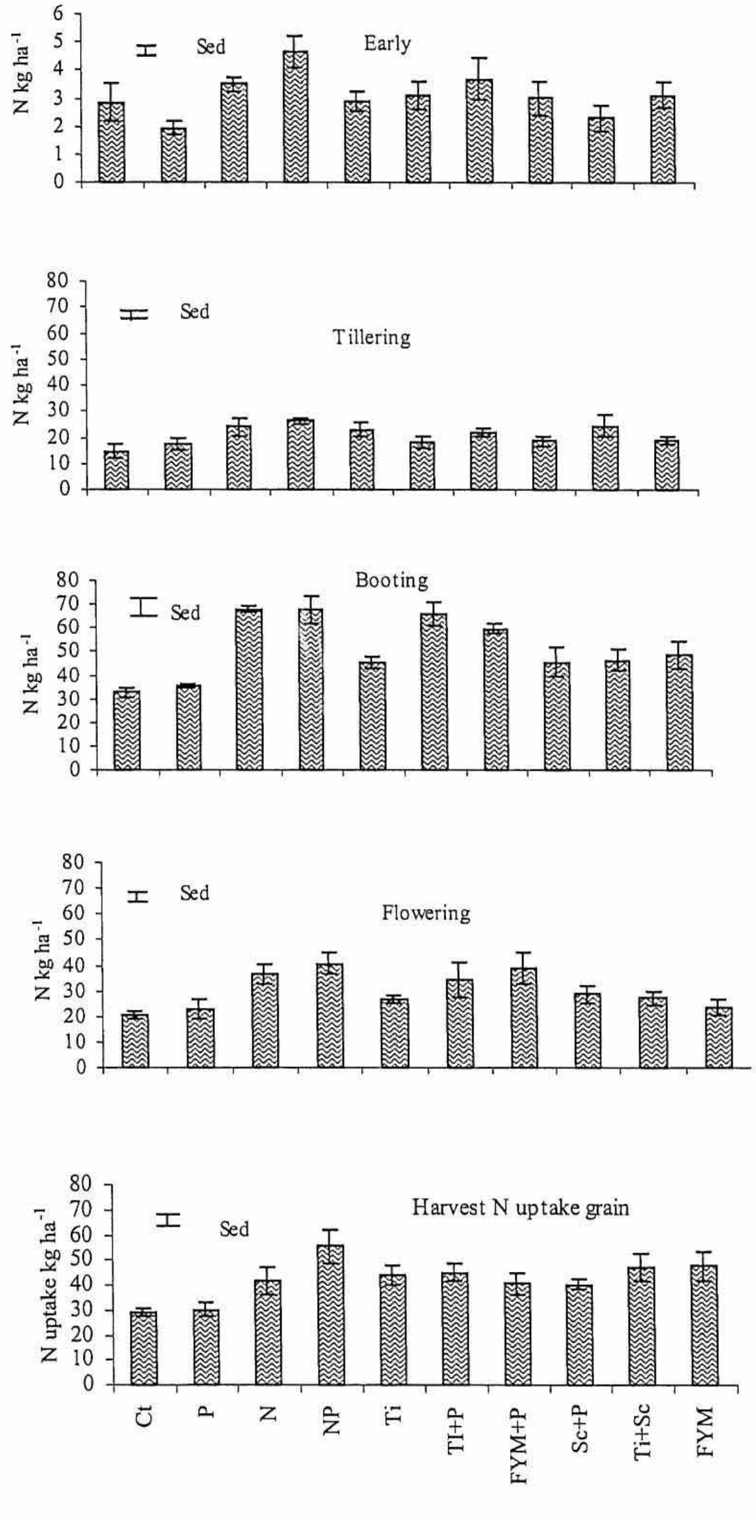


Figure 4.15: N uptake by the rice crop at various growth stages of rice in 1999.

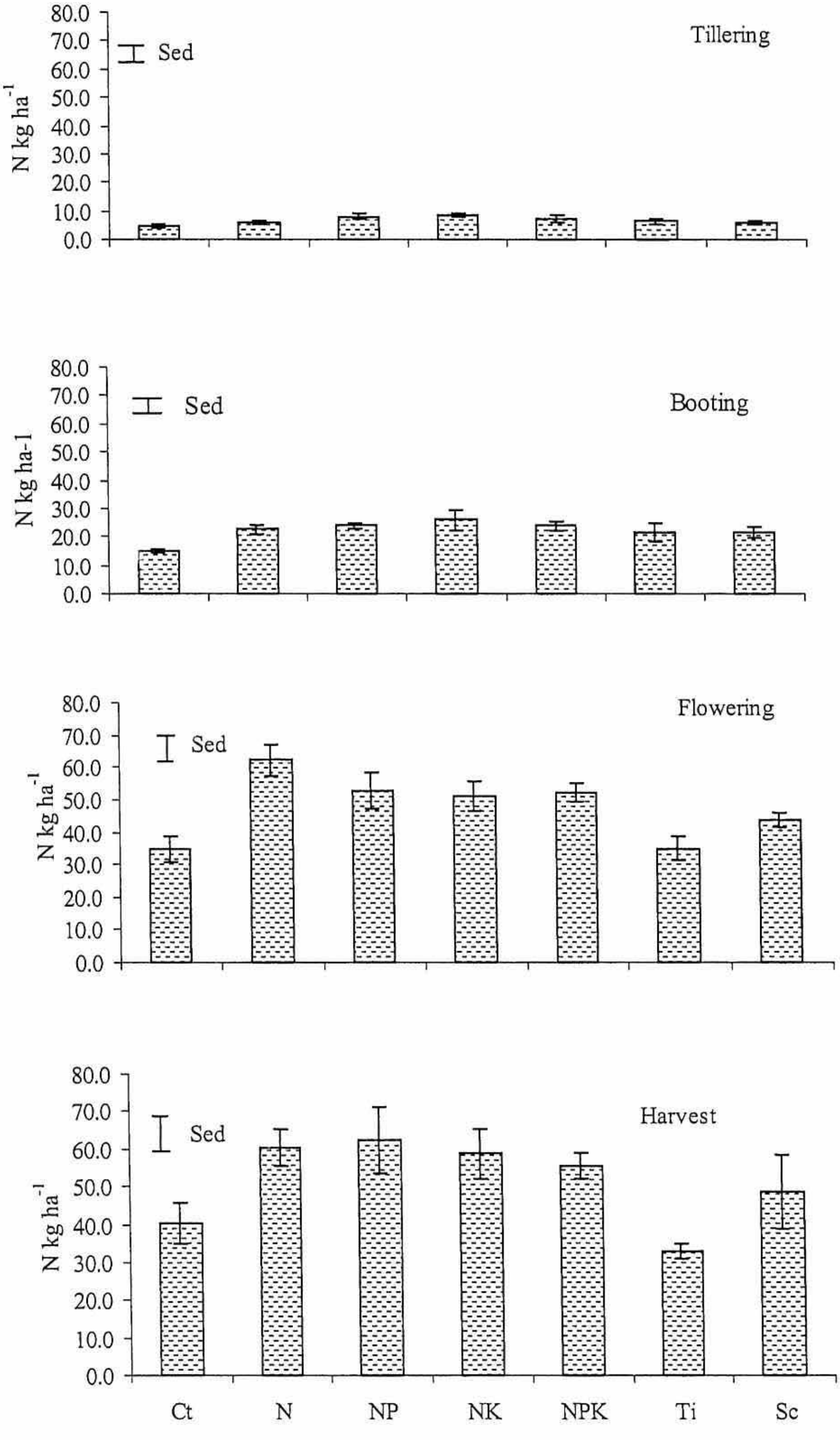


Figure 4.16: N uptake by rice plants at different growth stages in 2000 (inflorescence and grain not included in flowering and harvest samples).

Table 4.5: Nitrogen use efficiency in 1999

Selected treatment	Nitrogen use efficiency %
	Grain
T4. NP	34.8
T5 100% tithonia (Ti)	19.4
T6. 50% tithonia + 50% Single super phosphate (Ti+P)	21.1
T7. 50% FYM + 50% Single super phosphate (F+P)	15.3
T8. 50% sesbania + 50% single super phosphate (Sc+P)	14.6
T9. 45% tithonia + 55% sesbania (Ti+Sc)	23.5

4.3.13 Soil nitrogen dynamics

In 1999, both NH_4-N and NO_3-N were found in the resin bag extracts throughout the experiment. However, NH_4-N was the dominant form of inorganic–N in the first three occasions, which corresponded with the time when standing water was present in the plots. From flowering onwards, NO_3–N was dominant and this corresponded to the plots drying out in the dry autumn period (Figure 4.17).

In 1999, inorganic–N concentration was low in the early stages but there was an increase in NH_4-N concentration at the tillering stage (30 to 35 days after seedlings were transplanted). The highest values for NH_4-N were 9.9 mg l^{-1} measured from Ti+P followed by 9.1 mg l^{-1} (N only). After 30 to 35 days there was a sharp decline in NH_4-N concentration and an increase in NO_3-N. At the booting stage the highest concentration of NH_4-N (3.35 mg l^{-1}) was measured in the sole tithonia treatment. This amount was significantly higher than the other treatments except for sole inorganic N from urea (Figure 4.17).

Around 90 days after incorporation of the green manure and fertiliser application NO_3-N concentration had increased from around 0.1 to 0.3 mg l^{-1} at the earlier stages

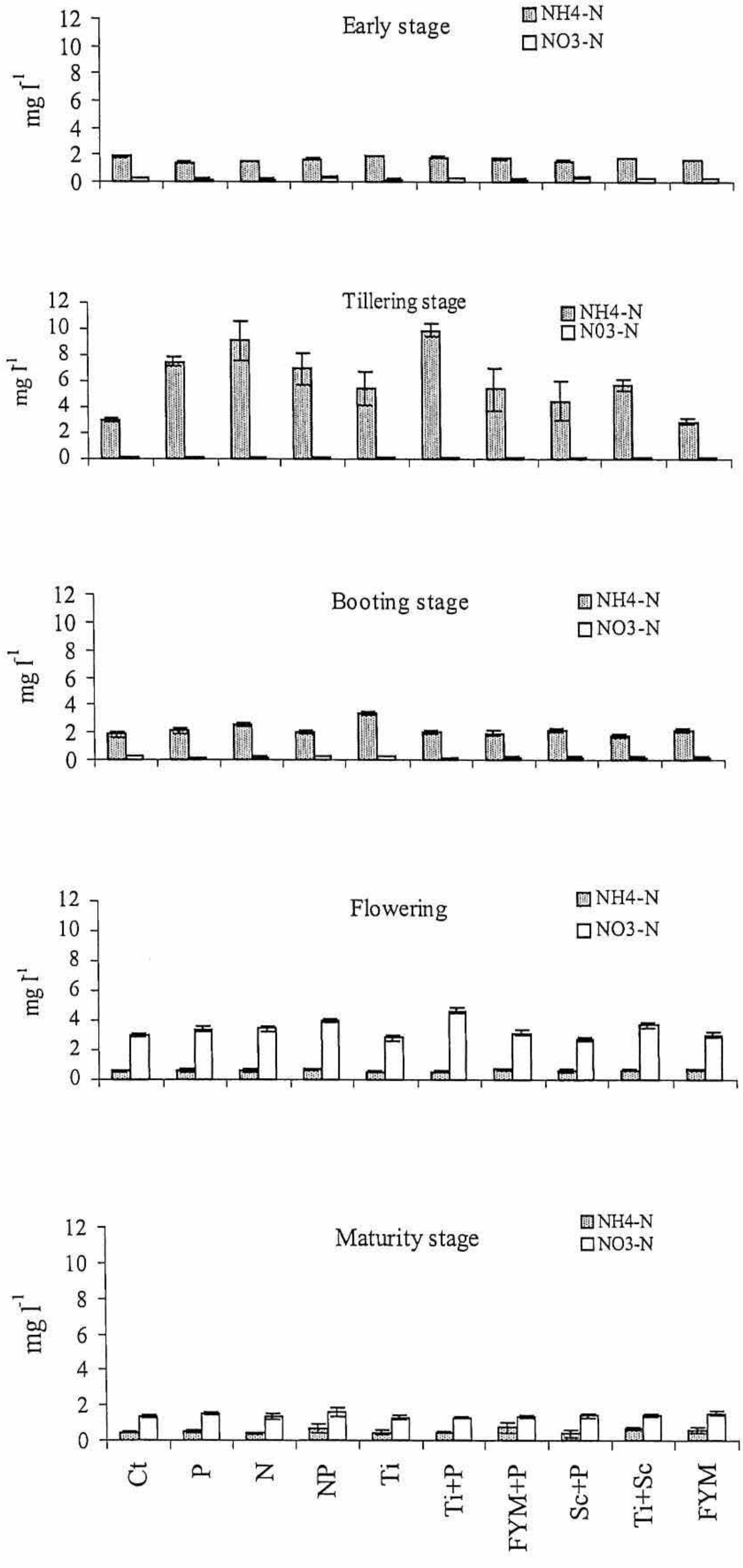


Figure 4.17: Inorganic N concentrations in resin bag extracts at various growth stages of rice in 1999.

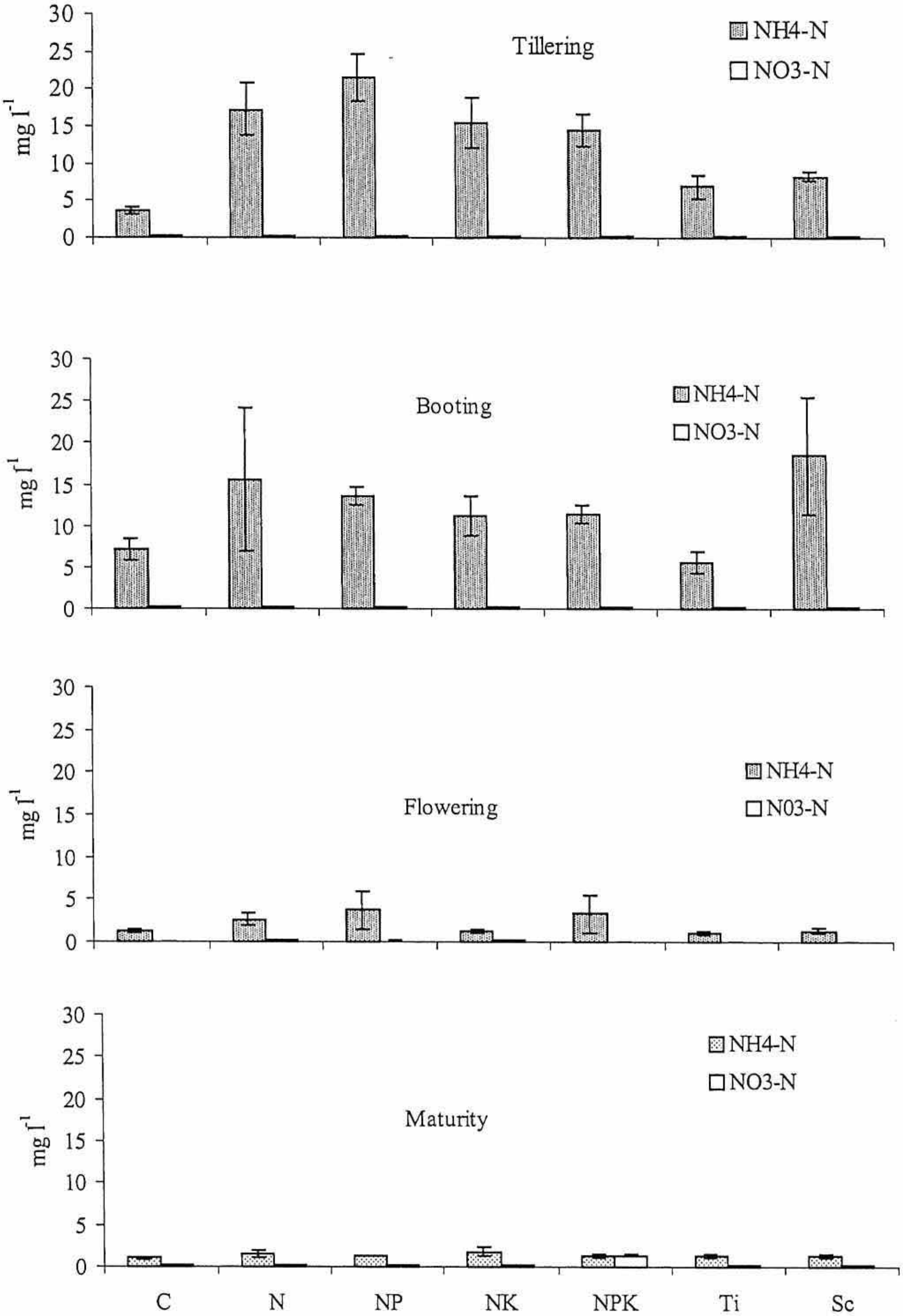


Figure 4.18: Inorganic N concentrations in resin bags extracts at various growth stages of rice in 2000.

to more than 2 mg l^{-1} in all the treatments but not significantly different. The sole tithonia treatment had only 2.82 mg l^{-1} at this time whereas other treatments, which received urea top dressing, had higher NO_3-N concentration, ranging from 3.47 to 4.42 mg l^{-1} (N, NP and Ti+P) at the time of the flowering to grain filling stages.

In 2000 at the early stage of this experiment all treatments which received N as urea had higher NH_4-N concentration than the green manure treatments. There was no apparent pattern to the results obtained from the tillering and booting stages and at the final stage all treatments showed similar, low concentrations (Figure 4.18). In the year 2000, the concentration of NO_3-N was lower at all the times than NH_4-N concentration, in contrast to 1999 when NO_3-N dominated in the dry later stages. The 2000 result could be because of a more prolonged submerged condition in the field due to continuous rainfall late in the season (Figure 4.18).

4.3.14 Mass of N loss

N loss from the litterbags were much more gradual than P in the early stages. For N the loss in the initial stage was fast but at the later stage the loss was steady. At the initial stage the loss from tithonia (Ti) and tithonia along with SSP (Ti+P) fertiliser was rapid compared to sesbania along with SSP (Sc+P). At the later stage sesbania was also slower in releasing N than tithonia (Figure 4.19).

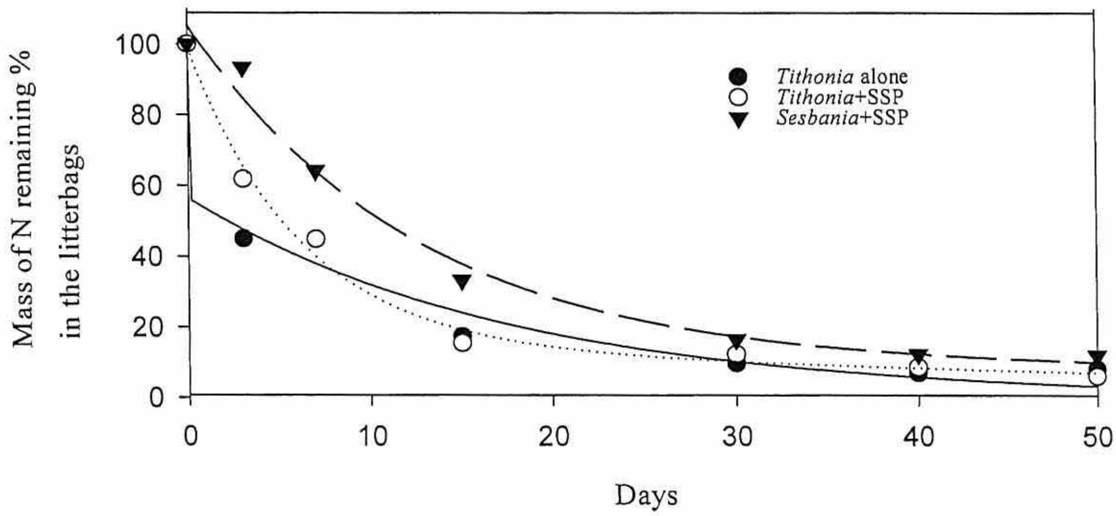


Figure 4.19: Mass of N remaining (% of initial mass) in the litterbags in year 1999

4.3.15 K concentration in the rice crop at various growth stages

In 1999, at all growth stages except at harvest, plant K concentrations were significantly different due to treatment (Figure 4.20). Highest concentrations of K in the early and tillering stages were in the tithonia treatment (Ti), mixture of tithonia and sesbania (Ti+Sc) and tithonia with inorganic P (Ti+P). In the early stage the sole tithonia treatment had significantly higher ($p \leq 0.01$) K than the N and NP treatments. The treatment with a mixture of tithonia and sesbania also had significantly higher K ($p \leq 0.01$) than the control, P, NP, FYM+P and Sc+P (Figure 4.20).

Treatments where chemical fertiliser only were applied and the control treatment had the lowest concentrations of K. K concentrations in grain was not different from one another (Figure 4.20).

In year 2000, at the tillering stage highest K concentration was measured in the tithonia treatment (3.21%) but the concentration was not different from the chemical fertiliser treatments where K was included. Treatments in which no K was included (N and NP) had significantly ($p \leq 0.01$) lower K concentrations than the tithonia treated plots (Figure 4.21). At the end of the experiment, the tithonia treatment had the highest K concentrations suggesting tithonia is a more effective supplier of K throughout the life of the rice crop than artificial fertiliser and sesbania.

There was a decreasing trend in K concentration over the growing period (Figure 4.21).

4.3.16 K uptake by the rice crop at various growth stages

In 1999, highest K uptake was found in the three treatments that incorporated tithonia (Ti, Ti+P and Ti+Sc) but surprisingly the Sc+P did not enhance K uptake as much. Statistically K uptake by rice grain was not different between the treatments (Figure 4.23).

In 2000 K uptake at harvest was highest in the tithonia treatments and the treatment receiving N and K in artificial fertiliser. However, the sesbania treatment (Sc) had a K uptake value at harvest only slightly higher than the control. Treatments receiving K in artificial fertiliser (NK and NPK) had substantially higher K uptake than in those not receiving inorganic K except for the N only treatment, which had a surprisingly high uptake. Application of N and P alone as artificial fertiliser resulted in a depression of uptake of K compared to the control (Figure 4.23).

4.3.17 Available K in soil

Resin extractable K

Substantial differences in resin extractable K between treatments were evident (Figure 4.24). The most obvious difference is between the tithonia treatment, especially in the early stage, (when values were 4 to 5 times higher) and the control and other treatments not receiving K in artificial fertiliser. In contrast, values for the sesbania treatment (Sc) were quite low. Inclusion of K in the artificial fertiliser also raised extractable K levels in the early stage above those without K added. K concentration declined over time (except in the control), and by flowering/grain filling, concentrations were similar in all treatments.

Results for ammonium acetate extractable K closely matched those for resin extractable K. There was much higher K in the tithonia treatments than in the other treatments at the early stage, but this difference had disappeared by the following sample dates (sampled after early stage). Treatments when K was applied in artificial fertiliser had also higher K values in the early stages than those without K (Appendix 4.5).

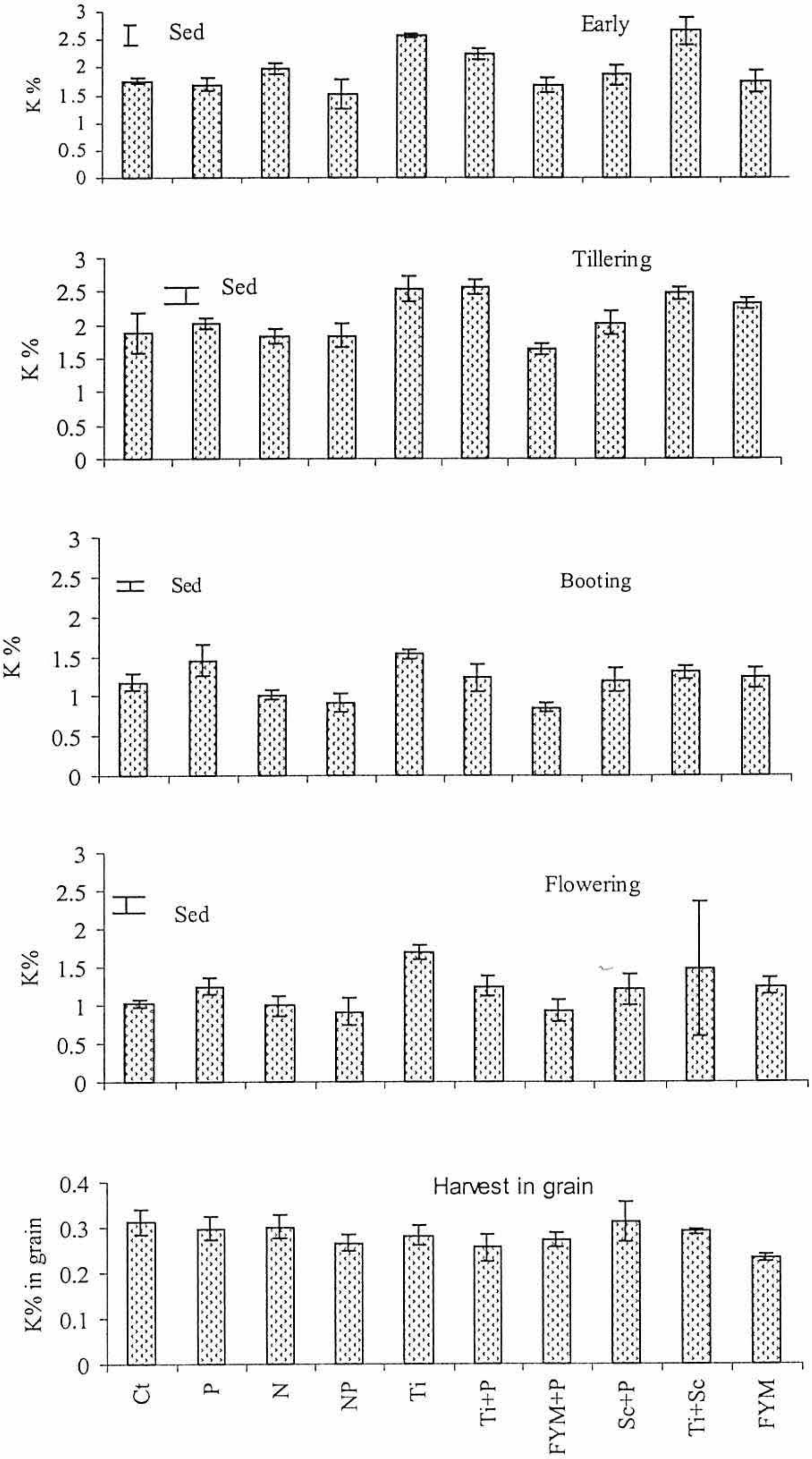


Figure 4.20: Concentration of K in rice plants at various growth stages in 1999.

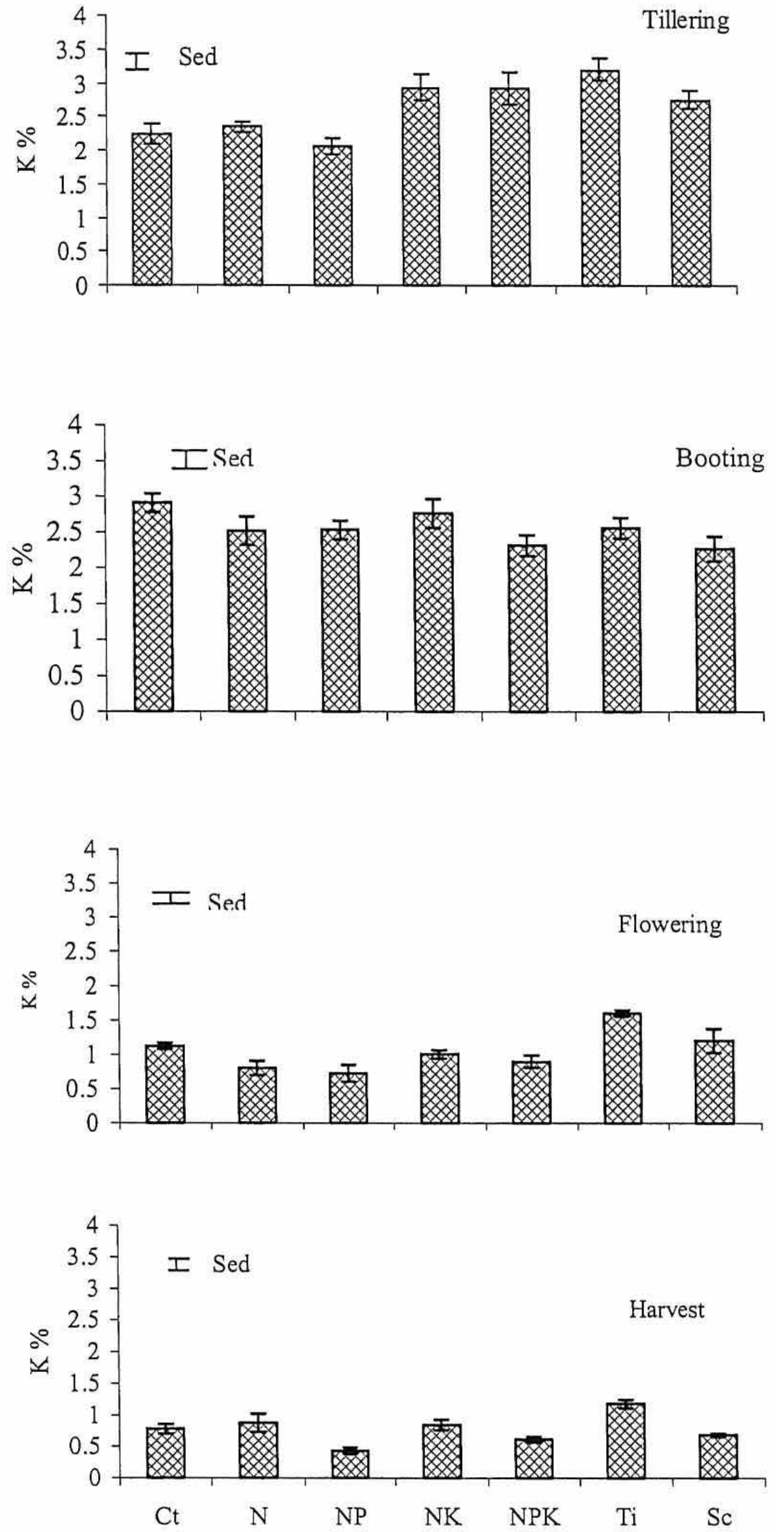


Figure 4.21: Concentrations of N in rice plants at various growth stages in 2000

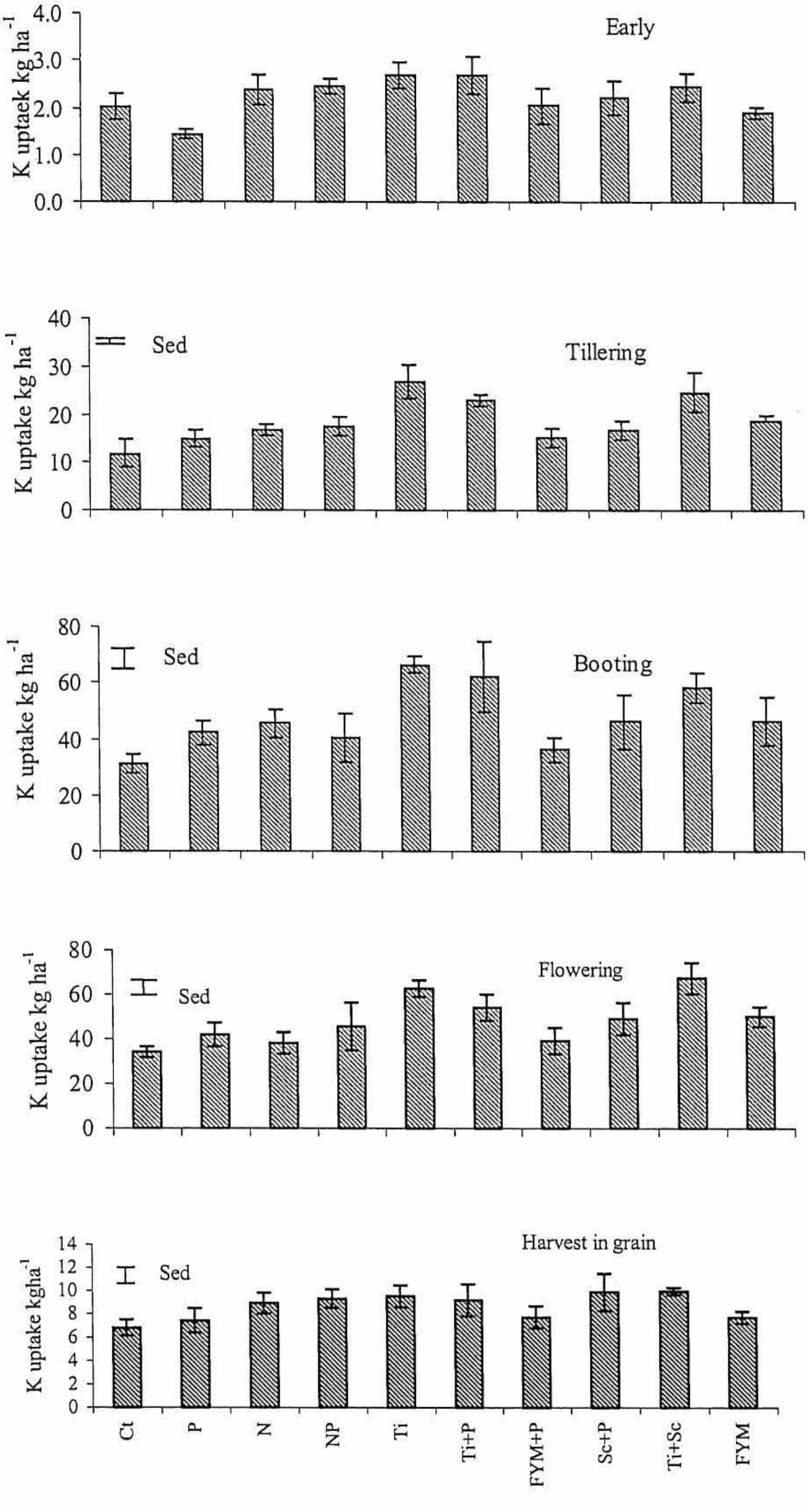


Figure 4.22: K uptake by the rice crop at various growth stages in 1999

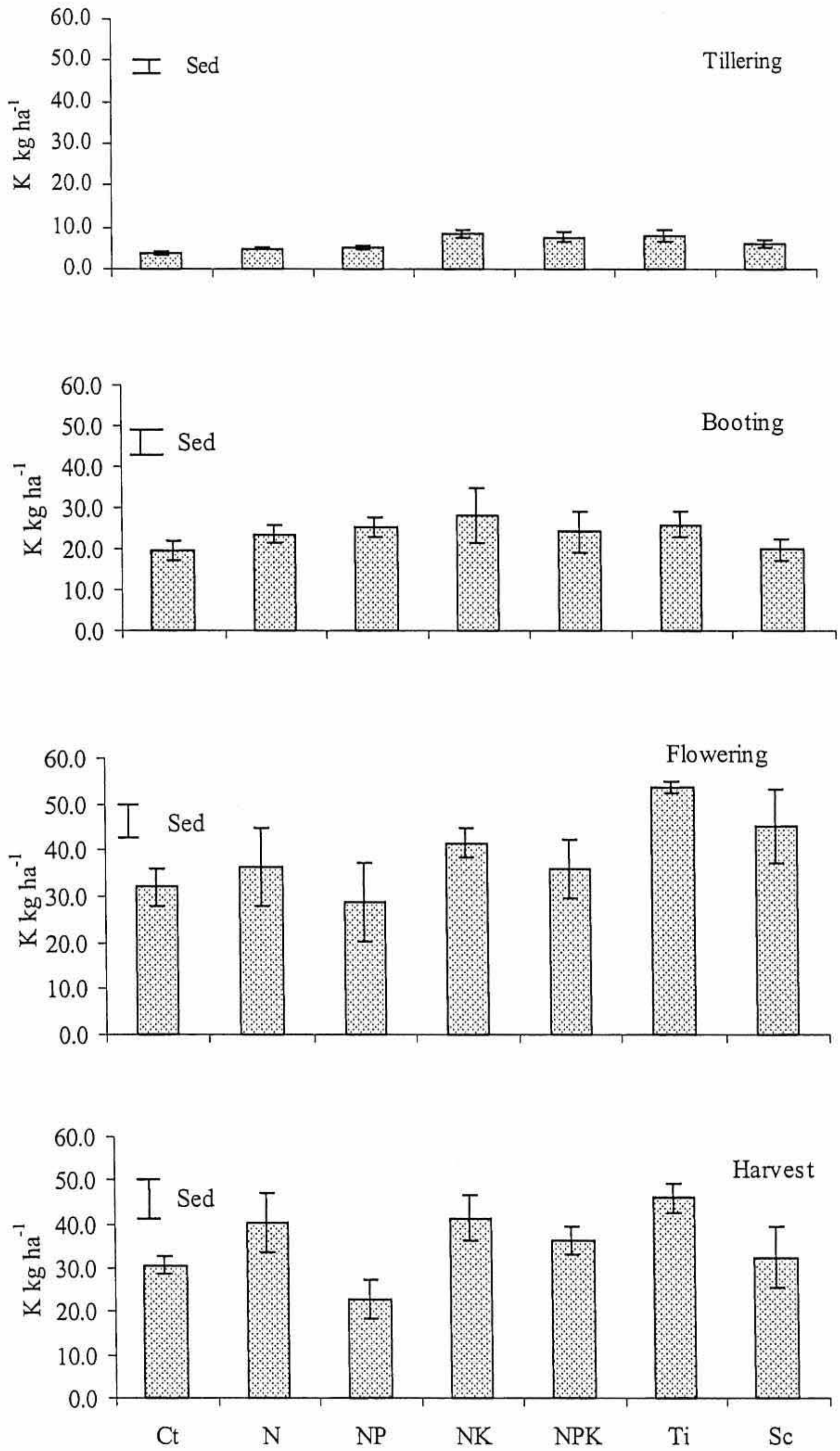


Figure 4.23: K uptake by the rice crop at various growth stages in 2000 (grain not included).

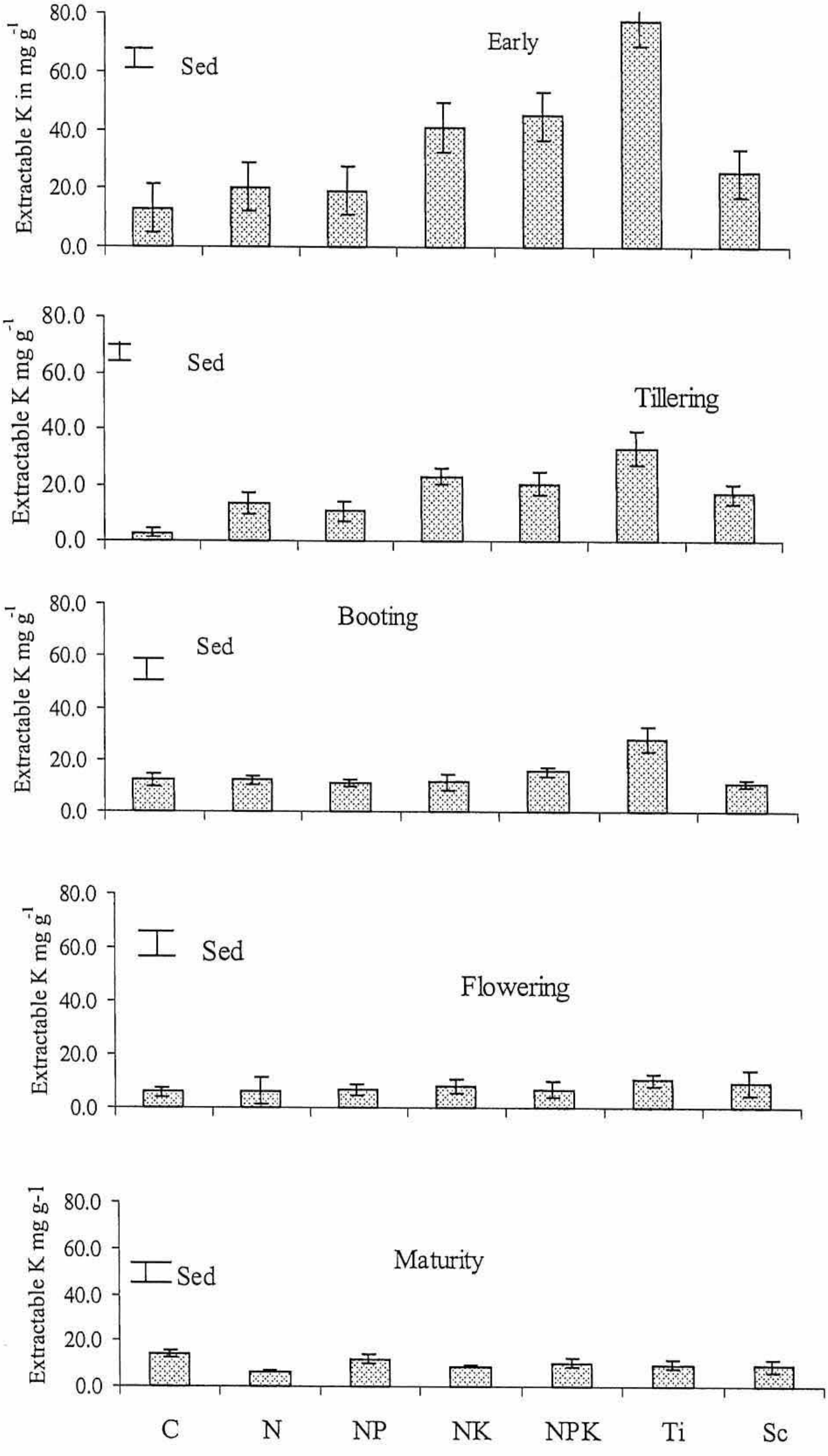


Figure 4.24 : Resin extractable K in soil solution 2000.

4.3.18 Resin extractable Zinc in the soil solution

The results are presented in the Appendix 4.6 due to inconsistent of test results it was not discussed further.

4.4 DISCUSSION

4.4.1 Tithonia as a fertiliser

The results show that *Tithonia diversifolia* has considerable potential as a green manure plant to improve the productivity of rice in a high production potential system. In 1999 tithonia applied at 2.5 t ha^{-1} dry matter equivalent to 75:10:0 kg NPK ha^{-1} produced grain yields similar (3367 kg ha^{-1}) to those obtained from the chemical fertiliser treatment (3496 kg ha^{-1}). The straw yields were 5749 kg ha^{-1} and 5511 kg ha^{-1} from tithonia and chemical fertiliser respectively and was not different from each other statistically. The production of rice was substantially (though not significantly) higher when 50% P was supplied through chemical fertiliser (SSP) plus 50% P from tithonia, which would be consistent with work showing that the integrated use of tithonia and triple super phosphate (TSP) fertiliser results in greater soil biological activity (ICRAF, 1996). The mixture of sesbania and tithonia also has potential as a green manure since sesbania is rich in N and tithonia contains a high concentration of P. A comparable yield can also be obtained by adding inorganic P to sesbania (3132 kg ha^{-1}).

Nagarajah and Nizar (1982) reported that fresh biomass of tithonia when used as a green manure for a rice crop at a rate of 9 t ha^{-1} along with 40:24.2:10 kg $NP_2O_5K_2O$ ha^{-1} produced a rice yield equivalent to recommended chemical fertiliser amount at a rate of 81.8:28.5:38.4 kg $NP_2O_5K_2O$ kg ha^{-1}. In addition they reported that an improvement in rice grain yield was obtained when tithonia biomass was applied along with the chemical fertilizer compared to tithonia alone. Tithonia may also be useful as a green manure for crops other than rice. Results have shown that tithonia biomass used as a green manure increases productivity of maize. Gachengo *et al.* (1999) reported that tithonia green manure doubled yields of maize compared to the control and a senna (*Senna spectabilis*) + TSP treatment. The production of maize was three times higher when tithonia + TSP was applied compared to the control and senna + TSP and since other nutrients were not measured this could be because tithonia supplied other limiting nutrients in addition to N and P.

The year 2000 field trial was conducted to confirm the promising result from the 1999 season. Rice production from the application of tithonia as a green manure was similar to the previous year 1999 (Figure 4.4a and 4.4b). In 2000 rice grain yield (3194 kg ha^{-1}) obtained from tithonia alone were, however, significantly lower at $p < 0.05$ to that obtained from 75:10:30 kg NPK ha^{-1} (3813 kg ha^{-1}) applied as artificial fertiliser. The grain and straw yields from the tithonia and sesbania treatments were almost identical.

One of the features of the year 2000 experiment was the response to K. A greater response from paddy to K than P could indicate low K availability in the soil (Appendix 4.5). A greater yield response would be expected when K is supplied along with nitrogen and phosphate fertiliser (Tisdale *et al.*, 1985). Joshy and Deo (1976) reported a quadratic response ofa rice crop to P when the amount of phosphorus was increased from 44.8 kg P_2O_5 ha^{-1} to 179.2 kg P_2O_5 ha^{-1} along with the 112 kg N ha^{-1} and 67.2 K_2O kg ha^{-1}.

4.4.2 Response to nitrogen, potassium and phosphorus

In both years, nitrogen was found to be the most limiting plant nutrient for rice growth since the rice responded to nitrogen application by producing a higher grain and straw yield. In 2000 there was a significant difference in grain and straw yields between the NK (3715 kg ha^{-1}) and the NP (2865 kg ha^{-1}) treatments. A significantly higher straw yield can be obtained when a balance of nutrients is supplied. Reduction of yield due to absence of K is significantly higher than due to the absence of P with nitrogen was applied. There was an indication of a response to K but a significant difference was not observed between N only and the NK on straw and grain yields (Figures 4.4a and 4.4b). The reason for a negative yield from NP application in year 2000 is not clear.

4.4.3 Response to zinc

In the 1999 summer season the rice crop suffered from zinc deficiency but the plants in the plots where tithonia was used were less affected and they had a higher zinc concentration. There was an indication of a response of the rice crop to zinc application when zinc was included along with tithonia, sesbania and sole use of chemical fertiliser in 2000, but the differences were not significant at $p>0.05$. These results suggest that rice does not respond to zinc application when artificial fertiliser is applied but that there may be benefit of using zinc in green manure systems. Addition of zinc fertiliser (25 kg ha^{-1}) had no significant contribution in increasing straw yield (Appendix 4.3.). The resin extractable Zinc also did not indicate any definite trend in soil solution (Appendix 4.6).

4.4.4 Comparison between tithonia and sesbania as a fertiliser

The beneficial effect of sesbania as a green manure for rice cultivation is well known and recognised (Beri *et al.*, 1989a;Yadvinder- Singh *et al.,* 1991). Sesbania biomass as a fertiliser has been investigated as a substitute for N fertiliser. Beri *et al.* (1989) found that rice produced a grain yield comparable to that when 120 kg N ha^{-1} was applied as artificial fertiliser when green manured with sesbania applied at a rate of 4.6 t ha^{-1}. In both the years rice grain from sesbania either as a sole application or in combination with inorganic P was comparable to tithonia treatments. This experiment suggests that tithonia biomass is similar in its usefulness as a fertiliser for rice as sesbania.

4.4.5 Supply of major plant nutrients and their efficiency of use for improving crop yield

Major nutrient (N, P and K) concentrations at all the important stages of the growing rice crop were at adequate levels in the green manured plots in both the 1999 and 2000 experiments. However, the concentrations decreased as the crop grew. In year 1999 the uptake of P by grain was 7.08 kg ha^{-1} in the tithonia treatment whereas in the chemical fertiliser treatment (75:10:30 NPK) it was only 5.95 kg ha^{-1} in 2000. Doberman *et al.* (1996) have estimated that from 1.8 to 4.2 kg of P is needed to produce 1 t of rice, so the P uptake measured here is within this range, at the low end for the rice fertilised with inorganic nutrient sources and towards the middle for rice fertilised with tithonia.

The efficiency of especially P use by the rice crop was also higher in rice grain from plots with tithonia as an organic fertilser (26.1% of P) than plots where nutrients were supplied inorganically. However, N use efficiency in rice grain was higher when some inorganic fertilizer was applied than when tithonia was used alone. This could be because the split application of N fertiliser (urea) leads to more effective utilization of N and because the later application may result in more N being available to the crop at later stages of development. Sesbania when applied in conjunction with artificial chemical P fertilizer then the efficiency of N and P uptake was not encouraging. The release of N from green manure declines gradually over time due to loss of biomass on decomposition_but it could be argued that the gradual supply of N from green manure should be more efficient than the application of urea that will result in pulses of high N concentration in the soil rather than a more gradual release.

A significant relationship was also observed between N, P and K uptake by grain and grain yield of rice in the year 1999. But in the year 2000 the relationship between the N and P uptake in straw and grain was non significant, whilst there was a significant relationship between K uptake and straw yield in the year 2000 (Figures 4.25 and 4.26). The reason is not clear why there was a different result.

The value of green manure for improving crop yields is through its effect on soil microbial activity, by enhancing microbial biomass and bacterial populations (Bhardwaj and Datt 1995). The chemical function of applied green manure is also very important in improving availability of plant nutrients in soil. The saloid bound P increased while Fe-P and Al-P and Ca-P decreased significantly as a result of green manuring on a range of soils (Yashpal *et al.*, 1993; Vig *et al.*, 1997). Hundal *et al.* (1988) observed that decomposition of green manure under alkaline anaerobic soil conditions reduced the bonding energy and P adsorption maxima of P released during mineralisation of those plant residues. Also because organic acids are produced, green manure significantly reduces P sorption capacity, helps solubilisation of native P and reduces fixation of P added as fertiliser (Yashpal *et al.*, 1993 and Yashpal *et al.*, 1995).

4.4.6 Synchronisation of nutrient demand and supply

In both 1999 and 2000 there was not a good match between the nutrient released from the applied green manure and the crop demand. Since in most cases the nutrients are released immediately. However the crop demand is gradual. The critical period for nutrient demand is from tillering to the flowering stage for rice. But Medhi and De Datta (1997) reported that the release of plant nutrients is gradual from decomposing green biomass and therefore there is likely to be better utilisation of nutrients by crops because of the synchronisation of nutrient demand and supply. In these experiments a significant relationship was observed in both years between nutrient uptake (N, P and K) by crops and grain yield thus providing evidence that efficient utilisation of nutrients improves the dry matter yield and eventually increases grain production.

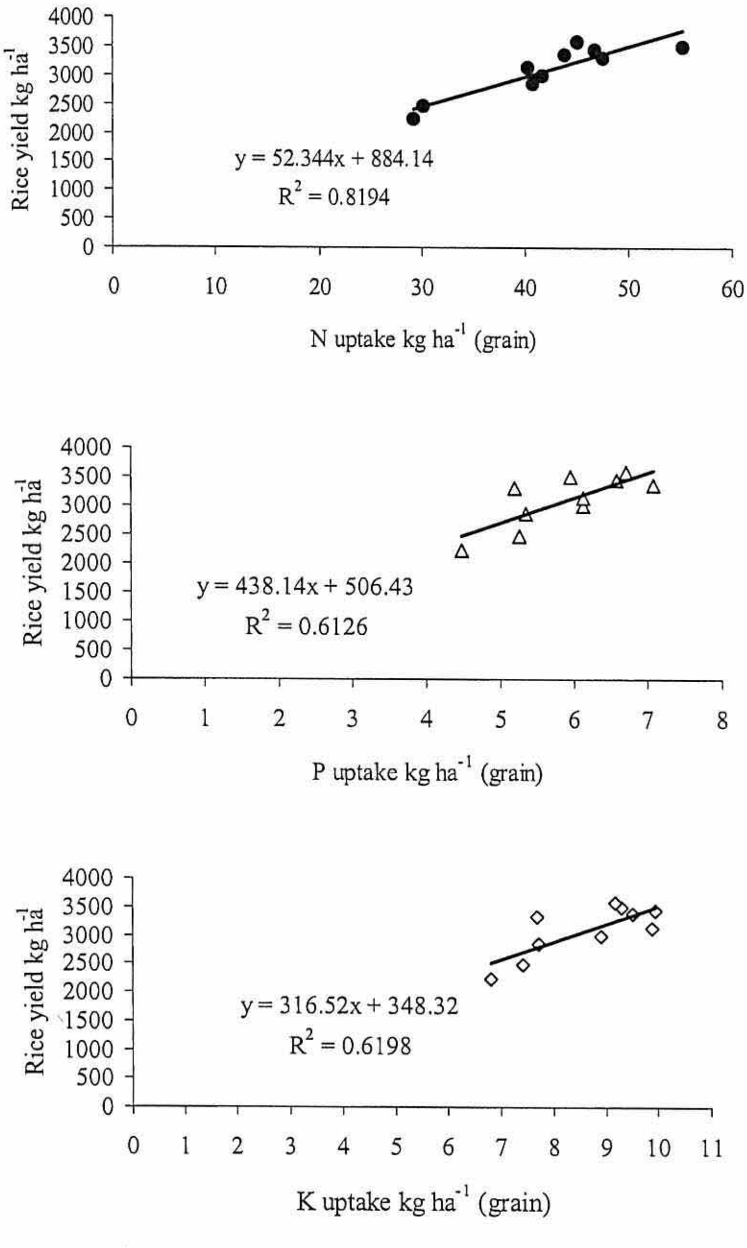


Figure 4.25: Relationship between N, P and K uptake and grain yield of rice in 1999.

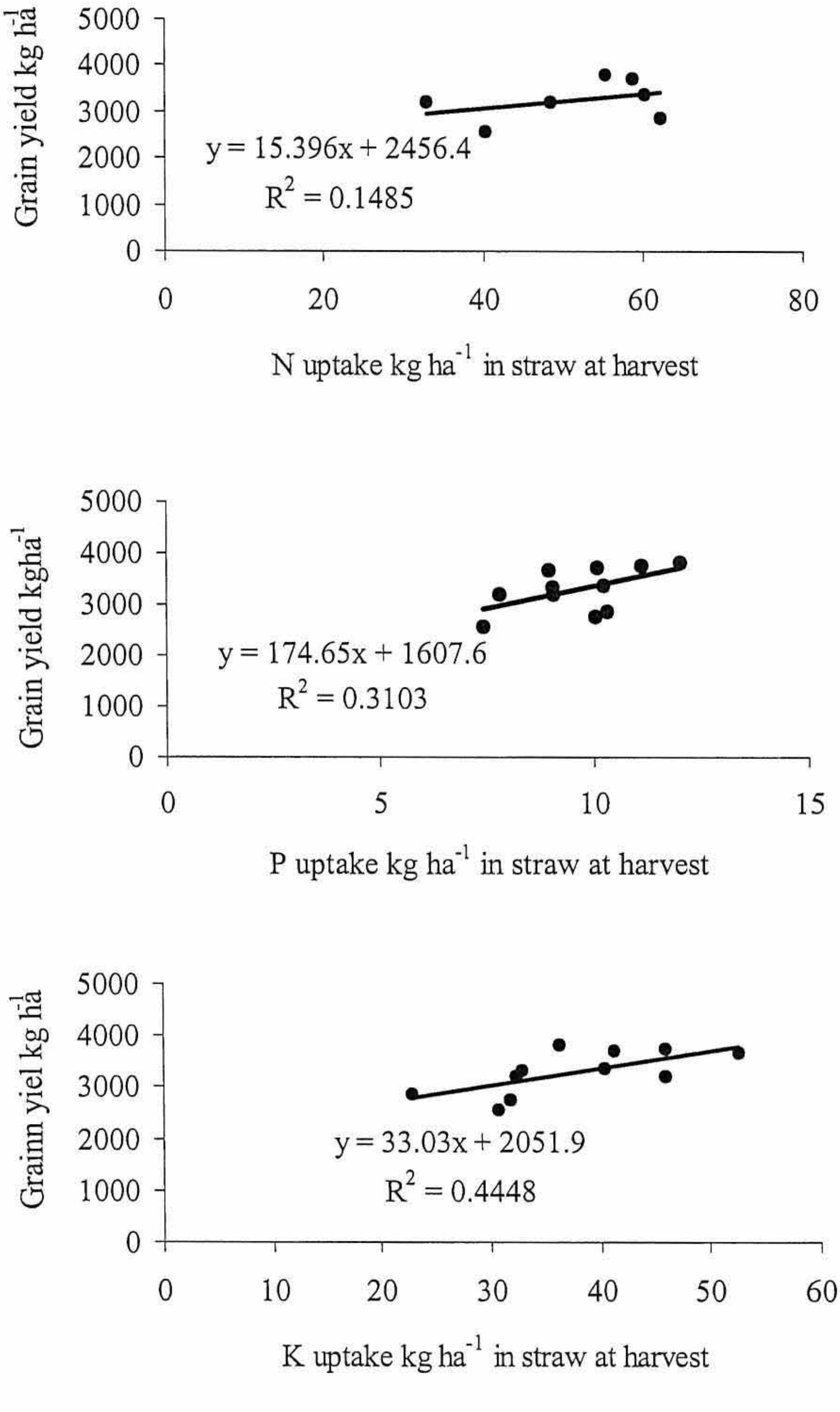


Figure 4.26: Relationship between N, P and K uptake by rice straw and grain yield in 2000

4.4.7 Phosphorus dynamics

The results showed that tithonia biomass improves the availability of P in the soil as much as from artificial fertiliser. This is supported by the Olsen-P and the iron oxide strip data, which showed that P availability was similar in tithonia and artificial fertiliser treatments, as confirmed by the yield response and P uptake by the rice. Although the amount of available P from tithonia is not greater than from the sole use of chemical fertiliser from the farmer's point of view, it may be a benefit if the tithonia is obtained more cheaply than chemical fertiliser.

There have been reports that under submerged conditions the release of P from organic matter increases particularly from phytates (Goswami and Banerjee 1978). Ponnamperuma (1965) reported that acidic soil under submerged conditions may increase P solubility by hydrolysis of $FePO_42H_2O$ and $AlPO_4.2H_2O$ caused by the increased pH. Reduction of ferric compounds to a more soluble ferrous form in the flooded soil increases solubility of the phosphorus (Patrick and Reddy, 1978).

Lack of a significant response to P in these soils could be because the submerged conditions for most of the time makes P readily available, and also because the available P was above the critical level for rice production. However, the critical level for Olsen-P can vary from 4 to 29 mg P kg^{-1} (Doberman *et al.*, 1996). Rahman *et al.* (1995) reported that the critical level of P for a rice crop in the alluvial flat land of Bangladesh measured as Olsen-P is only 9 mg kg^{-1} in which case the field used here had more than adequate available P.

The importance of P cannot however, be ignored, since there is a cycle of drying and wetting during the growth of rice. During the drier period P fixation is expected and therefore there is likely to be deficiency of P. And immediately after rice harvest a winter crop is planted that requires higher P than rice. The winter crops are mostly grown on residual soil moisture with little rainfall, therefore on drying, the solubility of the soil and fertiliser P decreases (De Datta *et al.*, 1990).

4.4.8 Nitrogen dynamics in soil under rice cultivation

In general green manure biomass is applied more than one week prior to rice seedling transplantation and decomposition of green manure and mineralisation of N starts immediately. However, the mineralisation rate is influenced by many factors, such as environmental conditions, quality of biomass used and incorporation method. Nitrogen is a unique nutrient in that transformations occur under submerged or flooded conditions. Nitrogen transformations in wetland and upland conditions have been studied by a number of scientists (De Datta and Buresh, 1989, George *et al.*, 1993; Tripathi *et al.*, 1997; Khadka, 1997). On anaerobic decomposition of green manure, plant N is released into the NH_4^+ form. Released N may be either adsorbed on to the soil exchange complex as NH_4-N may remain in the soil solution (Tripathi *et al.*, 1997). There are also many pathways that the released N may follow including de-nitrification, volatilisation, nitrification or leaching.

The results from our experiment show that immediately after application of biomass of tithonia and sesbania, either alone or in combination with chemical fertilisers, NH_4-N started to be released. The concentration of NH_4-N reached a maximum within 30 days after application (Figures 4.17 and 4.18). Then the concentration of NH_4-N started declining. A small quantity of NO_3-N was also found in the soil during the early period. Later, when the rice crop approached flowering to maturity, the NO_3-N form of N dominated the N-pool in soil system and NH_4-N was almost negligible. But overall the amount of N in soil or exchange complexes decreased. Nagarajah *et al.* (1989) also reported that in the presence of plants soil solution NH_4-N peaked around 15 to 30 days after flooding and then declined, due to N being taken up by plants. But Beri *et al.* (1989) observed rapid release of KCl extractable NH_4-N during 7 to 15 days from green manure application to the rice field. Buresh *et al* (1993) observed that when weeds and *Sesbania rostrata* were incorporated after soil flooding the release of NH_4-N reached a maximum by 36 days after incorporation. Nagarajah and Nizar (1982) have cited the findings of N. Joachim and Kandiah (1929) that NH_4-N concentration peaked 2 weeks after incorporation of tithonia green manure under semi-arid and flooded conditions. They also observed a decline later of NH_4-N to a very low level. The depletion of NH_4-N could be largely attributed to plant uptake (Medhi and De Datta, 1997).

For most of the time the rice field remains submerged but occasionally there is an alternating wet and dry environment (Tripathi *et al.*, 1997; Shrestha and Ladha, (1999). Because of this, oxygen in the soil profile increases and both NH_4-N and NO_3-N are found. However, in the later stage when approaching maturity the fields remain drier than before and therefore oxygen is not limited compared to the early stage and therefore NO_3 -N dominates the pool of inorganic N in the soil. Buresh *et al.* (1993) observed that soil water content is likely to be an important factor in nitrate formation before soil flooding. Accumulation of nitrate may result when the water filled pore space (WFPS) and consequently aeration, is favourable for nitrification. Shrestha and Ladha (1998) reported that a NO_3-N peak coincides with 60% soil WFPS, the optimum for aerobic microbial activity and when maximum nitrification is expected. The weather information recorded during the experimentation (Appendix 4.1) showed a variation in moisture regime in the field due to the duration of the monsoon that may affect the transformation of N in the rice field.

Islam and Islam (1973) observed that the increase in ammonium concentration under flooded conditions was due to mineralisation of organic N in the soil stopping at the ammonium stage because of lack of oxygen, which would otherwise result in nitrification. The overall decline of N concentration in the soil solution or exchange complexes over time could be because nutrients (N) have been taken up by growing plants and because the pool of available N being released from the applied biomass would also decline. Indeed, more than 50% of N mass had been lost by decomposition (Figure 4.19) after 15 days. However, the N efficiency is low from the green manure treatment could be as a result of losses of N either through leaching or denitrification. In the rice field both aerobic and anaerobic zone is close therefore the NO3-N is subjected to losses by denitrification or leaching upon flooding (Ponnamperuma, 1972; Broadbent, 1978; Tripathi *et al.*, 1997). But the field results are available that green manuring practice may reduce the loss of mineral N by leaching and decrease ammonia volatilization (Mahapatra *et al.*, 1996).

4.4.9 Available K

The available K in soil was in the low range (0.2 to 0.3 m.eq.100 g^{-1}) based on both the rating values cited by Landon (1991) and recommendations developed by the Soil

Science Division (SSD, 1994). However, other reports suggest that the soils of the Chitwan valley are not deficient in K due to abundant K-bearing primary minerals and alluvial deposits (Maskey, 1982; LRMP, 1986). Ghosh and Mukhopadhyay (1996) estimated that 113 kg K ha^{-1} is the critical level of K for rice plants in the West Bengal, a part of the Indo-Gangetic plain. But Saleque *et al.* (1995) reported a slightly lower critical level (0.075 meq 100 g^{-1}) of ammonium acetate extractable K for lowland rice in Bangaladesh, which is also part of the Indo-Gangetic plain. Since tithonia contains high concentrations of N, P and K this could be a reason for the comparable and higher yields to those treatments without K applied. Very little intensive work on the K aspect of green manure crops or tithonia has been carried out since K is not considered as a major yield-limiting nutrient in most parts of the world. But recently long term soil fertility experiments carried out in India and south east Asia have indicated increasing responses to K application (Doberman *et al.*, 1996).

There are also reports that upon flooding, the K concentration of the soil solution increases due to exchange with increased concentration of Fe^{++} and Mn^{++} (Ponnamperuma, 1965; Islam and Islam, 1973). Datt (1996) reported that after incorporation of fresh leaf prunings at a rate of 10 t ha^{-1} of 12 multipurpose forest tree species increases in water soluble and exchangeable K content occurred as compared to the control plot. Initially the concentration increased then declined after 2 to 4 months. Pande *et al.* (1993) also reported that the concentration of K in soil decreased under submerged conditions over time. The decline in concentration in soil solution could be K taken up by the crop or loss by leaching during the flooding period. ICRAF (1996) also reported an increase in the extractable K in soil upon applying tithonia biomass on to the soil. Our results are consistent in that K concentration was high in rice plants at all the stages and both ammonium acetate and resin extractable K were higher in soil in the tithonia treated plots than in other treatments except where K was supplied from artificial fertiliser (Figure 4.26). The concentrations of K in the rice plant was within the range of critical level 2 to 5% at early and tillering stages which is considered to be very important for better growth (Figures 4.20 and 4.21). Therefore it is expected that the uptake of K is not restricted. The relationship between the grain yield and total K uptake in both the years was significant (Figures 4.25 and 4.26).

Response to K is greater than to P in the presence of nitrogen though for both the nutrients a high moisture regime is favourable for increasing availability of P and K. But still the K requirement as estimated by Doberman *et al.* (1996) is at 17.0 to 30.0 kg K to produce one thousand kg of rice and in our experiment the uptake by rice grain was lower than in his experiments.

4.5 CONCLUSIONS

Tithonia diversifolia biomass could be a valuable source of nutrients in the high production potential system in the terai because it had a similar effect on productivity of rice as popular leguminous green manure crops and compound artificial fertilizer and a larger effect than farmyard manure. A comparable grain yield of rice to that obtained from chemical fertiliser applied at a rate of 75:10:30 kg NPK ha^{-1} can be obtained from tithonia biomass when applied at the required level to deliver 10 kg P ha^{-1}. Yields were not significantly different where the nutrients were supplied from sesbania, mixtures of tithonia and sesbania or mixtures of the biomass of these species and inorganic sources. A strong relationship between N, P and K uptake by grain and grain yield was found. Initially the focus of the present work was on P, but tithonia clearly supplies more than one essential plant nutrient to the soil and they are released in most cases at the early stage when the growing rice crop needs them. The release of all the three major nutrients (N, P and K) was higher in the early stage of the rice crop and soil concentrations gradually declined towards the maturity stage, because of nutrients being taken up by the crop and loss of biomass through decomposition.

Both the Olsen-P and the iron oxide strip method found no major differences in the available P in the various treatments, irrespective of whether P was supplied from tithonia, chemical fertilizer or a mixture of both. This does not support, for the present conditions, reports that tithonia may increase availability of inorganic P to crops through increased biological activity in soil or the action of organic acids released on its decomposition on mineralisation of organic P (ICRAF, 1996). Some caution is required, however, since this may be because the soil has a low P fixation capacity and the measurement of plant available P remains problematic, although both methods used here have been recommended for submerged conditions (Medhi and De Datta, 1997).

Under flooded conditions NH_4-N dominated the inorganic N-pool during the active growing stage of the rice crop but later on NO_3-N was present at higher concentrations as the site dried out. The form of N was clearly influenced by the soil moisture content. Potassium concentration was higher in tithonia treated plots when measured with resin bags and normal ammonium acetate extraction, but no significantly higher yield was found associated with this.

There is a pressing need to investigate the efficiency of tithonia for supplying P plus other nutrients in specific agriculture systems. Most successful results so far are from an upland environment but in the Indian sub-continent and in South East Asia green manuring practices are associated with rice cultivation. Farmers' perception of green manure is in wetland cultivation but there are also options for using green manure for other crops such as wheat and maize grown in rotation with rice.

In terms of the initial focus on P availability and the hypotheses at the outset, there was no direct evidence from soil analyses that tithonia increased the amount of plant available P in soil more than other forms of P applied, but in 1999 there was some evidence for greater uptake of P by rice grain where tithonia was the sole or partial source of nutrients than with artificial fertilizers alone. In 2000 however N, P and K uptake by straw was similar between the treatments. Plant uptake is a more reliable measure of availability than chemical analyses of soil. This higher uptake of applied nutrients with green manures may be because of closer synchrony of release and plant uptake than because of more complex nutrient transformations in soil and it resulted significantly higher grain yields. It is also likely that higher nitrogen and phosphorus contents in grain may be important for nutritional quality (Grist, 1975). More importantly, in the soils in the Chitwan area, with low P fixation capacity and nutrient limitation other than P, it appears that the ability of tithonia to provide a range of macronutrients in appropriate quantities and in reasonable synchrony with crop demand is probably more significant than its specific impact on P dynamics.

CHAPTER 5

THE FERTILITY EFFECTS OF GROWING TITHONIA WITHIN FIELDS ALONE AND IN CONJUNCTION WITH OTHER SPECIES AND INPUTS

5.1 INTRODUCTION

Rice followed by wheat is an important sequential cropping system practised on about 22 million ha in south and eastern Asian countries including Bangladesh, Bhutan, China, India, Myanmar, Nepal and Pakistan (Mann and Garrity, 1994; Yadav, 2000). Both crops are major sources of food and income to many farming families in Nepal (Regmi, 1998). Rice and wheat are heavy users of plant nutrients. Mann and Garrity (1994) suggest that a crop sequence yielding 7.0 t ha^{-1} rice and 3.9 t ha^{-1} wheat may remove as much as 316 kg N, 28 kg P, and 337 kg K ha^{-1} from the soil. Research is, therefore, required to examine plant nutrient management issues under the rice-wheat cropping system, especially as declining productivity of both rice and wheat crops has been observed in Nepal (Regmi, 1998). The scope for inclusion of green manure crops within rotations is expanding with the introduction of very early maturing rice varieties (K D Joshi and D Poudel personal communication) and the inclusion of green manure in the rice-wheat system has been shown to have potential to improve soil fertility and increase productivity of crops and so farm income (Maskey and Bhattarai, 1984; Panth, 1989; Yadav *et al.*, 1999).

One of the most commonly used green manures is sesbania (*Sesbania cannabina*), which is typically grown after the wheat harvest in May or June in the Indo-Gangetic plain of India and the South East Asia region more generally (Beri *et al.*, 1989a; Mann and Garrity 1994). In the Terai region of Nepal roughly 60 to 75 days are available to grow sesbania before main season rice transplanting takes place. However, the time available depends upon many factors such as the onset of the monsoon and the particular wheat and rice varieties grown in the rotation. So far research efforts have investigated only N fixing green manure crops such as sesbania (Beri *et al.*, 1989a and b; Bhardwaj and Dev, 1985; Yadvinder-Singh, 1991; Young, 1997). These research findings show that the majority of soils have low to medium levels of P and, therefore, the performance of most N fixing green manure crops suffers in P deficient soil (Garrity and Becker, 1994; McLaughlin *et al.*, 1989). There are also reports of more general nutrient depletion such that other plants nutrients, formerly considered as adequate in most soils, are becoming critically low (Doberman *et al.*, 1996).

Tithhonia diversifolia is a non-leguminous plant with high tissue nutrient contents, which has recently been used as a source of organic fertiliser especially in central Africa, South East Asia, Philippines and Indonesia (ICRAF, 1996). An interesting area for investigation is the possible benefits of integrating tithonia, which is high in P, with nitrogen fixing crops. Earlier strategies in which P was not applied to rice have been found to be less sustainable and often the following crop, usually wheat, suffers from P deficiency (Yadvinder-Singh, *et al.*, 2000). On soils with high P fixation capacity economic returns to P fertilisation may decline as P depletion progresses because P added as fertiliser is rapidly fixed in forms unavailable to plants. Use of tithonia has been reported to improve efficiency of P fertilisation (Sanchez *et al.*, 1997) but the generality of this effect and the mechanisms by which it occurs are not known.

It is also not known whether tithonia can be effectively integrated into the rice-wheat system and what the comparative advantages of doing so may be over the existing fertility management practices. The efficiency of tithonia has been studied by a number of researchers under marginal upland conditions largely with maize (Gachengo *et al.*, 1999) but little information is available on its performance for highly intensive production systems in a lowland environment. Therefore field experiments were conducted in the Chitwan valley of Nepal to test the following hypotheses:

- tithonia is agroecologically viable as an *in situ* green manure,
- tithonia grown in rotation with rice and wheat accesses soil nutrients not available to the crops and makes them available to them,
- tithonia and sesbania together are a more effective nutrient source than either alone because sesbania is high in N and tithonia is high in P and K, and .
- to investigate whether there is a difference between the above ground parts and below ground parts of tithonia plant as a source of nutrients.

5.2 MATERIALS AND METHODS

5.2.1 Experiment No 1 1999 summer season

A field experiment was conducted with four replicates and eight treatments in a randomised complete block design in the summer season of 1999. The detailed descriptions of treatments are as follows:

T1 (Ct.) = Control plot (No chemical fertiliser and no manure).

T2 (Ti) = Tithonia grown *in situ*.

T3 (Sc) = Sesbania grown *in situ*.

T4 (Ti+Sc) = Tithonia 50% and sesbania 50% grown *in situ*.

T5 (FP) = Farmers practice (2.5 t ha^{-1} poultry manure + 70:20:20 kg N P_2O_5 K_2O ha^{-1}) Representing category A household (food sufficiency more than 12 months) farmers. Half of the N was top dressed at maximum tillering stage.

T6 (Ti+N) = Tithonia grown *in situ* plus 30 kg N ha^{-1} top dressing at the time of maximum tillering.

T7 (Ti stm) = Tithonia grown *in situ*, with above ground parts only incorporated. Whole plants were pulled up and separated into shoots and roots, the latter were discarded.

T8 (Ti rts) = Tithonia grown *in situ* below ground parts only used (above ground parts discarded).

The plot dimensions were 4 m by 5 m with plots separated by 50 cm and blocks by 1 m. Tithonia seeds were broadcast in appropriate plots at a rate of 30 kg ha^{-1} on April 2, 1999. Sesbania was broadcasted on May 5th, 1999 at a rate of 45 kg ha^{-1}. Fresh biomass of both crops was cut on July 11 and incorporated into the experimental plot (Figure 5.2). The total growing period for tithonia was 100 days. Thirty -one day old rice seedlings were transplanted on July 11, 1999. Row- to- row and hill-to-hill spacing was 20 cm. In each station three seedlings were transplanted. The rice variety was Sabitri. The crop was harvested on November 15, 1999 leaving two border rows from all sides excluded from analysis. Grain yield was calculated at 12% moisture while straw yield was taken after sun drying for two days. The lay out plan of the experiment is given below:

Figure 5.1: Lay out plan of the experimental treatments

Block	Treatments							
Block_1	T3	T6	T5	T4	T1	T2	T7	T8
Block_2	T4	T5	T8	T7	T2	T1	T6	T3
Block_3	T2	T4	T6	T1	T3	T8	T7	T5
Block_4	T5	T7	T2	T3	T4	T1	T8	T6

After the rice harvest the field was dug manually by spade. Then wheat seeds were sown on November 21, 1999. The wheat variety was RR21, an early maturing variety. No extra chemical and organic fertilisers were applied and the crop was grown on residual nutrients. The seeding rate was 120 kg ha^{-1}. Because of acute N deficiency symptoms appearing in all the treatments, the crop was top dressed with urea at a rate of 30 kg N ha^{-1} at the maximum tillering stage to save the crop. The wheat crop was harvested on March 27. Wheat yield was adjusted to 12% moisture. Wheat straw was sun dried and the weight recorded.

5.2.2 Experiment No 2 summer season 2000

The same experiment was repeated in the main rice season of 2000 with little modification of the previous year's treatments. The experimental plots were maintained for the new trial. Two treatments, tithonia above ground parts (Ti stm) and tithonia below ground parts (roots only), were replaced by N top dressing and *asuro* (*Adhatoda vasica* Nees) (biomass transfer) respectively. The purpose of the experiment was to confirm the result of 1999. The treatments were as follows:

T1 (Ct) Control plot.

T2 (Ti) Tithonia grown *in situ*.

T3 (Sc) Sesbania grown *in situ*.

T4 (Ti+Sc) Tithonia and sesbania grown *in situ* (alternate rows of sesbania and tithonia).

T5 (FP)	Farmers practice (FYM was applied in place of poultry manure).
T6 (Ti+N)	Tithonia grown *in situ* plus N top-dressed at a rate of 30 kg ha^{-1}.
T7 (N)	N top-dressed from urea at a rate of 30 kg ha^{-1}.
T8 (Asuro)	*Asuro* equal biomass amount to T3 (biomass transfer from nearby shrubs).

In 2000 instead of FYM poultry manure was applied in the treatment T5 due to unavailability of FYM in the area. After harvesting the wheat, tithonia seeds were sown in the appropriate plots. The seeds were collected from the Chitwan valley and Palpa district. The seed rate was roughly equal to 30 kg ha^{-1} because it was difficult to separate seed from leaf dust. The seeds were sown on April 15 and plants harvested on July 5. The total number of growing days was 80. Due to poor germination of tithonia seeds by May 1, gap filling was done with more seeds and a few cuttings were propagated in the plots as well. The fresh biomass weight of tithonia is given in Figure 5.3. Sesbania seeds were sown on May 10 at a rate of 40 kg ha^{-1} because of fast growth rate, which is a common practice in the study area.

The rice variety was Sabitri. Thirty day old rice seedlings were transplanted on July 6, 2000. Three seedlings were transplanted in each station. The land preparation and application of manure and fertiliser was generally according to local practice. However, according to local practice, farmyard manure (FYM) or poultry manure is incorporated before land is ploughed and green biomass is incorporated generally 7 days before transplanting rice seedlings. But in this trial biomass was incorporated just one day before transplanting because rapid initial release of nutrients was anticipated due to fast decomposition (see Chapter 2). The sources of chemical fertilisers were urea, diammonium phosphate (DAP) and muriate of potash (MoP) for T5, T6 and T7 treatments.

The rice crop was harvested on November 8, 2000. Straw and grain yield was estimated from an area of 10.64 m^2 in each plot. Grain weight was adjusted to 12% moisture level, a standard practice in Nepaland straw was sun-dried for two days and then weighed. In both years at harvest time observations on various yield attributes such as plant height, number of tillers per hill, panicle length, number of grains per panicle and thousand grain weights were measured.

Rice plant samples were taken from four stations per plot to analyse for dry matter, N, P and K content at each of five sampling occasions. Four stations were chosen randomly from the destructive rows. The schedule of sampling was 3, 20, 31 62, 92 and 122 days after seedlings were transplanted. At 122 days the crop was harvested and, therefore, resin sampling for nutrient analyses was not done. Similarly for the first date, nutrient concentration of plant samples were not measured because the very young seedlings were too small for this to be worthwhile. The corresponding growth stages at the sampling times were: early establishment, tillering, booting, and flowering to grain filling and maturity. Soil samples were taken on each occasion and iron oxide impregnated filter papers placed in the soil; also on each occasion resin bags were also used.

5.2.3. Decomposition of green manure biomass

Decomposition rates of the green manures (e.g. tithonia, sesbania and *asuro)* were studied in the selected treatments (Ti, Sc, asuro and Ti+N) using the litterbag technique. The method has been described in detail in Chapter 2 and was used here with 10 g fresh weight of green manure biomass in each bag. The sampling schedule was 3, 7, 15, 30, and 40 days after litterbag incorporation into the soil. Due to very rapid decomposition the sampling interval was kept very narrow.

5.2.4 Soil and plant analysis procedures

In the first year, soil and plant samples were not taken. In year 2000, available P in soil was measured using the Olsen–P and iron oxide impregnated filter papers (*in situ*) at the LI-BIRD Laboratory. Plant analyses were done at the Henfaes Farm laboratory, University of Wales, Bangor. Concentration of N, P and K was analysed in the vegetation samples left in the litterbags at each sampling occasion and in rice plant samples as well. In addition, information on nutrient concentration in the initial green manure samples was measured and is given below in Table 5.2. The detailed analytical procedures have already been described in Chapter 4.

Table 5.1: Major nutrient concentrations and polyphenolic compounds.

Vegetation	N %	P %	K %	C %	Lignin %	Polyphenolic %
1. Tithonia	3.1	0.54	6.4	44	14	2.4
2. Sesbania	3.7	0.48	1.4	47	23	2.3
3. *Adhothoda vasica* (Asuro)	4.3	0.39	4.3	43	6.9	3.4

Note:- Method of analysis is given in the Chapter 2 under materials and methods

5.2.5 Statistical analyses

The statistical software Minitab version 13.1 was used for ANOVA analysis. Both standard error of difference and least significant difference between means were determined. Information has been presented in a graphical form with error bars for individual treatments and a vertical line indicating the value of standard error of difference (Sed) across all treatments. The grain and straw yield and yield contributing attributes were analysed to examine treatment effects. N, P and K concentration in rice plants and uptake at various growth stages were examined and analysed to see the effect of treatments. Soil fertility parameters such as available P, resin K, resin NH_4-N and NO_3-N were also analysed on five occasions corresponding to the important growth stages of rice crop to see the dynamics.

5.3 RESULTS

5.3.1 *In situ* production of green biomass

Production of tithonia and sesbania biomass in the 1999 summer season from each experimental treatment is shown in Figure 5.2. A large variation in the production of tithonia biomass occurred because of uneven germination in the plots, the range being from 6 300 kg ha^{-1} to 8 300 kg ha^{-1}. The total number of growing days was 100, which allowed time for biomass production. Sesbania was seeded 33 days later than tithonia according to normal farmers practice and the average production was 7 625 kg ha^{-1} (Figure 5.2).

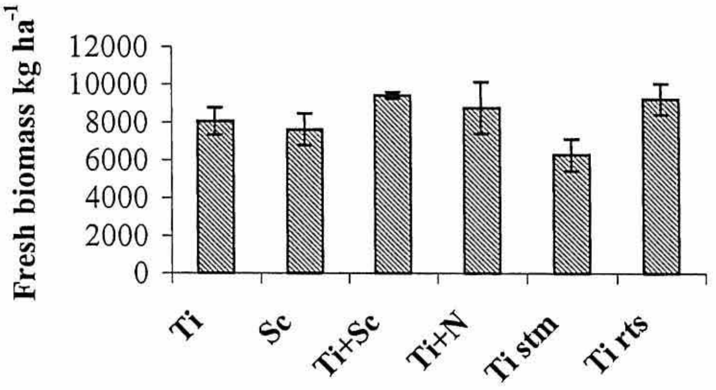


Figure 5.2 Mean above ground biomass production of tithonia and sesbania in 1999

In the summer season of 2000, tithonia was grown for only 80 days. This was the maximum time available after wheat harvest and before rice transplanting in that year. The production of tithonia was less than in 1999. This could be because less growing time was available and/or growth not being as vigorous as in 1999. The average production of tithonia ranged from 6 000 to 6 625 kg ha^{-1} when grown alone but when grown in mixture the production of tithonia was only 3 750 kg ha^{-1}. The production of sesbania when grown alone was high (Figure 5.3).

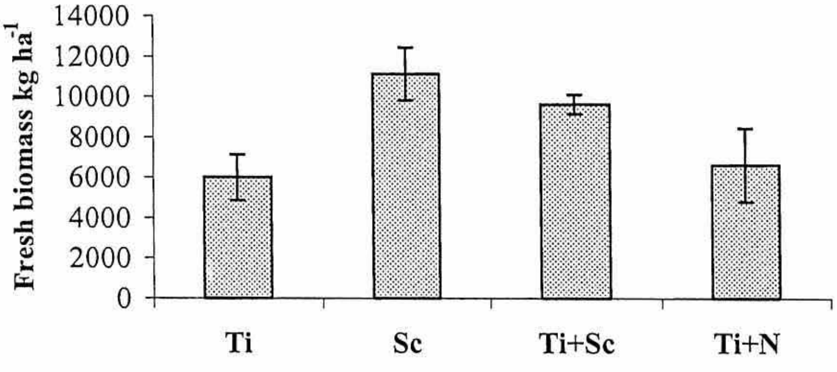


Figure 5. 3 Mean above ground biomass production of tithonia and sesbania in 2000

Ti = sole tithonia, Sc = sole sesbania, Ti+Sc = tithonia and sesbania mixed and Ti+N = sole tithonia and latter N was top dressed on rice crop.

5.3.2 Effect of green manure on rice production

In 1999 the highest grain yield of rice was obtained from Ti+N, which was not significantly different from the mixture of tithonia, and sesbania (Ti+Sc) and farmers practice (FP) but was higher than tithonia alone. Lowest grain yield was observed in the control treatment (2 627 kg ha^{-1}), which was significantly lower than all other treatments except the tithonia roots and, marginally (a 0.1% higher yield would have reached a significant difference at $p>0.05$), the sesbania only treatments. The tithonia and sesbania alone and when mixed were not significantly different from each other or from farmer practice although the mixture yielded > 10% more than either green manure alone (while a difference of > 16% was required for the difference to be significant at $p>0.05$). The same pattern was observed with straw yield, Ti+N, FP and the mixture gave the highest yield, the control the lowest, and the other treatments intermediate (Figures 5.4 and 5.5 and Appendix 5.1).

In year 2000 the lowest and highest grain yields were from sesbania *in situ* alone (2 659 kg ha^{-1}) and asuro biomass transfer (3 959 kg ha^{-1}) respectively, all other treatments were not significantly different from the control or each other ($p>0.05$). Top dressing the rice crop with N at a rate of 30 kg ha^{-1} with urea along with tithonia *in situ* green manure (Ti+N) did not increase the grain yield above that of tithonia without top dressing (Ti) whereas it had done so in 1999. Unlike in 1999 the yield obtained from sesbania alone was significantly lower ($p\leq0.05$) than all other treatments despite an adequate amount of biomass being incorporated.

The straw yield followed the same trend as the grain yield. The highest yield was from *asuro* alone (6 273 kg ha^{-1}) followed by farmers practice at 5 651 kg ha^{-1}. Treatments Ti and Sc produced yields of 4 699 kg ha^{-1} and 4 088 kg ha^{-1} respectively and they were not significantly different at the $p=0.05$ level. The additional top dressing of tithonia at maximum tillering stage produced more straw but it was not significantly higher than Ti. Top dressing alone (N) yielded straw in similar quantity to Ti treatment but was significantly higher ($p\leq0.01$) than Sc (Figure 5.7 and Appendix 5.2).

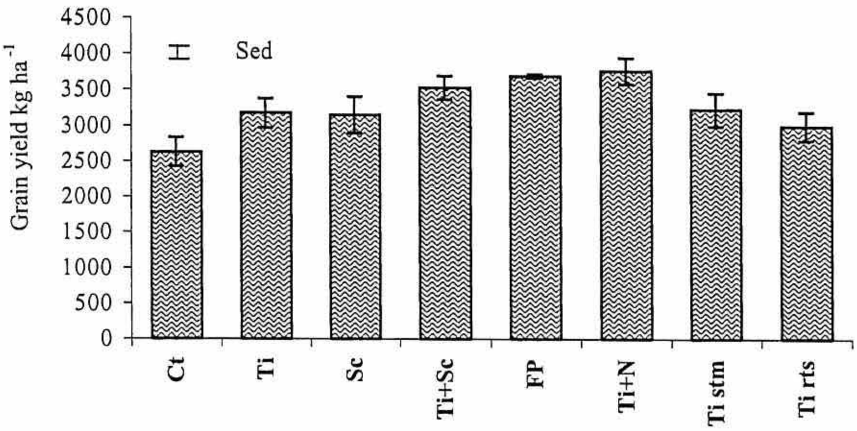


Figure 5.4: Mean grain (± standard error) yield of rice in year 1999

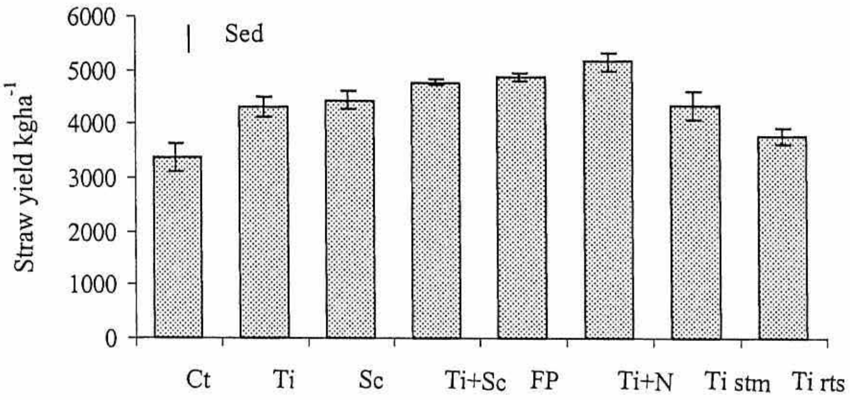


Figure 5.5: Mean straw (± standard error) yield of rice in year 1999

5.3.3 Yield contributing attributes

In 1999 the heaviest thousand grain weight (22.5 g) was from the green manure mixture (Ti+Sc) and the lightest was from Ti+N (20.8 g) and Ti rts (roots only; 21.0 g) respectively. Thousand grain weight of tithonia alone (21.4 g) and sesbania alone (21.0 g) were lower than the mixture at the p=0.01 level. Thousand grain weights were not different between treatments Ct, Ti, Sc, FP, Ti stem and Ti rts (Appendix 5.1).

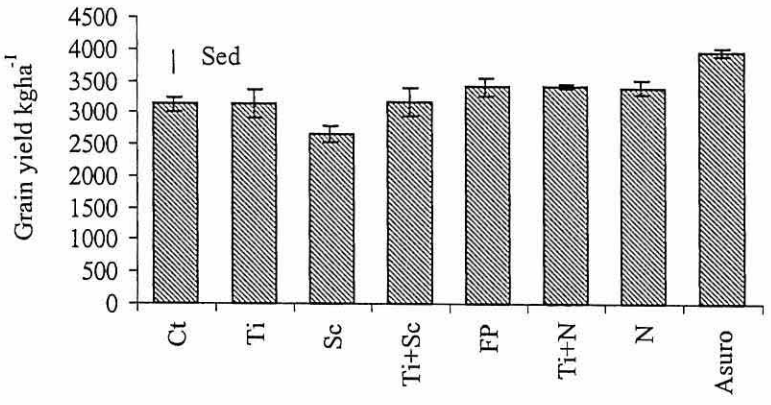


Figure 5.6: Mean (± standard error) grain yield of rice in year 2000

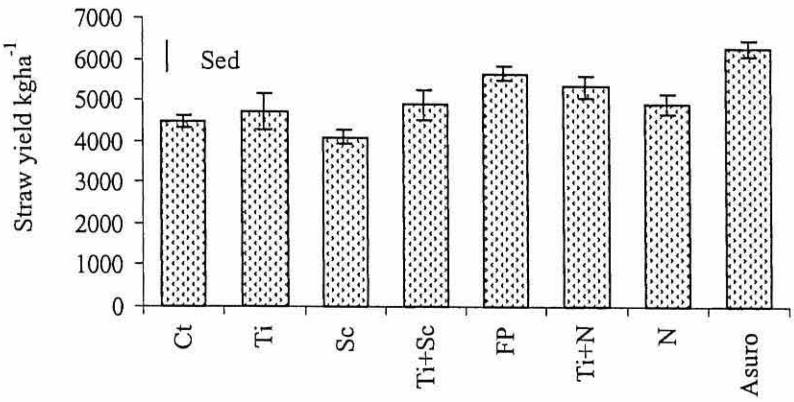


Figure 5.7: Mean (± standard error) straw yield of rice in year 2000

In 2000 the lowest thousand grain weight was obtained from sesbania alone (20.8 g) and it was significantly lower ($p \leq 0.05$) than all other treatments. There was no significant difference among the rest of the treatments at $p \leq 0.05$ (Appendix 5.2).

Statistically the number of grains per panicle and panicle length were not significantly different at the $p = 0.05$ level (Appendix 5.2).

Tallest plants (101.7 cm) were from the FP treatment and statistically there was no difference between them and treatments Ti+N, Ti stm (tithonia above ground parts), and

Ti rts (tithonia roots only). Ct, Ti Sc and the mixture had plant heights ranging from 92.6 cm to 97.5 cm and there was no significant difference at the 0.05 level between these treatments (Appendix 5.1).

In year 2000 the number of tillers per hill was also not significantly different from one another. Tallest plants at 95.7 cm were in the asuro treatment (T8) and shortest plant height at 77.7 cm was from the sesbania treatment (Appendix 5.2).

5.3.4 Residual effect of tithonia on winter wheat crop (winter season 1999-2000)

No significant residual effect of the treatments was seen on subsequent yield of wheat following the rice crop (Figure 5.8). Overall productivity was low and variable due to an attack of yellow rust (*Puccinia striiformis*) at the active vegetative growth stage. The wheat variety used in the experiment was RR-21, which is susceptible to yellow rust. Despite this, farmers like this variety because it is early maturing and the yellow rust disease does not appear every year.

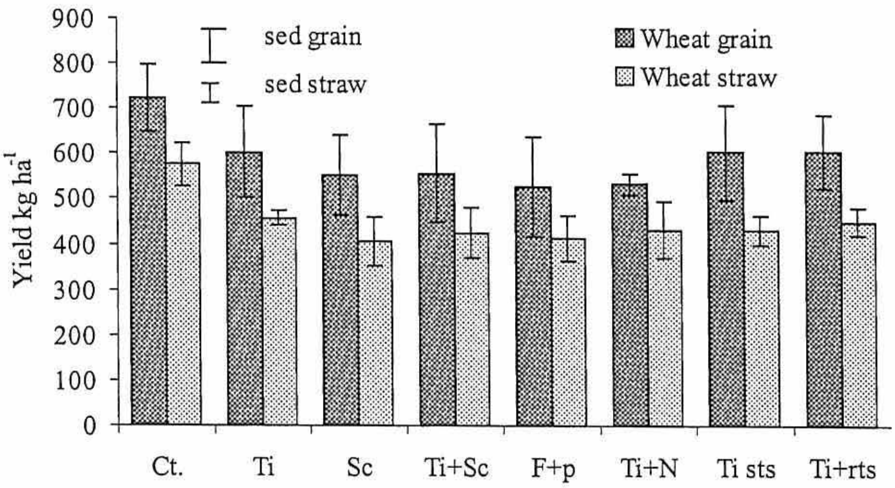


Figure 5.8: Mean (± standard error) grain and straw yield of wheat a residual effect of tithonia and sesbania.

5.3.5 Nitrogen concentration and uptake by rice crops

5.3.5.1 Nitrogen concentration

In 2000 all treatments showed a decline in N concentration over the growing period. No significant effect of the treatments was found in N concentration at tillering, booting and harvest stages. However, at the flowering stage a higher concentration of N was found in the tithonia plus N top dressing (1.33%) followed by N top dressing only and sesbania alone (1.05%). No significant differences between were found in N concentration between the rest of the treatments (Figure 5.9).

5.3.5.2 Nitrogen uptake

The amount of nitrogen taken up in the rice crop varied considerably across the treatments, but was significantly different only at tillering and booting stages (Figure 5.9). Highest N uptake at the tillering stage was from farmers' practice (11.0 kg ha^{-1}), whereas tithonia only and tithonia alone plus N top dressing had only 4.3 kg ha^{-1} and 4.5 kg ha^{-1} respectively. Nitrogen uptake in the mixture of tithonia plus sesbania, asuro and the control treatments were similar.

At booting stage nitrogen uptake by rice crop in tithonia (Ti) and tithonia + N top dressing (Ti+N) improved and the amount was similar to other treatments except the FP and N alone which had significantly higher N uptake. But at the flowering and harvest stage there were no significant differences in nitrogen uptake (Figure 5.10).

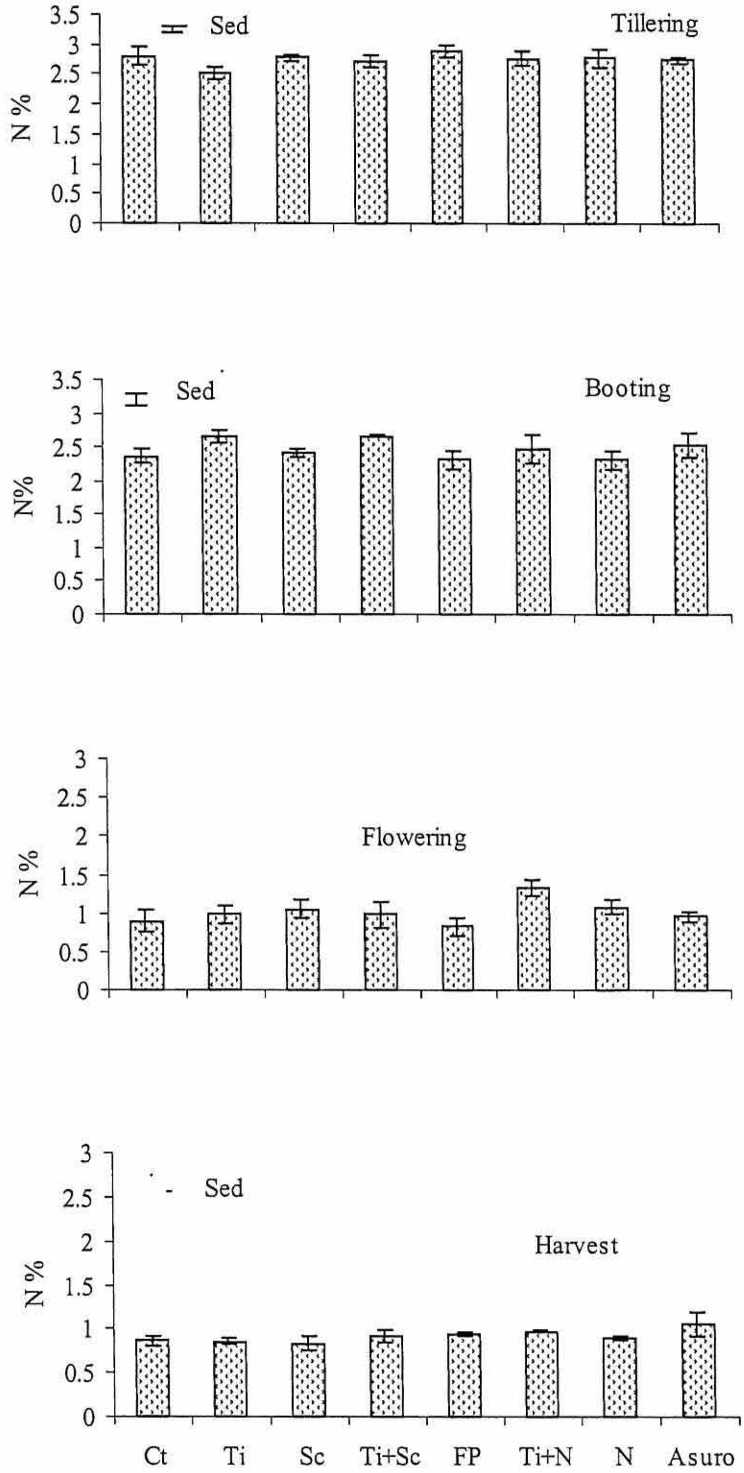


Figure 5.9: Nitrogen concentration in rice plants at important growth stages in 2000.

5.3.5.3 Nitrogen dynamics under wetland paddy conditions

Two forms of nitrogen, NH_4-N and NO_3-N, were monitored at important growth stages of rice. The NH4-N form of nitrogen was found to be dominant at all stages and NO_3-N was at very low concentrations at all stages. The concentrations of NH_4-N at the early stage were higher from the chemical fertiliser treated plots (FP, Ti+N and N) probably because these plots were supplied with urea fertiliser and nitrogen is released instantly. After 7 days the tithonia alone treatment, the mixture with sesbania and farmers practice showed higher concentration of NH_4-N though they were not significantly different to the remaining treatments (Figure 5.11). In general the concentration of NH_4-N decreased rapidly between the tillering and booting stages and was low thereafter. NO_3-N concentrations were always lower than the NH_4-N and there was no significant difference between the treatments. The lower concentration of NO_3-N is likely to be because of submerged conditions in the field most of the time.

5.3.5.4 Mass of N loss from the vegetation on decomposition under wetland paddy conditions

The decomposition curves showed that mass loss of N at the initial stage was not significantly different between types of vegetation or between selected treatments. Sesbania alone and the mixture of tithonia and sesbania had slightly higher mass of N remaining (%) in the litterbags compared to asuro and tithonia alone (Figure 5.12). At the latter stage there were no large differences and the mass of N remaining (%) was similar in all treatments. However, *asuro* was comparatively faster in releasing N than other materials examined. The overall mass loss of N, which is considered to mirror the release of nitrogen to crops, indicated a faster rate at the initial period after which release was steady.

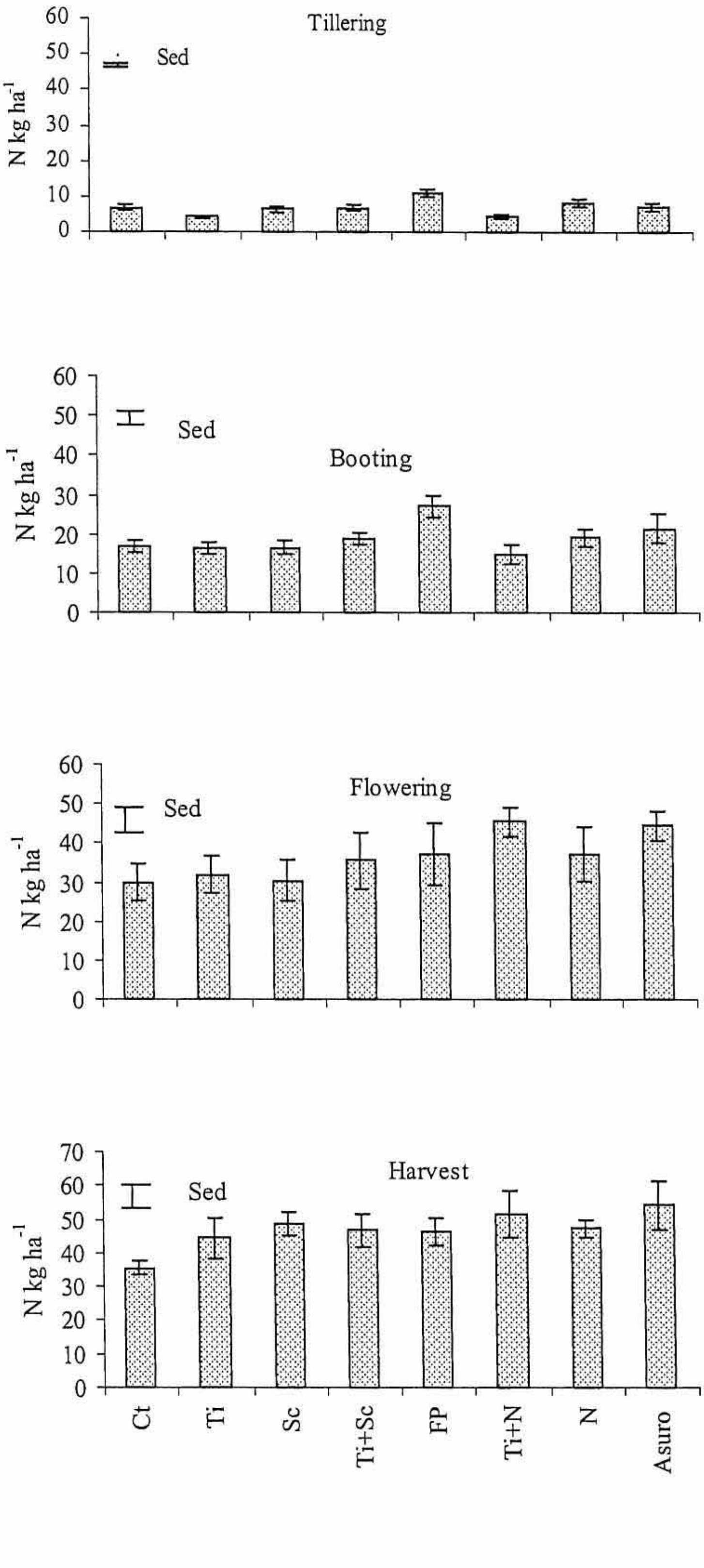


Figure 5.10: Nitrogen uptake by rice crop at different stages

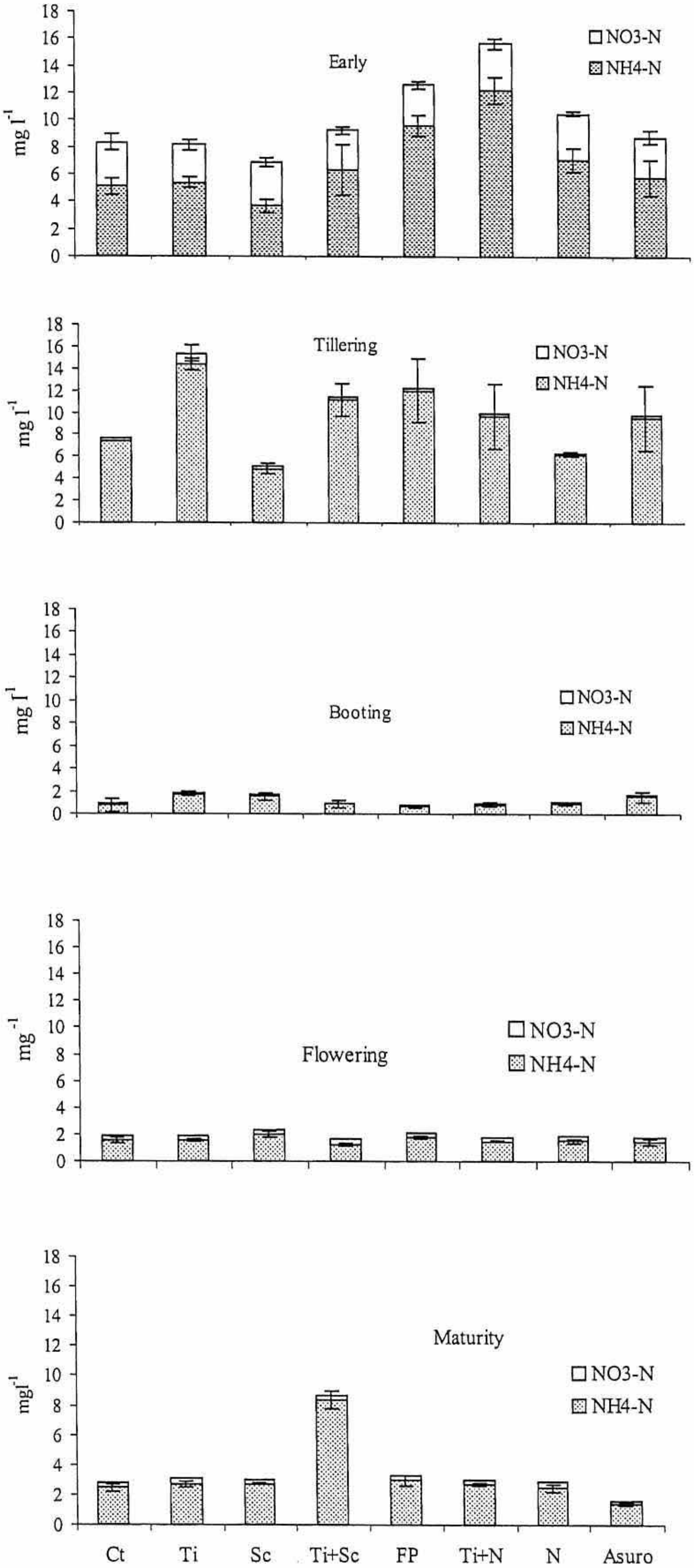


Figure 5.11: Inorganic N concentrations in resin bag extracts at various stages of growing rice in 2000.

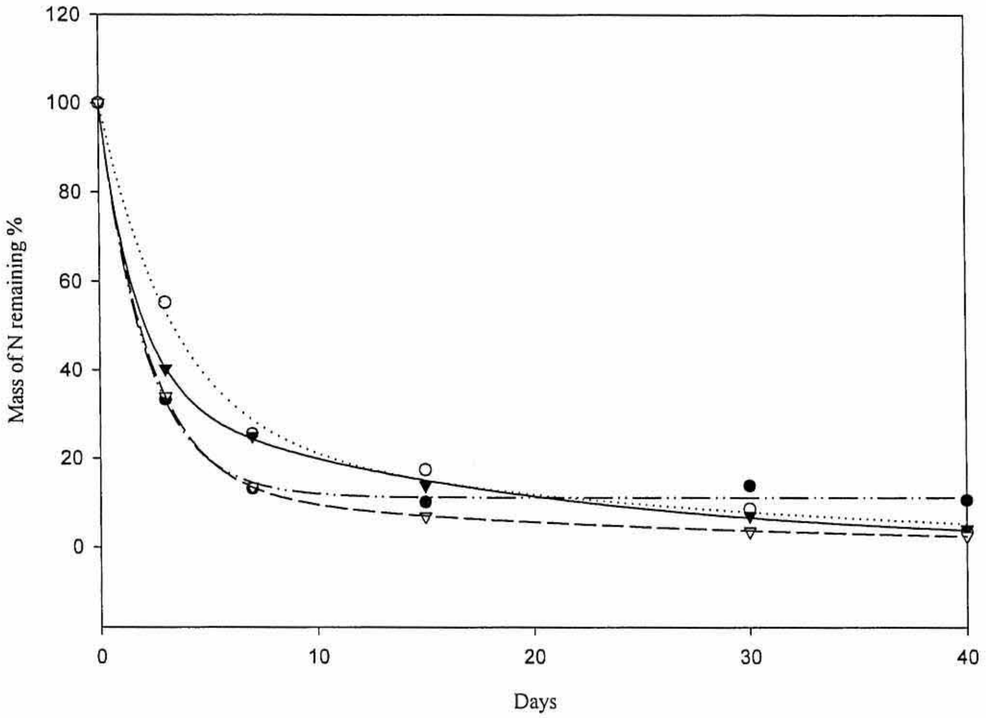


Figure 5. 12:Mass of nitrogen remaining (% of initial mass) in the litterbags in year 2000. Legends; Tithonia leaves (•), Sesbania leaves (○), Mixture (tithonia + sesbania) (▼) and Asuro leaves (∇)

5.3.6 P concentrations and uptake by rice

5.3.6.1 P concentration

Similar to nitrogen, rice plant phosphorus concentration declined substantially in all treatments, especially between booting and flowering with no significant treatment effects at tillering, booting and harvest stages. At flowering, the highest P concentration was found in tithonia plus N top dressing (0.21%) and lowest with farmers practice (0.18%). P concentration in tithonia alone, N top dressing and asuro were not different from one another. In general the differences between the treatments were very small (Figure 5.13).

5.3.6.2 P uptake by rice crop

Phosphorus uptake also varied considerably across treatments but only at the tillering and flowering stages were significant differences seen. Tithonia alone and tithonia plus N top dressing had very low P uptake at the early stage (Figure 5.14). At the flowering stage highest P uptake was seen in the asuro treated plot (9.4 kg ha^{-1}) followed by FP and Ti+N. P uptake was not different between the control and tithonia treated plots. At harvest no significant differences were observed (Figure 5.14).

5.3.6.3 Changes in soil P at important growing stages of rice

Olsen-P and the iron oxide impregnated (Pi) methods were used to measure the changes in available P concentrations in soil. These methods have been found to be appropriate under submerged conditions (Medhi and De Datta, 1997).

Only at the early stage was a significant difference in Olsen P evident. Farmers practice (FP) and N top dressing had higher measurable P levels at 1.14 mg 100 g^{-1} and 1.21 mg 100 g^{-1} respectively. Tithonia alone, tithonia plus N top dressing and the mixture of tithonia and sesbania did not differ significantly from the control plot. For the remaining periods there was no significant difference in Olsen P due to the treatments, but in general there was a decreasing amount of P over time (Figure 5.15).

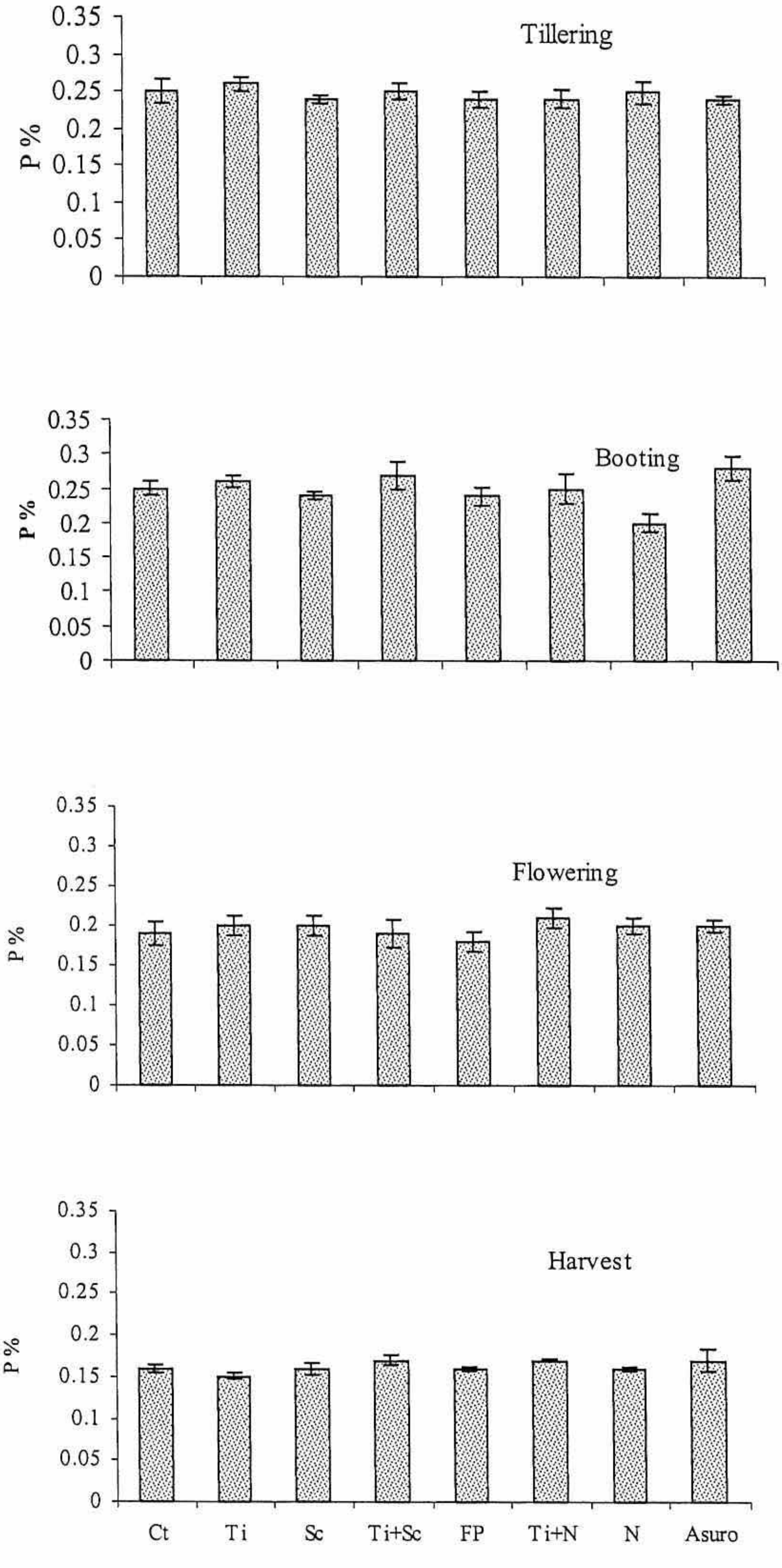


Figure 5.13: Concentrations of P in rice plants at different growth stages

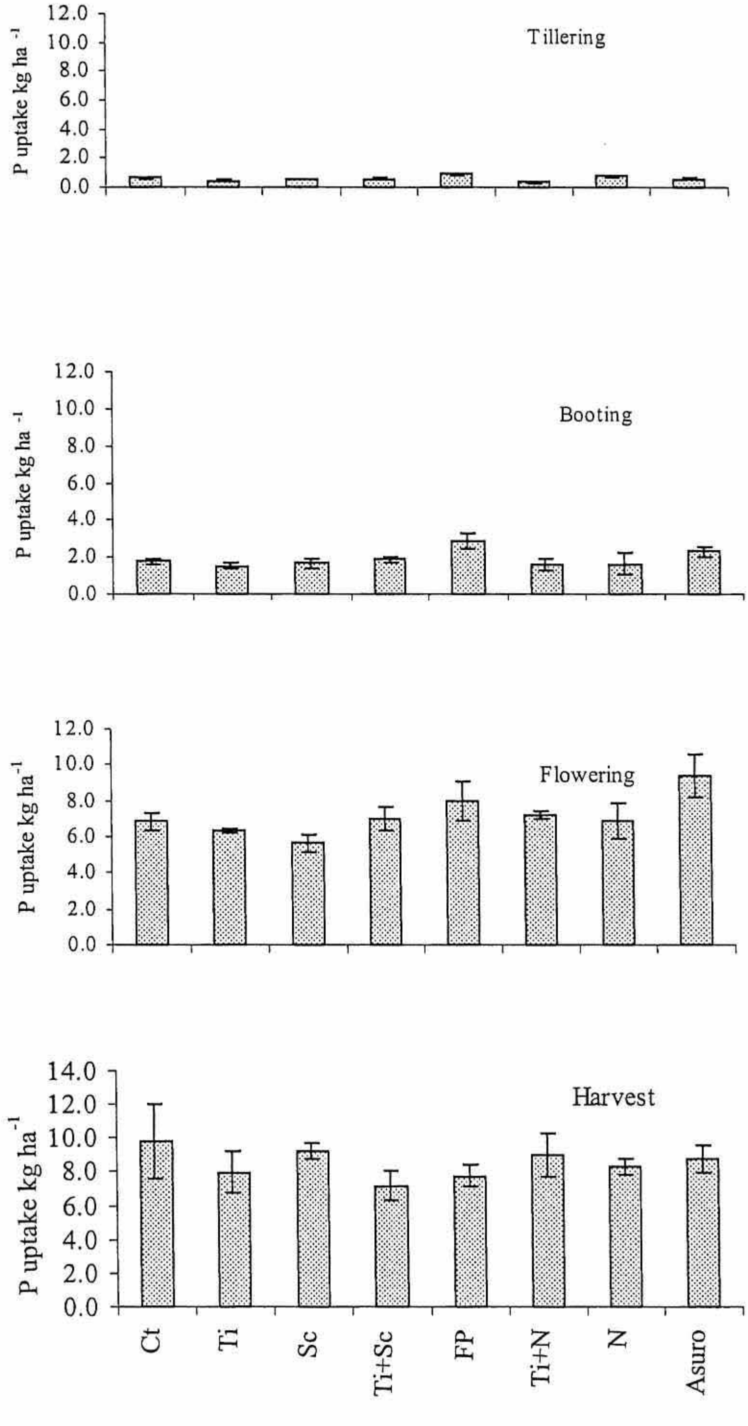


Figure 5.14: Phosphorus uptake by rice at different growth stages 2000.

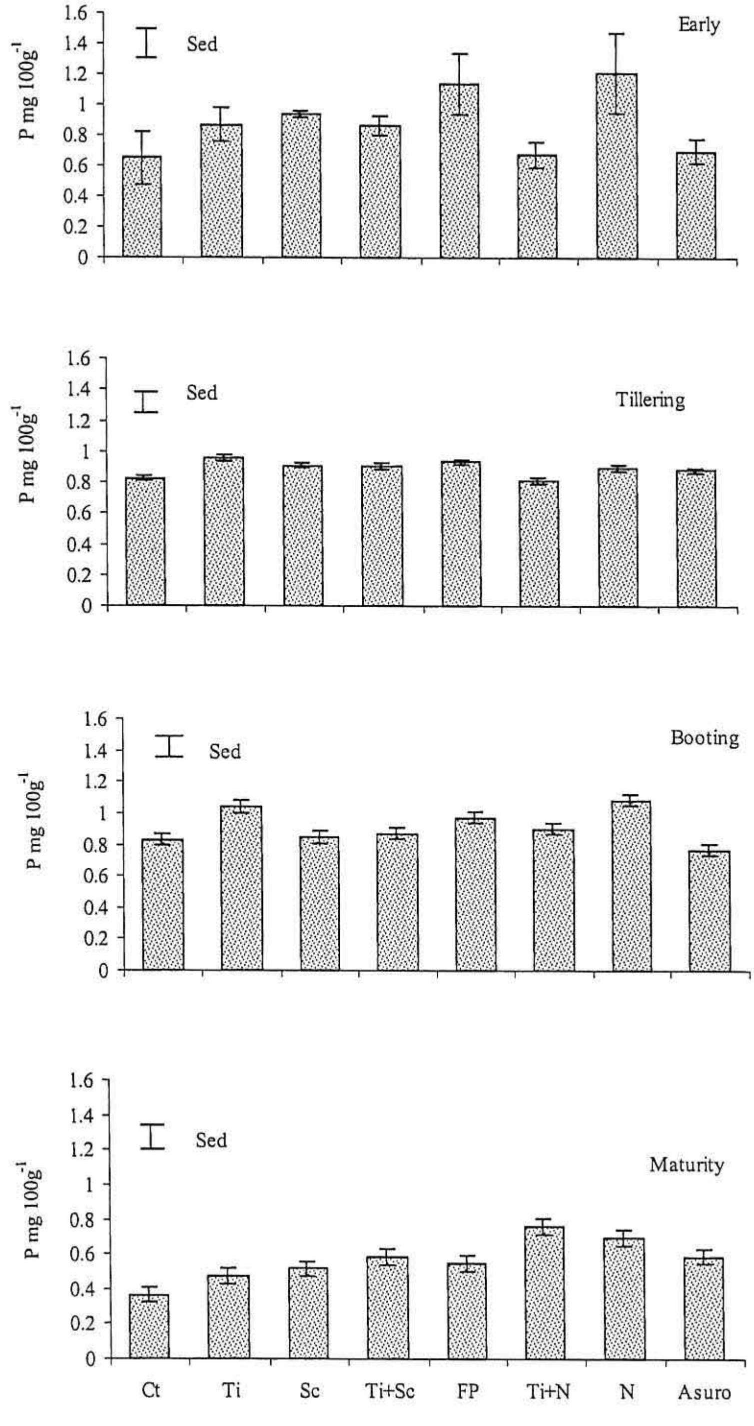


Figure 5.15: Available Olsen-P in soil at different growth stages of rice in 2000

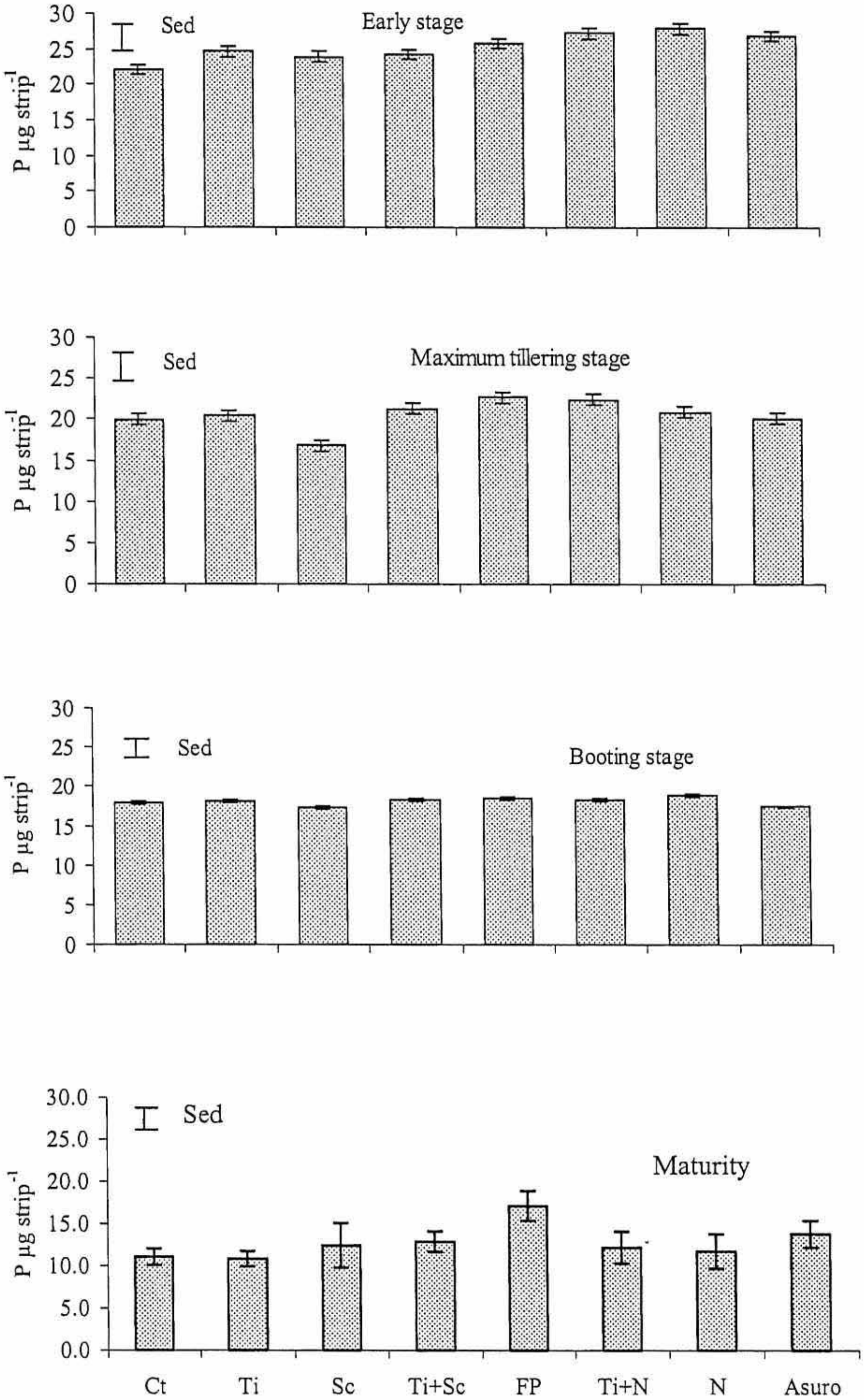


Figure 5.16: Available P in soil measured using iron oxide filter papers at different growth stages of rice in 2000.

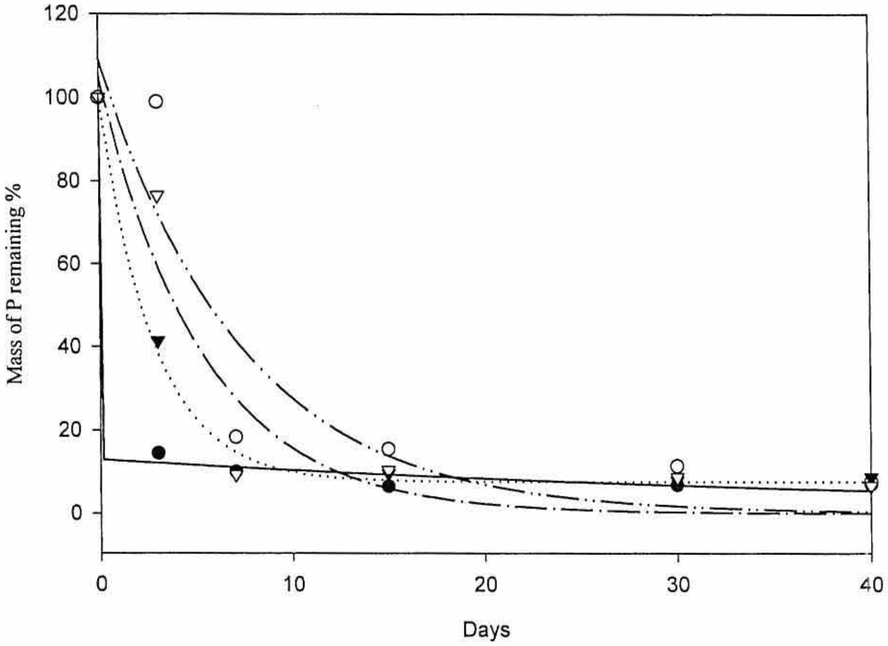


Figure 5.17: Mass of P remaining (% of initial mass) in the litterbags in 2000
Legend: Tithonia leaves (•), sesbania leaves (o), mixture tithonia+ sesbania (▼) and asuro leaves (∇)

Iron oxide strip P recovery was found not to be affected by the treatments, with no significant difference at the 0.05 level. Again in general, P was found to decrease over the growing period of rice (Figure 5.16).

5.3.6.4 Mass of P loss on decomposition

There was quite a variation between mass of N and P lost. In the initial stage tithonia loss very high amount of P. The double exponential model also did not fit well with the tithonia treatment. Only P lost was found very low from sesbania compared to the rest of the treatments (Figure 5.17). At the latter stage there was not much variation in the mass of P loss during this stage (Figure 5.17)

5.3.7 K concentration and uptake by rice

5.3.7.1 K concentration

Potassium concentration declined substantially in all treatments, especially between booting and flowering but significant differences between treatments were found only at the booting stage. *Asuro* gave the highest concentration at 3.14% whereas sesbania alone (Sc) had only 1.92%, significantly lower than the control Ct and tithonia alone ($p \leq 0.05$) (Figure 5.18).

5.3.7.2 K uptake by rice crop

K uptake was quite varied between the treatments at different stages of the growing rice crop. FP and *asuro* showed consistently higher K uptake at tillering, booting and flowering stages. At tillering Ti and Ti+N top dressing had lower K uptake than other treatments but at later stages K uptake was similar to most other treatments, but lower than FP and asuro and higher than sesbania alone (Sc) (Figure 5.19).

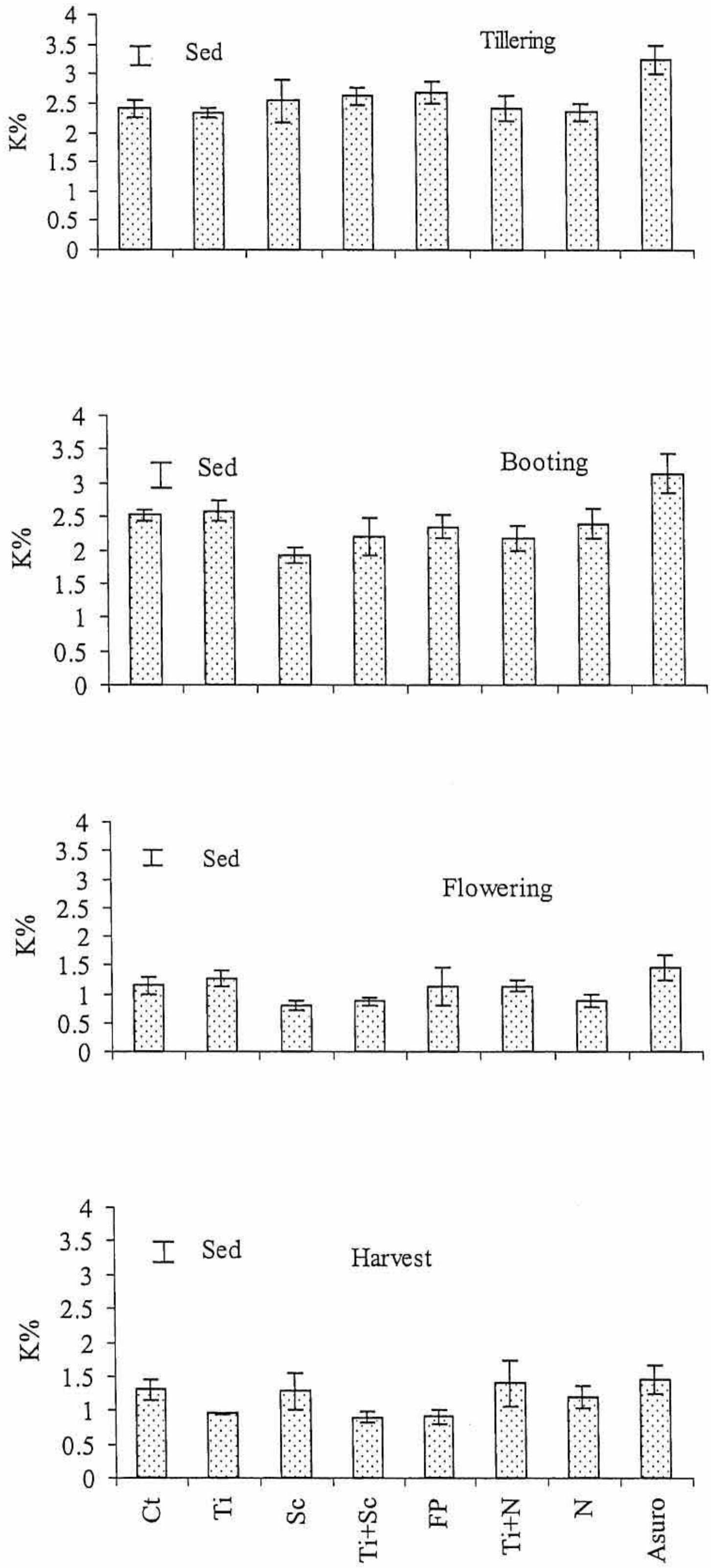


Figure 5.18: Concentrations of K in the growing rice plant at the various growth stages

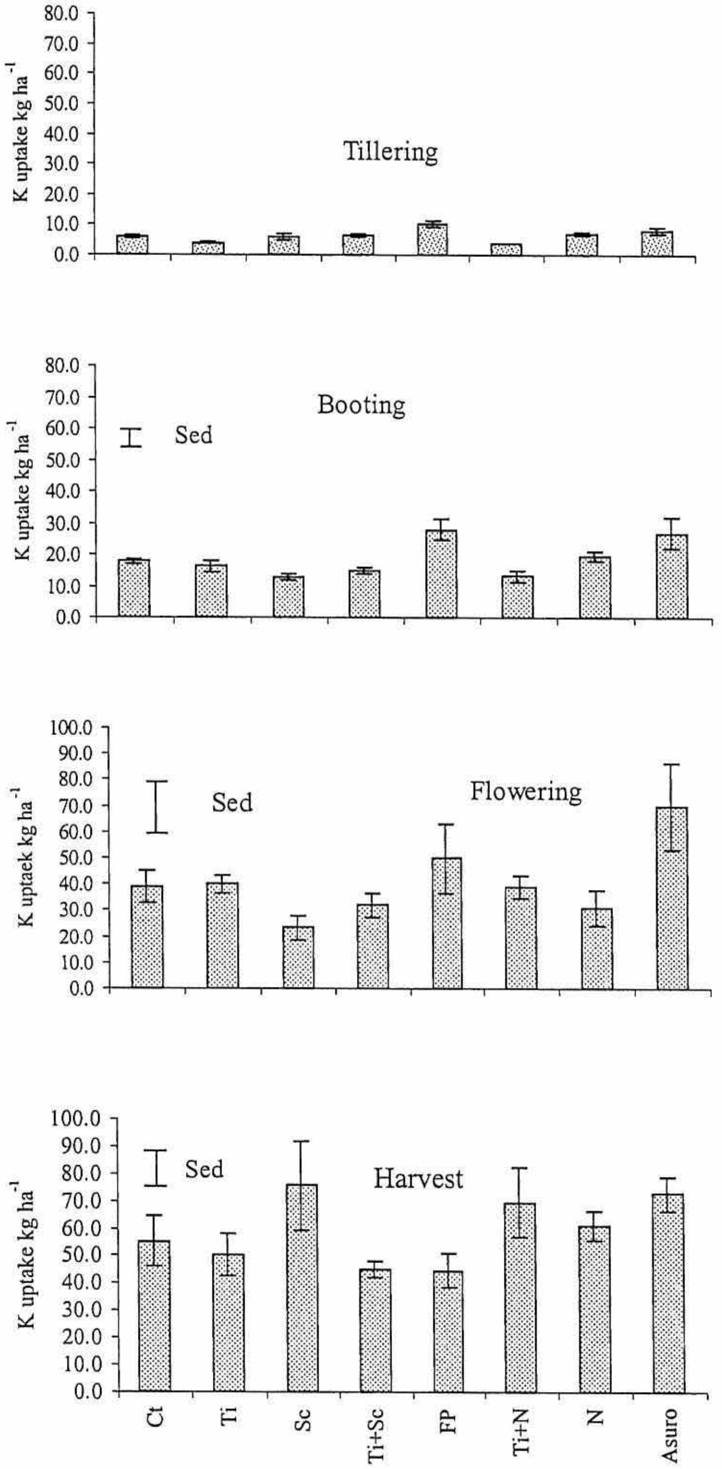


Figure 5.19: K uptake by rice at different growing stages

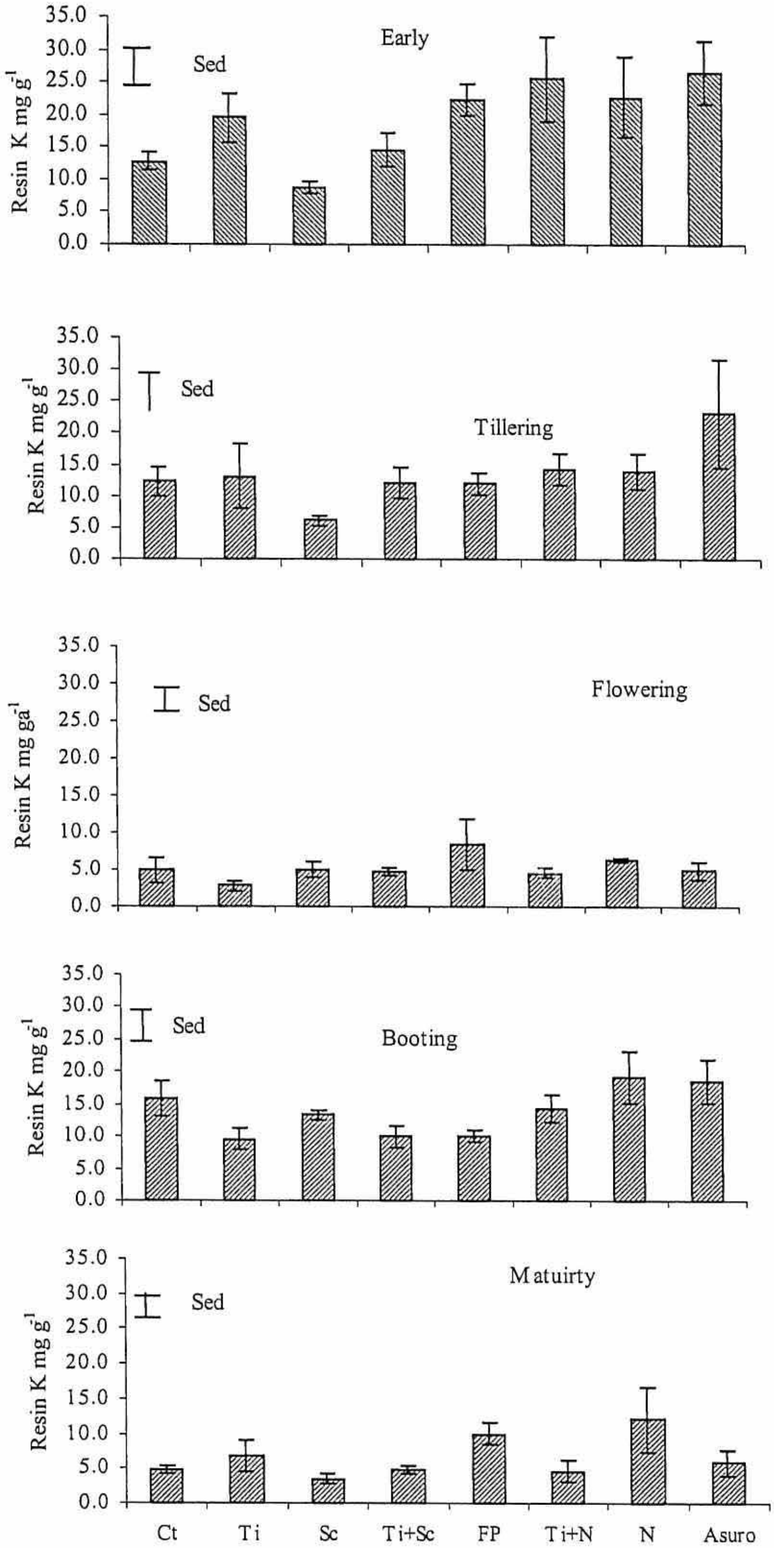


Figure 5.20: Resin extractable K in soil solution at different growth stages of rice in 2000.

5.3.7. 3 Changes in resin extractable K

Potassium was found to be unaffected by the treatments at early, tillering and flowering stages but at booting and maturity stages there was a significant difference. At booting asuro and N top dressing alone gave higher K at 18.75 mg g^{-1} and 19.2 mg g^{-1} respectively (Figure 5.20) compared to the rest of the treatments There was no significant difference between tithonia and sesbania either alone or in mixture and farmers practice. At the maturity stage farmers' practice and N top dressing gave higher K. Tithonia alone had lower K than the N top dressing treatment at the maturity stage. There was no significant difference between the rest of the treatments.

5.4 DISCUSSION

5.4.1 *In situ* production of biomass

The results from both years revealed that reasonable quantities of tithonia biomass could be produced if planted in the month of April although germination of seeds was unreliable. The time available between wheat harvest and the main season rice transplanting was sufficient. However, growth rate and dry matter accumulation was slow for tithonia compared to sesbania in 2000, although the subsequent rice crop grew better in the tithonia plots as discussed below. The production of tithonia ranged from around 6 000 to 8 000 kg fresh weight ha^{-1} over 80 to 100 growing days depending upon germination rate and impacts of water logging (Figures 5.2 and 5.3). The growth and fresh biomass production rate of sesbania was faster either because the sesbania was planted later as in 1999 or higher biomass was accumulated as in 2000 (Figures 5.2 and 5.3). Dry matter production of *Sesbania aculeate* (Pers.) and *Sesbania canabina* (Retz.) reported by Beri *et al.* (1989a and b) and Bhardwaj *et al.* (1981) in similar conditions were 5000 kg ha^{-1} and 5300 kg ha^{-1} respectively, but their growing period was only 60 and 55 days respectively. Considering the time allowed to grow both tithonia and sesbania, the dry matter accumulation of tithonia was lower. Propagation of tithonia through seeds was poor and once established, plants could not withstand waterlogged conditions when the monsoon began early. This will hamper adequate biomass production in field conditions.

The farmers have shown a concern with respect to two aspects (farmers reactions are more thoroughly discussed in Chapter 7). Firstly the growth of tithonia at this time of year is slow compared to other types of green manure crops available to them and secondly tithonia is sensitive to the rise of the water table as affected by the monsoon.

Both tithonia and sesbania were grown without any external inputs. Some farmers in the Chitwan valley have started top dressing sesbania using urea to improve growth. The reason could be soils are deficient in nitrogen content. Therefore a starter dose of N and P fertiliser might have been beneficial to tithonia for better vegetative growth (P B Shah, country Coordinator, PARDYP project, ICIMOD, personal commun.). Panta and Shrestha (1987) reported a beneficial effect of application of small amounts of nitrogenous fertiliser on green manure.

5.4.2 *In situ* green manure value of tithonia

In 1999 straw and grain yield was higher from tithonia than in the control plot treatment and the yield was similar to that from sesbania. But the same effect was not found in the 2000 season. The yield difference in 2000 between the control and the *in situ* tithonia was non-significant ($p>0.05$) but was higher than the *in situ* sesbania. The straw yield was also found to be similar (Figures 5.4 and 5.5).

Tithonia by itself produced a grain yield equivalent to the farmers' practice of applying farmyard manure and chemical fertiliser in both years but the straw yield was lower. The farmers practice is 'best' practise, that is applied by farmers with sufficient resources but few farmers have 2.5 t ha^{-1} farmyard manure and the requisite chemical fertiliser (70:20:20 kg $NP_2O_5K_2O$ ha^{-1}), so green manures may represent attractive alternatives where capital (for fertiliser purchase) is more constrained than labour (required for growing and incorporating green manure) or there are problems in availability of chemical fertilizer on time when needed as is common in Nepal (Sherchan and Gurung, 1995). The additional N applied in the form of top dressing did not result in any beneficial effect on grain and straw yield in both years (except that supplementation with N improved yield over tithonia alone in 1999). However, top dressing with urea is a very common practice in the study area on rice crops at the stages of tillering to panicle initiation. The reason for lack of response to top dressing in the present study may have been standing water in the field leading to nitrogen loss through denitrification.

The mixture of tithonia and sesbania had a similar effect to tithonia alone. Since sesbania is an N fixing crop and tithonia contained high P concentration, our hypothesis was to make available both the essential plant nutrients to crops by growing together. However in this case the visiting farmers commented that the practice of growing tithonia and sesbania together in the same plot would not be feasible since the sowing timing is different and agricultural labour is a constraint in the study area.

The results from 1999 suggested advantages to use of green manures grown *in situ* that were not evident in 2000. This raises some critical issues. Is *in situ* green manuring in the absence of external inputs really a sustainable practice or not? The relatively high yield from the control plot in 2000 was possibly because of the advantage of a fallow period (while green manures were being grown in other treatments) and of course nutrients removed by the preceding crops were lower than treatments with higher yields since the experiment 1999/2000. Tithonia was grown in the same plot for two consecutive years without any additional nutrients, which could explain the lack of response in rice yield to tithonia in the second year. An inconsistent effect of sesbania on rice grain yield has also been reported based on a two year field experiment from 1983 to 1984 by Panta and Shrestha (1987).

Asuro appeared to be a promising green manure compared with tithonia and sesbania but the since the asuro was grown elsewhere (rather than *in situ*) its effects are not directly comparable with those from the other two species in this trial. The yield increment over the control plot with asuro was 27% and 40% on grain and straw yield respectively. Sthapit (1990) reported a yield increment of rice grain ranging from 19 to 39% over farmers practice and 19 to 49% over chemical fertiliser applied at a rate of 60:30:30 kg NPK ha^{-1} when fresh biomass of asuro was used at a rate of 10 t ha^{-1}. Sherchan *et al.* (1991) reported a field experiment of three years from 1988 to 1990 where the yield increment from the application of *asuro* ranged from 23 to 56% over the control plot. Maskey and Bhattarai (1984) reported a 63% increase in rice grain yield over the control with asuro. Therefore there is consistent evidence to suggest that that asuro is a good organic fertiliser.

5.4.3 Residual effect of green manure on a subsequent wheat crop

In 1999 the residual effect of the various treatments was studied on the wheat crop grown after the rice and the results were discouraging. A variety of residual effects of green manure on succeeding crops have, however, been reported elsewhere. Lauren *et al.* (1996) reviewed the subject extensively and found more cases with a positive residual effect than otherwise. Yadav *et al.* (2000) have also reported that when sesbania was used as green manure on rice a residual effect on wheat was observed. The lack of a residual effect on wheat in our case could be due to the low amount of biomass incorporated and also loss of plant nutrients on decomposition (denitrification) that may have left insignificant amounts of nutrients in the soil. In addition, the wheat crop was attacked by yellow rust at the active growing stage and so yield potential could not be fully explored, making this aspect of the present trial inconclusive, though the lack of detectable residual effects in situations that farmers are likely to encounter, is meaningful in itself.

5.4.4 Nutrient concentration and uptake by crops

N and K concentrations were in the rice plant were at the range of 2 to 5% which is considered to be optimum for plant growth (Marschner, 1995). However, P concentration was lower (0.18 to 0.21% at flowering); Marschner (1995) reported that P concentration should be above 0.3%. N and P concentrations in the rice plants were not influenced by nutrient source (organic or inorganic), although at the flowering stage N and P concentrations were higher where top dressing from urea was done. Irrespective of treatment the concentrations of all these major plant nutrients decreased as growth progressed. However under normal conditions the concentration of these mobile nutrients N, P and K are high at transplanting and decrease gradually with growth (Von Uexkuell, 1968). The amount of nutrient uptake is more strongly affected by dry matter production than nutrient concentration in the plant. It was clearly revealed that external sources of plant nutrients both under the farmers practice and *asuro* (biomass transfer) resulted in higher K uptake compared to the rest of the treatments.

5.4.5 Availability of major plant nutrients (N, P and K)

Both the methods of P determination used, the Olsen-P and iron oxide impregnated filter paper, did not detect differences between the treatments in soil P. The reason for this could be that after flooding reduction of ferric oxide phosphate compounds would be expected to result in increased solubility of P (Willet, 1986; De Datta and Kundo 1991). NH_4-N dominated the inorganic N pool in the soil solution due to excessive moisture in the soil profile restricting aerobic nitrification. The concentration of NH_4 increased with the increasing decomposition period of vegetation and slowly declined after roughly the second week of biomass application. As discussed earlier (Chapter 4) the decreasing concentration could be either due to the crop taking up nutrients or the excessive nitrogen lost through various pathways. The results on mass loss of N and P in litterbags also agree with these findings. Nitrate nitrogen was negligible. Similar results on N dynamics have been reported by a number of workers (Nagarajah *et al.*, 1989; McDonagh *et al.*, 1995).

Tithonia did not supply significantly higher amounts of K when used as *in-situ* manuring contrary to the positive effects measured from biomass transfer (Chapter 4). However, *asuro* treated plots, which were biomass transfer, showed a consistently higher resin extractable K in soil solution than the rest of the treatments. The reason for this could be nutrients that are being transferred from outside.

5.4.6 Implications for existing farmers practice

While sesbania, the most commonly grown green manure crop locally, was impressive in biomass accumulation, it did not improve crop yield more than tithonia in one year and under performed even the control in the second year, possibly because of low K content in its biomass of sesbania. Tithonia and mixtures of it with sesbania were an effective substitute for farmyard manure supplemented with chemical fertilizer indicating considerable potential. The results on nutrient release from the vegetation on decomposition and concentration of nutrients in soil solution indicate that the existing practice of farmers, which involves allowing a minimum period of one week for decomposition prior to planting, may not make best use of nutrients. To make best utilisation of the released nutrients rice seedlings should be transplanted immediately after biomass is incorporated into soil. Bhardwaj and Dev (1988) and Beri *et al.* (1989a and 1989b) have also reported similar results. If seedling transplanting is delayed then there is very high chance of losing the nutrients (NO_3-N) through denitrification and leaching.

5.5 CONCLUSIONS

The results of both seasons indicated that *Tithonia diversifolia* could be fitted into the rice-wheat cropping rotation in as much as a reasonable biomass yield is attainable. Tithonia appears to have value as a green manure and can be considered as a source of multiple nutrients. But the value of tithonia as a source of P under submerged condition requires further study. The performance of tithonia under *in situ* and biomass transfer situations is quite contrasting. From the results it is clearly revealed that biomass transfer (Chapter 4) is more advantageous than *in situ* practice. Since under biomass transfer system the nutrients are transported from other fields so there is an additional supply of the plant nutrients. But under the *in situ* system plant nutrients are recycled within the field. First green manures take up from the soil and then the biomass are incorporated back to the field. In the latter situation the nutrient depend upon the availability of nutrients in the soil profile. Though it is envisaged that green manures take up plant nutrients from the deep soil profile due to tap root system that cannot be taken up by most other cereal crops. Therefore it could be said from this experiment that there is no additonal benefit from plant nutrients supply point of view. However, there is need to confirm the findings. Growing tithonia and sesbania together is not thought feasible by farmers because of their different growth habits. In the study area there are a very limited number of plant species that could be used as a green manure, therefore, inclusion of tithonia or other species with similarly high P, K and micronutrient contents may increase the diversity and provide farmers with a wider choice. Other species should be screened.

In general the initial hypotheses that initiated the *in situ* trials were not borne out by the results. Under the *in situ* situation the role of tithonia as a green manure without other nutrient supplementation does not appear viable. Since tithonia is a non legume crop therefore it does not fix the atmospheric nitrogen. Other reason could be that the soil of the study site does not have P fixing properties. Therefore there is unlikely a situation that tithonia will improve the availability of the fixed P by solubilising. The combination of tithonia and sesbania was also not successful in pragmatic terms due to different moisture and agronomic requirements. This is because of more agronomic difficulty to grow both crops together. However it has been demonstrated that tithonia can be grown under the Terai environment of Nepal although it requires a longer time than sesbania to accumulate high dry matter and suits only well drained land.

CHAPTER 6

THE POTENTIAL OF RELAYING TITHONIA AND SESBANIA WITH MAIZE AND THEIR IMPACT ON SUBSEQUENT RICE CROP YIELD

6.1 INTRODUCTION

Nutrient management under an intensive cultivation system is crucial for sustainable soil fertility management. Those farmers who have been using chemical fertiliser for any length of time complain that they need to increase the amount of chemical fertiliser every year to achieve the same level of production from a unit of land. Farmers also complain that due to continuous use of chemical fertiliser, the soil becomes difficult to plough due to increased hardness (Gurung and Sherchan, 1996). Under such circumstances the use of green manuring plants to improve the fertility of soil or improve the availability of plant nutrients may be a sustainable solution for soil fertility management. Research mainly carried out in the Indo-Gangetic plain and South East Asia has proved that green manuring is a sustainable, economically viable and an environmentally sound technology (Baker *et al.*, 1995; Yadvindra-Singh. *et al.*, 1991; Mann and Garrity, 1994).

Despite a beneficial effect of green manuring on rice production, there is still a low adoption of the practice among farmers in high production potential areas. There are four main reasons for the low adoption. First, a farmer's major priority is cereal grain production, and therefore food security, farmers do not want to sacrifice their land for the sake of green manuring. Secondly, green manuring involves extra costs in the form of labour and capital. Thirdly, there is a lack of information about agronomic practices for green manure for farmers operating intensive cultivation systems. Finally, under the triple cropping system, the fallow period is not long enough to grow green manuring crops (Subedi *et al.*, 1995; Neupane, 1993).

Relay and inter-cropping have been considered advantageous in utilising scarce land resources and improving biological efficiencies (Francis, 1989; Odulaja, 1996). Relay or mixed cropping of leguminous crops with maize in the hills of Nepal is a common practice (Subedi, 1998). In some places in the Chitwan valley, farmers grow green manure such as sesbania (*Sesbania rostrata)* and sesame (*Sesamum indica)* along with maize as a companion crop but such practices are not very widespread (Rana *et al.*, 199; Brede, 1998). Mann and Garrity (1994) reported results of field trials conducted in the Philippines showing that a green manuring crop indigo (*Indigofera tinctoria*) could be inter-cropped with wheat. There was no negative effect on the wheat crop and after the wheat harvest there was time available to accumulate more green manure biomass. Gurung and Sherchan (1998) reported that sesbania (*Sesbania aculeata*) could be grown with maize as a relay crop planted at the time of the second hoeing of maize. Subedi *et al.* (1995) also reported that sesbania and rice bean (*Vigna umbellata*) can be relayed under a maize crop at the pre-tasseling stage and can be incorporated later into soil before rice transplanting. The effect of these two green manuring crops on rice grain production was equivalent to the yield produced from 60:30:30 kg NPK ha^{-1} chemical fertiliser and there was no negative effect on maize yield.

Field experiments conducted in the Chitwan valley have indicated that *in-situ* production of tithonia could become part of a potential green manuring practice to improve rice production (Chapters 4 and 5). However, there is a lack of information on agronomic practices. It is not known whether tithonia can be grown together with maize so as to produce a green manure for rice production without affecting the maize yield. It was suggested that farmers growing spring maize (March and April planting) could benefit by relaying tithonia with maize. Therefore an experiment was carried out in the Chitwan valley with the following objectives:

- to identify the optimum time for planting tithonia with maize,
- to determine the biomass yield of tithonia under relay/mixed cropping with maize, and
- to quantify the effect of green manuring on rice production.

6.2 MATERIALS AND METHODS

A field experiment was laid out in a randomised complete block design (RCBD) with nine treatments replicated four times. A description of the treatments is given below. The sesbania species was *Sesbania cannabina* (Ritz.).

T1 (Ct)	Control plot (compost 10 t ha^{-1} applied to maize crop only)
T2 (Sc)	Sesbania alone (seed rate 45 kg ha^{-1}) (planting at knee high stage of maize)
T3 (Ti)	Tithonia alone (seed rate 22.2 kg ha^{-1}) (planting at early knee high stage of maize)
T4 (Sc+mz1)	Sesbania sowing at the time of second hoeing of maize or at the knee-high stage (seed rate 45 kg ha^{-1})
T5 (Ti+mz1)	Tithonia seeds broadcast between rows of maize at early knee high stage of maize (seed rate 22.2 kg ha^{-1}).(Tithonia seed was a mixture of seeds and other flower parts as it was found difficult to separate seeds out.)
T6 (Ti+mz2)	Tithonia seeds broadcast between the rows of maize at early knee high stage of maize (seed rate 44.4 kg ha^{-1}).
T7 (Ti+mz3)	Tithonia seeds broadcast between rows of maize at early tasseling stage of maize (seed rate 22.2 kg ha^{-1}).
T8 (Ti+Sc)	Alternate rows of tithonia and sesbania seeds sown with maize at knee high stage. Seeding rate was same as in the treatments T4 and T6 for sesbania and tithonia respectively
T9 (FP)	Farmers practice for maize and rice compost 10 t ha^{-1} and 30 kg N ha^{-1} top- dressed with urea at knee high stage.

Experimental plots were 4.5 m by 5 m. Space between plots was 50 cm and between the blocks 1 m. Space between rows for maize was 75 cm and space between plants was 25 cm. The maize variety was Arun-2, which is a short and early maturing variety which fits well into a relay cropping system. The seed rate of maize was 25 kg ha^{-1}. Compost was applied at a rate of 10 t ha^{-1} to all the plots. Maize was sown on March 15 and harvested on June 20.

The lay out of the experiment was as follows:

Figure 6.1: Lay out of the experiment

Block	TREATMENT								
Block_4	T2	T5	T8	T6	T3	T1	T9	T7	T4
Block_3	T9	T3	T4	T1	T7	T8	T2	T6	T5
Block_2	T1	T8	T2	T5	T9	T4	T3	T4	T7
Block_1	T7	T6	T9	T4	T5	T8	T2	T3	T1

Composite soil samples were taken from the four blocks. Soil analysis results are given below:

Table 6.1: Base line soil test information (block wise)

Blocks	Soil pH	Organic matter %	Available K mg g^{-1}	Available P mg g^{-1}
Block_1	4.82	2.14	0.025	0.034
Block_2	4.92	1.82	0.030	0.030
Block_3	4.98	2.01	0.030	0.041
Block_4	5.06	1.81	0.027	0.030

Biomass production of tithonia and sesbania is presented in Figure 6.2. The same experimental plots were retained for rice transplanting. The vegetative materials of each plot were chopped by sickle and incorporated into the soil and ploughed and puddled one day before rice transplanting. Research findings indicated that rice production would be high if green manure biomass is incorporated into the soil just one-day prior to transplanting the rice (Beri *et al.*, 1989a; Bhardwaj and Dev, 1985). Twenty-five day old rice seedlings, were transplanted the following day (10^{th} July). There were three seedlings per hill. Distance between rows and stations was 20 cm. The rice variety was Pant 10, an early and semi-dwarf variety, which is most suitable for upland conditions or partially irrigated conditions. The rice crop was harvested on

10th October. Rice grain and straw yield was estimated from an area of 15.54 m^2, leaving the two border rows from each side of the plot, to avoid edge effects.

6.3 RESULTS

6.3.1 Biomass production of tithonia and sesbania under relay and sole conditions

Production of fresh biomass of both tithonia and sesbania grown separately from maize were 30 t ha^{-1} and 25 t ha^{-1} respectively. Under relay conditions, the production of tithonia at low and high seed rates were 11.7 t ha^{-1} and 16.9 t ha^{-1} respectively (Figure 6.2), whereas the production of biomass of sesbania was only 7 t ha^{-1} and 4.5 t ha^{-1} when sown at the knee high stage maize. When tithonia and sesbania were sown in alternate rows with maize, the production fresh biomass was very low (Fig. 6.2). Plates 6.1 and 6.2 show tithonia grown under different stages of maize.

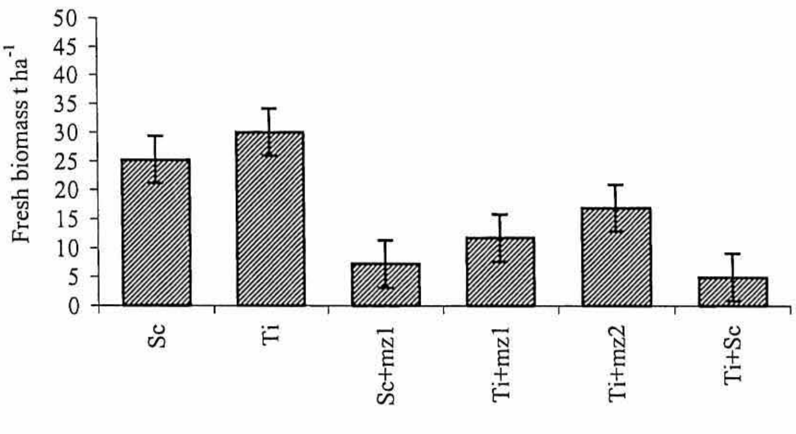


Figure 6.2: Biomass production of tithonia (Ti) and sesbania (Sc) grown separately or in a relay situation. Sc+mz1=Sesbania sown at the time of second hoeing of maize at the knee high stage, Ti+mz1=Tithonia sown at early knee high stage of maize, Ti+mz2=Tithonia sown at early knee high stage with a high seed rate and Ti+Sc= Tithonia and sesbania sown together at knee high stage of maize.

Note: The treatment (Ti+mz3) is not shown because biomass could not be obtained due to poor germination of tithonia seeds.

6.3.2 Effect of green manuring crops relayed with maize on maize yield

Farmers practice (FP) produced the heaviest grain weight of maize at 2 773 kg ha^{-1} and was significantly ($p \leq 0.01$) higher than treatments Ti+mz1, Ti+mz2 and Ti+Sc. The lightest grain weight was obtained from Ti+mz2 (1 794 kg ha^{-1}). Statistically there was no yield difference between Ct, Ti+mz1, Ti+Sc, Sc+mz1 and Ti+mz3 (Fig 6.3). However a yield difference was obtained between Sc+mz1 and Ti+mz1 at ($p \leq 0.05$) level (Appendix 6.1).

Stover yield of maize was higher (7 036 kg ha^{-1}) from the farmers practice (FP) ($p \leq 0.05$) than all other treatments; there were no significant differences ($p > 0.05$) between the remaining treatments (Figure 6.3)

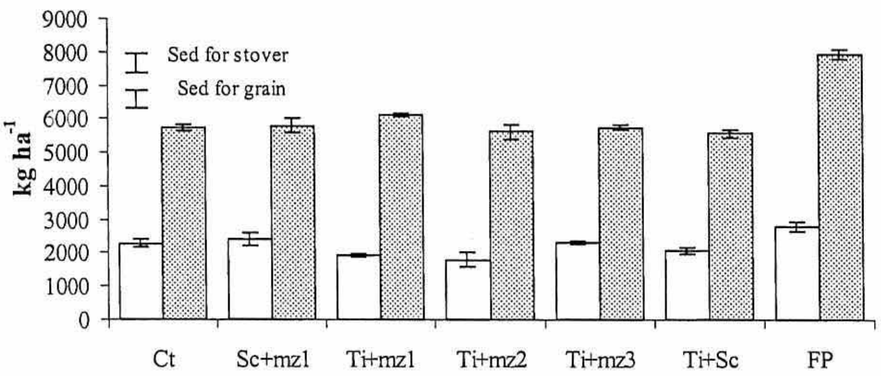


Figure 6.3 Grain and stover yield of maize when grown with tithonia and sesbania under relay systems. Legend: straw and grain

Ct=Control plot (no green manure crop), Sc+mz1=Sesbania sown at knee high stage of maize, Ti+mz1=Tithonia sown at early knee high stage of maize (seed rate 22.2 kg ha^{-1}), Ti+mz2=Tithonia sown at early knee high stage of maize (seed rate 44.4 kg ha^{-1}), Ti+mz3=Tithonia sown at early tasseling stage of maize,Ti+Sc= Tithonia and sesbania sown together and FP = Farmer's practice.

6.3.3 Effect of tithonia green manure on rice production

6.3.3.1 Rice grain production

The heaviest grain yield of rice (3 147 kg ha^{-1}) was obtained when 25 t ha^{-1} fresh biomass of sesbania was incorporated into the soil as green manure (Sc). Tithonia biomass when applied for green manuring at a rate of 30 t ha^{-1} (mean weight of fresh biomass) produced a rice grain yield of 3 098 kg ha^{-1} and there was no significant difference ($p>0.05$) between the two rice yields (Appendix 6.1 and Fig. 6.4).

Plate 6.1: Tithonia relayed with maize at first hoeing time. The maize is at tasseling stage.

Plate 6.2: Tithonia relayed with maize at the time of first hoeing of maize. The maize crop is at grain filling stage.

Sesbania (Sc+mz1) when relayed with maize at knee high stage of maize and incorporated into soil produced 2 834 kg ha^{-1} rice grain, which was significantly higher ($p \leq 0.01$) than from the control plot (1 917 kg ha^{-1}). The yield difference was also significantly higher ($p \leq 0.05$) than the control plot when tithonia was relayed at early knee high stage with low and high seed rates (Appendix 6.1 and Figure 6.4). But when tithonia was relayed with maize at an early pre tasseling stage then there was no yield difference between the control and Ti+Sc plots (>0.05).

The rice yield from the farmers practice (FP) treatment was lower than Sc and Ti but the yield was similar to the rest of the treatments (Fig. 6.4).

6.3.3.2 Rice straw production

The yield from Sc, Ti, Sc+mz1, Ti+mz1 and Tti+mz2 was significantly greater than from the control plot (3 002 kg ha^{-1}). There was a non-significant difference between the farmer's practice (FP) and sesbania alone (Sc) and tithonia alone (Ti) treatments (Appendix 6.1). The straw yield was similar amongst the treatments Ct, Ti+mz3, Ti+Sc and FP (Figure 6.4).

The heaviest straw weight of 4 329 kg ha^{-1} was obtained from Sc+mz1 treatment when sesbania was green manured. This production was similar to the treatments Sc, Ti, Ti+mz1 and Ti+mz2 but the difference was highly significant ($p \leq 0.01$) between the Sc+mz1 and the Ti+mz3 and Ti+Sc treatments (Fig. 6.4).

6.3.3.3 Components of yield

No significant differences between treatments in the components of yield such as thousand-grain weight, tiller number per hill, panicle length, and number of grains per panicle and plant height were found (Appendix 6.2).

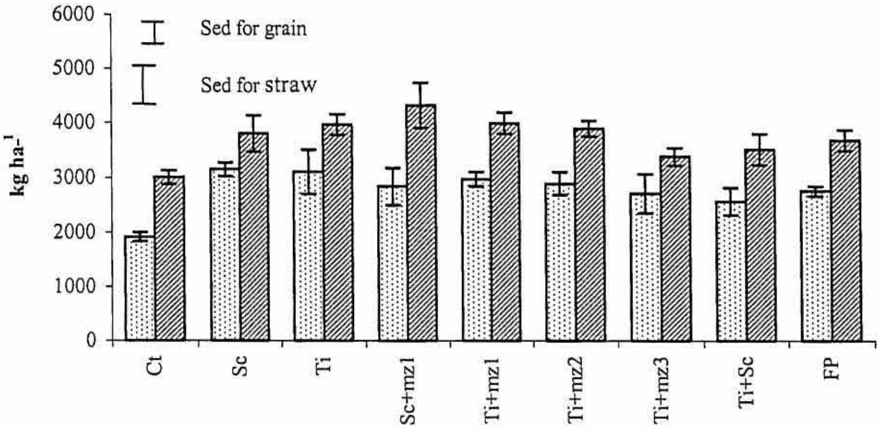


Figure 6.4: Effect of green manuring on rice grain and straw production .
Legend: Grain and straw

Ct=Control plot (no green manure crop), Sc+mz1=Sesbania sown at knee high stage of maize, Ti+mz1=Tithonia sown at early knee high stage of maize (seed rate 22.2 kg ha^{-1}), Ti+mz2=Tithonia sown at early knee high stage of maize (seed rate 44.4 kg ha^{-1}), Ti+mz3=Tithonia sown at early tasseling stage of maize,Ti+Sc= Tithonia and sesbania sown together and FP = Farmer's practice.

6.4 DISCUSSION

6.4.1 Tithonia biomass production

Production of tithonia biomass (Ti) was found to be greater than sesbania (Sc). One of the reasons for this was that tithonia had more growing time (80 growing days). However, farmers in the Chitwan valley usually prefer 30 to 45 day old sesbania plants for fast decomposition (Chapter 7). Therefore, in order to incorporate this factor into the experiment sesbania was planted later than tithonia to follow farmers' practice.

Planting tithonia alone at an early knee high stage (20 days after maize seeds sown) produced the highest biomass yield of tithonia (Figure 6.2). The pre-tasseling stage of maize is not suitable for relaying tithonia as tithonia germination was poor in the plots, although this may reflect seed viability rather than an effect of the crop. The shadding of maize plant could be a factor for poor germination. The maize canopy might have hindered the growth of tithonia as the few tithonia plants present did not gain height. A serious N deficiency was also observed when tithonia was relayed with maize(Plate 6.2).

When planted alone, *Sesbania aculeate* (Pers) produced dry matter yield equal to 4.6 t ha^{-1} when grown for 60 days (Beri *et al.*, 1989). Gurung and Sherchan (1996) also reported that on average 28.7 t ha^{-1} fresh biomass of *S. aculeata* could be produced after 60 days when grown alone in the lower hills of Nepal at a seed rate of 60 kg ha^{-1}. Bhardwaj and Dev (1985) reported that the fresh biomass of the same species when grown for 45, 55 and 65 days was 18, 28 and 37 t ha^{-1} respectively.

Subedi (1998) and Subedi *et al.* (1995) reported that at the pre tasseling stage of maize sesbania (*S. aculeate*) can be relayed successfully to get a fresh biomass of 8.4 t ha^{-1} without reducing the yield of an accompanying maize crop. The following rice yield was equivalent to the yield produced from 60:30:30 kg N:P:K ha^{-1}. Gurung and Sherchan (1996) also reported that when sesbania was relayed with maize at first hoeing and at second earthing up, then 12.6 t ha^{-1} and 8.9 t ha^{-1} biomass could be produced respectively. The results confirm that sesbania can be grown under relay conditions with maize. Though the biomass yield in this experiment was only 4.5-7.2 t ha^{-1}, there could be many possible reasons for this lower yield such as environmental factors, quality of seeds and other management factors such as application of fertilizer and timely irrigation.

6.4.2 Effect of tithonia on accompanying maize crop under relay situation

Under relay conditions the yield of the companion crop maize was found to be affected by tithonia. Reduction of maize yield compared to farmers' practice was 30.6% and 35% when tithonia was relayed at early knee high stage of maize with low and high seed rates respectively (Figure 6.5). Sesbania did not affect the maize yield as much as tithonia when relayed with maize with a reduction in yield of only 12.8%. In contrast, the maize stover yield was found to be equally affected by both the green manure crops.

Tithonia is a non-N fixing plant. One possible reason for a negative effect on maize yield could be a strong competition for N sources since maize has a large demand for nitrogen and the Nepalese soils are low in nitrogen content (Carson, 1992). Most of the field research on inter cropping has been conducted with N fixing leguminous crops combined with cereal crops. Findings have indicated that these combinations have a positive effect on crop productivity, and are also economically sustainable (Robinson 1997; Ikeorgu and Odurukwe, 1990; Rerkasem and Rerkasem, 1988; Devkota and Rekrasem, 2000).

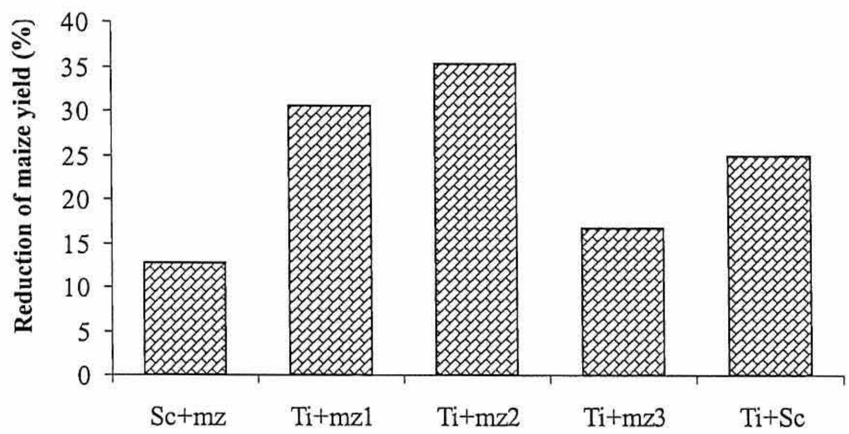


Figure 6.5: Reduction of maize yield (%) under relay cropping (yield from the farmers' practice is considered as 100%).

Legend: Sc+mz1=Sesbania sown at knee high stage of maize, Ti+mz1=Tithonia sown at early knee high stage of maize (seed rate 22.2 kg ha^{-1}), Ti+mz2=Tithonia sown at early knee high stage of maize (seed rate 44.4 kg ha^{-1}), Ti+mz3=Tithonia sown at early tasseling stage of maize and Ti+Sc= Tithonia and sesbania sown together

From the results of present experiment tithonia has very high depression effect on maize. However, looking at the green manuring value of tithonia for rice production there is scope to fit tithonia into the current cropping pattern where rice-vegetable-maize and rice-wheat-maize are grown. When tithonia was grown alone, plots produced significantly higher rice grain and straw yield than the control plot and yields were similar to the current farmers' practice (Fig. 6.4). Therefore, if the cost of chemical fertilizers is taken into account then the use of tithonia as an organic fertilizer may be justified. However, further research is required to look in detail at the time of relaying with maize and with other cereal crops, so that a critical stage can be identified. Another potential area of field research would be identifying the most suitable type of maize variety for relay cropping since farmers grow both tall, short and medium varieties and early maturing varieties.

A slightly lower yield of companion crops such as maize, is acceptable to farmers. From the farmers' point of view some reduction in both the crops when they are either relayed or mixed together is acceptable. Farmers usually grow main companion crops at a low density when they are relayed with green manure crops like sesbania and sesame and farmers do not give very high priority to grain production. There might be a need for further study to investigate the most appropriate plant density combination. In this study there was a high plant density that might have caused strong competition between the relay crops for light, nutrients and water.

6.5 CONCLUSION

Green manure crops such as sesbania and tithonia have been observed to affect the main companion crop, maize, when they are relayed. However there is a degree of acceptance amongst farmers regarding this reduced yield which is offset against the benefit of the green manure on subsequent crops. As these results are only for one year, there is a need to repeat the treatments to confirm the findings. At the same time there is also a need to investigate the timing when tithonia should be relayed with maize, together with the optimum plant density and type of maize variety. With respect to rice production, the results are encouraging and the potential value of green manuring should not be ignored. But the *in situ* practice is discouraging since there has been no substantial benefit for increasing rice yields (Chapter 5). At the same time the availability and viability of tithonia seeds may prevent the promotion of this technology in the area. Farmers prefer to propagate from seeds because propagation by other means such as stem cuttings, is very labour intensive. During this peak period, labour supply is one of the major constraints in this intensive farming area.

CHAPTER 7

FARMERS PERCEPTIONS AND REACTIONS TO VARIOUS GREEN MANURE SPECIES

7.1 INTRODUCTION

The importance of green manure to sustain crop production and to improve soil quality have been known for some time and highlighted in recent years (Sthapit, 1988; Bhattarai *et al.*, 1987; Subedi 1997). Indigenous species suitable for use as green manure in the hills of Nepal have been identified and evaluated for their efficacy for increasing crop production (Bhattarai *et al.*, 1987; Sthapit 1990; Sherchan *et al.*,1991). However, the adoption of green manure technology throughout the country is not very high. Recent field studies conducted in the Chitwan valley and Syangja district of Nepal have indicated that farmers understand a lot about green manuring practices (Moss, 2000; Brede, 1998) and have their own well developed attitudes to using them.

Results from the researcher managed field experiments described in chapters 4 and 5 indicate possible benefits in crop yields from the use of traditional and novel green manures alone and in combination with other nutrient sources. But to evaluate green manure species in farmers' conditions, a participatory research and development approach is required (Joshi *et al.*, 1997). By seeing what farmers themselves do with a range of potential green manure species it is possible to understand more about their extrapolation domain and the reasons controlling adoption by farmers. Therefore, an on-farm, participatory green manuring plant selection trial was carried out in Chitwan and Nawalparasi districts.

The adoption of green manure technology may be enhanced if farmers' perceptions are known, since the choice of a technology depends upon many factors (Joshi, 2001).

7.2 OBJECTIVE

The objective of the research reported in this chapter was to acquire from farmers in the Chitwan area their perceptions and reactions regarding the use of green manure species. Initially, in interacting with farmers about this topic, the aim was to obtain qualitative information about how green manure crops might fit into the farming system and the constraints, issues and opportunities that pertain in on-farm conditions. It was, therefore, decided to give farmers green manure germplasm and observe what they did with this and then explore their criteria for evaluating them.

7.3 MATERIALS AND METHODS

7.3.1 Site selection

Three sites were selected representing quite diverse socio-economic and farming system types in the Chitwan and Nawalparasi districts. A participatory crop improvement (PCI) project run by Local Initiatives for Bio-diversity Research and Development (LI-BIRD) and the Centre for Arid Zone Studies, University of Wales, Bangor had established contacts with farmers in these areas, facilitating entry. In the Chitwan valley two clusters of households were selected in Eastern Chitwan (EC) and Western Chitwan (WC). The Eastern Chitwan cluster represents a quite high input and market driven agricultural system. The application of chemical fertilizer, pesticides and insecticides is consequently quite high in this area. The Western Chitwan cluster represents an area where double rice farming practices are dominant because of low lying land, with an assured irrigation facility. Other farmers in this area operate a rice and wheat cropping pattern. The third cluster at Nawalparasi represents a less intensive agricultural context, the environment is drier and irrigation is one of the major constraints for agriculture production (Rana *et al.*, 1997).

The majority of inhabitants in both the Chitwan and Nawalparasi valleys are people who have migrated to the terai from the hills. According to a wealth ranking exercise conducted by LI-BIRD (Rana *et al.*, 1997) there are three categories of wealth class in the area referred to as A, B and C. A represents a household that has food surplus for more than 12 months in the year and are able to sell food grains. B represents a household whose food production is sufficient for 6 to 12 months in a year, while C represents a household whose food grain production meets requirements for less than 6 months in a year.

Soils are derived mainly from alluvium materials. Soil in the Western cluster is relatively old compared to Nawalparasi and the Eastern cluster. The soils in the Eastern cluster are colluvial while soils in the Nawalparasi cluster are relatively younger alluvium material. These soils are deep and have sandy loam texture. Land is well drained in the Nawalparasi and the Eastern Chitwan clusters but in the Western cluster poorly drained land occupies a major portion of the area.

7.3.2 Selection of plant species

Several of the most common green manuring plants in the terai region were chosen for comparative analysis in this experiment. These included sesbania *(Sesbania cannabina)*, sesame (*Sesamum indicum*), sunn hemp *(Crotolaria juncea)* and rice bean *(Vigna umbelleta)*. Tithonia (*Tithonia diversifolia*) is a candidate for introduction in the Chitwan valley as described in the previous chapters in this thesis and so was also included as a species in the trial.

7.3.3 Selection of participating farmers

Farmers in each cluster were briefed about the objectives of the study and 18 volunteer farmers from each cluster were identified and the wealth category to which they belonged was recorded. Each selected farmer was given one packet of tithonia seeds and one packet of one of the other green manure species (at random) (either rice bean, sunn-hemp, sesame or sesbania) to compare between tithonia and other green manures. The amount of seeds given to each farmer was sufficient for 0.033 ha of land (one *kattha*). The participating farmers decided to use their own rice and maize varieties in the field trials. The participating farmers followed their own intercultural and husbandry practices and cropping pattern. No inputs such as chemical fertilisers and insecticides were given. The decision on what to do with the seed was left fully up to the farmers.

The procedure described for Farmer Managed Participatory Research (FAMPAR) and Informal Research and Development (IRD) trials as mentioned by Joshi (2001) for main crop varietal trials were modified to suit evaluation of green manure technology. The LI-BIRD Community Orgnaiser (CO) and the author visited farmers from time to time to inspect the fields and to get feedback from them. In each cluster a farm walk and focus group discussions were conducted while the trial species were growing, shortly before the green manure crops were harvested.

Discussion was also held from time to time mainly on the critical growth stages of crops and important events of the farming calendar such as land preparation, transplanting, harvesting and incorporation of biomass during the field visit to get farmers opinions regarding green manure crops. A semi-structured questionnaire partly based on experience from the on-station field research was developed and after a pre-test of the questionnaire, administered in each cluster. The respondents were selected from the participating farmers, representing all three wealth categories and only those farmers who remained willing to participate in the interview process were included since all the participants were unable to take part at the time of interview. However the distribution of wealth categories of households varied from one cluster to another. In east Chitwan more households were represented from the C category and in West Chitwan the majority of households B, whilst in Nawalparasi, B and C were represented in equal proportions. A final questionnaire was developed and interviews were held separately with male and female farmers (Appendix 7.1).

7.4 RESULTS

7.4.1 Respondents

The number of respondents who participated in the final survey is given in Table 7.1. In the Nawalparasi (NP) cluster sesame did not germinate perfectly and sesbania plant populations were very low due to lack of irrigation and as a result, farmers who had received sesame and sesbania abandoned the green manure trial. More than half of farmers in East Chitwan and more than two thirds in West Chitwan successfully completed the trial. The success rate was higher with wealthier households than with less wealthy households. In East Chitwan sesame and sesbania also had low germination and by chance the farmers who received seeds of these species were largely from the B category. The poor germination was because of very heavy rain just after seeding. In general, however, the B category households had a lot of interest in the technology testing. The land holding and composition of male and female farmers who participated actively in the final survey is given in Tables 7.2 and 7.3.

Table 7.1: Number of respondents who participated in the final round survey

Cluster and wealth class	East Chitwan		West Chitwan		Nawalparasi		Total	
	Original number	Participated	Original number	Participated	Original number	Participated	Original number	Participated
H.H. _A	4	4	4	3	3	3	11	10
H.H._B	6	2	8	6	7	2	21	10
H.H._C	8	4	6	3	8	2	22	9
Total	18	10	18	12	18	7		

Note: *H.H.=Household*

Table 7.2: Mean landholding for wealth categories in each cluster

Cluster	East Chitwan			West Chitwan			Nawalparasi		
Wealth class	Sample size	Mean (ha)	Se	Sample size	Mean (ha.)	Se	Sample size	Mean (ha)	Se
A	4	1.86	0.29	3	1.94	0.68	3	0.84	0.19
B	2	0.53	0.13	6	1.65	0.27	2	0.38	0.05
C	4	0.38	0.14	3	0.59	0.03	2	0.50	0.26

Note: Se = standard error

Table 7.3: Gender of respondents who participated in the survey.

Cluster	Sex of respondent		Total respondent
	Male	Female	
East Chitwan	8	2	10
West Chitwan	7	5	12
Nawalparasi	4	3	7
Total	19	10	29

7.4.2 Farmers' perceptions regarding soil fertility of their land

Table 7.4, 7.5, and 7.6 illustrate the soil type and fertility level in each cluster according to the farmers' classification system and laboratory tests. There were clear differences amongst participating farmers in each district. Loam predominated in both East and West Chitwan but whereas about a third was clay in the East there was no clay at all in the West. In Nawalparasi there were equal amounts of clay and loam and a small proportion (<15%) classified as sandy loam. Farmers, fertility classification was not very revealing since most farmers in all districts classified nearly all their land as of medium fertility, indicating that either conditions are remarkably uniform or that this terminology was not eliciting a response from farmers that distinguished soils in a meaningful way.

Soil samples were collected from the participating farmers' fields and analysed at LI-BIRD laboratory. Only 24 soil samples could be analysed. Soil samples from other participating farmers' field could not be taken on time and were therefore not analysed.

Table 7.4: Percentage of respondents (types of soil texture).

Soil type in each cluster	% of respondents			Total
	East Chitwan	West Chitwan	Nawalparasi	
1. Sandy loam (*balaute*)	20%	33%	14%	24%
2. Loam (*dumont*)	50%	67%	43%	55%
3. Clay (*chimte*)	30%	Nil	43%	21%
Total	100%	100%	100%	100%

Table 7.5: Percentage of respondents of soil fertility class of farms.

Soil fertility class	Cluster			Total
	East Chitwan	West Chitwan	Nawal Parasi	
Poor (*rukho*)	20%	0%	14%	10%
Medium (*madhyam*)	70%	92%	86%	83%
Fertile (*malilo*)	10%	8%	--	7%

Laboratory analysis showed that in general, soil pH varied from slightly acidic to neutral. Across all sites the organic matter content was low and available P ranged from very high to very low and the K also varied from low to medium (Table 7.6). Therefore a wide range of fertility status was observed, which did not tally with the farmers perceptions.

Table 7.6: Nutrient status of soils in each cluster.

Soil Parameters	East Chitwan (n=11)			West Chitwan (n=9)			Nawalparasi (n=4)		
	Range	Mean	Se	Range	Mean	Se	Range	Mean	Se
Soil pH	5.50-7.48	6.5	0.24	5.44-5.87	5.7	0.09	5.2 – 5.4	5.4	0.05
O.M.(%)	0.91-1.53	1.2	0.05	0.89-1.53	1.1	0.08	1.35-1.76	1.6	0.14
Available P (mg kg^{-1})	8.40-90.2	31.2	7.25	20.9-170	100.3	16.88	12.8-182	63.3	40.25
Available K (mg kg^{-1})	39.1-221.2	90.2	16.0	23-121	63.5	9.87	64.8-204.2	111.0	31.85

Note: n = sample size and Se = standard error

7.4.3 Cropping pattern in the study area

All participating farmers grew green manure as a part of the rotation. Different cropping patterns were observed in the study areas and were the result of the small size of land holdings, different land types, diverse socioeconomic groups and different market opportunities. However, the major cropping patterns followed by the participating farmers were rice-wheat-fallow, rice-vegetable-maize, rice-wheat followed by mustard or maize, rice-lentil-fallow, or rice-fallow-maize. These represent only one-year crop rotations. In double rice cultivation systems, the crop rotation is early rice (*chaite* rice) followed by main season rice and fallow.

7.4.4 Time of planting under sole and relay practices

The green manure crops are included in the crop rotation mostly during the fallow period normally after wheat harvest, or are relay planted with maize if no fallow period is included in the rotation. These two alternatives will be referred to as sole and relay practices respectively. Over 80% of farmers responded that under the relay system green manure seeds were sown when the maize crop was at the knee high stage which coincided with the first hoeing operation. Only one farmer reported planting green manure seeds at the second hoeing stage. Second hoeing of maize is not very common in the study area due to time and labour constraints. Planting time for maize varies between the first week in April and the third week in May.

Two thirds of the participating farmers responded that under the sole system, green manure seeds are sown in the second week of May, while 17% farmers reported that the first week of June is appropriate for sowing green manure under sole conditions. According to the farmers as soon as the wheat crop is harvested, green manure seeds should be sown but this is not always the case because of climatic conditions and a lack of labour.

7.4.5 Actual and preferred age of green manure when incorporated

The age of green manure at harvest is very important because this determines the decomposition rate and supply of plant nutrients. In each cluster because of different agronomic practices both under the relay and sole cropping practice, the age of green manure when incorporated varied considerably from less than 30 days to more than 50 days (Table.7.7.)

Table 7.7: Age of green manure at incorporation (% of respondents).

Age of green manure at incorporation	East Chitwan		West Chitwan		Nawalparasi		Total	
	(%)	Number	(%)	Number	(%)	Number	(%)	Number
< 30 days	30	3	8	1	29	2	22	6
30 to 50 days	30	3	50	6	57	4	46	13
> 50 days	40	4	42	5	14	1	32	10
Total	100	10	100	12	100	7	100	29

The age at which the green manure is incorporated into the soil is not necessarily the age at which farmers would prefer to incorporate it into the soil (compare Tables 7.7 and 7.8) although preferences clearly vary and explain some but not all of the variation in actual times of cutting green manure crops. The fact that age at which farmers would like to incorporate green manure into the soil is not the same as the age at which they actually do reflects the time and labour constraints imposed upon farmers in these areas.

Table 7.8: Percentage of respondents and preferred age of green manure crops.

Age of green manure	East Chitwan		West Chitwan		Nawalparasi		Total	
	(%)	Number	(%)	Number	(%)	Number	(%)	Number
< 30 days	30	3	8	1	-	-	13	4
30 to 50 days	50	5	50	6	100	7	67	18
> 50 days	20	2	42	5	-	-	20	7
Total	100	10	100	12	100	7	100	29

When farmers were asked why they have preferences for particular ages of green manure plants the answers were as follows:

- Green manure below 30 days old is still young and tender and decomposes fast.
- In green manure over 50 days old hardness will develop and, therefore, it takes time to decompose. Besides which a plant more than 50 days old (sesbania especially) will be very tall and difficult to incorporate into the soil and will require a tractor to do so.
- Green manure between 30 and 50 days is the most suitable from the biomass production point of view. Plant height will be neither too tall nor too short and the material is easy to incorporate. A few farmers who had attended a training course organised by the District Agriculture Development Office (DADO) said that at the age of 50 days sesbania would have a large number of nitrogen fixing nodules, which would improve the quality of the green manure plants and consequently have a positive effect on rice productivity.

7.4.6 Method of incorporation

The method of incorporation is important from a decomposition and labour requirement point of view. The following is the result of the survey. Among the participating farmers 68% reported that they used a tractor to incorporate biomass into the soil and 26% used a bullock pair and plough. Only 7% incorporated biomass manually. In the Nawalparasi cluster incorporation of biomass using bullocks was prevalent but in the remaining clusters the use of bullocks was negligible. The main reasons for using tractors were as follows:

- It was not possible to incorporate the green manure into the soil without a tractor because the plants were so tall. It is also easy to chop up plant materials when a tractor is used.
- Hiring a tractor is cheaper than human labour.
- Tractor ploughing is popular in the area and tractors are available.

The views expressed by farmers who used a bullock pair and plough

- They have their own bullock pair.
- Tractors are not easily available.
- Due to the small terrace size the use of tractors is not feasible in (particularly in one village in East Chitwan).

7.4.7 Time of transplanting rice

Different strategies were observed regarding the transplanting of rice seedlings after biomass had been incorporated. There were three strategies adopted; 22% of farmers transplanted seedlings on the same day as the biomass was incorporated; 59% of farmers transplanted rice seedlings one week after biomass had been applied and 19% transplanted rice more than one week after biomass had been applied (Table 7.9).

Table 7.9: Percentage of respondents transplanting seedlings after biomass incorporated.

Transplanting of seedlings after biomass incorporation	East Chitwan		West Chitwan		Nawalparasi		Total	
	(%)	Number	(%)	Number	(%)	Number	(%)	Number
On the same day	40	4	10	1	14	1	22	6
In the first week	60	6	50	6	72	5	59	7
> one week			40	5	14	1	19	6
Total	100	10	100	12	100	7	100	29

The reasons for transplanting at different times are summarised in Table 7.10.

Table 7.10: Reasons for transplanting rice seedlings at different times after green manure incorporation.

Reason	East Chitwan %	West Chitwan %	Nawalparasi %	Total %
1. To allow decomposition	46	63	13	44
2. To avoid a negative effect on rice seedlings	-	25	-	11
3. Time constraint forced to transplant on the same day	55	7	38	28
4. Peak season of labour demand	-	-	13	6
5. Lack of irrigation	-	6	38	11

Women farmers do the transplanting of rice seedlings manually. The women farmers in the West cluster find that transplanting is easy when sesame biomass has been applied. The puddled field becomes slippery which speeds up transplanting. It is preferred to transplant on the same day as incorporating the green manure because if done later the decomposition process causes the soil temperature to rise and gas (methane) is produced, thus making it uncomfortable to transplant seedlings.

7.4.8 Farmers' perceptions of green manure growth rate

The farmers of West Chitwan are familiar with *Sesbania* spp., locally known as *dhaincha* , and sesame and 75% of farmers have experience with green manure. But 90% of the participating farmers from the East Chitwan have no experience of green manuring and had not heard of the practice before. However, the farmers of East Chitwan were aware of asuro (*Adhatoda vasica*) since they are migrants from the hills. Seventy-one percent of participating farmers of the Nawalparasi cluster were not aware of which green manure plants can be grown in crop fields and only 29% of farmers knew about sesbania. Therefore, when comparing growth and other parameters, sesbania and sesame were used as the standards against which farmers compared other green manures. A majority of farmers in all districts thought that both sunn hemp and rice bean grew faster than sesbania.

Table 7.11: Comparison of growth rate of green manure species (% of responding farmers).

Growth rate of rice bean and sunn hemp compared to sesbania.	East Chitwan	West Chitwan	Nawal Parasi*	Total
1. Growth is faster	70	58	100	76
2. Comparable	30	42	-	24

Note: - *At Nawalparasi only rice bean and sun hemp were grown successfully. Farmers abandoned sesbania growing in the rice field because of lack of irrigation whereas the germination of sesame seeds was poor due to poor land preparation.*

Plate 7.1: A woman farmer participating in on-farm green manure trial in the Eastern Chitwan cluster. Rice bean (*Vigna umbellata*) relayed with maize.

Plate 7.2: A participating farmer discussing with the Community Organiser, Hari Ghimire, Sesbania growing as a relay crop with maize. Sesbania has dominated the maize crop because of its plant density.

7.4.9 Farmers' perceptions on biomass production

Information was collected on farmers' perceptions of green manure production and the reasons for variation in production. The highest biomass production was obtained from rice bean followed by sunn hemp and sesbania. The majority of participating farmers mentioned that production of rice bean biomass was quite high compared to sesbania in West Chitwan and East Chitwan. In the case of Nawalparasi the comparison was between rice bean and sunn hemp only, and biomass production of rice bean and sunn hemp was similar to sesbania. Only 8 to 10% of the participating farmers reported that the production of biomass was low compared to sesbania.

The reasons for low production of sesbania, tithonia and sesame are as follows;

- Time of seeding was inappropriate
- Land was not suitable, especially for tithonia, because of poor drainage
- Lack of experience with sunn hemp, rice bean and tithonia
- The amount of seed distributed was not enough for one *kattha* (0.033 ha) of land due to different seeding practice among the farmers.

7.4.10 Decomposition of green manure crops

The decomposition rate of green manure is one of the indicators for judging the quality of green manure. According to the farmers, the faster the growth rate of green manure, in general, the faster is its rate of decomposition. Sesame decomposes faster than sesbania because it has a larger proportion of leaves. The following are the responses received from the farmers on decomposition characteristics of the green manure crops.

Table 7.12: Farmers' perceptions regarding decomposition of different green manure crops (%).

Green manure crop		East Chitwan	West Chitwan	Nawal Parasi	Total
Rice bean	Fast	20	17	43	24
	Slow	-	-	-	-
Sunn hemp	Fast	20	25	47	31
	Slow	-	25	-	10
Sesame	Fast	10	-	-	3
	Slow	10	17	-	10
Sesbania	Fast	30	-	-	10
	Slow	10	16	-	10

Farmers pointed out four main reasons for slow decomposition. They are the species characteristics of the green manure crop, the method of incorporation, the age of green manure when incorporated and the availability of irrigation facilities (Table 7.13).

Table 7.13: Reason for fast or slow decomposition (number of respondents)

Reasons for fast or slow decomposition	East Chitwan	West Chitwan	Nawal parasi	Total
1. Green manure characteristics	4	4	1	9
2. Method of incorporation	3	5	3	11
3. Irrigation facility	4	2	3	9

7.4.11 Effect of green manure on rice growth and maturity

According to 16 farmers (56%) the effect of green manure on rice growth is more pronounced at an early stage. Only three farmers reported that the effect on rice growth is also seen at a later stage. The other respondents said that the effect is uniform from beginning to end. However, farmers of West Chitwan stated that the effect of sesame as a green manure for rice crops is only noticeable at an early stage, and at later stages the crop shows N deficiency. Top dressing is done when sesame is applied as a green manure. On the other hand, if sesbania is applied then a urea top dressing is generally not required. The majority of farmers mentioned that green manuring is suitable only for improved rice varieties since they are responsive to increasing the amount of chemical fertilizer. Local rice varieties generally lodge when green manure is applied.

7.4.12 Effect of green manure on rice grain and straw production

In each cluster the majority of farmers (72%) responded that there is an increased yield of grain and straw due to the application of green manure. Only one farmer in East Chitwan replied that the yield was reduced, because a heavy amount of green manure was applied causing a lodging effect on the rice. However, 24% of farmers mentioned that the yield was the same whether green manure was applied or not.

Table 7.14: Effect of green manure on rice production.

Effect of green manure application on rice yield	East Chitwan		West Chitwan		Nawal parasi		Total
	No.	%	No.	%	No.	%	%
Yield increased	6	60	9	75	6	86	72
Yield same	3	30	3	25	1	14	24
Yield reduced	1	10					3
Sub total	10	100	12	100	7	100	100

Table 7.15: Effect of green manure application on rice straw yield.

Effect of green manure application on rice yield	East Chitwan		West Chitwan		Nawalparasi		Total
	No.	%	No.	%	No.	%	Total%
Yield increased	6	60	6	50	1	14	45
Yield same	4	40	6	50	6	86	55
Sub total	10	100	12	100	7	100	100

7.4.13 Farmers' perceptions on the effects of relay cropping green manure on the companion maize crop

Farmers prefer to relay green manure with maize so that they can harvest two crops - maize for grain and fodder, and green manure for nutrient supply. In East and West Chitwan 57% and 20% of farmers respectively reported that there was a negative effect on maize yield when a green manure crop was grown as relay. The majority of farmers said that the yield of maize was the same. The negative effect on the companion crop (maize) wa attributed to a high plant population density of green manure crops. All participating farmers mentioned that weeds, especially banso *(Digitaria adsceadeneas),* are a big problem in the area for spring maize but when green manure is grown, particularly sesame and sesbania, then weed growth is suppressed.

Table 7.16: Effect of relay cropped green manures on a companion maize crop.

Effect on maize crop when grown relayed	East Chitwan		West Chitwan		Nawalparasi		Total	
	No.	%	No.	%	No.	%	No.	%
Yield increased	4	57	1	20	-	-	5	29
Yield the same	3	43	3	60	5	100	11	65
Yield reduced	-	-	1	20	-	-	1	6
Sub-total	7	100	5	100	5	100	17	100

Note:- The remaining farmers grew green manure under a sole cropping practice

7.4.14 Farmers' perception on the effect of green manure on soil fertility

In total 69% of all farmers interviewed thought that the incorporation of green manure led to an improvement in soil quality and only 31% of respondents said there was no positive effect on soil quality. Some of the indicators of a positive effect mentioned by farmers as some of the participant farmers have experience since long time were:

- Soil is dark and black
- Soil is friable and loose

- Soil is easy to plough
- There is a higher earthworm population
- Yields of rice are higher

7.4.15 Farmers' perception of possible roles for green manure

There was an indication that green manure technology could be promoted in the valley. Factors that suggest that green manure might be usefully adopted were as follows.

- All respondents expressed the view that the green manure species distributed to them fitted well into their current cropping pattern.
- Rice-wheat-maize or rice-fallow-maize cropping patterns allow green manure to be included either in relay with maize or sequentially after wheat.
- After the wheat harvest there is adequate time to grow a green manure crop since in general the main season rice can be delayed by a few days by planting a late season variety.
- Green manure is quite compatible as a relay crop with spring maize. Short duration maize varieties also allow sequential use of green manure.
- Grain production from spring maize is not guaranteed, because of lack of irrigation and the uncertainty of the monsoon. Therefore, the maize crop for grain production can be sacrificed and used for fodder. This view has been expressed particularly by the large land holding farmers. An additional green manure relayed with it, enhances its function when other yields are low.
- In all three clusters there was a demand for green manure seeds from the neighbours of the participants. The same households were asked whether they would be interested in taking part in the same activity in the next season and only one farmer declined. He did not need green manure since he has sufficient animals and his production of farmyard manure and compost was adequate. He thought that biomass incorporation was time consuming and a tractor was not available during the peak time of rice transplanting.

- Almost all farmers said that they would like to increase the land area for green manure in the coming season.

7.4.16 Acceptance of green manure technology

Reasons for accepting the green manure technologies were:

- increased rice yields,
- improved soil quality,
- it is a simple low cost technology,
- it reduces the amount of compost and chemical fertilizer required,
- for Category A farmers, their large land holding means they have space available for this technology,
- after the wheat crop harvest, green manure is a preferred fallow to what may regenerate naturally if land is not being utilized, because it rejuvenates soil fertility.

7.4.17 Constraints in the use of green manure

The farmers' perceptions of the constraints to using green manure technology were as follows:

- seeds were not easily available,
- there was little experience with new green manure species,
- irrigation was not available at the beginning of land preparation and biomass incorporation and farmers have the perception that an adequate amount of water is required for fast decomposition,
- if paddy fields are not flooded after sesbania biomass has been harvested the sesbania will resprout and compete with the rice crop,
- a range of seeding dates are required, but there is still not much experience in growing green manure, and
- labour cost was high and tractors not easily available when required.

7.4.18 Preferences for green manure crops

Ironically, only in the West Chitwan area was green manuring popular, but this was because farmers already had experience of it but only with a very limited selection of green manure plants. Sesbania (*Sesbania spp.*) was the only type that farmers of West Chitwan were familiar with, and only two species of sesbania were available, *Sesbania rostrata* and *Sesbania cannabina.* Use of green manures in West Chitwan was, therefore, very limited.

Since tithonia population in the field was too low that could not be assessed. Farmers need another season for the experimentation. Rice bean was the most popular green manure overall with farmers and sunn hemp was second. The farmers of Western Chitwan demanded new green manure crops whereas the farmers of the other two clusters demanded more time for experimentation. Ranking was a difficult task in the current farmers field trials because of an inadequate number of green manure species and so no conclusive results are available on this. Also, the performance of green manure crops varied from one location to another. The ranking was between rice bean and sunn hemp in Nawalparasi. In East Chitwan the ranking was between rice bean, sun hemp and sesbania. In West Chitwan the ranking could be done on three green manure species: rice bean, sunn-hemp and sesbania. Few farmers possessed their own seeds of sesbania. The criteria for ranking green manures identified by farmers themselves are given below and they are in order of priority.

- Growth rate.
- Decomposition rate.
- Amount of biomass production.
- Effect on rice crop yield.
- Effect on companion crop.

7.5 DISCUSSION

7.5.1 Desirable characteristics of a green manure crop

Selection of the most desirable characteristics for a green manure crop is at an early stage in the Chitwan area where green manures are a new concept for many farmers and some farmers have expressed a need for more time for experimentation. The practice of green manuring is not very common and not regularly practised in the study area. However, from the survey a few features have been identified as important. They are growth rate; decomposition properties; synchronization between nutrient release and crop nutrient demand; compatibility with crops when grown as a relay crop, suitability for a wide range of planting dates; low demand for inputs and, last but not least that the practice has a demonstrable effect on rice productivity. It is not possible to fulfill all these desirable traits with a single green manure species (Joshi, 2001). Therefore, there is a need to increase the diversity of green manure species that can be grown on cropland. In the hills there is a large diversity of plant species that could be used for green manuring purposes (Moss, 2000; Subedi 1997). However, they generally are either undomesticated shrubs or trees whose biomass is collected from forest areas. By increasing the diversity of crop species and varietal diversity within species, the adoption of green manure technology in the area might be improved. Farmers have also shown interest in dual purpose green manure species such as rice bean, since grains of rice bean can fetch a good price in the market. Untill now emphasis has been given to only the summer green manure crops but the potential of winter green manure crops should be explored.

7.5.2 Agronomic and management practice

Due to the lack of assured irrigation and unpredictability of the monsoon, farmers may not have an exact date for planting and, therefore, the green manure should have a wide range of possible planting times. Neupane (1993) pointed out that one of the most desirable characteristics of green manure is that it should be non-photoperiod sensitive so that growth is not strongly affected by planting date.

Farmers have expressed great concern regarding the labour requirements for incorporation of biomass into the soil before transplanting rice. Palaniappan and Budhar (1994) found that the incorporation of green manure biomass into the soil involved a heavy demand for labour and it was particularly difficult for farmers who use hand made ploughs. The use of a tractor for incorporation of biomass seems to be an appropriate practice, but this requires the mechanization of farming which in itself may have implications for the widespread promotion of green manure technology in Nepal. Resource poor farmers may not benefit from the technology if the tractor becomes an essential element for green manuring practices.

7.5.3 Positive effects of green manure on rice production

Farmers generally compared the yield advantage due to green manure either from memory with the previous harvest, or with another fertilized plot or sometimes with the green manured plot of neighbouring farmers. The majority of the participating farmers had a positive opinion regarding the use of green manure for increasing rice production, which confirms the results of field trials reported by many agriculturists. Economic analysis also suggests that the use of green manure for rice production is viable (Poudel and Upasena 1995; Neupane, 1993). However a survey conducted by Ali and Narciso (1994) in Nepal, Philippines and India reported that a large number of farmers in India thought that the use of green manure was not economic whilst a positive response was obtained from Philippines and Nepal. Therefore, it appears that green manuring technology could be a useful practice under the intensive farming system in the Chitwan area, if farmers were exposed to a sufficient variety of options in terms of species and planting niches.

7.5.4 Constraints on the promotion of green manure technology

Two important issues have arisen from the survey. Land holding size of a household determines a) the adoption of green manure technology, and b) the selection of a cropping system that can incorporate green manure into the existing system. It has been found that farmers with large land holdings (category A) are more likely to adopt sole crop green manure technology and they are more interested in growing green manure crops in the field after the wheat harvest. The farmers with small land holdings (category C) were more interested in relay cropping green manure under maize, because this minimizes risk and maximises food security.

Green manuring practices also vary with the type of rice cultivar. It has been found that farmers prefer using green manure with improved rice varieties due to their high nutrient demand whereas the local rice varieties do not respond to high doses of green manure. Therefore, the adoption of an improved rice variety may promote the adoption of green manure technology and varietial improvement programmes might consider packaging new varieties with advice on green manures and an appropriate range of seeds.

Demand for seeds and an increasing number of participating farmers in the research activities (neighbouring farmers wishing to join those already participating) indicate that there is a high potential for green manure technology in the area. For the promotion of green manuring in the area, seed production and distribution have proved to be big constraints. Baker *et al.* (1995) and Ali and Narciso (1994) also found availability of green manure seeds to be a limiting factor as these seeds are not commercially produced, and little attention has been paid by the agencies concerned with seed production to green manure technology. Unlike cereal crops there is lack of commercial production in the green manure seed market and also a lack of proper seed quality certification procedures for making effective green manure seed enterprises (Palaniappan and Budhar, 1994). As a result the quality of green manure seeds is often a major problem. Therefore, there is a need to create a market opportunity and information exchange mechanism to promote the production of green manure seeds.

7.5.5 A role for tithonia?

Poor viability of tithonia seeds is a major concern for the promotion of tithonia in the area and farmers were reluctant to carry out stem cutting propagation for biomass production because of the labour involved. Poor germination has disappointed farmers. The cause of poor germination is not known, whether it is because of poor land preparation, poor seed quality or simply the wrong environment for tithonia. However it has been confirmed by the field trials that tithonia is very sensitive to the depletion of oxygen in the soil if it is waterlogged. Therefore, the right niche for the promotion of tithonia could be upland in the terai region.

7.5 CONCLUSION

Some farmers in Chitwan had limited but valuable experience of green manure but many had no previous awareness of either the concept or the plant species that might be appropriate to implement it. Participating farmers were, however, able to articulate selection criteria for green manure species that were well matched with the scientific evidence on nutrient release and there is clearly an urgent need to increase the diversity of green manure species and varieties available so that farmers can exercise choice. To promote green manure technology, seed sources must first be secured. A market opportunity for seeds should be developed and an information exchange mechanism set up. Tithonia, because of its intolerance of waterlogging, only has a specific domain on upland land types within the terai and only if reliable seed could be produced. It may be more suited as a contour hedgerow species in the low and middle hills, where propagation from cuttings is more viable and capture and recycling of nutrients a critical requirement.

CHAPTER 8

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH AND PROMOTIONAL ACTIVITIES

This chapter presents a summary of the key findings generated from the field research carried out during the past two and half years in the high production potential area of the Terai region of Nepal. The potential role of tithonia (*Tithonia diversifolia)* as a green manure for improving crop productivity elsewhere in Nepal is also discussed. Some constraints associated with the adoption of tithonia in farm communities, specifically in the high productive potential areas, will be discussed. Future areas of research are identified based on the experiences gained from the current research project, and recommendations are made for promotional activities to disseminate the technology over a wider area.

8.1 Summary of conclusions

8.1.1 Propagation techniques for tithonia and its incorporation into the agronomic regime of the high production system

Since seeds and saplings are the main source for the production of biomass it is imperative to understand the technique for mass production and the environment suitable to tithonia. The results have indicated that tithonia can be propagated successfully using both semi hard stems and roots and in both the winter and summer seasons. However, growth is faster in the summer. Jama *et al.* (2000) also reported the results of King'ara, (1998) that tithonia is more easily propagated from stem cuttings than from seeds. Propagation using seed is not reliable as seed viability declines rapidly. It was found that the seeds collected in January and February were no longer viable after May, germination being almost nil under field conditions. For better germination, seeds can be sown in the month of March and April for the production of biomass that can be used to manure the main season rice from June - July onwards.

The farmers involved in consultation and field trials were not in favour of stem or root cutting propagation methods for large-scale cultivation, despite the success of the techniques, because of labour constraints. They had a strong preference for propagation using seeds.

Tithonia plant is sensitive to depletion of oxygen in poorly drained land when it becomes waterlogged. Such conditions occur prior to planting of the rice crop, so the potential of tithonia cannot be entirely realised in this system. Therefore, well-drained upland terraces in the Terai are likely to be more suitable for tithonia. Tithonia also appeared to be more suited to fertile soils; unlike the commonly used green manures tithonia is a non-leguminous plant and may require a starter dose of fertiliser where soil nitrogen is limited.

8.1.2 Biomass production and growth habit

Biomass production of tithonia was lower than common green manures such as sesbania and sunn hemp. One of the requirements from the farmers' point of view is that green manure should have a fast growth rate and tithonia takes longer to produce the same amount of dry matter than sesbania (*Sesbaina cannabina*).

The results have shown that 1 to 1.5 t tithonia dry matters can be harvested from 1 ha of land within 70 to 80 days of planting. However, the amount of biomass depends upon management and climatic conditions. On average, 1 t of dry matter will supply 31.5 kg N, 4.05 kg P and 10.4 kg K. A quadratic relationship explained the concentration of major nutrients in the plant at its various growth phases. But the concentrations of N and P did not change significantly with the age of tithonia but the relationship was significantly negative with sesbania that is concentrations decreased with the growing sessbania plant (Section of 3.4.2 and 3.4.3 of the chapter 3). Despite its slow growth rate and hence low biomass production, tithonia was interesting to farmers because of its high nutrient concentrations compared to other green manure crops. Typically P and K concentrations are higher in tithonia than alternative green manures and N concentrations are similar to N fixing green manure crops like sesbania.

8.1.3 Decomposition and nutrient release pattern

The most important attributes of a green manure from the farmers' perspectives are the rate of decomposition when incorporated into soils and the nutrient releasing behaviour. A double negative exponential regression model was used to interpret the relationship between i) mass loss and ii) nutrient loss against time (Section 2.3.5). The results indicated that the labile fraction of tithonia biomass decomposes faster than asuro (*A. vasica)* and bakaino (*M. azedarchta)* but the recalcitrant fraction showed no significant difference in decomposition rate amongst the species. It was also observed that mass loss was not a good indicator of nutrient release. Bakaino (*M. azedarchta)* supplies N faster and P more slowly than asuro whilst tithonia was intermediate in supplying N and P compared with these two common green manures (Sections 2.4.4, 2.4.7, 2.5.2 and 2.5.3). Farmers associate growth rate of green manures with their subsequent decomposition rates, although this was not borne out by the field trials and litterbag experiments in the present research.

The method of incorporation was the most important determining factor for both mass loss and nutrient release (Schomberg *et al.*, 1994). Surface mulching, which is not a very common practice among farmers was least effective and incorpration with irrigation the most effective practice in terms of rate of decomposition and nutrient release (Section 2.5.3).

Current farmers' practice allows a minimum of 10 to 15 days for a complete decomposition of green manure biomass before rice seedlings are transplanted. The results show that nutrients are released immediately biomass is incorporated into soil, with typically half of the nutrients released within 10 days. There is a high chance of losing plant nutrients if there is a delay between incorporation and transplanting (Beri *et al.*, 1995; Bhardwaj and Dev, 1985). Therefore, to utilise plant nutrients effectively, rice transplanting should be done on the same day as the biomass is incorporated (Bhardwaj and Dev, 1985).

Farmers may require green manures that supply plant nutrients at later stages of plant growth as well as early on. An alternative approach could be mixing slowly decomposing vegetation with tithonia so that nutrients were released gradually to match the nutrient requirements of crops. This would also help to reduce nutrient losses and improve nutrient uptake by crops. However care should be taken that an immobilisation should not take place because of concentrations of N and P occurring below the critical level in the applied biomass. The critical level for mineralisation has been considered 1.74% and 0.24% of N and P respectively (Fox *et al.*, 1990; Palm *et al.*, 1999). Therefore, an adaptive field research study would be needed to see the effect of mixing high and low quality vegetation before recommending this to farmers.

8.1.4 Fitting green manuring with tithonia into a rice and wheat crop rotation.

In situ production of green manure biomass is more common in the Terai than biomass transfer, which is restricted to areas close to forest resources to which farmers have access. In general, the fallow period is utilised to grow sufficient biomass within a limited time span after wheat is harvested and before transplanting rice. In this instance, it is possible to grow tithonia within the rice and wheat crop rotation system. However, the results indicate that the time available for biomass production is marginal. Generally, variation in the growing season for different rice and wheat varieties, and the timing of onset of the monsoon, will determine the time that is available for tithonia biomass production and hence its viability as a green manure crop.

In the wheat and rice rotation system the productivity of the rice crop was improved through the addition of tithonia green manure in the first year. The results are comparable with those for other common green manures or the addition of balanced chemical fertiliser applications (section 5.3.2). However, the results from the field experiments carried out in the last two summer seasons were inconsistent. There is evidence that the nutrients recycled through the production of tithonia may not be adequate to meet the nutrient demand of the crop, since in the second year the control plot gave a similar rice yield to the tithonia treatment. In the absence of external inputs, tithonia may have unsatisfactory biomass production and also it may exhaust plant nutrients from the soil if grown repeatedly on the same piece of land. The plant nutrients removed by crops may not be replenished through tithonia under the *in situ* green manure system. Therefore, there is a need to confirm the results by conducting a long-term experiment to understand fully the role of green manures under an *in situ* green manuring system whether this system is sustainable in the long run or not.

8.1.5 The value of tithonia alone and in conjunction with other fertilisers for improving rice productivity

The results have consistently indicated that tithonia may be a potential source of plant nutrients for increasing crop productivity of rice under biomass transfer systems. The productivity of rice fertilised with tithonia biomass was comparable with that achieved when artificial chemical fertiliser was applied at a rate of 75:10:30 kg NPK ha^{-1}. This is equivalent to 2.5 t of dry matter yield of tithonia. The efficiency of plant nutrients can be further enhanced by supplying 50% of the P from chemical fertiliser (single super phosphate). P is not a biologically fixed nutrient so cutting P requirement by 50% by supplying tithonia could be a great benefit to farmers, especially since P fertiliser is becoming increasingly expensive. The benefit of using tithonia as a fertiliser has also been reported by a number of workers both under wetland and upland conditions (Nagarajah and Nizar, 1982; Gachengo, 1999 and Jama *et al.*, 2000).

One of our hypotheses was that the productivity of rice could be improved if both sesbania and tithonia are applied together as a source of nutrients, sesbania being rich in N and tithonia rich in P. From the agronomic point of view however, the production of both green manure crops at the same time was not feasible even though under experimental conditions a beneficial effect on crop production was found. The main constraint is the different time for planting and different growth habits.

8.1.6 Source of plant nutrients and dynamics

Tithonia supplies significant quantities of all three major plant nutrients (N, P and K) to the growing rice crop to meet the demands at various critical stages of crop growth. On decomposition of the tithonia biomass, the major nutrients N, P and K are released and were detected in soil solution *in situ* and by analysis of soil samples in the laboratory. A significant relationship was also found between grain yield and total nutrient uptake, confirming that the increased yield was due to increased availability of nutrients to the growing plant. However, the rice crop responded most significantly to the applied nitrogen rather than phosphorus and potassium. Since there is a synergetic effect between these three major plant nutrients (Tisdale *et al.*, 1985) that enhances nutrient uptake and thereby improves the crop yields. Therefore, for a sustainable soil fertility management attention should be given to a balanced application of plant nutrients. In this respect tithonia is better than other common green manure crops because tithonia is rich in N, P and K nutrients.

Phosphorus was measured in the standing rice field using the routine method of Olsen-P, and the iron oxide impregnated filter paper method. Neither method measured differences in available P at different crop stages between any treatments. This could be due to the submerged conditions of the rice paddy where availability of P is enhanced due to reduction of iron and favourable change in soil pH (Ponnamperuma, 1965). The soil pH at the experimental site was towards acidic and upon flooding an increase in pH is expected which may enhance the availability of plant nutrients (section 4.4.7).

The results have indicated that N, P and K in soil decline as the growth of the rice plant progresses and such observation have been reported by many workers (Von Uexkuel, 1988) There are several possible explanations. It is true that the growing rice crop takes up nutrients; the release of nutrients from the green manure biomass decreases over time; or a substantial amount of N, P and K gets lost through leaching and denitrification of N (Tripathi *et al.*, 1997).

The results of the resin extract method have indicated that NH_4^+-N is dominant in the early stages of rice growth when the field is flooded. However, it has been observed that the moisture status in the field determines the form of N since at the later stages when the soil profile dries out NO_3^- N becomes dominant (Buresh and De Datta, 1991; Tripathi *et al.*, 1997; Shresth and Ladha, 1998). The release of N from green manure attains a maximum within 7 to 15 days after incorporation into the soil then declines steadily. Since N is an element that undergoes transformation into various forms, management of N is crucial under submerged conditions (Yavinder-Singh *et al.*, 1991). Farmers follow a split application of N with chemical fertiliser which utilises N effectively by reducing losses. Farmers have also commented that N top dressing is essential in later stages of the rice crop if the fields have been green manured.

In both years K was found significantly similar in the plot treated with tithonia compared with the plot where K was supplied from artificial fertiliser (Section 4.3.17). The availability of K in soil is generally low at the site and there are contradictory reports as to whether K is a limiting plant nutrient in the Chitwan valley or not. However under *in situ* systems a substantial improvement in the availability of K was not measured (Sections 5.3.7.3 and 5.4.5). The possible explanation could be that the experimental plots did not supply K to the growing green manure crops due to repeated cultivation of green manure on the same plots under no external input conditions. An uptake of K is dependent upon the availability from soil to the growing green manure crops. There was no indication that the green manure species have an additional benefit under *in situ* production systems for accumulating P and K nutrients from the soil system. However, there are a number of findings that leguminous green manure crops such as sesbania are well known as N fixing crops and improves soil and crop productivity even under the *in situ* production system.

8.1.7 Relay cropping of Tithonia with early maize as a green manure for rice

Relaying sesame and sesbania with spring maize as a green manure for the main season rice is found in some places under upland conditions where lack of soil moisture is one of the major constraints and early rice is not feasible, so spring maize is grown. Under a relay system farmers might have to accept some reduction in maize yield, but are often prepared to do so. The results with tithonia indicated that it was very competitive with maize when relay cropped leading to a large reduction in maize yield (section 6.4.2). The yield reduction might have been caused by N deficiency since at the later stages the symptoms of N deficiency were distinct and severe.

The productivity of rice was found to be statistically similar under *in situ* sesbania (3147 kg ha^{-1}) and tithonia (3098 kg ha^{-1}) production systems. When sesbania and tithonia were relayed with maize and the biomass was applied as green manure then the productivity of rice was 48% and 55% over the control plot respectively and was significantly higher than a control plot receiving no fertiliser additions (Section 6.4.2).

Therefore there is a doubt as to the suitability of tithonia as relay crop under maize but as a green manure for rice production it has a high potential.

8.2 Farmers perceptions and the major constraints to adoption of green manure technology

8.2.1 Farmers' knowledge

Some farmers in the study area possessed considerable knowledge about the use of green manure plants, but this varied from one location to another. Brede (1998) and Moss (2000) have collected and documented farmers' local knowledge of the use of vegetation as green manure. The majority of farm communities which migrated from the hills know about asuro (*Adhithoda vasica*), a very popular green manure in the lower hills of Nepal. But not all farmers are aware that green manure plants can be grown to increase crop production, except farmers in Western Chitwan. Farmers in Nepal more generally do have sophisticated knowledge on the fodder value of various tree and shrub species (Thapa *et al.*, 1997; Walker *et al.*, 1999; Thorne *et al.*, 1999) which might be expected to be related to nutrient content and decomposition characteristics. Unlike their knowledge of fodder, farmers have very little understanding about green manure in Terai conditions. This is partly because of the limited diversity of plants presently used as green manure in the region and the fact that green manuring is not part of the daily routine like fodder collection or feeding animals.

Farmers' strategies surrounding green manure technology are complex. Farmers consider multiple factors in adopting green manure practices. The survey conducted in the present research revealed that the major attributes that were essential to satisfy the need of farmers varied under different circumstances. However, the most important characteristics were a) decomposition properties b) the rate of nutrient release c) biomass production with minimum input level in a limited time, and d) a positive effect on crop yield (Section 7.4.19). Farmers gave priority to fitting green manure mainly into the rice-wheat system since it is their understanding that wheat generally exhausts nutrients from soil (Tripathi, 1996; Doberman *et al.*, 1996). The farmers in the terai region have developed practice to apply artificial chemical fertilisers and they expressed that if wheat is repeatedly grown without adequate plant nutrients then the productivity is declined. Besides the value of green manure for crop production, farmers like green manure to control some of the very noxious weeds such as banso (*Digitaria adscendiens*) that cannot be controlled using herbicide and cause great problems in the study area.

8.2.2 Promotional activities

Farmers in the study area were positively disposed to the use of green manure technology. But the major constraint for the promotion of green manure is the supply and distribution of seeds (Section 7.5.4). Currently a mechanism for information exchange is also completely lacking. If there is a good market opportunity then the private agencies or commercial growers can be attracted into the seed supply business, since unlike other crops, all farmers cannot produce seeds of green manure crops. This is due to the unsuitability of land, mainly poor drainage, but also because it may take longer to produce seed from the green manure crops than is possible within the usual cropping sequence. Another constraint for the promotion of green manure may be the mechanization aspect. The survey has indicated that the majority of farmers prefer tractor ploughing in order to incorporate the biomass uniformly into the field. This is not feasible using bullock drawn ploughs or manually, and it is very labour intensive which farmers would like to avoid. This would affect the uptake of green manure technology by these resource poor farming communities.

8.3 Future potential areas for further research

8.3.1 Seed research

Seed germination problems are a major constraint, particularly for tithonia and, therefore, there is a need to look into various aspects of the production strategy of seeds if *in situ* production technology is to be promoted. The right time to harvest, seed dormancy and seed viability are some of the areas to examine (Section 7.4).

8.3.2 Agronomic research

Although the results have shown that there is a negative effect on the yield of the companion crop under the relay system, there is still scope to look into the appropriate plant population combination of tithonia and maize so that an acceptable yield of maize can be obtained. The upland environment is perhaps a more appropriate location for the maize/tithonia relay system, because of the well-drained land and the adequate time for the production of biomass that can be used to green manure the main summer rice. Under these upland conditions later planting of rice is normal because of irrigation problems. Therefore, tithonia would fit better into the rice-vegetable-maize/green manure crop rotation than the rice-wheat-green manure system if a relay system were targeted. In addition, there is also a need to investigate the critical stage when tithonia and sesbania can be relayed with the maize crop with minimum negative effect on both the crops.

8.3.3 Soil research

8.3.3.1 Soil fertility

Under the submerged paddy conditions prevalent at the Terai site for most of the rice crop period, both K and P were not limiting, according to soil analysis, therefore the crops may not be limited by deficiencies of these major nutrients. However this is very much site specific and cannot be generalised, since moderate P fixing soils have been reported in the western Terai region of Nepal (Regmi, 1997a) where P is a problem. The soil of the Chitwan valley does not possess P fixing properties since it has developed from recent alluvial deposits and the texture is light with very low clay content. One of the initial hypotheses that tithonia improves P cycling by mineralising organic P remains untested on soils deficient in P and with a high P fixation capacity, which is where such an effect might be expected to be manifest. It would also be worth while testing tithonia under upland environments such as on red clay soils in the sloping terraces and *tar* (old glacier deposit river terraces) in the hills where P levels have been found problematic (Schreier *et al.*, 1999). The majority of beneficial results from using tithonia have also came from research conducted in upland environments (Gachengo *et al.*, 1999). It has been reported that soil with high P fixing properties may require a higher amount of green biomass of tithonia. Jama *et al.* (2000) recommended that a minimum 5 t dry matter per ha would be required to reduce P sorption. Regmi (1997) reported that a lower dose of phosphate fertiliser for P fixing soil might not give response in a short time. Hundal *et al.* (1988) and Vig and Chand (1993) have also reported results from the use of sesbania as green manure to improve the availability of P. As suggested by Jama *et al.* (2000) the use of tithonia for high value crops would be more profitable than for crops requiring high amount of nutrients. However for any type of soils and crops an integrated use of organic sources such as tithonia and inorganic sources would be more feasible. The results also revealed that 50% of nutrients supplied each from organic and inorganic source improved N and P use efficiency (Section 4.3.6 and 4.3.12). This practice will cut down biomass management to more realistic levels . It also has the advantage that organic sources of fertiliser maintain and improve soil health (see below).

8.3.3.2 Improvement of soil physical properties

The survey results have pointed out that green manure can be successfully fitted into the rice–wheat system in the highly productive farming system. Till now our main emphasis has been on the nutrients supplied or recycled to enhance crop productivity. But it has been well recognised that under the rice-wheat system the degradation of soil physical properties is problematic since the puddling of rice soil leads to the breakdown of soil aggregates, resulting in reduced pore sizes and the formation of a plough pan (Hobbs and Morris, 1996). This causes an adverse effect mostly for other crops in the rotation following the rice. Therefore, there might be scope to use green manure crops to improve the physical properties of soil, because green manure crops supply large amounts of organic matter and thereby improve physical properties of soil (Bouldin, 1988). In addition to this the green manure crops with a tap root system may have an ability to penetrate the plough-pan and improve soil aeration. Research on selected green manure species that develop strong vertical roots is merited.

8.3.4 Screening of green manure species to meet diverse agroecological and socio-economic requirements

Green manure crop species are available that suit different land types and climatic conditions. Ali and Narciso (1994) reported some green manure species such as indigo (*Indigofera tinctoria*) do not suit waterlogged conditions and therefore are popular in the upland environment in the North Philippines, sunn hemp (*Crotolaria juncea*) and kolonji (*Tephrosia purpurea*) are drought tolerant and popular in Southern India. Sunn hemp is also suitable for very clayey soil (Ali and Narciso, 1994). Most of the sesbania species are considered to be suitable under low external input conditions. Therefore, given the heterogeneity of farm circumstances in the Terai, there is a need to increase the diversity of green manure crops in the terai environment. In an initial farm trial, rice bean was most popular amongst farmers in Terai as it is in the hills. Farmers appear to be attracted more towards the green manure crops that may have green manure value as well as grain production as well. There might be scope for winter green manure crops since so far our attempt have been restricted to summer green manure crops. Milk vetch (*Astragalus sinicus*) could be a candidate for introduction as a winter green manure crop to South East Asia including the terai region of Nepal (Shanti Bhattarai personal communication). This may help to utilise the winter fallow land for more productive use.

8.3.5 No till system for green manure crops

Farmers have pointed out that land preparation is one of the constraints for the promotion of green manure crop because of the additional cost incurred. Therefore farmers are reluctant to invest extra money for land preparation. Research to identify a specific cropping system or a niche where the no till system could be utilised could be a valuable innovation. For example lentil is relayed with rice under a no till system when land preparation for a winter crop is not feasible due to excessive moisture in the field and planting of lentil (*Lens culinaris*) becomes too late if planted after rice harvest. This practice is already popular in the terai region of Nepal and northern part of India.

8.3.6 Phytotoxic and allelopathic effects of tithonia on soil

There are reports that on decomposition *Tithonia diversifolia* liberates some organic compounds (sesquiterpene lactones and secondary metabolites) that have a negative effect on the seed germination of some vegetables (cucurbits, radish) and cereal crops (Baruah *et al.*, 1994; Tongma *et al.*, 1998). Tithonia may also affect if immediate planting of rice seedlings after biomass incorporation. If the level or degree of toxicity were very high, tithonia would not be a useful plant to promote. But it may also have a positive effect in controlling soil nematodes, which could be beneficial. Soil nematodes are a problem in the Chitwan valley (Ramesh Pokhrel, Senior Lecturer, Institute of Agriculture and Animal Science, Rampur Chitwan, personal communication) and therefore there is a need to confirm these effects under field conditions.

8.3.7 On-farm participatory research

The participatory research approach has been proved to be very cost effective and efficient (Joshi, 2000). The first year of the on farm trial was not conclusive and use of tithonia and other alternative species in the Terai is still young. Therefore, it would be appropriate to get feedback from a wider set of farming communities through farmer testing of various green manure species and options. This might usefully be done as a joint venture with the District Agriculture Development Office.

In conclusion, the introduction of *Tithonia diversifolia* has increased the diversity of green manure plants in the area and stimulated research on green manure more generally. The field experiments have shown a high potential value of tithonia biomass to fertilise crops. While there are possible niches for using tithonia as an *in situ* green manure crop in the complex cropping patterns of the terai it is more likely to be useful grown on stream banks and roadsides for biomass transfer. For this purpose a joint action programme with the farm communities could be established. However there is need to be looked upon the economic feasibility of the system.

Tithonia could also be more advantageous in the hilly region of Nepal where it can be introduced as a contour hedgerow species on the sloping agricultural fields, or on terrace risers to capture nutrients that would otherwise run-off or be leached. Compared to the high production potential system, in the hills the land competition is less. There is also a long fallow period and intensity of cropping is low due to unavailability of moisture. In addition due to lack of transportation facility in the hills there is still the consumption of chemical fertiliser is very low compared the areas where transportation is not a problem. Therefore there is likely to be potential scope to promote the tithonia as a green manure plant in the hills.

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Appendix 2.1a: Skeleton of ANOVA for the split plot experiment.

Source of variation	d.f.	s.s.	m.s.	v.r.	F. pr
1. Reps	3				
2. Main plot	2				
3. Residual	6				
3. Sub plot	3				
4. Main plot*Sub plot	6				
5. Residual	27				
6. Total	47				

Appendix 2.1b: Skeleton of ANOVA for the double exponential regression.

Source of variation	**d.f.**	**s.s.**	**m.s.**	**F**	**P**
Regression	**3**				
Residual	**3**				
Total	**6**				

Appendix 2.2a: Coefficients of double exponential regression lines between mass remaining % and time.

Species			**Surface mulch (M1)**			
Coefficient	f_l	$k_l t$	f_r	$k_r t$	r^2	F test
Tithonia leaves	39.0516	0.4126	61.8293	0.0033	0.94	***
Tithonia leaves+stems	33.2366	0.4721	66.8468	0.0037	0.99	***
Asuro leaves	23.562	1.7881	76.4378	0.0042	0.99	***
Bakaino leaves	19.71	0.3592	79.9483	0.0068	0.97	***
Species			**Ploughed in, dry (M2)**			
Coefficient	f_l	$k_l t$	f_r	$k_r t$	r^2	
Tithonia leaves	57.879	0.1327	43.6099	0.0028	0.98	***
Tithonia leaves+stems	24.4712	0.9898	72.5687	0.0085	0.95	***
Asuro leaves	27.4483	0.4117	72.1573	0.0078	0.98	***
Bakaino leaves	44.8758	0.1040	52.8756	0.0034	0.98	***
Species			**Ploughed in, paddy (M3)**			
Coefficient	f_l	$k_l t$	f_r	$k_r t$	r^2	
Tithonia leaves	44.529	0.2844	55.8809	0.0061	0.94	***
Tithonia leaves+stems	34.4434	0.7027	65.5462	0.0079	0.99	***
Asuro leaves	21.3223	1.4087	78.6833	0.0100	0.98	***
Bakaino leaves	49.6912	0.124	47.3818	0.0035	0.96	***

Note:- $p \leq 0.001$ = ***

Appendix 2.2b: Coefficients of double exponential regression curves between of mass of N remaining % and time.

Species			Surface mulch (M1)			
Coefficient	f_l	$k_l t$	f_r	$k_r t$	r^2	F test
Tithonia leaves	25.7219	0.3881	75.5253	0.0045	0.83	***
Tithonia leaves+stems	27.0402	0.2385	73.002	0.0033	0.94	***
Asuro leaves	30.0737	0.7623	69.7521	0.0048	0.93	***
Bakaino leaves	25.2238	1.1869	74.7652	0.0056	0.98	***
Species			**Ploughed in, dry (M2)**			
Coefficient	f_l	$k_l t$	f_r	$k_r t$	r^2	
Tithonia leaves	67.7481	0.0896	37.419	0 .000	0.93	***
Tithonia leaves+stems	24.7988	0.0831	72.0012	0.0076	0.91	***
Asuro leaves	38.6113	0.3353	61.7476	0.0059	0.96	***
Bakaino leaves	58.0591	0.0954	36.6977	0.0032	0.92	***
Species			**Ploughed in, paddy (M3)**			
Coefficient	f_l	$k_l t$	f_r	$k_r t$	r^2	
Tithonia leaves	57.4544	0.1274	45.4186	0.0066	0.97	***
Tithonia leaves+stems	23.5778	1.2300	76.4381	0.0106	0.90	***
Asuro leaves	27.3669	18.9227	72.6325	0.0133	0.86	***
Bakaino leaves	42.7661	0.1971	54.4771	0.0128	0.97	***

Note:- $p \leq 0.001$ = ***

Appendix 2.2c: Coefficients of double exponential regression curves between mass of P remaining % and time.

Species			Surface mulch (M1)			
Coefficient	f_l	$k_l t$	f_r	$k_r t$	r^2	F test
Tithonia leaves	36.1754	0.5197	64.5585	0.0015	0.72	***
Tithonia leaves+stems	43.4065	0.4146	56.1996	0.0002	0.58	NS
Asuro leaves	52.4921	171.7361	47.5076	0.0016	0.97	***
Bakaino leaves	11.1823	104.5162	88.8177	0.0038	0.48	NS
Species			**Ploughed in, dry (M2)**			
Coefficient	f_l	$k_l t$	f_r	$k_r t$	r^2	
Tithonia leaves	43.5874	0.1365	57.2994	-0.0015	0.50	NS
Tithonia leaves+ stems	26.4257	52.886	73.5743	0.0044	0.91	***
Asuro leaves	51.3511	1.0947	48.6516	0.0012	0.93	***
Bakaino leaves	32.0611	0.0022	60.0492	0.002	0.45	NS
Species			**Ploughed in, paddy (M3)**			***
Coefficient	f_l	$k_l t$	f_r	$k_r t$	r^2	
Tithonia leaves	44.1332	0.1906	57.2458	0.0071	0.89	***
Tithonia leaves+ stems	28.768	46318958	71.232	0.01	0.92	***
Asuro leaves	45.8053	20.1856	54.1945	0.0097	0.86	***
Bakaino leaves	42.9643	0.0144	48.2991	0.0064	0.88	***

Note:- $p \leq 0.001$ = ***, $p > 0.05$ and ns = non significant

Appendix 2.2d: Coefficients of double exponential regression curves for C:P ratios.

Species			Surface mulch (M1)			
Coefficient	f_l	$k_l t$	f_r	$k_r t$	r^2	F test
Tithonia leaves	31.39	.038	89.560	000	.76	NS
Tithonia leaves+stems	NAc					
Asuro leaves	91.00	.0034	125.91	.0033	.50	NS
Bakaino leaves	56.37	.0768	114.43*	000	.02	NS
Species			**Ploughed in, dry (M2)**			
Coefficient	f_l	$k_l t$	f_r	$k_r t$	r^2	
Tithonia leaves	5074	2.63	91.99	.0073	.87	NS
Tithonia leaves+stems	53.02	.070	86.42	000	.78	NS
Asuro leaves	66.35	.053	147.17	.0045	.91	*
Bakaino leaves	129.3	.146	71.51	71.50	.88	NS
Species			**Ploughed in, paddy (M3)**			
Coefficient	f_l	$k_l t$	f_r	$k_r t$	r^2	
Tithonia leaves	38.71	00	51.81	00		
Tithonia leaves+stems	6957	2.68	102.5	00	.65	NS
Asuro leaves	402.9	.897	179.06	.006	.97	**
Bakaino leaves	89.10	.176	95.7	00	.95	*

Note:- $p \leq 0.001$ = ***, ns = non significant ($p > 0.05$)

Appendix 2.3: Mean weight remaining (%) for each vegetation type/incorporation combination and summary of anova results.

Mass of vegetation remaining	Day_2	Day_5	**Day_10**	Day_30	Day_60	Day_90
Method X Species						
M1 Leaves Tithonia	81.7	62.1	58.0	61.7	50.7	44.5
M1 Leaves+ stem Tithonia	79.6	68.5	63.4	61.3	54.2	46.7
M1 Leaves Asuro	76.4	76.1	73.0	66.1	58.2	53.3
M1 Leaves Bakaino	87.6	80.6	78.1	61.7	52.8	44.6
M2 Leaves Tithonia	91.5	69.4	59.2	39.6	39.3	32.6
M2 Leaves+ stem Tithonia	75.6	66.1	72.4	52.9	43.5	35.0
M2 Leaves Asuro	81.6	75.0	67.0	56.7	42.7	37.9
M2 Leaves Bakaino	85.1	79.7	67.6	50.4	41.3	39.7
M3 Leaves Tithonia	80.6	67.8	48.9	52.7	36.2	32.0
M3 Leaves+ stem Tithonia	72.9	64.3	59.8	51.8	42.6	30.7
M3Leaves Asuro	78.2	78.6	67.9	56.8	43.7	32.5
M3 Leaves Bakaino	82.1	70.6	65.3	41.3	39.5	34.4
F test	ns	ns	ns	ns	ns	ns
s.e.m	5.06	3.84	5.49	4.53	3.81	3.05
s.e.d.	7.15	5.44	11.17	6.40	5.39	4.31
l.s.d	14.0	11.06	12.3	13.03	11.05	8.77
Incorporation method						
M1 (surface mulch)	81.3	71.8	68.1	62.7	54	47.3
M2 (ploughed in, non-irrigated)	83.5	72.6	66.6	49.9	41.7	36.3
M3 (ploughed in, paddy)	78.4	70.3	60.5	50.7	40.5	32.4
F test	ns	ns	*	***	***	***
s.e.m	2.76	1.65	1.76	1.62	2.23	1.46
s.e.d.	3.91	2.34	2.49	2.29	3.16	2.07
l.s.d	9.56	5.72	6.08	5.6	7.72	5.06
cv%	6.8	4.6	5.4	5.9	9.8	7.6
Vegetation types						
Tithonia leaves	84.6	66.4	55.4	51.3	42.1	36.3
Tithonia leaves+ stems	76.0	66.3	65.2	55.3	46.8	37.5
Asuro leaves	78.8	76.6	69.3	59.9	48.2	41.2
Bakaino leaves	84.9	77.0	70.3	51.1	44.5	39.6
F test	ns	***	***	ns	ns	ns
s.e.m	2.82	2.31	2.31	2.82	2.06	1.78
s.e.d.	3.99	3.27	3.26	3.98	2.92	2.52
l.s.d	9.19	6.71	6.7	8.18	5.98	5.17
cv%	12.10	12.00	12.30	17.90	15.70	16.00

Note: M1 = Surface mulch, M = Ploughed in non-irrigated and M3 = ploughed in paddy

s.e.m = Standard error of means   ns = Non significant ($p>0.05$)

s.e.d. = Standard error of difference   * = ($p\leq0.05$)

l.s.d. = Least significant difference (0.05)   ** = ($p\leq0.01$)

c.v. = Coefficient of variance   *** = ($p\leq0.001$)

Appendix 2.4: Mean of N concentration (%) of the vegetation samples left in the litterbags and summary of anova results.

N concentration %	Day_2	Day_5	Day_10	Day_30	Day_60	Day_90
Method X Species						
M1 Leaves Tithonia	4.43	4.32	4.14	4.41	4.16	3.83
M1 Leaves+ stem Tithonia	3.17	3.55	3.11	3.2	3.06	3.32
M1 Leaves Asuro	4.74	4.74	4.09	4.58	4.27	4.26
M1 Leaves Bakaino	4.15	4.47	4.25	7.77	4.72	5.02
M2 Leaves Tithonia	4.22	4.35	3.82	3.47	4.15	3.83
M2 Leaves+ stem Tithonia	3.37	3.52	3.66	2.97	3.24	2.84
M2 Leaves Asuro	4.87	4.38	4.14	4.91	4.58	4.85
M2 Leaves Bakaino	4.16	4.65	4.18	3.34	3.69	3.26
M3 Leaves Tithonia	4.39	4.08	3.97	2.95	2.85	2.89
M3 Leaves+ stem Tithonia	3.03	3.11	3.15	3.80	2.54	2.53
M3Leaves Asuro	3.95	5.00	4.03	4.61	3.58	2.79
M3 Leaves Bakaino	4.46	4.71	4.17	4.04	2.98	2.64
F test	*	ns	ns	ns	ns	***
s.e.m	0.1915	0.193	0.260	0.3822	0.2756	0.2942
s.e.d.	0.2708	0.2729	0.368	0.5400	0.3897	0.4160
l.s.d	0.5539	0.5574	0.75		0.7938	0.8534

Incorporation method						
M1 (surface mulch)	4.12	4.27	3.90	4.24	4.09	4.11
M2 (ploughed in, non-irrigated)	4.16	4.22	3.95	3.67	3.91	3.69
M3 (ploughed in, paddy)	3.95	4.22	3.83	3.85	2.98	2.69
F test	ns	ns	ns	ns	***	***
s.e.m	0.1095	0.1062	0.0808	0.2788	0.1379	0.1766
s.e.d.	0.1549	0.1502	0.1140	0.3943	0.1950	0.2490
l.s.d	0.3790	0.376	0.2796	1.0926	0.4773	0.6100
cv%	5.4000	5.000	4.2000	28.4500	7.6000	10.000
Vegetation types						
Tithonia leaves	4.35	4.25	3.98	3.61	3.72	3.52
Tithonia leaves+ stems	3.19	3.39	3.31	3.32	2.95	2.86
Asuro leaves	4.52	4.71	4.08	4.70	4.14	3.97
Bakaino leaves	4.25	4.61	4.20	4.05	3.79	3.64
F test	***	***	***	***	***	***
s.e.m	0.1047	0.1070	0.1650	0.0487	0.159	0.1568
s.e.d.	0.1481	0.1519	0.2330	0.312	0.2249	0.2218
l.s.d	0.2708	0.3117	0.4787	0.848	0.4615	0.4550
cv%	8.9000	8.8000	14.6000	19.5	15.5	15.500

Note: M1 = Surface mulch, M2 = Ploughed in non-irrigated and M3 = Ploughed in paddy
s.e.m = Standard error of means ns = Non significant ($p>0.05$)
s.e.d. = Standard error of difference * = ($p\leq0.05$)
l.s.d. = Least significant difference (0.05) ** = ($p\leq0.01$)
c.v. = Coefficient of variance *** = (≤0.001)

Appendix 2.5: Mean mass of N remaining (%) for each vegetation types/incorporation method combination and summary of anova results.

N mass remaining %	Day_2	Day_5	Day_10	Day_30	Day_60	Day_90
Method X Species						
M1 Leaves Tithonia	90.7	74.2	66.8	75.2	58.1	46.9
M1 Leaves+ stem Tithonia	88.4	83.3	68.8	69.3	58.9	54.3
M1 Leaves Asuro	74.3	74.2	61.1	62.2	50.8	46.2
M1 Leaves Bakaino	76.1	75.4	69.5	61.3	52.2	46.8
M2 Leaves Tithonia	100.0	83.0	62.6	37.5	44.7	34.2
M2 Leaves+ stem Tithonia	89.0	80.2	85.0	55.1	49.6	34.8
M2 Leaves Asuro	81.6	67.5	56.2	56.9	39.9	37.2
M2 Leaves Bakaino	73.7	77.6	58.8	35.0	31.8	27.1
M3 Leaves Tithonia	93.4	76.1	53.9	41.5	28.5	25.7
M3 Leaves+ stem Tithonia	77.1	68.7	66.6	60.9	37.0	26.5
M3Leaves Asuro	62.9	80.9	56.0	53.2	32.3	20.0
M3 Leaves Bakaino	75.9	69.7	56.3	35.0	23.9	19.4
F test	ns	ns	ns	ns	ns	Ns
s.e.m	4.33	5.43	4.64	6.03	4.10	3.155
s.e.d.	6.12	7.68	6.56	8.53	5.80	4.462
l.s.d	12.50	15.64	1.35	17.50	11.81	9.141
Incorporation method						
M1 (surface mulch)	82.4	76.8	66.6	67.0	55.0	48.6
M2 (ploughed in, non-irrigated)	86.1	77.1	65.7	46.1	41.5	33.3
M3 (ploughed in, paddy)	77.3	73.8	58.2	47.6	30.4	22.9
F test	***	ns	*	*	***	***
s.e.m	1.04	2.06	1.74	3.64	1.61	1.859
s.e.d.	1.47	2.92	2.46	5.15	2.27	2.629
l.s.d	3.59	7.14	6.01	12.61	5.56	5.434
cv %	2.10	5.40	5.50	13.60	7.60	10.60
Vegetation types						
Tithonia leaves	94.8	77.8	61.1	51.4	43.8	35.6
Tithonia leaves+ stems	84.8	77.4	73.5	61.8	48.5	38.5
Asuro leaves	72.9	74.2	57.8	57.4	41.0	34.5
Bakaino leaves	75.2	74.2	61.6	43.8	36	31.1
F test	***	ns	***	***	**	*
s.e.m	2.80	3.35	2.87	3.20	2.52	1.699
s.e.d.	3.96	4.74	4.06	4.53	3.56	2.403
l.s.d	8.13	9.72	8.32	9.30	7.30	4.931
cv %	11.80	15.30	15.60	20.70	20.60	16.800

Note: M1 = Surface mulch, M2 = Ploughed in non-irrigated and M3 = Ploughed in paddy

s.e.m = Standard error of means ns = Non significant ($p>0.05$)

s.e.d. = Standard error of difference * = ($p\leq0.05$)

l.s.d. = Least significant difference (.05) ** = ($p\leq0.01$)

c.v. = Coefficient of variance *** = (≤0.001)

Appendix 2.6: Mean concentration of P (%) of the vegetation samples left in the litterbags and summary of anova results.

P concentration %	Day_2	Day_5	Day_10	Day_30	Day_60	Day_90
Method X Species						
M1 Leaves Tithonia	0.361	0.359	0.357	0.417	0.451	0.415
M1 Leaves+ stem Tithonia	0.303	0.321	0.248	0.363	0.272	0.417
M1 Leaves Asuro	0.195	0.221	0.225	0.231	0.231	0.274
M1 Leaves Bakaino	0.286	0.345	0.270	0.472	0.362	0.387
M2 Leaves Tithonia	0.349	0.459	0.385	0.490	0.726	0.645
M2 Leaves+ stem Tithonia	0.309	0.364	0.320	0.417	0.463	0.417
M2 Leaves Asuro	0.226	0.219	0.222	0.337	0.334	0.394
M2 Leaves Bakaino	0.279	0.367	0.363	0.544	0.586	0.530
M3 Leaves Tithonia	0.414	0.430	0.358	0.378	0.335	0.329
M3 Leaves+ stem Tithonia	0.302	0.360	0.341	0.398	0.322	0.251
M3Leaves Asuro	0.181	0.268	0.245	0.254	0.249	0.201
M3 Leaves Bakaino	0.288	0.347	0.354	0.489	0.372	0.307
F test	ns	ns	ns	ns	***	***
s.e.m	0.02167	0.0222	0.0245	0.0449	0.03626	0.02928
s.e.d.	0.03067	0.3147	0.03464	0.0635	0.05128	0.04141
l.s.d	0.06290	0.0647	0.07045	0.1292	0.01058	0.08439
Incorporation method						
M1 (surface mulch)	0.2864	0.3114	0.2749	0.371	0.3290	0.3733
M2 (ploughed in, non-irrigated)	0.2907	0.352	0.3225	0.447	0.5272	0.4962
M3 (ploughed in, paddy)	0.2962	0.3515	0.3244	0.380	0.3197	0.2722
F test	ns	ns	*	*	***	***
s.e.m	0.0130	0.0139	0.0098	0.0173	0.02346	0.01490
s.e.d.	0.0185	0.0197	0.0139	0.0245	0.03318	0.02115
l.s.d	0.0453	0.0483	0.0341	0.0599	0.08118	0.05174
cv%	9.0000	8.0000	6.4000	8.7000	12.00000	7.90000
Vegetation types						
Tithonia leaves	0.375	0.416	0.367	0.428	0.504	0.463
Tithonia leaves+ stems	0.305	0.349	0.303	0.393	0.352	0.362
Asuro leaves	0.201	0.236	0.231	0.274	0.271	0.290
Bakaino leaves	0.285	0.353	0.329	0.502	0.440	0.408
F test	***	***	***	***	***	***
s.e.m	0.0115	0.01150	0.01495	0.0276	0.0184	0.01679
s.e.d.	0.0163	0.01633	0.02114	0.0390	0.0260	0.02374
l.s.d	0.0340	0.03350	0.04335	0.0810	0.0538	0.04871
cv%	13.700	11.80000	16.90000	24.0000	16.3000	15.30000

Note: M1 = Surface mulch, M2 = Ploughed in non-irrigated and M3 = Ploughed in paddy

s.e.m = Standard error of means	ns	=	Non significant ($p>0.05$)
s.e.d. = Standard error of difference	*	=	($p\leq0.05$)
l.s.d. = Least significant difference	**	=	($p\leq0.01$)
c.v. = Coefficient of variance	***	=	(≤0.001

Appendix 2.7: Mean weight of P remaining (%) for each vegetation type/incorporation method combination and summary of anova results.

Weight of P remaining %	Day_2	Day_5	Day_10	Day_30	Day_60	Day_90
Method X Species						
M1 Leaves Tithonia	80.4	61.8	57.7	71.8	63.1	51.0
M1 Leaves+stem Tithonia	73.1	66.8	47.5	68.9	44.4	59.2
M1 Leaves Asuro	44.2	49.4	48.8	45.5	40.1	43.0
M1 Leaves Bakaino	85.0	92.2	75.4	100.0	68.0	60.6
M2 Leaves Tithonia	88.7	87.5	63.4	53.3	78.6	57.9
M2 Leaves+stem Tithonia	70.6	71.5	69.7	67.7	61.6	44.4
M2 Leaves Asuro	54.3	48.2	44.2	54.1	42.5	43.7
M2 Leaves Bakaino	81.4	95.7	85.2	88.9	84.7	74.0
M3 Leaves Tithonia	86.5	80.1	49.2	53.6	34.2	30.5
M3 Leaves+ stem Tithonia	66.4	68.9	61.7	61.3	39.9	23.7
M3Leaves Asuro	41.5	62.8	49.4	42.1	31.5	19.9
M3 Leaves Bakaino	81.8	85.6	80.3	70.7	50.6	38.6
F test	ns	ns	ns	ns	ns	ns
s.e.m	6.17	5.15	6.39	8.05	5.87	4.85
s.e.d.	8.72	7.29	9.04	11.39	8.30	6.87
l.s.d	18.20	14.82	18.38	23.2	16.91	14.02
cv%						
Incorporation method						
M1 (surface mulch)	70.7	67.5	57.4	72.1	53.9	53.5
M2 (ploughed in, non-irrigated)	73.8	75.7	65.6	66.0	66.9	55.0
M3 (ploughed in, paddy)	69.1	74.4	60.1	56.9	39.0	28.2
F test	NS	NS	NS	**	***	***
s.e.m	4.33	2.29	2.68	2.61	3.03	2.69
s.e.d.	6.13	3.24	3.80	3.69	4.29	3.80
l.s.d	15.00	7.92	9.29	9.02	10.5	9.31
cv%	12.20	6.30	8.80	8.00	11.4	11.80
Vegetation types						
Tithonia leaves	85.2	76.5	56.7	59.5	58.7	46.4
Tithonia leaves+ stems	70.1	69.0	59.7	66.0	48.6	42.4
Asuro leaves	46.7	53.5	47.5	47.2	38.0	35.5
Bakaino leaves	82.7	91.2	80.3	87.2	67.8	57.7
F test	***	***	***	***	***	***
s.e.m	2.93	3.08	3.86	5.08	3.35	2.69
s.e.d.	4.14	4.35	5.47	7.18	4.73	3.81
l.s.d	8.49	8.93	11.21	14.74	9.71	7.82
cv%	14.30	14.70	21.90	27.10	21.80	20.50

Note: M1 = Surface mulch, M2 = Ploughed in non-irrigated and M3 = Ploughed in paddy

s.e.m = Standard error of means ns = Non significant ($p>0.05$)
s.e.d. = Standard error of difference * = ($p\leq0.05$)
l.s.d. = Least significant difference (.05) ** = ($p\leq0.01$)
c.v. = Coefficient of variance *** = (≤0.001)

Appendix 2.8: Mean of C/N ratios for each vegetation type/incorporation combination and summary of anova results.

C/N ratios	Day_2	Day_5	Day_10	Day_30	Day_60	Day_90
Method X Species						
M1 Leaves Tithonia	9.4	9.8	9.5	9.3	9.4	10.1
M1 Leaves+stem Tithonia	13.2	13.5	12.5	12.8	13.4	12.2
M1 Leaves Asuro	9.6	9.3	10.0	9.5	10.0	10.0
M1 Leaves Bakaino	11.0	10.5	10.0	9.4	9.3	9.0
M2 Leaves Tithonia	9.6	9.14	9.1	8.9	9.2	9.0
M2 Leaves+stem Tithonia	12.4	11.6	10.7	12.2	11.6	13.1
M2 Leaves Asuro	8.9	10.1	9.3	8.2	8.5	7.8
M2 Leaves Bakaino	10.7	9.33	9.7	11.0	11.0	11.8
M3 Leaves Tithonia	9.3	9.5	8.6	9.0	10.1	10.2
M3 Leaves+*stem* Tithonia	13.7	11.4	10.7	10.9	13.0	12.2
M3Leaves Asuro	11.2	9.0	9.8	8.6	7.9	7.6
M3 Leaves Bakaino	10.1	9.7	9.4	10.3	12.2	11.1
F test	ns	ns	ns	*	***	***
s.e.m	0.506	0.458	0.428	0.468	0.462	0.446
s.e.d.	0.716	0.648	0.606	0.662	0.653	0.630
l.s.d	1.461	1.319	1.233	1.347	1.347	1.290
Incorporation method						
M1 (surface mulch)	10.8	10.8	10.5	10.2	10.5	10.3
M2 (ploughed in, non-irrigated)	10.4	10	9.7	10.1	10.1	10.5
M3 (ploughed in, paddy)	11	9.9	9.6	9.7	10.8	10.3
F test	ns	ns	*	ns	ns	ns
s.e.m	0.276	0.231	0.166	0.197	0.295	0.260
s.e.d.	0.391	0.326	0.235	0.278	0.418	0.367
l.s.d	0.957	0.798	0.575	0.681	1.022	0.899
cv%	5.100	4.500	3.300	3.900	5.600	5.000
Vegetation types						
Tithonia leaves	9.4	9.4	9.1	9.1	9.6	9.8
Tithonia leaves+ stems	13.1	12.2	11.3	11.9	12.7	12.5
Asuro leaves	9.9	9.5	9.7	8.8	8.8	8.5
Bakaino leaves	10.6	9.8	9.7	10.2	10.8	10.7
F test	***	***	***	***	***	***
s.e.m	0.283	0.264	0.263	0.283	0.237	0.241
s.e.d.	0.400	0.373	0.372	0.401	0.335	0.341
l.s.d	0.820	0.765	0.764	0.822	0.688	0.700
cv%	9.100	8.900	9.100	9.800	7.800	8.000

Note: M1 = Surface mulch, M 2 = Ploughed in non-irrigated and M3 = Ploughed in paddy
s.e.m = Standard error of means ns = Non significant ($p>0.05$)
s.e.d. = Standard error of difference * = ($p\leq0.05$)
l.s.d. = Least significant difference (.05)** = ($p\leq0.01$)
c.v. = Coefficient of variance *** = ($p\leq0.001$)

Appendix 2.9: Mean of C/P ratio for each vegetation type/incorporation method combination and summary of anova results.

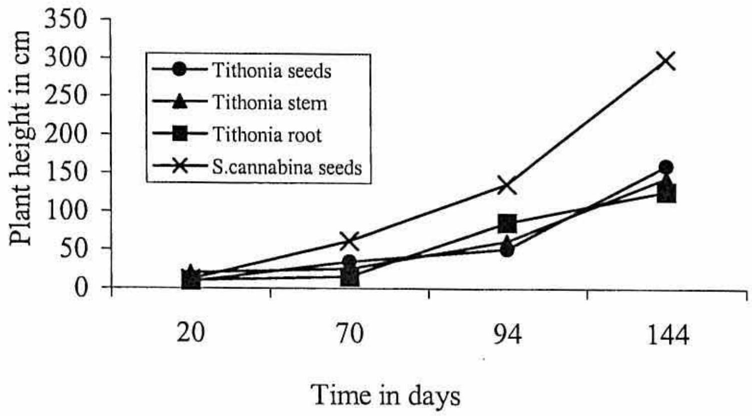
C/P ratios	Day_2	Day_5	Day_10	Day_30	Day_60	Day_90
Method X Species						
M1 Leaves Tithonia	115	119	110	101	87	94
M1 Leaves+stem Tithonia	140	153	159	115	150	101
M1 Leaves Asuro	231	200	205	191	188	155
M1 Leaves Bakaino	163	138	164	96	124	118
M2 Leaves Tithonia	117	87	92	67	54	54
M2 Leaves+stem Tithonia	136	114	119	91	82	91
M2 Leaves Asuro	196	208	177	136	121	96
M2 Leaves Bakaino	172	118	112	69	69	73
M3 Leaves Tithonia	100	90	96	65	89	101
M3 Leaves+ stem Tithonia	135	99	98	98	103	112
M3Leaves Asuro	243	177	163	155	112	100
M3 Leaves Bakaino	158	132	111	90	97	99
F test	ns	ns	ns	ns	*	*
s.e.m	13.46	12.19	16.02	14.29	9.52	10.21
s.e.d.	13.64	17.23	22.66	20.21	13.46	14.44
l.s.d	38.19	35.15	46.25	41.45	27.39	29.48
Incorporation method						
M1 (surface mulch)	162	153	160	126	137	117
M2 (ploughed in, non-irrigated)	155	132	125	91	81	78
M3 (ploughed in, paddy)	159	125	117	102	100	103
F test	ns	*	***	ns	***	***
s.e.m	7.55	6.43	4.29	8.57	3.84	2.54
s.e.d.	10.68	9.10	6.07	12.13	5.43	3.59
l.s.d	26.14	22.26	14.84	29.67	13.29	8.79
cv%	9.50	9.40	6.40	16.10	7.20	5.10
Vegetation type						
Tithonia leaves	111	99	99	77	77	83
Tithonia leaves+stems	137	122	126	101	112	101
Asuro leaves	234	195	182	160	140	117
Bakaino leaves	165	130	129	85	97	96
F test	***	***	***	***	***	**
s.e.m	7.43	6.9	10.29	7.67	5.81	6.59
s.e.d.	10.51	9.76	12.56	10.78	8.21	9.32
l.s.d	21.56	20.02	29.87	22.11	16.85	19.13
cv%	16.20	17.50	26.60	24.80	18.90	22.90

Note: M1 = Surface mulch, M 2 = Ploughed in non-irrigated and M3 = Ploughed in paddy
s.e.m = Standard error of means ns = Non significant ($p>0.05$)
s.e.d. = Standard error of difference * = ($p\leq0.05$)
l.s.d. = Least significant difference (0.05) ** = ($p\leq0.01$)
c.v. = Coefficient of variance *** = ($p\leq0.001$)

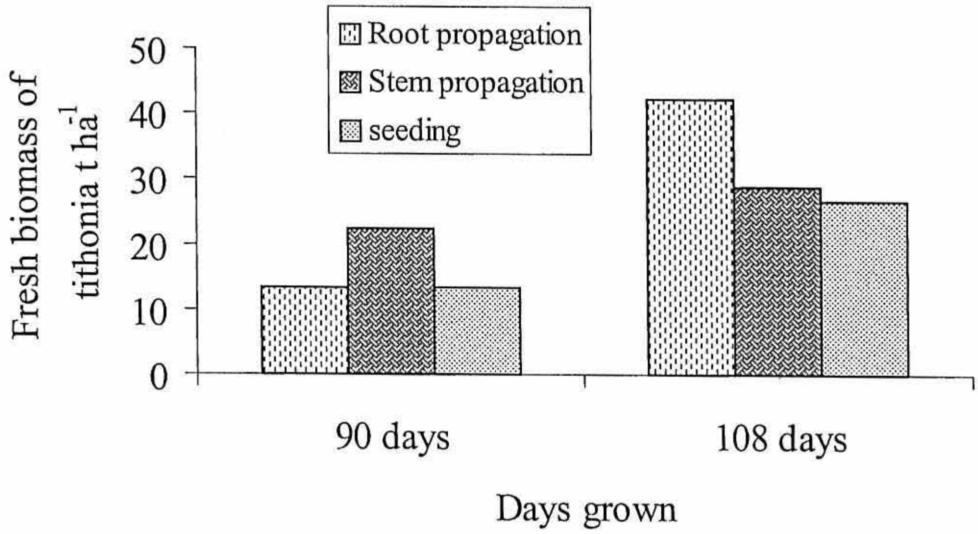
Appendix 2. 10: Standard error for the C/N ratios of the green manure samples and method of incorporation

	Tithonia leaves	Tithonia leaves	Tithonia leaves
Days	**Method_1**	**Method_2**	**Mehtod_3**
2	0.320	0.392	0.052
5	0.227	0.340	0.485
10	0.288	0.374	0.171
30	0.526	0.160	0.634
60	0.351	0.240	0.395
90	0.120	0.133	0.212
	Tithonia leaves+stems	Tithonia leaves+stems	Tithonia l eaves+stems
	Method_1	**Method_2**	**Method_3**
2	0.677	0.531	0.992
5	0.738	0.854	0.373
10	0.473	0.963	0.291
30	0.409	0.668	0.577
60	0.785	0.476	0.725
90	0.543	0.852	0.753
	Bakaino leaves	Bakaino leaves	Bakaino leaves
	Method_1	**Method_2**	**Method_3**
2	0.556	0.097	0.434
5	0.484	0.406	0.289
10	0.277	0.654	0.243
30	0.592	0.386	0.460
60	0.409	0.371	0.294
90	0.569	0.348	0.234
	Asuro leaves	Asuro leaves	Asuro leaves
	Method_1	**Method_2**	**Method_3**
2	0.220	0.425	0.406
5	0.309	0.086	0.095
10	0.148	0.274	0.252
30	0.351	0.122	0.128
60	0.320	0.159	0.299
90	0.142	0.102	0.306

M1 = Surface mulch (non irrigated)
M2= Ploughed in incorporation (non irrigated)
M3= Ploughed in, paddy incorporation (irrigated daily)

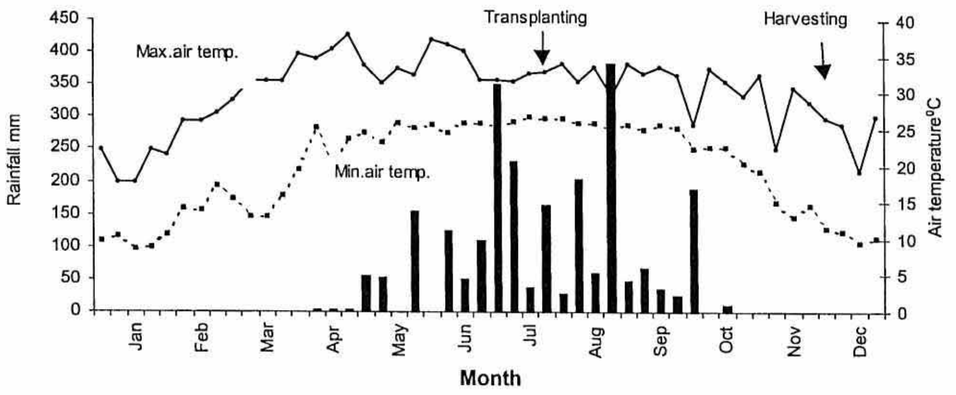


Appendix 3.1: Plant height measured at different time intervals for the different propagation methods

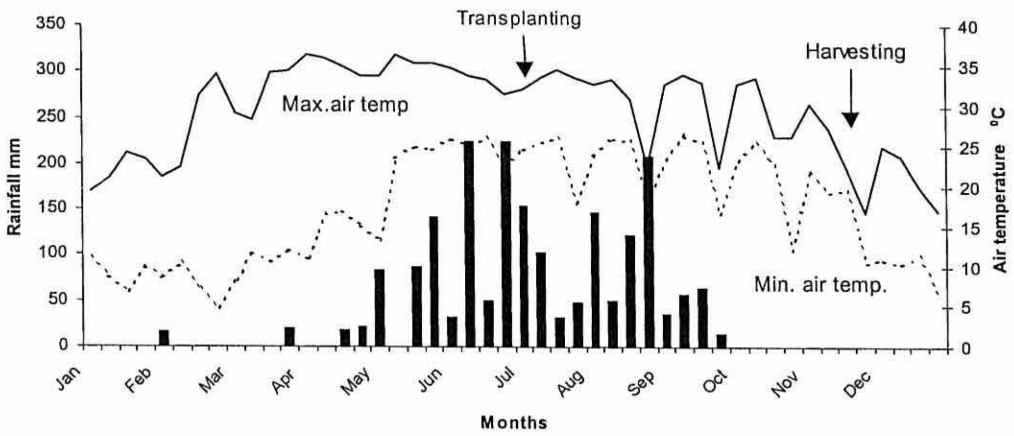


Appendix 3.2: Fresh biomass production of tithonia harvested after 90 days and 108 days using three propagation methods

Appendix 4.1: Weather information recorded at the experimental sites in 1999 and 2000



a). Year 1999



b). Year 2000

Appendix 4.2: Mean grain and straw yields and yield-contributing attributes

Treatment	Grain (kg ha^{-1})	Straw (kg ha^{-1})	Thousand grain weight (g)	Number of tillers per hill	Panicle length (cm)	Plant height (cm)
T1control	2230	4092	21.2	8.3	21.3	81.5
T2.P	2465	4866	20.6	7.6	22.3	84.8
T3.N	2995	5933	20.4	12.3	22.3	87.0
T4.NP	3496	5511	20.6	11.3	21.2	81.0
T5.Tithonia	3367	5749	22.0	10.6	22.5	93.8
T6.50%Tithonia+50% SSP	3582	5541	21.6	9.4	22.7	90.9
T7.50%FYM+50%SSP	2849	5786	21.3	12.8	21.6	86.0
T8.50% Sesbania+50%SSP	3132	5146	21.1	9.3	22.8	88.8
T9.MixtureTithon+sesbania	3433	5924	22.0	9.9	22.1	90.5
T10.100%FYM	3311	5812	20.4	9.3	22.8	92.3
F test	***	ns	*	***	ns	*
se±	192.8	437.8	0.4078	0.492	0.445	2.92
sed	279.72	619.1	0.577	0.696	0.629	4.135
lsd (0.05)	559.4	-	1.184	1.428	-	8.49
lsd (0.01)	775	-	-	1.929	-	-
cv%	12.5	16.1	4.3	9.8	4.5	6.7

Note- $p \leq 0.001$ = *** , $p \leq 0.05$ =* and $p > 0.05$ = ns (non significant)

Appendix 4.3: Mean grain and straw yields of rice and yield contributing attributes (2000)

Treatment	Grain (kg ha^{-1})	Straw (kg ha^{-1})	Plant height (cm)	No tillers per hill	Panicle length (cm)	Number of grain /panicle	1000 grains weight (g)
T1. Control plot	2561	5325	81.9	6.8	22.2	96	21.5
T2. N	3371	7207	85.6	8.4	20.4	89	22.4
T3. N:P	2865	6537	80.6	8.8	20.7	81	22.9
T4.N:K	3715	8355	91.2	8.3	22.9	111	23.1
T5. N:P:K	3813	8897	88.9	8.7	21.7	100	22.6
T6. N:P:K+Zn	3747	8514	93.3	9.1	21.9	94	22.4
T7.N:P+Zn	2762	6537	77.1	8.4	20.7	84	22.8
T8. Sole Tithonia	3194	7430	85.0	7.9	22.0	104	23.0
T9. Tithonia +Zn	3660	8450	87.7	8.3	22.2	103	20.6
T10. Sole sesbania	3195	7175	82.0	8.6	20.7	90	22.5
T11. Sesbania + Zn	3328	7366	81.1	9.1	20.0	105	22.5
F test	***	***	***	ns	ns	ns	***
Sem±	165.8	314.0	2.29	0.45	0.765	6.51	0.402
Sed	234.5	444.2	3.24	0.64	1.082	9.21	0.569
lsd (0.05)	481.2	911.4	6.65	-	-	-	1.167
lsd (0.01)	649.8	1230.8	8.98	-	-	-	1.576
cv%	10.06	9.2	5.4	10.7	7.15	13.5	3.6

Note:- $p \leq 0.001$ = *** and $p > 0.05$ = non significant (ns)

Appendix 4.4a: Organic and total P before and after crop harvest

Treatment	Organic_P (ppm)		Total_P %	
	Before planting crop	After crop harvest	Before crop planting	After crop harvest
T1. Control	5.83	5.80	0.054	0.050
T2.P	5.80	5.20	0.055	0.054
T3.N	5.85	5.95	0.056	0.051
T4.NP	5.85	5.68	0.055	0.054
T5.100% Tithonia	5.58	5.58	0.055	0.054
T6.50% Tithonia + 50%SSP	5.93	5.33	0.052	0.060
T7. 50% FYM+50%SSP	5.85	5.58	0.061	0.059
T8.50% Sesbania+ 50%SSP	5.93	5.28	0.055	0.057
T9. Mixture sesbania+tithonia	5.63	6.05	0.059	0.056
T10. 100% FYM	6.18	5.58	0.057	0.053
F test	ns	ns	ns	ns
P value	0.809	0.713	0.751	0.262
Sed	0.3288	0.4796	0.0042	0.0040
CV%	7.9	12.1	10.6	5.7

Note: p>0.05 = ns (non significant)

Appendix 4.4b: PSI of soil initial and after crop harvest

Treatment	PSI	
	Before planting crop	After crop harvest
T1.Control	8.90	11.40
T2.P	8.20	12.35
T3.N	9.10	11.28
T4.NP	9.95	14.63
T5.100% Tithonia	9.85	12.00
T6.50% Tithonia+50% SSP	8.45	11.88
T7. 50% FYM+ 50%SSP	9.38	12.00
T8. 50% Sesbania+50%SSP	9.38	14.05
T9. Mixture tithonia+sesbania	10.25	11.98
T10. 100% FYM	9.13	12.10
F test	ns	ns
P value	0.481	0.216
Sed	0.928	1.285
cv%	15.6	14.6

Note: p>0.05 = non significant

Appendix 4.5: Available K measured using the Ammonium acetate method (pH 7.0) (mg l^{-1})

Treatment	Early	Tillering	Booting	Flowering	Maturity
T1. Control plot	32.4	28.4	23.4	11.3	5.5
T2. N	33.1	28.9	20.2	11.5	8.2
T3. N:P	30.9	28.6	19.1	19.8	8.9
T4.N::K	49.9	30.2	40.0	11.4	9.7
T5. N:P:K	65.9	28.3	30.3	12.2	9.8
T6. N:P:K+Zn	45.6	30.7	38.8	8.1	7.1
T7.N:P+Zn	29.0	30.9	20.3	13.7	7.9
T8. Sole tithonia	81.9	37.1	55.1	19.9	10.4
T9. Tithonia+Zn	71.4	33.2	40.4	13.1	8.2
T10. Sole sesbania	35.2	30.3	26.2	10.9	6.7
T11. Sesbania + Zn	35.0	30.1	28.5	9.9	11.0
F test	**	ns	ns	ns	ns
sem±	8.11	2.36	3.24	2.78	1.67
Sed	11.47	3.34	4.58	3.93	2.36
lsd (0.01)	31.54	-	-	-	-
cv%	34	15.3	21	43	39

Note: p≤0.01= ** and p>0.05= ns (non significant)

Appendix 4.6: Extractable Zinc from resin mg g^{-1} of resin

Treatment	Early	Tillering	Booting	Flowering	Maturity
T1. Control plot	0.113	0.094	0.398	0.198	0.155
T2. N	0.119	0.302	0.528	0.274	0.189
T3. N:P	0.155	0.148	0.240	0.144	0.160
T4.N::K	0.209	0.556	0.457	0.132	0.197
T5. N:P:K	0.323	0.133	0.582	0.371	0.190
T6. N:P:K+Zn	0.263	0.285	1.009	0.473	0.248
T7.N:P+Zn	0.163	0.236	0.679	0.680	0.349
T8. Sole tithonia	0.242	0.479	0.527	0.359	0.189
T9. Tithonia+Zn	0.097	0.297	0.595	0.388	0.382
T10. Sole sesbania	0.365	0.187	0.665	0.319	0.141
T11. Sesbania + Zn	0.094	0.368	0.880	0.379	0.930
F test	**	ns	*	*	**
Sem±	0.0469	0.1065	0.126	0.0961	0.1024
cv%	46	76	42	53	72

Note: p≤0.01= ** and p>0.05= ns (non significant)

Appendix 5.1: Rice yield and yield contributing attributes (summer 1999).

Treatment	Straw ($kg\ ha^{-1}$)	Grain ($kg\ ha^{-1}$)	1000 grain wt (g)	Grains per panicle	Plant height (cm)	Panicle length (cm)
T1. Control plot	3380	2627	21.1	122.8	92.6	23.9
T2. Tithonia *in situ*	4312	3175	21.4	108.5	93.6	23.8
T3. Sesbania *in situ*	4433	3151	21.1	109.5	93.7	24.3
T4. Mixture tithonia & sesbania	4772	3531	22.5	106.8	94.4	23.9
T5. Farmer's practice	4889	3693	21.7	121.4	101.7	24.4
T6. Tithonia + N top dress	5170	3766	20.8	112.0	98.9	24.5
T7. Tithonia shoots only	4358	3228	21.5	118.6	97.8	24.5
T8. Tithonia roots only	3791	2998	21.0	113.4	97.5	24.3
F test	***	**	**	ns	*	ns
sed	231.13	253.3	0.35	8.98	2.65	0.528
lsd 0.05	480.7	526.8	0.73	NA	5.512	NA
lsd 0.01	654.33	717.1	1.0	NA	NA	NA
cv %	7.4	10.1	3.1	11.13	3.9	3.0

Note: $p \leq 0.001$ =*** , $p \leq 0.01$ = **, $p \leq 0.05$ = * $p > 0.05$ = ns (non significant), sed = standard error difference, lsd = least significant difference and cv = coefficient of variance

Appendix 5.2: Mean rice yield and yield contributing attributes (summer 2000).

Treatment	Straw (kg ha^{-1})	Grain (kg ha^{-1})	1000 grain wt (g)	Number tillers /hill	Plant height (cm)	Panicle length (cm)
T1. Control plot	4476	3123	22.2	8.7	86.8	22.2
T2. Tithonia in situ	4699	3134	22.3	9.7	82.8	22.5
T3. Sesbania in situ	4088	2659	20.8	9.5	77.7	21.6
T4. Mixture tithonia+sesbania	4887	3155	21.6	11.3	85.9	22.9
T5. Farmer's practice	5651	3411	21.7	11.2	86.8	21.8
T6. tithonia + N top dress	5334	3419	21.9	10.9	85.7	22.7
T7. N top dressing only	4911	3393	22.0	9.1	86.3	23.7
T8. Asuro	6273	3958	22.4	11.3	95.7	21.8
F test	***	***	*	ns	***	*
sed	328.0	183.3	0.4	1.03	3.07	0.62
lsd (0.05)	682.3	381.3	0.82	NA	6.39	1.29
lsd (0.01)	928.3	518.9	NA	NA	8.70	NA
cv%	9.2	7.9	2.5	14.0	5.05	3.9

Note: p≤0.001 =*** , p≤0.05 = *, p>0.05 = ns (non significant), sed = standard error difference, lsd = least significant difference and cv = coefficient of variance

Appendix 6.1: Grains, straw and stover yield of rice and maize

Treatment	Rice grain (kg ha^{-1})	Rice straw (kg ha^{-1})	Maize grain (kg ha^{-1})	Maize stover (kg ha^{-1})
Ct	1917	3002	2283	5721
Sc	3147	3801	Fallow	Fallow
Ti	3098	3970	Fallow	Fallow
Sc+mz1	2834	4329	2418	5797
Ti+mz1	2974	3995	1924	6096
Ti+mz2	2890	3899	1794	5611
Ti+mz3	2211	2734	2306	5744
Ti+Sc	2462	3185	2081	5560
FP	2751	3682	2773	7936
F test	***	***	***	*
sed	246.13	334.26	201	731
cv%	12.9	13.0	12.8	17

Note:- *** = p<0.001 and * = p<0.05)

Appendix 6.2: Yield contributing components of rice

Treatment	1000 grain weight (g)	Plant height (cm)	No of tillers per hill (mean of 5 hills)	Panicle length cm (mean of 5 panicles)	Grain per panicle (mean of 5 panicles)
Ct	25.84	83.3	6.3	23.8	92.1
Sc	23.82	84.5	7.0	24.4	99.6
Ti	26.78	90.6	7.8	24.6	89.0
Sc+mz1	26.39	89.2	7.3	25.1	96.6
Ti+mz1	26.0	90.6	7.6	24.4	94.1
Ti+mz2	26.93	86.6	7.2	25.2	95.9
Ti+mz3	26.25	85.9	6.6	25.1	107.9
Ti+Sc	26.39	84.1	6.7	24.7	91.3
FP	26.44	84.3	6.4	24.3	89.0
F test	ns	ns	ns	ns	ns
sed	1.83	4.4	0.696	0.821	8.94
cv%	9.9	7.2	14	4.7	13.3

Note: ns = non significant, sed = standard error of difference, cv % = coefficient of variance

Appendix 7.1: A sample of questionnaires for survey

FARMERS PERCEPTIONS AND REACTIONS
TO VARIOUS GREEN MANURE SPECIES
(Questionnaires for qualitative assessment)

Date................

1. Name....................................Sex of Respondent... M/F.................
2. Cluster...
i). EC (East Chitwan), ii). WC (West Chitwan and iii). NP (Nawalparasi)
3. Village...................................
4. Farmer's wealth category: A B C
5. Land holding..............*Khet* (irrigated land or low land).............*Bariland* (upland).
6. Land type:
   a. Ghol /low land.
   b. Intermediate terrace
   c. Upland (Tandi) or Upper Piedmont
7. Farmers Soil classification
8. Soil fertility classification
9. Green manure species given
- Rice bean
- Sunnhemp
- Sesame
- Sesbania
10. Have you sown green manure crop before ......Yes/No......
11. Species if yes.......................
12. Since how long you have been growing green manure crop?...........
13. Current cropping pattern ....
14. Method of green manure production
15. GM planting date ....
16. Fertilizer applied
a. Chemical fertilizer......... .kg/kattha.......
b. Compost/FYM .... kg/kattha.......
c. FYM and Chemical fertilizer not applied
17. Observation on green manure growth rate (*Sesbania* or *Sesamum* as a check ?
18. Did you observe any disease insect problem ? Yes / No..........
19. If yes ... could you identify them... ....

20 Green manure harvesting days.........or Total days green manure grown..........

21 Green manure biomass production

a. High
b. Medium
c. Low

22 Reason for low production (possible reasons more than one can be choose)

23 Reason for high production

24. Incorporation method

25. Which method of incorporation is most practical for your situation?

26. Method of incorporation appropriateness why ?

27. Age of green manure when incorporated into soil.

28. Preferred age of green manure

29. Reason why?

30. Green manure plant height suitable for incorporation...

31. Number of days between green manure incorporation and rice seedlings transplanted.

32. Why you prefer to transplant on a specific time?

33. Type of rice variety grown or green manured

34. Maturity time of rice variety

35. Nutrient demand of rice variety

36. Which variety responds to green manure application?

37. Decomposition rate of green manure

38. Reason for slow or fast decomposition of biomass of green manure

39. Other positive observations from the application of green manure

40. Effect of green manure on companion maize crop when relayed or mixed

41. Maize variety grown for relaying with green manure

42. Time of planting of green manure under relay system

43. Reason for negative or positive effect or what may be reason?

44. Effect of green manure (Visual observation) on rice growth stage

45. Effect green manure on maturity of rice

46. Effect green manure on rice grain yield

47. Effect of green manure on rice straw yield

48. Did you observe effects or changes on soil fertility or land quality after application of green manure?

49. Indicators (positive or negative) according to farmers' criteria

50. Does it fit into the existing cropping system?

51. Reasons for Yes.

i. ....

52. Reasons for No

i. ....

53. Have you saved green manure plants for seed production purposes for next year's planting?

54. Reason for not saving seeds

55. Have your neighbour asked for seeds of green manure crop?

56. Would you like to grow green manure next year?

Yes or No if Yes give us your plan

57. Reasons for rejecting green manure

58. Reason for accepting

59. On what type of land are you planning to grow green manure crop?

60. What type of cropping system you will choose?

61. Will you use a particular type of cropping pattern? Reason for yes or no

62. Is there any appropriate planting date you think best?

63. Comparison between the current green manure and the green manure you have been growing for a long time?

64. Preference ranking (Based on the farm walk, observation from neighbouring fields and past experiences)

65. Major characteristics of green manure you think important

66. List the major constraints to green manuring priority wise

67. General or overall comments on green manure

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