

**EFFECT OF RELAY INTERCROPPING OF *SESBANIA*
SESBAN ON SOIL FERTILITY IMPROVEMENT, AND
MAIZE AND FIREWOOD PRODUCTION AT MOROGORO,
TANZANIA**

BY

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ABSTRACT

This study was carried out at the Sokoine University of Agriculture (SUA) Farm, Morogoro, Tanzania to examine the effect of relay intercropping of *Sesbania sesban* and maize on soil fertility improvement, and production of maize and firewood. An existing 1 year 2x3x3 factorial relay intercropping experiment arranged in a randomized complete block design with three replications in which *S. sesban* was allowed to grow after the harvesting of maize during the dry season was studied. Firewood biomass after 1 year of intercropping was 3 t ha⁻¹. Maize was intercropped with and without *S. sesban* at 0, 20, and 40 kg ha⁻¹ each of N and P fertilizers. Intercropping slightly increased soil mineral N status. Maize grain yield was significantly ($P < 0.05$) higher in *S. sesban* plots without fertilizer (2.43 t ha⁻¹) as compared to control (2.09 t ha⁻¹). The three levels of N and treatment interaction effects had no significant ($P > 0.05$) effect on maize yield. In contrast, the three levels of P differed significantly ($P < 0.05$) on their effects on maize grain and stover yield. Maize grain yield from plots which received 20 kg P ha⁻¹ was 2.39 t ha⁻¹ and 40 kg P ha⁻¹ was 2.36 t ha⁻¹ compared with the control (2.02 t ha⁻¹).


In order to determine decomposition rate and nutrient release of selected species, a 10 week decomposition

experiment involving litter bags containing green manure from *Albizia lebbeck*, *Gliricidia sepium*, *Senna siamea*, *Sesbania sesban* and *Tephrosia vogelii* arranged in a randomized complete block design with three replications and sampled at 0, 1, 2, 4, 6, 8 and 10 weeks in a repeated measures manner, after placement was also studied. Significant ($P < 0.05$) differences existed in decomposition rates in the order (*G. sepium* > *S. sesban* > *A. lebbeck* = *S. siamea* > *T. vogelii*), N release in the order ($P < 0.01$) (*S. sesban* > *G. sepium* > *T. vogelii* > *A. lebbeck* > *S. siamea*) and phosphorus release in the order ($P < 0.01$) (*T. vogelii* > *G. sepium* > *S. sesban* > *S. siamea* > *A. lebbeck*). Nitrogen and phosphorus release ranged between 128-202 kg N ha⁻¹ and 7.76-12.88 kg P ha⁻¹ respectively. Most of the N and P were released within the first four weeks of decomposition.

Based on these results, *S. sesban*, *G. sepium* and *T. vogelii* showed greatest potential for use as green manure and that relay intercropping of *S. sesban* and maize has potential in increasing maize yield even without fertilizer inputs. It is concluded that at Morogoro (SUA Farm) and any other areas with similar soil characteristics P may be a more limiting factor for maize production than N.

DECLARATION

I Sheku Amadu Tejan Fasuluku, do hereby declare to the Senate of Sokoine University of Agriculture, that this dissertation is a result of my own original work and it has never been submitted for a degree award in any other University.

Signature:..........

Date:.....25th JUNE, 1998.....

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DEDICATION

I dedicate this dissertation to my late father, Paramount Chief Fasuluku, my mother Ndayeh Fasuluku, my brother Njama and my two elder sisters Kawama and Femba.

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ABBREVIATIONS AND SYMBOLS

ANOVA	Analysis of variance
asl	Above sea level
B	Boron
BNF	Biological nitrogen fixation
Ca	Calcium
cm	Centimetre
Conc	Concentration
D	Diameter 10 cm above ground
D ₁	Diameter 30 cm above ground
E	East
e.g.	For example
<i>et al</i>	And others
etc.	And many more
g	Gramme
g/cm ³	Gramme per cubic centimeter
FAO	Food and Agricultural Organization
GLM	General Linear Models
H	Total tree height (cm)
ha	Hectare
HCl	Hydrochloric acid
i.e.	That is
ICRAF	International Centre for Research in Agroforestry
ln	Base of natural logarithm
K	Potassium

KCl	Potassium chloride
kg	Kilogramme
m	Metre
M	Molar
Mg	Magnesium
mm	Millimeter
Mineral-N	Mineral nitrogen
MPTs	Multipurpose tree species
N	Nitrogen
NH ₄ F	Ammonium fluoride
NH ₄ ⁺	Ammonium ion
NH ₄ ⁺ -N	Ammonium nitrogen
NO ₃ ⁻	Nitrate ion
NO ₃ ⁻ -N	Nitrate nitrogen
HNO ₃	Nitric acid
NO ₂	Nitrous oxide
P	Phosphorus
P. Commun.	Personal communication
pH	Hydrogen ion concentration
ppm	Parts per million
R ²	Coefficient of determination
RCD	Root collar diameter
S	South
SAS	Statistical Analysis Systems
SE	Standard error
SUA	Sokoine University of Agriculture
t	Tonne

TSP	Triple super phosphate
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
Wks	Weeks
°C	Degree Centigrade
°E	Degree East
°S	Degree South
=	Equal to
>	Greater than
<	Less than
μ	Microgramme
%	Percent

CHAPTER 1**1. INTRODUCTION**

The economy of Tanzania, like other developing countries, is largely dependent on the agriculture sector. Its population is estimated at 30 million with an annual growth rate of 3.36 % (United Nations, 1993). The country has been facing chronic problems related to agricultural production particularly in the semi-arid areas. Soils in most semi-arid areas in Tanzania including Morogoro have low organic matter content and low inherent base exchange capacity (Kaaya et al., 1994). Insecure harvests are caused by wide fluctuations in weather conditions, decline in soil fertility and lack of fertilizers to intensify agriculture. Moreover, the ability of soils to retain mineral fertilizers is low. However, the use of non-sustainable inorganic fertilizers is not a solution due to lack of capital, hence the productivity of the farmlands have been declining with time.

Traditionally, shifting cultivation farming practices are common in rural areas in the tropics including Tanzania. Shifting cultivation has been sustainable in the past, however, due to increasing population densities and associated expansion of areas under cultivation, it is

becoming increasingly difficult to sustain the practice (FAO, 1994). As a result, farmers who cultivate the land can no longer give it enough time to fully recover and are forced to go for short fallows. This results in soil degradation and consequently to decreasing crop yields since natural vegetation does not have sufficient time to revert to grassland and woodland (Mugasha and Nshubemuki, 1988; Rao *et al.*, 1990). For instance, in Kondoa central Tanzania, the ratio of cultivation to fallow period was 5:2 (Mugasha and Nshubemuki, 1988). Additionally, extending the area cultivated is not an alternative, and where such potential does exist the land is often of poor quality and often is even more vulnerable to environmental degradation.

Sustainable agriculture relies greatly on proper management of renewable resources, and on-farm nitrogen contributions are achieved through biological nitrogen fixation (BNF). Biological nitrogen fixation helps in maintaining and/or improving soil fertility by using N_2 , which is in abundance in the atmosphere (Wani *et al.*, 1995). Intensive agricultural systems are characteristically expanded nutrient cycles involving the export of crops from a farm and require continued import of nutrients to the farm. Intercropping of food crops with trees has been generally found to increase yield of food crops, an effect partly attributed to improved nutrient relations (Kang *et al.*, 1985; Wani *et al.*, 1995). However, agroforestry

technologies (mixed planting and alley cropping) introduced in semi-arid areas in the tropics to alleviate prime arable land shortages and to solve problems associated with the traditional shifting cultivation, in most cases have so far failed as crop yield tend to decline with time. This is mostly related to an increase in below ground competition for moisture and nutrients between food crops and trees (SseKabembe, 1985; Singh *et al.*, 1989; Kang, 1993; Chamshama *et al.*, 1994; Ong, 1994). Soil moisture availability is not a critical problem in humid areas where alley cropping technology was developed but it is one of the important factors limiting food crop production in semi-arid areas.

In view of the current environmental and food crisis, the considerable increase in human and animal population, and the high price of mineral fertilizers, farmers in Tanzania, like in other developing countries, are forced to adopt semi-intensive agricultural systems. As noted above, following the failure of earlier agroforestry technologies introduced in semi-arid areas including Morogoro, there is a need for developing alternative agroforestry technologies for semi-arid areas of Tanzania. This means that there is a need to devise appropriate technologies or scientific principles to improve traditional methods, in this case to improve on traditional short fallow periods and to make them more efficient in order to increase food and fuelwood production. Two of such agroforestry technologies are

improved fallow and relay intercropping as possible alternatives to traditional shifting cultivation. Prins (1986) defined an improved fallow as a targeted use of planted tree/shrub species in order to achieve one or more of the aims of natural fallow within a short time or on a smaller area. Improved fallows are reported to be suitable in the humid and sub-humid tropics as an improvement of shifting cultivation (ICRAF, 1993). However, it has been reported by Kwesiga and Coe (1994) that improved fallows can also be used in semi-arid areas where land is not limiting.

In places with only one rainy season a year and where land holdings are limited, the practice of relay intercropping could be an option in which land is not left to fallow but annual crops are interplanted with fast growing nitrogen fixing shrubs/trees (ICRAF, 1993). Shrubs/trees are allowed to grow during the dry season after crop harvest and just before the next cropping season, all shrubs/trees are cut down and biomass that is not useful as fuelwood is returned to the soil. However, the dynamics of soil fertility under improved fallow and relay intercropping are not well understood. Unravelling the processes occurring within the soil will help in explaining the effect of relay intercropping/improved fallow farming systems. They will also help in developing suitable soil fertility management techniques for greater benefits.

According to Nair (1993), in many agroforestry systems, leaf biomass (litter or leafy prunings) of multipurpose trees (MPTs) is added as a source of nitrogen and other nutrients to crops. Decomposition and mineralization (nutrient release) of the biomass so added are key processes by which nutrients locked up in the plant parts eventually become available to crops (Mugendi and Nair, 1997). However, the success of application of green manure will depend largely on our understanding of the dynamics and processes of green manure decomposition and nutrient release. Data on the contribution of leaves from *Sesbania sesban* (L.) Merr. and green manure of other MPTs to soil nutrient for food crops and soil conservation are not currently available for Morogoro conditions. This is because most of the previous agroforestry studies have mainly dealt with the following: tree growth, and fodder, wood and crop yields.

This dissertation is based on two experiments carried out concurrently: (i) Effect of relay intercropping of *S. sesban* on soil fertility improvement, and maize and firewood production; (ii) Decomposition and nutrient release from foliar green manure of five multipurpose trees/shrubs i.e. *Albizia lebeck* (L.) Benth., *Gliricidia sepium* (Jacq.) Walp., *S. sesban*, *Senna siamea* Lam. and *Tephrosia vogelii* (F.) Hook.. These tree species have been widely used in agroforestry systems, largely because of

their N-fixing (except for *S. siamea*), rapid growth and their ability to coppice readily (Young, 1988; Nair, 1993). *Senna siamea* is included here because of its ability to grow well in semi-arid areas and its foliage has relatively high N content.

The main objective was to exploit the soil improving potential of *S. sesban* in maize production in situations of small land holdings while the specific objectives were:

- (a) To determine the soil improving potential of *S. sesban* grown in relay with maize and left to occupy the field during the dry season after maize harvesting.
- (b) To determine the growth and yield of maize under relay intercropping with *S. sesban*.
- (c) To determine the influence of *S. sesban* mulch incorporated into the soil on fertilizer utilization efficiency by maize.
- (d) To determine the firewood yield of *S. sesban* intercropped with maize.
- (e) To compare the decomposition rate and nutrient release of *S. sesban* green manure with those of *A. lebbeck*, *S. siamea*, *G. sepium* and *T. vogelii*.

CHAPTER 2

2. LITERATURE REVIEW

2.1. Traditional shifting cultivation

Man has always adopted diverse management practices for maintaining soil fertility. Traditional shifting cultivation is a common agricultural practice in rural areas of the tropics including Tanzania. For centuries shifting cultivation, a universal agricultural practice, had been used to restore soil fertility (Rao *et al.*, 1990). It involves cutting and burning relatively small forest/woodland plots and production of crops in the burned-over area, taking advantage of the nutrients in the ashes from the burned plants (Brady, 1994). After 2 - 3 years, the nutrients are depleted and weed competition becomes a problem necessitating farmers to abandon their plots for 10-20 years, to permit the regrowth of forest/woodland species (Sanchez, 1976). After abandoning the plots the farmers move on to another forested plot, which they slash-and-burn and then crop 2-3 years before these plots are abandoned as previously. These steps are then repeated until another cycle is completed.

The original vegetation and the fallowed areas in which trees and woody species grow provide several benefits for

agricultural crops (Nair, 1990). During the fallow period, the potential of trees for soil fertility improvement can be manifested by the increase in soil organic matter through litter fall, fine root turn-over, accretion of nitrogen by nitrogen-fixing trees, nutrient recycling and reduction of nutrient losses. Litter production and direct addition of leaves and branches as mulches or incorporated in the soil have been shown to increase soil organic matter (Szott *et al.*, 1991). Likewise, trees accumulate nutrients in their biomass, which are transferred as ash to the soil upon burning. Since slash and burn is practised in areas with little access to chemical fertilizers, the trees serve as agents for nutrient cycling from deeper soil layers to the surface layer where most crop roots are found.

Due to increasing population densities and associated expansion of areas under cultivation, it is becoming increasingly difficult to sustain the practice (FAO, 1994). According to FAO (1992), approximately 300,000 - 400,000 ha. of natural forest land, whether gazetted as forest reserves or considered as public land, are being deforested every year in Tanzania. The main reasons for deforestation are expansion of agriculture in the form of over-cultivation, over-grazing by huge livestock population, bush fires, uncontrolled harvesting of selective timber trees, charcoal burning and fuelwood gathering for domestic consumption.

2.2 Improved fallow/relay intercropping

Traditional fallows take several years to restore soil fertility. Natural vegetation is slow in reaching the peak of biological productivity. By contrast, agroforestry systems (such as improved fallow or relay intercropping systems) in which fast growing trees/shrubs are selected, planted and managed in fallows can grow and mature within a short time thereby enhancing soil fertility by bringing up nutrients from lower soil layers, litterfall and atmospheric nitrogen fixation (Sanchez *et al.*, 1985, Wani *et al.*, 1995). At the end of the fallow period the trees/shrubs are harvested and biomass that is not useful as fuelwood is returned to the soil (Kwesiga and Coe, 1994).

For any tree/shrub to be incorporated in the fallow, it should establish quickly, grow quickly, fix nitrogen and produce a large amount of biomass. Improved fallow/relay intercropping systems will be of great importance in developing countries where peasants cannot afford inorganic fertilizers, and want rapid labour investment returns. Improved fallows are used in the humid and sub-humid tropics as an improvement of shifting cultivation (ICRAF, 1993). However, it has been reported by Kwesiga and Coe (1994) that improved fallows can also do well in semi-arid areas.

In places with only one rainy season a year and where land holdings are limited, the alternative to improved fallow is the practice of relay intercropping in which land is not left to fallow but annual crops are interplanted with fast growing nitrogen fixing shrub/tree (ICRAF, 1993). Both crops and trees are planted at the beginning of the rains, but the crops grow rapidly and the tree slowly, thus minimising competition. In Malawi where relay intercropping has been tested, maize is planted on 45 cm wide ridges spaced at 90 cm. Maize is planted on top of each ridge at a spacing of 90 cm (Mugasha, P. Commun. 1997). Two maize plants are planted per planting hole. Within each ridge shrubs (*S. sesban*, or *Cajanus cajan* (L.) Millsp. or *T. vogelii*) are planted between maize crop at 45 cm spacing. Shrubs/trees are allowed to grow during the dry season. Just before the next planting season all shrubs/trees are also cut, placed between ridges and covered by soil. This process is repeated from year to year. Alternatively, species such as *Gliricidia* trees are planted at 0.9 m spacing in troughs between each pair of ridges. Two to three weeks before planting of maize, ridges are split open, leaves/twigs/litter arranged uniformly in open ridges and covered with soil. During the cropping season, trees are subjected to one or two more cuts and leaves/twigs/litter incorporated into the soil with weeds during weeding through re-ridgeing. In this way the roots of maize will not be damaged.

2.3 Trees/shrubs and soil fertility improvement

The contribution of trees to ameliorate soil chemical properties has been widely highlighted; factors such as balanced nutrient supply, a slow release of nutrients and protection from leaching, and a buffering effect against soil acidity have been reported (Aweto, 1981; Young, 1989; Kwesiga and Coe, 1994; Wani et al., 1995). Studies carried out in humid and sub-humid tropics have shown significant effect of trees in alley cropping and improved fallow systems to increase pH, B, P (Adesina, 1990), exchangeable K, Ca, Mg and NO_3^- levels in soil solution (Kang et al., 1985). However, the production and accumulation of organic matter depends on the length of the fallow period, the nature of the fallow vegetation, soil properties, the management intensity and climatic factors (Rao, 1989).

Organic matter, including green manure, is of great importance to soil fertility and hence productivity.

Manures are bulky organic materials, mainly plant residues, animal excreta and urban wastes, which are returned to the soil either directly or after some sort of processing (Sarrantonio, 1992). The incorporation of green manure of legumes into the soil is not only effective for the production of the succeeding crops but also for the maintenance of some plant nutrients like inorganic nitrogen and available phosphorus (Sarrantonio, 1992; Nair, 1993;

Mappaona *et al.*, 1994)

Green manure from leguminous plants show a high potential for N accumulation of which the major portion is derived from biological N₂ fixation. On average N accumulation rates, green manure can entirely substitute for mineral fertilizer N at current average application rates. With similar N use efficiency, green manure N is less prone to loss than mineral fertilizer N, and continuous green manure use may improve soil physical and chemical properties. In the long-run, green manure use may help restore degraded soils and enhance the production sustainability of agricultural systems (Becker *et al.*, 1995). However, the contribution of legume prunings to crop production and soil conservation do not entirely satisfy the crop N requirement and that supplementary N fertilizer is often required to achieve maximum yield (Xu *et al.*, 1992; Kwesiga and Coe, 1994).

The function of roots in soil fertility is attributed to maintenance of soil organic matter and physical condition and to uptake of water and nutrients from deeper soil layers, returning them, via litter, to the surface, and thereby increasing the ratio of uptake to leaching loss (Young, 1989). However less is known about the contribution of roots to soil organic matter, and thus to soil fertility (Sanchez *et al.*, 1989; Nair, 1993). Roots have the ability

to improve soil organic matter (Young, 1989) through root turnover, and this, continues even when above-ground biomass is removed (Dhyani et al., 1990; Van Noordwijk et al., 1995). It is estimated that about 20 to 25 percent of the total living biomass of trees is in roots (Armson, 1977) but it may be as low as 15 percent in some rainforests or as high as 50 percent or more in semi-arid and arid climates (Nair, 1993) and that there is constant addition of organic matter to the soil through dead or decay roots (Young, 1989). Andriessse et al. (1987) reported the following amount of nutrient stored in root systems at two sites on successional shifting cultivation forest fallows in Sri-Lanka and Malaysia: nitrogen 76 kg ha⁻¹, phosphorus, 3.5 kg ha⁻¹ and potassium, 22 kg ha⁻¹. These amounted to 14.5%, 18.5%, and 15.5% of N, P and K, respectively, of the total nutrients in the plant biomass.

In Kenya, farmers have observed that nitrogen derived from *S. sesban* is not cycled through leaf-litter but through the decomposition of the roots accompanied by shedding of nitrogen-fixing nodules when the trees are felled (Rocheleau et al., 1988). In Morogoro, Tanzania, Jonsson et al. (1988) reported fine-root (< 2 mm diameter) biomass of two-year-old *Eucalyptus tereticornis* (532 kg ha⁻¹), *Leucaena leucocephala* (616 and 744 kg ha⁻¹ in two different sites), *Senna siamea* (780 kg ha⁻¹) and six-year-old *Leucaena leucocephala* (1276 kg ha⁻¹).

2.4 Nitrogen Fixation

Biological nitrogen fixation (BNF) plays an important role in sustaining production of soils in the semi-arid tropics. Soil fertility can be maintained through BNF. Nitrogen fixing trees/shrubs have been used in cropping systems for soil improvement since long time ago (Sarrantonio, 1992). Under certain conditions a legume cover or green manure crop can provide biologically fixed nitrogen, increase soil organic matter, provide protection against soil erosion, improve soil structure, make other nutrients more available and interrupt cycles of diseases and insect pests (Ahlback, 1994).

However, mere inclusion of legumes in the cropping systems in the semi-arid tropics including parts of Tanzania will not ensure N contribution to the system through biological nitrogen fixation (BNF). The important issue is how best we can exploit BNF technology for developing sustainable cropping systems in the semi-arid tropics (Ong, 1994, Wani *et al.*, 1995). There is a need to accurately quantify N₂ fixation by legumes in a system after taking into account the N₂ fixed in the roots and fallen plant parts. Nitrogen fixed by selected woody species is presented in Table 1. Such information will help us to identify the systems which

Table 1: Estimates of N₂ fixation by some woody species suitable for agroforestry systems

Species	N ₂ fixation (kg N ha ⁻¹ yr ⁻¹)
<i>Acacia mearnsii</i>	200
<i>Casuarina equisetifolia</i>	60-110
<i>Erythrina poeppiana</i>	60
<i>Faidherbia albida</i>	20
<i>Gliricidia sepium</i>	186
<i>Inga jinicuil</i>	35-40
<i>Leucaena leucocephala</i>	197
<i>Sesbania rostrata</i>	83-109

Source: Nair (1993)

really maintain or improve the soil N status. Host controlled factors also play an important role in regulating BNF but have not received their share by researchers. Nitrogen fixation is reported to be limited by soil moisture content, pH and P availability (Nair, 1993). We need to identify type and genotype of legume which yields more and also derive large part of its N requirement from fixation in a particular cropping system.

2.5 N-availability potential

Nitrogen is added to the soil through organic matter, BNF, atmospheric wet and dry deposition and fertilizer input.

Plants can only utilize inorganic soil nitrogen compound in the form of ammonium (NH_4^+) and nitrate (NO_3^-) (Piccolo et al., 1994). Uriyo and Singh (1974) and Tisdale et al. (1990) reported that, nitrogen in the soil is mainly in organic forms, and a small fraction in inorganic forms such as ammonium (NH_4^+), nitrate (NO_3^-), nitrite (NO_2^-), nitrous oxide (N_2O), nitric oxide (NO), and elemental nitrogen (N_2). Most of the cultivated soils have total N content ranging from 0.06% to 5%. The process of transforming organic nitrogen (N) to inorganic ammonium nitrogen (NH_4^+) and nitrate (NO_3^-) is called mineralization, and is mediated by enzyme activities from microorganisms. Thus, mineralization of nutrients from dead organic matter is the critical process that determines N supply and site productivity (Waring and Schlesinger, 1985). The rate of nitrogen mineralization and nitrification and total quantity of N in tropical soils are indicators of soil fertility and affect the ability of these soils to retain N following disturbance such as forest cutting (Piccolo et al., 1994). Net nitrogen mineralization and nitrification are often equated with nitrogen availability (Anderson and Ingram, 1993).

Alexander (1977) pointed out that the rate at which organic nitrogen is converted to ammonium and nitrate (mineralization), and the rate of such release in environments receiving nitrogen rich crop residues ranges

from less than 1.0 to 20 ppm day⁻¹. He also added that this is closely correlated with the total nitrogen content of the soil, implying that sites rich in total nitrogen liberates more of the inorganic ions than deficient areas in a given time interval. Nitrate (NO₃⁻) ions however, were reported to be dominant form of mineral nitrogen in agricultural soils since they are in soil solution (i.e. readily available and easily removed) which make them to be much more susceptible to leaching than ammonium (Alexander, 1977; Tisdale et al., 1990; Nduwayezu, 1997; Maliondo et al., In press). In a mixed intercropping experiment in Malawi, Maliondo et al. (In press) observed an increase in soil mineral N two weeks after *Gliricidia* amendment ranging from 16 kg ha⁻¹ in the control to 58 kg ha⁻¹ in the treated plot representing a sixfold increase over values measured one day before manuring. In a nitrogen mineralization experiment involving green manure of *Gliricidia sepium* leaves in Kitete, Tanzania, Nduwayezu, (1997) reported that 67-81% of the total mineral N was in the form of NO₃⁻-N.

2.6 Effects of tree fallow/relay intercropping on crop yields

Rao (1989) claimed that if trees/shrubs are established in high densities and retained on the ground for 1 to 3 years the land can be enriched and brought back for food

production. According to Nair (1993) agricultural crops have well defined critical periods of high nutrients demands (e.g. 4-6 weeks for maize crop). If nutrients could be available to the crops during the period of high demand, therefore, the released nutrients would be used efficiently, leaching losses minimized and crop productivity increased. Increased crop yield after a fallow period has been widely reported (Young, 1989; Xu *et al.*, 1992, Kwesiga and Coe, 1994; Mappaona *et al.*, 1994; Otsyina *et al.*, 1996). In Zambia, Kwesiga and Coe (1994) have reported that *S. sesban* fallow can increase maize yield up to 2.3 t ha⁻¹ in a one year fallow and 4 t ha⁻¹ in a two year fallow. Results obtained from other places are presented in Table 2.

2.7 Description of species being evaluated

Albizia lebbek reported to be a native of India and Myamar (Burma) was introduced to other parts of Asia, as well as Africa, the Caribbean, and South America (Young 1989). It is reported to be widely adapted to dry and moist tropics (500 - 2000 mm annual rainfall), up to 1600 m altitude on a variety of soils (including acid, saline, and alkaline soils). It can attain up to 30 m in height with a spreading umbrella-shaped crown, and can be propagated by seeds, seedlings and root suckers.

Table 2: Some results of improved fallow/intercropping on maize grain yield

Species or type of fallow	Fallow period	Yield (t ha ⁻¹ yr ⁻¹)			Source
		1	2	3	
<i>A. nilotica</i> intercropping	-	1.0	1.5	0.4	Otsyina et al. (1996)
<i>A. polyacantha</i> intercropping	-	1.2	1.5	0.4	Otsyina et al. (1996)
<i>C. cajan</i> planted fallow	-	3.2	3.0	3.1	Tonye et al. (1997)
<i>F. albida</i> intercropping	-	1.9	0.5	-	Chamshama et al. (1994)
<i>L. leucocephala</i> intercropping	-	1.5	1.1	0.4	Otsyina et al. (1996)
<i>S. sesban</i> improved fallow	1	2.3	3.8	4.4	Kwesiga and Coe (1994)
<i>S. sesban</i> improved fallow	2	-	5.0	5.6	Kwesiga and Coe (1994)
<i>S. sesban</i> improved fallow	3	-	-	6.0	Kwesiga and Coe (1994)

Gliricidia sepium is a fast growing multistemmed leguminous tree/shrub native to Mexico and central America (Nair, 1993). It is easy to establish from seed or cuttings and used by farmers for variety of purposes including fodder, green manure, fuelwood, poles, and fencing material. If laterally pruned it is less competitive, at least above ground. It grows in dry to humid (600 - 3000 mm annual rainfall) conditions at 500-1600 m asl on moist to dry, and even saline soils.

Senna siamea is a native to Southeast Asia from Indonesia

to Sri Lanka and now widely introduced in Africa, the Caribbean, and South America (Nair, 1993). Found in lowlands (below 1700 m asl) in a wide range of climates from dry to humid (500 - 1000 mm annual rainfall) with 4 - 5 month dry seasons on neutral to acid, fairly rich soils with good drainage. It can attain up to 20 m height, shrubby, evergreen except during extreme drought, and can be propagated by seeding, seedling, and root suckers.

Sesban sesban is fast growing nitrogen-fixing tree/shrub which can be propagated by direct seeding and seedlings (Nair, 1993). Besides its apparent characteristics for management in improved fallow, it has low-spreading, aggressive crown, which eliminates weeds as it soon takes ecological dominance of the site. It can attain up to 6-8 m height and shows good potential of improving soil fertility (ICRAF, 1993). It is found on stream banks and beside seasonal ponds. It tolerates acid and saline soils. In an improved fallow experiment in Zambia, Kwesiga and Coe (1994) used *S. sesban* because of its suitable attributes such as fast growth, nitrogen-fixing ability, easy degradable biomass, adaptability to climatic and soil condition of the Miombo and ease of propagation and removal besides its compatibility with succeeding crops (no allelopathy to cereals). The species can also be used for firewood, poles, fodder, shade and mulch (Nair, 1993).

Tephrosia vogelii is a softly woody branching 1-4 m tall nodulated legume (Milne-Redhead and Polhill, 1971). It is reported to be widely adopted to dry and moist tropics (500-2500 mm annual rainfall). Although this species is widely distributed and cultivated as a fish poison in East Africa, it is of value as a leguminous cover crop in grass areas where it is believed to be relatively resistant to periodic fires. Farmers in West Cameroon plant *Tephrosia* seeds into fallowed land, then cut the plants after a few years to farm again (Rocheleau et al., 1988). In places where animals are traditionally allowed to graze crop residues in the fields after a harvest is completed, fallow species established in the maize crop would clearly be almost impossible to protect during this period. *T. vogelii* has been identified as a fallow species since it is unpalatable to animals (ICRAF, 1993).

CHAPTER 3

3. MATERIALS AND METHODS

3.1 Site description

The study site is located at Sokoine University of Agriculture (SUA) Farm (6°50' 24.7"S; 37°38'59.8"E; 526 m asl), Morogoro, Tanzania. The area experiences a sub-humid tropical climate with a bimodal rainfall pattern characterized by two rainfall peaks in a year with a definite dry season separating the short rains (October to December) and long rains (which fall from March to May). The long term mean annual rainfall is 870 mm, total annual evapotranspiration is about 1307 mm and the mean annual temperature is 24°C. Figure 1 show medium term (1970-95) and 1996 and 1997 cropping seasons (March to June) total rainfall. The 1996 and 1997 cropping season's rainfall were 470 mm and 478 mm respectively. Table 3 shows number of rain events and corresponding amount of rainfall for SUA Farm during 1997 cropping season.

The soils are classified as Acrisol (FAO, 1988). These soils are deep and well drained, predominantly clay loam (Appendix 1) with very low organic carbon and phosphorus

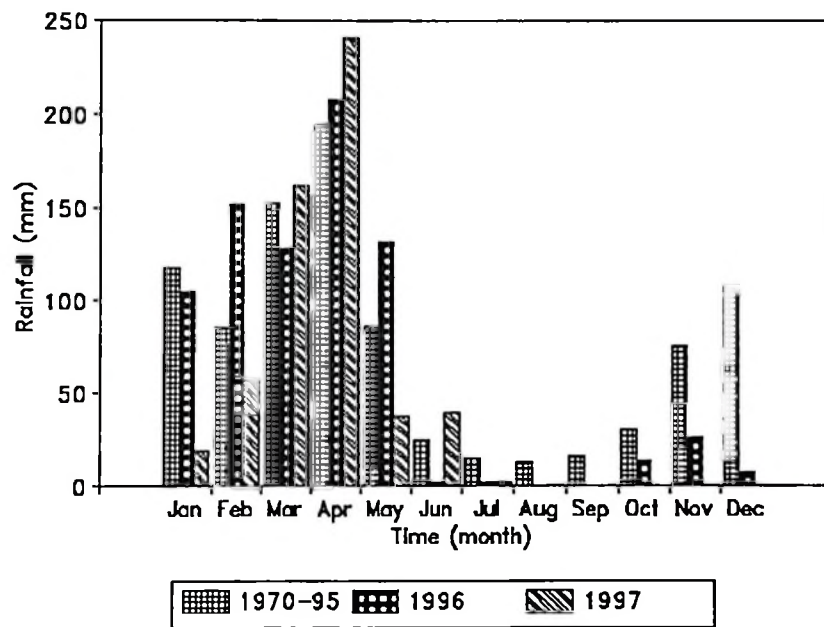


Figure 1: Mean monthly rainfall for SUA Farm, Morogoro, Tanzania

Table 3: Rainfall events during 1997 cropping season at SUA Farm, Morogoro, Tanzania

Date	15 ¹ -24/3	24/3 ² -31/3	7/4	21/4	5/5	19/5	2/6 ³	3 - 31/6 ⁴
Time interval								
(days)	0 - 10	10 - 17	17 - 24	24-38	38 - 52	52 - 66	66 - 80	80 - 108
Rainfall (mm)	71	86	23	171	53	16	24	34
Number of events	4	6	3	12	7	5	8	12

¹Date of sowing maize

²Date of green manure placement

³Final date for retrieval of green manure bags

⁴Final date for soil sampling for mineralization studies

contents and low to very low total nitrogen contents (Table 4). The overall inherent soil fertility is low. Soil bulk density is higher between 10-30 cm soil depth as compared to that of soil above and below this depth. This is related to soil compaction due to long term use of farm tractors during ploughing and harrowing.

3.2 Experimental design, treatments and management

Two experiments were carried out concurrently: (i) Decomposition and nutrient release of green manure from five multipurpose tree species (MTPs), and (ii) Effect of relay intercropping of *S. sesban* on soil fertility improvement, and maize and firewood production.

3.2.1 Green manure decomposition and nutrient release experiment

3.2.1.1 Field procedures

This experiment compared green manure decomposition and nutrient release among the five tree/shrub species (*A. lebbeck*, *G. sepium*, *S. sesban*, *S. siamea*, and *T. vogelii*). The site was a maize field in the season prior to establishing this experiment. Prior to establishment of the present experiment, the site was cleared by removing all weeds with a hand hoe. A randomized complete block design

Table 4: Some selected soil properties of the study site at the SUA Farm, Morogoro, Tanzania.

Soil properties	Soil depth (cm)				
	0 - 10	10 - 20	20 - 30	30 - 40	40 - 50
Textural class	clay loam	clay loam	clay loam	clay loam	clay loam
Bulk density (g/cm ³)	1.25 ¹ (0.04)	1.39 (0.40)	1.31 (0.01)	1.24 (0.01)	1.18 (0.02)
pH	5.60 (0.22)	5.03 (0.27)	4.86 (0.23)	4.85 (0.24)	4.71 (0.13)
Electrical conductivity (dS/m)	0.043 (0.014)	0.023 (0.003)	0.023 (0.003)	0.030 (0.020)	0.023 (0.013)
Organic carbon (%)	0.99 (0.034)	0.84 (0.023)	0.59 (0.023)	0.49 (0.017)	0.34 (0.026)
Total nitrogen (%)	0.13 (0.014)	0.16 (0.016)	0.14 (0.008)	0.13 (0.006)	0.11 (0.007)
Total phosphorus (ppm)	305.56 (30.92)	241.67 (21.38)	275.00 (31.55)	243.06 (22.34)	176.39 (36.19)
Available phosphorus (ppm)	2.95 (0.197)	1.96 (0.134)	0.58 (0.076)	0.38 (0.030)	0.32 (0.190)
Exchangeable cations (cmol(+) kg ⁻¹ soil)					
Na	0.51 (0.002)	0.31 (0.001)	0.34 (0.002)	0.41 (0.006)	0.37 (0.001)
K	1.66 (0.020)	1.09 (0.021)	0.68 (0.021)	0.81 (0.045)	0.32 (0.003)
Ca	4.60 (0.017)	3.65 (0.032)	2.91 (0.026)	2.60 (0.020)	2.29 (0.022)
Mg	3.07 (0.004)	2.70 (0.016)	2.52 (0.018)	2.75 (0.022)	2.85 (0.015)

¹Mean of three replications followed by Standard error in parenthesis.

experiment with three replications was laid out. For each block, there were five plots each measuring 2.5 x 2.5 m. Fresh foliar green manure samples of *A. lebbeck*, *G. sepium*, *S. sesban*, *S. siamea* and *T. vogelii* were obtained from respective fodder banks at SUA Farm. Green manure leaf

samples were randomly collected from each species 'fodder bank' in February 1997, placed into paper bags and taken to SUA Forest Biology Laboratory and oven dried (70°C) to constant weight. Green manure sub-samples were analyzed for N and P concentration as described in section 3.2.1.2. The initial N and P concentrations of green manure samples used for this experiment are shown in Table 5.

Table 5: Initial nitrogen and phosphorus concentration (%) and content (kg ha⁻¹) in green manure samples of five multipurpose trees/shrubs used in decomposition experiment at SUA Farm, Morogoro, Tanzania

Tree/shrub species	Nitrogen		Phosphorus	
	Conc	Content ¹	Conc	Content
<i>Albizia lebeck</i>	2.30	173	0.128	9.6
<i>Gliricidia sepium</i>	2.36	177	0.127	9.5
<i>Senna siamea</i>	2.21	166	0.138	10.5
<i>Sesbania sesban</i>	2.92	219	0.128	9.6
<i>Tephrosia vogelii</i>	2.56	192	0.194	14.6

¹Assumes 7.5 t ha⁻¹ of dry green manure.

One hundred and eighty litter bags each 20 cm x 20 cm were prepared. Mesh size of the bags was 1 mm, large enough to allow aerobic microbial activity and free entry of small soil animals and mycellia (Crossley and Hoglund, 1962), yet small enough to retain green manure leaves of all species. Immediately after oven drying the green

manure and cooling for 30 minutes, each of the 180 litter bags was filled with 30 g of oven dried leaves (i.e. 36 litter bags per species). To minimize sample breakage, all samples were thereafter moistened with distilled water. The bags were then closed by folding over the open end and stitched.

For each tree/shrub species, 12 litter bags (with dry green manure) were placed completely at random in one of five plots in each block at 10-15 cm soil depth on 24 March 1997 and covered with soil. For each plot, 6 positions (representing the six retrieval periods) were randomly located. At each location, two sampling points were established i.e. 12 sampling points/plot/species. Twelve litter bags/species were labelled and randomly assigned to each plot corresponding to the five multipurpose tree/shrub species in a block. After being buried in the soil, each litter bag location was marked with a special label and mapped. Green manure bag samples were retrieved from the field at 1, 2, 4, 6, 8 and 10 weeks after litter bag placement in the field. On each retrieval date, two litter bags per plot per species were retrieved and returned to the laboratory.

3.2.1.2 Laboratory procedures

In the Laboratory, foreign materials such as soil

particles, roots, etc. were removed from green manure samples by washing using distilled water. The green manure was then oven dried (70°C) to constant weight and weighed.

For the determination of total N and P concentration, the two green manure samples per plot per species per retrieval date were mixed thoroughly and ground in a wiley mill to pass through a 1 mm sieve. For each ground sample, 0.2 g was digested using concentrated sulphuric acid followed by oxidation by hydrogen peroxide (Lowther, 1980). Total nitrogen in each digest was determined by semi-macro Kjeldahl procedure (Bremner and Mulvaney, 1982). Total P in each digest was determined calorimetrically as described by Anderson and Ingram (1993).

3.2.2 Relay intercropping of *S. sesban* and maize experiment

This study was part of an ongoing large research project on relay intercropping and improved fallow farming systems being carried out by the Department of Forest Biology at SUA. Thus, I worked on an existing relay intercropping experiment established at SUA Farm in February, 1996.

3.2.2.1 Experimental design and treatments

A 2x3x3 factorial experiment arranged in a randomized complete block design (CRDB) with three replications was used for this experiment. The experimental factors were:

- (a) Two levels of the presence of trees:
 - No trees (no addition of tree foliage/twigs) as green manure (S_0)
 - With trees (incorporation of tree foliage/twigs) as green manure (S_1)

- (b) Three levels of inorganic nitrogen fertilizer:
 - Three levels of nitrogen
 - N_0 : no N (0 kg N ha^{-1})
 - $N_{1/4}$: quarter of recommended dose of N (20 kg N ha^{-1})
 - $N_{1/2}$: half of recommended dose of N (40 kg N ha^{-1})

- (c) - Three level of phosphorus fertilizer:
 - P_0 no P, (0 kg P ha^{-1})
 - $P_{1/2}$: half of recommended dose of P (20 kg P ha^{-1})
 - $P_{1/1}$: full dose of P; 40 kg P ha^{-1}

Urea was used as a source of N-fertilizer, while triple super phosphate (TSP) was used as a source of P. For N

fertilizer, maximum dose applied was 50% of the recommended dose. This is because it was anticipated that the rest of N would come from *S. sesban* green manure. The optimum level of P fertilizer was a full dose of the recommended dose because P is known to limit growth at SUA Farm than N (Mugasha, P. Commun. 1997). Moreover, *S. sesban* was not expected to provide sufficient P. There were 18 factorial treatment combinations as follows:

- | | | |
|--------------------------|--------------------------|---------------------------|
| 1. $S_0 N_0 P_0$ | 7. $S_0 N_{1/2} P_0$ | 13. $S_1 N_{1/4} P_0$ |
| 2. $S_0 N_0 P_{1/2}$ | 8. $S_0 N_{1/2} P_{1/2}$ | 14. $S_1 N_{1/4} P_{1/2}$ |
| 3. $S_0 N_0 P_{1/1}$ | 9. $S_0 N_{1/2} P_{1/1}$ | 15. $S_1 N_{1/4} P_{1/1}$ |
| 4. $S_0 N_{1/4} P_0$ | 10. $S_1 N_0 P_0$ | 16. $S_1 N_{1/2} P_0$ |
| 5. $S_0 N_{1/4} P_{1/2}$ | 11. $S_1 N_0 P_{1/2}$ | 17. $S_1 N_{1/2} P_{1/2}$ |
| 6. $S_1 N_{1/4} P_{1/1}$ | 12. $S_1 N_0 P_{1/1}$ | 18. $S_1 N_{1/2} P_{1/1}$ |

3.2.2.2 Experimental establishment and management

The experimental area was ploughed and harrowed before planting of the first crop in March, 1996. Plots measured 9.9 m x 9 m, distance between plots was 3 m and between blocks was 4 m. Two and half months old *S. sesban* potted seedlings were planted at 6 by 10 rows with 0.9 m spacing within row and 1.5 m between rows. The inner plots were 4 by 8 rows. Maize was planted at 0.3 m (within rows) and 0.75 m (between rows). For each alternate row of maize, there was mixing of trees and maize. Two maize seeds were

planted per planting station. No inorganic fertilizers were applied during the 1995/96 cropping season. All plots were weeded twice during the cropping season at 4 and 6 weeks after sowing of maize. Thereafter plots were weeded once during the dry season.

Just before the onset of the second cropping season i.e. February 1997, all *S. sesban* shrubs were measured for root collar diameter (10cm above ground), basal diameter at 30 cm above ground and total height, harvested and weighed and non-woody material manually incorporated into the soil along maize planting rows. The chemical composition of *S. sesban* green manure incorporated into the soil was 2.38% total nitrogen and 0.13% total phosphorus. On average, 771.63 kg ha⁻¹ of leaf/twig green manure of *S. sesban* was incorporated into each plot with trees i.e. 21 kg N ha⁻¹. The biomass data was obtained by using allometric equation described in sections 3.2.3.2 (a) and 4.2.1.

Prior to the incorporation of green manure, there was breaking of hardpan since preliminary data suggested that there was a hardpan within 10-30 cm depth (Table 1). As a result, in each plot, nine 20 cm (width), 30 cm (depth), and 81 cm (length) trenches were dug in order to break the hardpan.

During 1997 cropping season the plot size was reduced to 7.2 m x 8.1 m in order to protect control plots by increasing distance between *Sesbania* and control plots. Since there was competition between *Sesbania* plants during the previous dry season, seedling planting spacing was increased to 1.8 m x 2.0 m. There were 5 x 5 rows of *Sesbania*. Inner plots were 3 by 3 rows. In each plot, maize was planted in 9 rows at 0.45 m spacing within rows and 0.9 m spacing between rows. Two maize seed were sown per planting hole. For each alternate rows of maize, there was mixing of maize and three months old potted *S. sesban* seedlings. Triple super phosphate fertilizer was ring applied at the time of sowing of maize. Urea fertilizer was split applied in two equal rates of application at 4 and 6 weeks after sowing of maize. All plots were clean weeded as described above.

3.2.2.3 Assessments/data collection

(a) Tree sampling for development of allometric equations

A total of seventy (70) *S. sesban* trees from the nearby provenance trial experiment were randomly selected including all root-collar diameter classes. Each tree was measured for height using a digital measuring pole to the nearest 0.01 m and root collar and basal diameter at

respectively 10 and 30 cm above ground using a micro calliper to the nearest 0.01 cm. These trees were felled and partitioned into tree components i.e. leaves and twigs, branches and stems and then weighed green (fresh). All samples of each tree component were oven-dried (70°C) to constant weight and weighed. Tree component dry weights were used to develop allometric equations for firewood and foliar/twig biomass components as described in section 3.2.3.2.

(b) Measuring of tree/shrubs to estimate yield of firewood and foliar biomass

For each plot with *S. sesban*, all trees were measured for height, root collar and basal diameter in February, 1997 (i.e 12 months after planting) for the estimation of the above-ground biomass (firewood and foliar/twig biomass). These measurements were taken as described in section 3.2.2.3 (a). Thereafter, all tree/shrubs in each plot were cut down.

(c) Growth and yield of maize

During the 1995/96 growing season, grain yield was determined by counting and harvesting all maize plants on the 5th and 6th rows in each plot. The harvested maize was partitioned into grain and stover on plot basis in the

field. The partitioned maize grain was weighed on plot basis in order to determine its field moist weight. Subsamples of maize grain were weighed and oven-dried (70°C) to constant weight for moisture content determination and maize grain yield was later expressed on a hectare basis.

For maize growth assessment during the second cropping season i.e. 1996/97, maize root collar diameter (10cm above ground) and height were measured at the time of tasselling i.e. 8 weeks after sowing. For each plot, all maize plants in the 5th and 6th rows were first counted and then measured for height and root collar diameter (10 cm above-ground) as described above. For maize plant biomass determination, maize from the middle two rows (4th and 5th rows) were counted, harvested and separated into grain, cobs, and stover. The partitioned stover was weighed in the field on plot basis in order to determine fresh weight and sub-samples taken for laboratory analysis. Maize grain and cobs were separately weighed on plot basis in order to determine the field weight. Subsamples of stover, cob and maize grain were weighed and oven-dried (70°C) to constant weight for moisture content determination. Later on maize grain and stover/cobs were expressed on a hectare basis. Additional subsamples of stover and grain were taken for analysis of N and P content.

(d) Soil sampling for site characterization.

For each block, soil samples were taken from 5 randomly selected points between plots at 0-10, 10-20, 20-30, 30-40 and 40-50 cm soil depth before sowing of maize. Soil samples were then composited by block and by depth, mixed thoroughly and subsamples were taken for laboratory analysis.

Soil bulk density (g/cm^3) for undisturbed soil was determined according to Anderson and Ingram (1993). Soil samples were collected with coring cylinder measuring 5 cm length and 5 cm diameter. Five spots in each block were selected at random and because the soil was very dry, the spots were saturated with water a day before sampling. Soil samples were collected between 0-10, 10-20, 20-30, 30-40, and 40-50 cm depth. Soil from each core was oven dried (105°C) to constant weight and weighed. Soil bulk density (g/cm^3) was calculated by dividing the oven-dry weight of the soil sample by the volume of the coring cylinder.

(e) Soil sampling for determination of soil nitrogen availability potential

Soil samples for N mineralization were only collected from two plots/block i.e control and *S. sesban* without

fertilizer plots. For each plot, soil samples were taken from ten randomly selected points within the rows of maize at 0-10 and 10-20 cm depth at 0, 2, 4, 6, 8, 10, 12, and 14 weeks after incorporation of green manure in the inner plot. For each sampling date, these soils were bulked by soil depth, mixed thoroughly and a subsample was brought into the laboratory and stored in a refrigerator at 4-5°C for N-mineralization studies.

3.2.2.4 Laboratory procedures

(a) Analysis of soil samples for site characterization

All soil samples were air dried and sieved to pass through a 2 mm sieve. Soil particle analysis was determined by hydrometer method as described by Bouyoucos (1962). Total N and P were determined by digesting 0.3 g of each soil sample and analysed as described in section 3.2.1.2. Available phosphorus was measured by the Bray 1 test using 0.05M HCl and 0.03M NH₄F as acid extractants (Bremner and Mulvaney, 1982). Soil pH and electrical conductivity (EC) were determined potentiometrically by a glass-electrode pH-EC meter using 1:2.5 soil: water ratio and 1:2.5 soil: 0.01M KCl ratio (Landon, 1991). Soil organic carbon was determined by oxidation-titration method as described by Anderson and Ingram (1993). Soil exchangeable cations were determined by saturation method

(Uriyo and Singh, 1974). Each soil sample was saturated with ammonium acetate at 1:10 soil:ammonium acetate ratio and shaken for 30 minutes at pH 7. The displaced exchangeable K^+ and Na^+ were determined by flame photometer and the Ca^{2+} and Mg^{2+} were determined by atomic emission spectroscopy (Uriyo and Singh, 1974).

(b) Analysis of N and P content in maize and stover

Subsamples of stover and maize grain were weighed and oven-dried ($70^{\circ}C$) to constant weight. For the determination of total N and P concentration, subsamples of stover and grain were ground in a wiley mill to pass through a 1 mm sieve. Each ground sample was digested and analyzed for N and P concentration as described in section 3.2.1.2.

(c) Analysis for determination of soil nitrogen availability potential

For every sampling date, moisture content of all retrieved samples was determined as follows. For each sample, a subsample was oven dried ($105^{\circ}C$) to constant weight. In the laboratory, bulk density of each disturbed soil sample was determined by filling a crucible with each sample to the brim and oven drying ($105^{\circ}C$) to constant weight. Crucible volume was then determined by

filling it with distilled water to the brim and volume of this water was measured using a calibrated measuring cylinder. Sample bulk density (g/cm^3) was calculated by dividing the oven-dry weight of the sample by the volume of the crucible.

After determining the moisture content of each sample, the percentage of soil pore space was then determined by using the following formula:

$$\text{Porosity} = (1 - (\text{Bulk Density}/2.65)) \times 100$$

where: 2.65 is particle density of mineral soil (g m^{-3})

Fifty grammes of oven dry (105°C) soil was taken for aerobic incubation in the laboratory. Soil moisture for each sample was adjusted to 70% field capacity (It was assumed that field capacity is equal to 60% of total pore space), covered with polythene paper with small pores, weighed and then kept in a dark incubator for two weeks at 26°C . Every day the incubator was opened for 5 minutes to allow aeration and, at the same time moisture correction was made by monitoring the weight of the incubation cup and sample from the start of incubation. Any change in weight was corrected by adding the required amount of distilled water.

At the beginning of the incubation, an equivalent of 5 g oven dry (105°C) soil subsample on oven dry weight basis was taken from each sample for determination of initial mineral nitrogen (ammonium-nitrogen and nitrate-nitrogen) content. Each soil subsample was extracted with 1M K₂SO₄. A subsample of the extract was used to measure NH₄⁺-N by steam distillation and titration, and the NO₃⁻-N in the other duplicate extract was measured colorimetrically (Anderson and Ingram, 1993). Following the incubation of each of the 50 g subsample (oven dry weight basis), a 5 g subsample as above was taken, extracted and analyzed for NH₄⁺-N and NO₃⁻-N as described above.

3.2.3 Data analysis

3.2.3.1 Green manure decomposition and nutrient release experiment

Loss in green manure mass was calculated using equation 1.

$$\text{LML} = \{(M_i - M_a) \times 100\} / M_i \quad . . . \quad (1)$$

LML = green manure mass loss (%)

M_i = mass of green manure at the time of placement (30 g)

M_a = mass of green manure at the time of

retrieval (g)

Loss in litter N and P was calculated using equation 2.

$$\text{LNL} = \{(N_i - N_a) \times 100\} / N_i \dots (2)$$

Where: LNL = nutrient (N or P) loss (%)
 N_i = nutrient (N or P) concentration (% dry weight) of green manure at the time of placement
 N_a = nutrient (N or P) concentration (% dry weight) of green manure at the time of retrieval (g)

Total and periodic N and P released (kg ha^{-1}) from decomposing green manure was calculated using equations 3 and 4 respectively.

$$\text{TNL} = (10L_i \times T_i) / (0.04 \times 100) \dots (3)$$

$$\text{PNR} = \text{TNL}_i - \text{TNL}_{i+j} \dots (4)$$

TNL = total N and P released from green manure applied in kg ha^{-1}

PNR = periodic N and P released from green manure applied in kg ha^{-1}

- Li = mass of green manure at the time of placement (30 g) or mass of green manure remaining at a specific time of retrieval (g)
- Ti = nutrient (N or P) contents of green manure at the time of placement or (N or P) contents at a specific time of retrieval
- i = week (0, 2, 4, 6, 8, 10)
- j = week+2
- 10 = conversion factor from gram to kg ha⁻¹
- 0.04 = area of litter bag used (m²)

To test the hypotheses that there are no differences in the rate of decomposition and nutrient release among the foliage of the five MPTs, analysis of variance was carried out using General Linear Model (GLM) procedure of Statistical Analysis Systems (SAS) (SAS, 1991) on green manure mass loss (absolute and percentage), N and P concentration of green manure loss and on periodic and total N and P released in kg ha⁻¹. All percentages were transformed by arcsine transformation before statistical analysis. Significant differences between species in terms of decomposition rates and nutrients released were separated by Duncan's Multiple Range Test.

3.2.3.2 Relay intercropping of *S. sesban* and maize experiment

(a) Allometric equations

Two allometric equations (models) were fitted for the determination of *S. sesban* firewood and foliar biomass components as follows:

$$X = b_0 + b_1(Y_1) + b_2(Y_2) \quad (1)$$

$$\ln(X) = b_0 + b_1\ln(Y_1) + b_2\ln(Y_2) \quad (2)$$

where: \ln = base of natural logarithm

X = dependent variables (number of branches per tree or stem or branch or foliar biomass)

Y_1 = root collar diameter (cm) or diameter at 30 cm above ground

Y_2 = total tree height (m)

Allometric equation number 2 was selected because it was superior considering the goodness of fit in terms of R^2 and standard error (Table 7). This model is also simple to use. This equation was used to derive each component biomass per tree. All intercepts were corrected for bias that occurs when converting from logarithmic units (Baskerville 1972). Plot totals were then established and

expanded to a hectare basis as described by Maghembe and Prins (1994).

(b) Nitrogen availability potential (mineralization)

The hypothesis tested here holds that relay intercropping of *S. sesban* has no effect on nitrogen availability potential (mineralization). Prior to statistical analysis, data were first sorted by retrieval date and soil depth (two depths) i.e. 0-10 cm and 10-20 cm. For each retrieval date and depth, initial $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$ concentrations before incubation were subtracted from concentrations after 14 days of incubation to obtain net ammonium-N and nitrate-N respectively. Potentially available mineral N was obtained by summing up net ammonium-N and nitrate-N concentrations. Analysis of variance of RCBD of initial and net $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$ and potentially available mineral N was carried using the GLM procedure of SAS (SAS, 1991).

(c) Maize growth, yield, and nitrogen and phosphorus uptake

In order to test the hypothesis that *S. sesban* relay intercropping has no effect on maize growth and yield, analysis of variance was carried using GLM procedure of SAS (SAS, 1991). Each maize variable (collar diameter

(cm), height (cm), grain yield ($t\ ha^{-1}$), stover biomass ($t\ ha^{-1}$), and total N (%) and P (%) in grain and stover were subjected to ANOVA of a $2 \times 3 \times 3$ factorial experiment using plot means. Following ANOVA, significant responses to N and P fertilization were subjected to planned contrasts (Milliken and Johnson, 1984) using SAS. Within each block, nitrogen and phosphorus uptake efficiencies were calculated for each fertilizer treatment combination by using the following formula:

$$\text{N or P uptake efficiency (\%)} = \frac{\text{Sesbania plot} - \text{Control}}{\text{Control}} \times 100$$

CHAPTER 4

4. RESULTS

4.1 Shrub/tree species green manure decomposition and nutrient release

4.1.1 Green manure mass loss during decomposition

The results of green manure mass loss (%) of five multipurpose trees/shrubs at different sample retrieval dates are given in Figure 2. The influence of tree/shrub species on mass of green manure loss was significantly ($P < 0.05$) different throughout the 10 weeks study period (Appendix 2). Mass loss increased rapidly with an increase in decomposition time but the rate of increase decreased gradually after the first four weeks (Fig. 2). With the exception of *S. siamea* and *T. vogelii*, percent loss in mass was over 60% at week four. In week 10, *G. sepium* had mass loss of 92%, *S. sesban* was 84%, *A. lebbeck* was 75%, *S. siamea* was 72% and *T. vogelii* was 69%. Generally, mass loss was in the order *G. sepium* > *S. sesban* > *A. lebbeck* = *S. siamea* > *T. vogelii*.

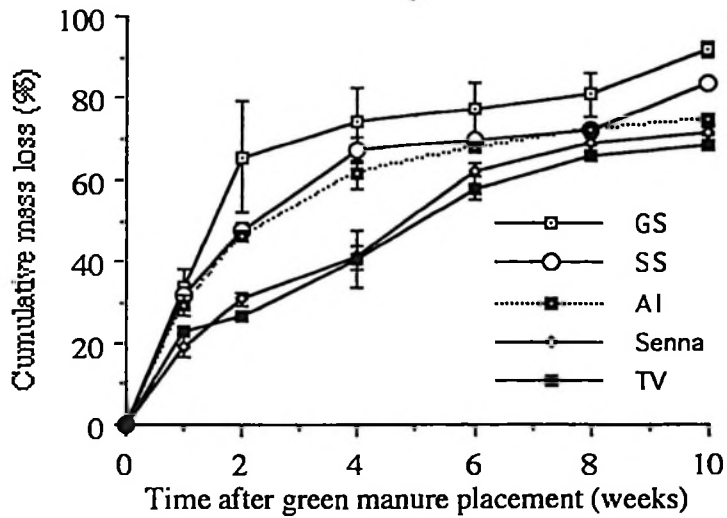


Figure 2: Green manure mass loss for five multipurpose tree/shrub species during 10 weeks of decomposition at SUA Farm, Morogoro, Tanzania. One arm of an error bar indicates the standard error of the mean of three replications. GS-*Gliricidia sepium*, SS-*Sesbania sesban*, AL-*Albizia lebbeck*, Senna-*Senna siamea*, TV-*Tephrosia volgelii*.

4.1.2 Green manure total N and P loss during decomposition

The results of total N-and P loss from decomposing green manure of five tree/shrub species are presented in Figures 3 and 4 respectively. Nitrogen loss from decomposing green manure was not significantly ($P > 0.05$ Appendix 2) different from week one to week six, but was significantly ($P < 0.01$) different at weeks 8 and 10 (Fig. 3). Nitrogen loss from *S. sesban* was very rapid within the first four weeks with *G. sepium* showing highest N loss thereafter.

There was no significant difference in P loss ($P > 0.05$) between species except in weeks 1 and 10 (Fig.4). Generally, *T. vogelii* had higher initial total P. Of interest, P loss increased with an increase in decomposition time. Phosphorus loss in *T. vogelii* and *S. siamea* were rapid within the first 4 weeks of green manure placement as compared to the other species. Loss of P from *G. sepium* and *S. sesban* green manure increased dramatically 4 weeks after placement. Phosphorus loss from *A. lebbeck* was fairly constant throughout the 10 weeks decomposition period.

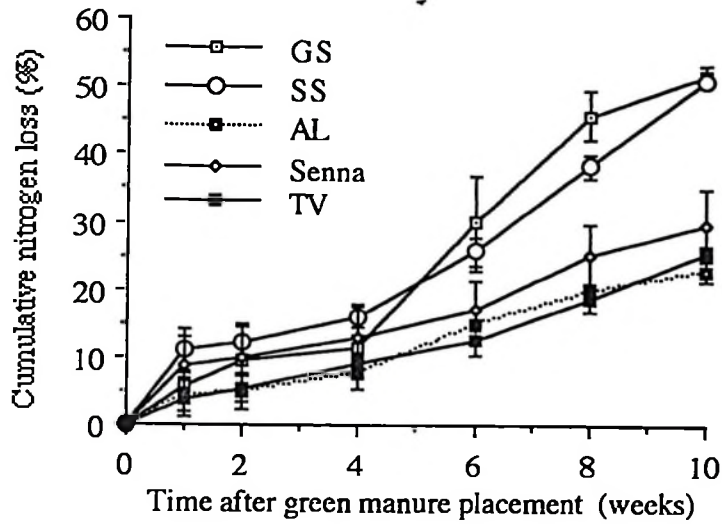


Figure 3: Total nitrogen loss from green manure of five multipurpose tree/shrub species during 10 weeks of decomposition at SUA Farm, Morogoro, Tanzania. One arm of an error bar indicates the standard error of the mean of three replications. GS-*Gliricidia sepium*, SS-*Sesbania sesban*, AL-*Albizia lebbeck*, Senna-*Senna siamea*, TV-*Tephrosia vogelii*.

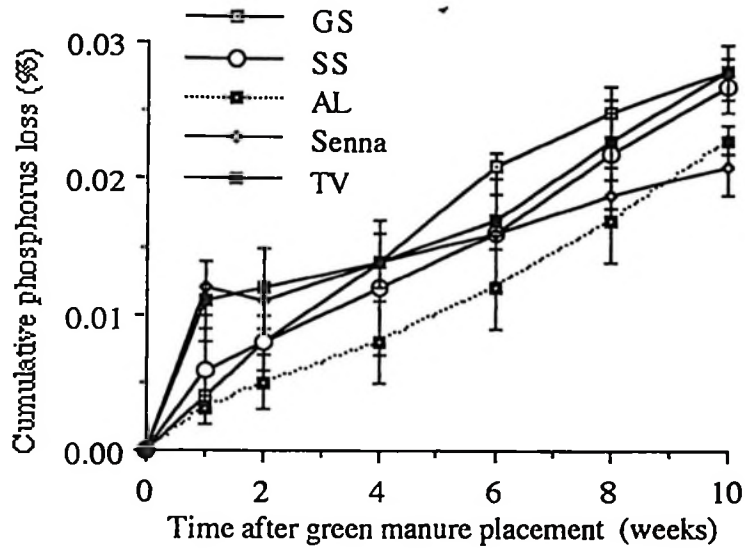


Figure 4: Total phosphorus loss from green manure of five multipurpose tree/shrub species during 10 weeks of decomposition at SUA Farm, Morogoro, Tanzania. One arm of an error bar indicates the standard error of the mean of three replications. GS-*Gliricidia sepium*, SS-*Sesbania sesban*, AL-*Albizia lebbeck*, Senna-*Senna siamea*, TV-*Tephrosia vogelii*.

4.1.3 Amount of nitrogen and phosphorus released by five MTPs during 10 week decomposition period

The results of the periodic and total amounts of N and P released during decomposition of green manure of five MTPs are summarised in Table 6. There were highly significant differences ($P < 0.01$) between species for periodic release of N in weeks one, two, six, and 10. In week 1, all the species released between 26-46% of their original N contents. By week 8, *S. sesban* had released (98%), *G. sepium* 94%, *A. lebbeck* 95%, *S. siamea* 93% and *T. vogelii* 91%. Total amount of N released per species per hectare during 10 week decomposition period were highly significant ($P < 0.01$). Generally, most of the N was released between weeks one and four which ranged between 26% and 78%. However, *S. sesban* released the highest quantity of 202 kg N ha⁻¹ and *S. siamea* released the lowest amount of 128 kg N ha⁻¹.

Periodic P released between species were not significantly different ($P > 0.05$) in weeks four, eight and 10 but was significant in weeks one, two and six ($P < 0.05$). Most of the periodic P was released between weeks one and four ranging from 28% to 83%. In week 8, *S. sesban* and *G. sepium* had released 96% of their original P contents. For the same period, *A. lebbeck* released 94%, *S. siamea* released 93% and *T. vogelii* released 92%. Total P (kg P ha⁻¹) released during

Table 6. Periodic and total amounts of N and P released during decomposition of green manure of five MTPs at SUA Farm, Morogoro, Tanzania

Species	Time after green manure placement (wks) ¹						Total
	1	2	4	6	8	10	
Nitrogen (Kg N ha ⁻¹)							
<i>Sesbania sesban</i>	100.59a ² (5.76)	32.59b (1.03)	34.74a (9.23)	8.66b (4.10)	5.23b (0.83)	20.16a (1.91)	201.97a (1.17)
<i>Gliricidia sepium</i>	77.41b (12.11)	49.97a (5.65)	11.21a (4.61)	10.43b (4.28)	10.62ab (4.99)	10.69b (3.79)	170.32b (1.51)
<i>Tephrosia vogelii</i>	50.22c (1.32)	8.89d (3.39)	27.53a (10.99)	35.47a (9.22)	16.88a (3.85)	8.77b (0.83)	147.86c (0.75)
<i>Albizia lebbeck</i>	55.45c (5.68)	29.71cb (4.13)	26.42a (5.24)	14.15b (2.82)	8.78ab (1.52)	7.87b (1.35)	141.62d (1.21)
<i>Senna siamea</i>	46.61c (5.06)	17.73cb (2.48)	11.17a (3.24)	33.47a (4.23)	11.57ab (2.43)	7.09b (1.37)	127.56c (1.22)
Phosphorus (Kg P ha ⁻¹)							
<i>Sesbania sesban</i>	3.42ab (0.27)	1.51ab (0.10)	1.95a (0.31)	0.34b (0.19)	0.35b (0.14)	0.96a (0.07)	8.53c (0.11)
<i>Gliricidia sepium</i>	3.46ab (0.36)	3.06a (1.29)	0.95a (0.55)	0.37b (0.19)	0.42b (0.18)	0.81ab (0.31)	9.07b (0.10)
<i>Tephrosia vogelii</i>	4.04a (0.28)	2.57b (0.19)	2.04a (0.95)	2.43a (0.78)	1.21a (0.28)	0.59ab (0.16)	12.88a (0.10)
<i>Albizia lebbeck</i>	2.98b (0.31)	1.70ab (0.18)	1.48a (0.21)	0.69b (0.24)	0.53b (0.10)	0.39b (0.09)	7.76c (0.04)
<i>Senna siamea</i>	2.87b (0.14)	1.04ab (0.16)	1.04a (0.47)	2.02a (0.12)	0.68a (0.13)	0.35b (0.09)	8.01d (0.03)

¹Initial nutrient content is given in Table 5.

²Mean of three replications, with standard error in parenthesis. For each nutrient, means followed by the same letter within the same column are not significantly different (P)0.05).

decomposition were significantly different ($P < 0.01$) between species. *T. vogelii* released the highest quantity of 12.9 kg P ha⁻¹ while *A. lebbeck* released the lowest amount of 7.8 kg P ha⁻¹. Generally, total P (kg P ha⁻¹) released was in the order *T. vogelii* > *G. sepium* > *S. sesban* > *S. siamea* > *A. lebbeck*.

4.2 Relay intercropping of *S. sesban* and maize

4.2.1 Firewood and foliar biomass yield

The equations used to estimate foliar biomass, branch biomass, and stem biomass per tree (kg) are shown in Table 7.

Table: 7 Summary of allometric equations for estimation of firewood and foliar biomass yields by 12 months old *Sesbania sesban* at SUA Farm, Morogoro, Tanzania

Dependent tree attribute	Equations	R ²	SE
Foliar/twig biomass	$V = 2.7182^{2.20} D^{2.462}$	0.81	1.28
Branchwood biomass	$X = 2.7182^{2.323} D^{2.907}$	0.85	1.18
Stemwood biomass	$Y = 2.7182^{2.792} D_1^{1.252} H^{0.839}$	0.95	0.76

Where: V = Foliar/twig biomass per tree (g)
 X = Branchwood biomass per tree (g)
 Y = Stemwood biomass per tree (g)
 D = Root collar diameter (cm)
 D₁ = Diameter 30 cm above-ground (cm)
 H = Total tree height (m)
 R² = Coefficient of determination
 SE = Standard error

The above allometric equations were used to obtain the foliar/twig biomass, branch biomass, and stem biomass per tree. Mean estimated tree component biomass are given in Table 8. Foliar/twig, branchwood and stemwood biomasses were 772, 1427 and 1102 kg ha⁻¹ respectively. On average total firewood (branchwood and stemwood) produced was 2529 kg ha⁻¹.

Table 8: Firewood and foliar/twig biomass yield by one year old *Sesbania sesban* grown in relay intercropping with maize at SUA Farm, Morogoro, Tanzania.

Tree component	Yield (kg ha ⁻¹)		
	Mean	Range	SE ¹
Foliar/twigs	771.6	324.7-1296.8	48.7
Branchwood	1426.6	523.7-2557.7	101.5
Stemwood	1102.3	525.4-1711.9	69.4
Total	3312.2	1347.0-5510.9	228.2

¹Standard error

4.2.2. Effect of *S. sesban* green manure on seasonal field mineral N status

The results of nitrate and ammonium nitrogen status during different sampling dates within 0-10 cm and 10-20 cm soil depths are shown in Figure 5. On all sampling dates, nitrate-N and ammonium-N of plots with and without *S. sesban* were not significantly different ($P>0.05$). However, the results show that for all sampling dates, nitrate-N was the dominant form of mineral nitrogen.

Throughout the study period, with an exception of week 4, nitrate-N was highest in the top soil horizon (0-10 cm) as compared to 10-20 cm soil depth in the *Sesbania* plots (Fig. 5a). In the control plot, nitrate-N increased within the 0-10 cm soil depth from week 0-4 when it reached a peak. However, after week 4, nitrate-N concentration increased within 10-20 cm soil depth relative to 0-10 cm depth. Generally, there were fluctuations in nitrate nitrogen concentration throughout the study period (Figure 5a).

Ammonium-N did not differ significantly ($P>0.05$) between treatments. The pattern of ammonium nitrogen concentration was very irregular although the treated plot showed high ammonium-N concentration compared with the control (Fig. 5b).

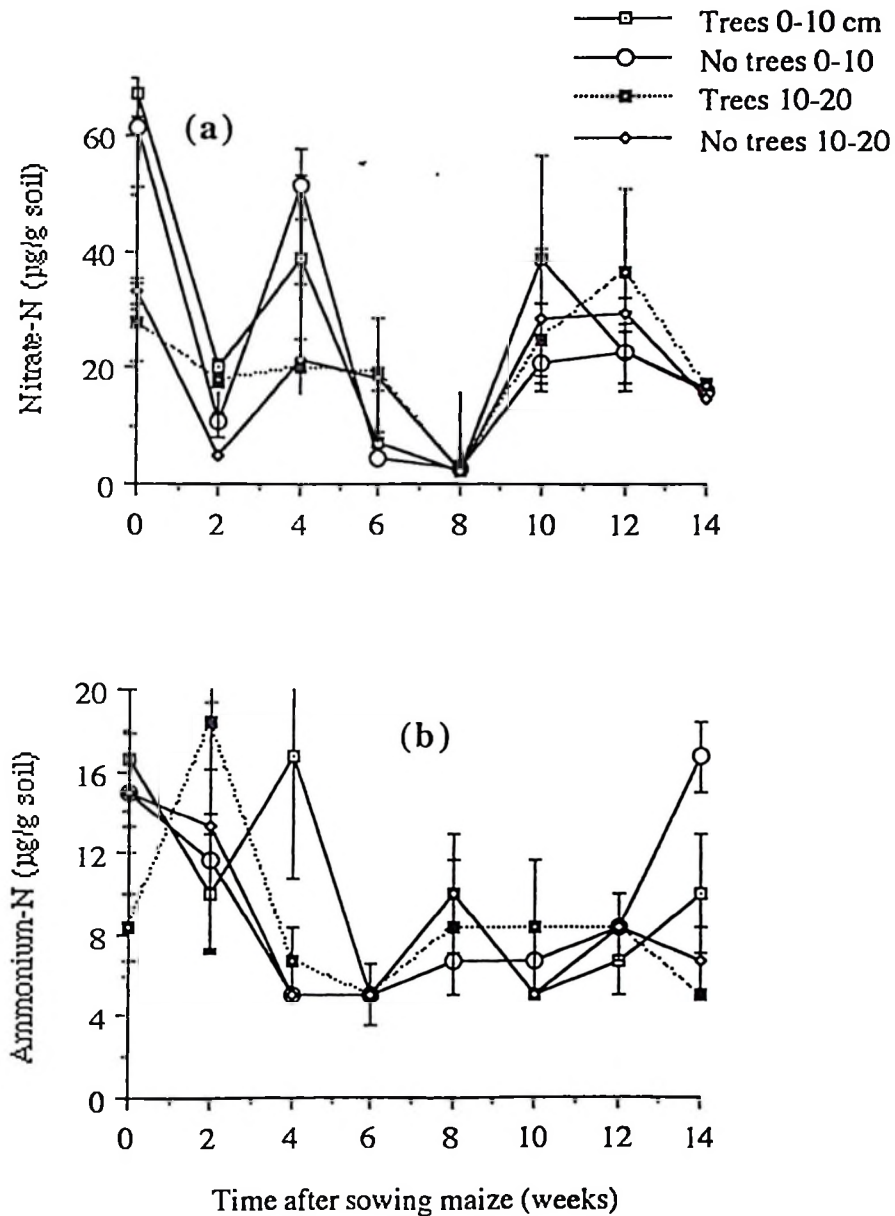


Figure 5: Seasonal field mineral nitrogen status in terms of nitrate-N (a) and ammonium-N (b) concentrations within 0-10 cm and 10-20 cm soil depth relay intercropping of *Sesbania sesban* with maize at SUA Farm, Morogoro, Tanzania. One arm of an error bar indicates the standard error of the mean of three replications.

4.2.3 Effect of *S. sesban* green manure on nitrogen availability potential

The results for net NO_3^- -N and NH_4^+ -N concentrations within 0-10 and 10-20 cm soil depths for soils taken at different sampling dates are presented in Figures 6a and b, while corresponding mineral N concentrations are given in Table 9. For each soil depth, there were no significant differences ($P>0.05$) between control and *Sesbania* plots. However, following incubation of soil samples sampled at 2, 4, 6, 8, 10, 12, and 14 weeks after sowing maize, nitrate-N was the dominant form of mineral nitrogen. Throughout the maize crop development, except in week 4, *Sesbania* plots showed the highest rates of nitrification within the first 8 weeks (Fig. 6a). This trend declined rapidly thereafter. In general, nitrate-N availability potential was higher in 0-10 cm soil depth than in 10-20 cm soil depth.

In the untreated (control) plots, there was a decline in net nitrification in the top soil horizon (0-10 cm) within the first 6 weeks and a slight increase thereafter. In these untreated plots, highest net nitrate-N accumulation in the sub-soil horizon (10-20 cm) occurred within the first 6 weeks (Fig. 6a)

For each sampling depth, net NH_4^+ -N was not significantly different ($P>0.05$) between depth and treatments, and had an

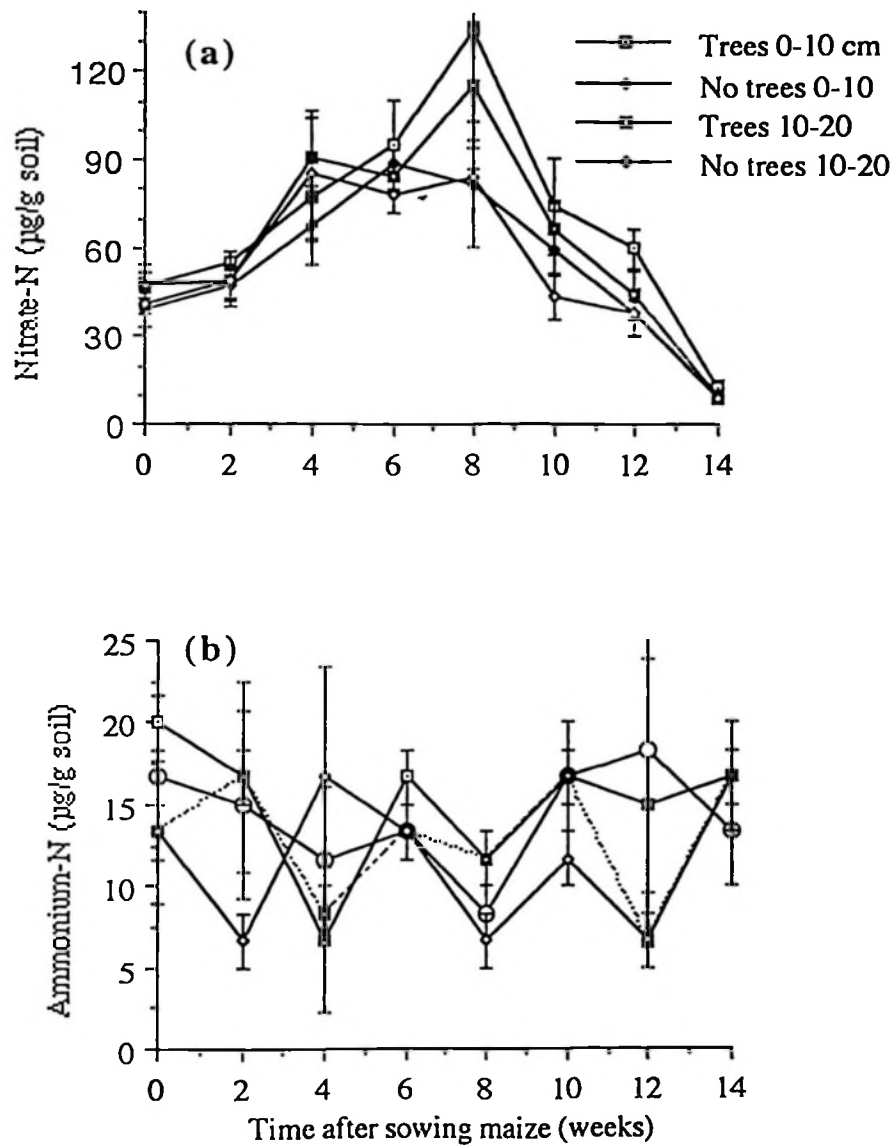


Figure 6: Mineral nitrogen changes in terms of nitrate-N (a) and ammonium-N (b) within 0-10 cm and 10-20 cm soil depths under relay intercropping of *Sesbania sesban* with maize at SUA Farm, Morogoro, Tanzania. One arm of an error bar indicates the standard error of the mean of three replications.

irregular pattern of release. Generally, results showed that in both *Sesbania* and control plots, net $\text{NH}_4^+\text{-N}$ was higher in the top soil horizon (0-10 cm) as compared to sub-soil (Fig. 6b).

For each sampling depth, green manure of *S. sesban* had no significant ($P>0.05$) effect on net mineral nitrogen levels on all sampling dates (Table 9). However, net mineral N was slightly high in *Sesbania* plots as compared to the control plots throughout the 14 weeks (Table 9). In both the *Sesbania* and control plots, net mineral N was high within the 10-20 cm soil depth from weeks 0-4 while from weeks 8-14 mineral N was highest within 0-10 cm.

Table 9: Net potentially available nitrogen ($\text{NO}_3^-\text{-N}$ plus $\text{NH}_4^+\text{-N}$) at SUA Farm, Morogoro, Tanzania

Depth	Presence of <i>Sesbania</i>	Time after sowing of maize (week)							
		0	2	4	6	8	10	12	14
		Potentially available N ($\mu\text{g/g}$ soil)							
0 - 10	With	62.44 ¹ (4.90)	65.52 (1.85)	94.41 (19.41)	100.57 (15.39)	144.90 (36.69)	80.27 (15.36)	65.29 (6.52)	22.91 (3.87)
	Without	56.05 (23.42)	58.47 (5.77)	72.41 (2.16)	93.80 (7.60)	88.76 (9.65)	66.55 (2.85)	44.71 (1.94)	21.70 (2.46)
10 - 20	With	49.47 (5.45)	67.71 (4.01)	97.58 (11.71)	89.27 (5.19)	126.00 (20.58)	75.27 (6.41)	51.43 (6.91)	13.67 (1.99)
	Without	62.39 (5.84)	61.60 (10.98)	90.21 (22.28)	83.11 (5.46)	94.87 (2.83)	48.53 (8.08)	45.22 (2.03)	17.08 (2.23)

¹Means of three replications with standard error in parenthesis

4.2.4 Maize growth and yield

The results of maize height and root collar diameter growth are presented in Figure 7 and Appendix 3. Maize mean height and root collar diameter at 8 weeks differed significantly ($P < 0.05$) between control and *Sesbania* plots. Mean maize height and root collar diameter in the *Sesbania* without fertilizer plots were 1.75 m and 2.09 cm while in the control were 1.62 m and 2.00 cm respectively.

The results of maize grain and stover yield in 1995/96 and 1996/97 cropping seasons are summarised in Figure 7c and d, and Appendix 3. In the 1995/96 cropping season, there were no significant ($P > 0.05$) differences in maize grain yield between the plots intercropped and not intercropped with *Sesbania*. However, in 1995/96 grain yield in the control plots were slightly high (0.69 t ha^{-1}) as compared with that from the *Sesbania* plots (0.58 t ha^{-1}). In contrast, in the 1996/97 cropping season, maize grain yield were significantly ($P < 0.01$) different between the plots intercropped and not intercropped with *Sesbania*. Maize grain yield was increased by 16.3% in *Sesbania* plots without fertilization (2.43 t ha^{-1}) as compared to control plots (2.09 t ha^{-1}) (Fig. 7c). Mean maize stover biomass were not significantly ($P > 0.05$) different between the control (3.71 t ha^{-1}) and *Sesbania* without fertilizer plots (4.13 t ha^{-1}).

The three levels of N fertilizer i.e. (0, 20 and 40 kg N ha⁻¹) had no statistically significant ($P > 0.05$) effect on maize growth and yield. On the other hand, the three levels of P fertilizer i.e. (0, 20 and 40 kg P ha⁻¹) had significantly ($P < 0.05$) different effects on maize height, root collar diameter, stover biomass and maize grain yield (Appendix 5 and 6). Maize grain yield from plots which received 20 kg P ha⁻¹ was 2.39 t ha⁻¹ and 40 kg P ha⁻¹ was 2.36 t ha⁻¹ compared with the control with 0 kg P ha⁻¹ was 2.02 t ha⁻¹. Stover yield was 3.29 t ha⁻¹ (control), 4.16 t ha⁻¹ (20 kg P ha⁻¹) and 4.33 t ha⁻¹ (40 kg P ha⁻¹). A significant ($P < 0.05$) linear relationship between maize growth and yield and the level of P showed that an increase in P was associated with an increase in the growth and yield of maize (Appendix 6 and 7). On the other hand, while maize growth showed a significant ($P < 0.05$) quadratic relationship with P, maize yield showed a non significant ($P > 0.05$) quadratic relationship implying that maize yield can further be increased with an increase in P.

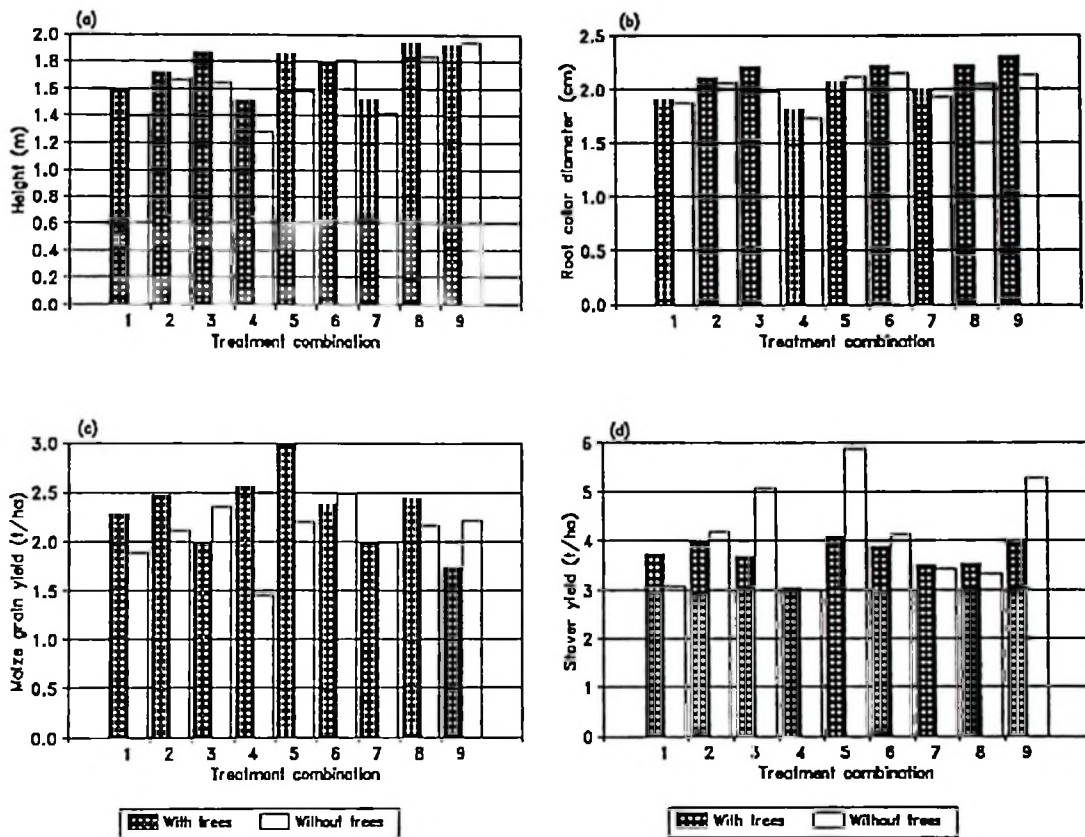
Generally, there were no significant ($P > 0.05$) interaction effects between treatments. However, overall maize grain results obtained from plots where N and P fertilizers were applied in the presence of *S. sesban* green manure gave comparatively better results than plots without *S. sesban* green manure (Fig. 7c and Appendix 3). Highest mean grain yield (2.98 t ha⁻¹) was obtained from intercropped plots

where 20 kg ha⁻¹ each of N and P fertilizer was applied. In contrast, highest mean stover yield (5.9 t ha⁻¹) was obtained in un-intercropped plots where 40 kg ha⁻¹ each of N and P fertilizer was applied.

4.2.5 Nitrogen and phosphorus uptake by maize

The results of N and P uptake by maize are presented in Figures 8 and 9 and Appendix 4. There were no significant (P>0.05) differences between plots with and without *S. sesban* with regard to grain N and P, stover N and P (Appendix 4), combined grain-stover (total) N and P uptake by maize (Fig. 9). However, except for stover P (1.89 kg ha⁻¹) which decreased by 5%, there was a general increase in grain N (35.5 kg ha⁻¹) by 18%, grain P (4.8 kg ha⁻¹) by 30%, stover N (26.8 kg ha⁻¹) by 47% in *Sesbania* plots without fertilizer (Fig. 8). Combined grain-stover total N (62.3 kg ha⁻¹) and P (6.7 kg ha⁻¹) uptake by maize in *S. sesban* plots increased by 29% and 18% respectively as compared with plots without *S. sesban* (Fig. 9).

Phosphorus fertilizer alone applied at a rate of 20 kg P ha⁻¹ in *S. sesban* intercropped plots, increased grain N by 53%, grain P by 31%, stover N and P by 2% (Fig. 8), combined grain-stover total N by 25%, and total P by 22% (Fig. 9) as compared with control plots. In similar *S. sesban* intercropped plots, P fertilizer alone at a rate of



Note: Treatment combination

1 = N_0P_0

4 = $N_{1/4}P_0$

7 = $N_{1/2}P_0$

2 = $N_0P_{1/2}$

5 = $N_{1/4}P_{1/2}$

8 = $N_{1/2}P_{1/2}$

3 = $N_0P_{1/1}$

6 = $N_{1/4}P_{1/1}$

9 = $N_{1/2}P_{1/1}$

Figure 7: Maize growth and yield: height (a), root collar diameter (b), grain yield (c), and stover (d) of maize under relay intercropping with *Sesbania sesban* at SUA Farm, Morogoro, Tanzania.

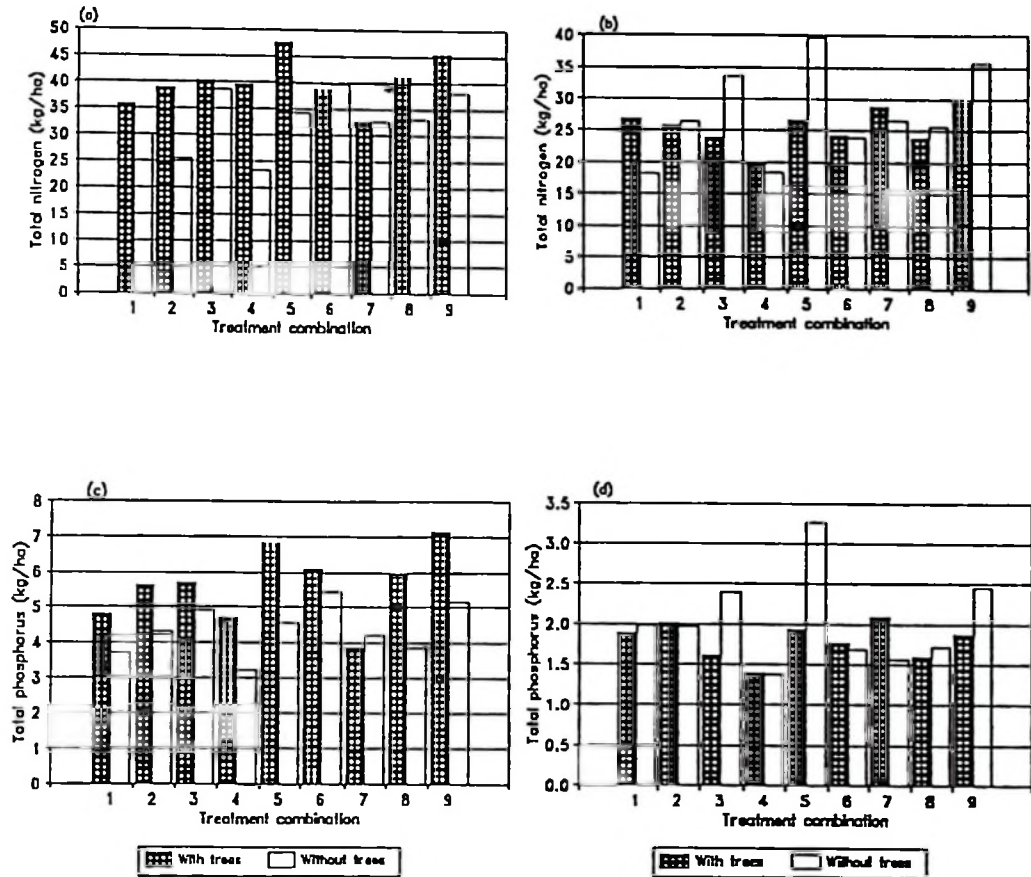


Figure 8: Partitioning of nutrient uptake: grain nitrogen (a), stover nitrogen (b), grain phosphorus (c), stover phosphorus (d) under relay intercropping of *Sesbania sesban* with maize at SUA Farm, Morogoro, Tanzania. Note: Treatment combination as defined in figure 7.

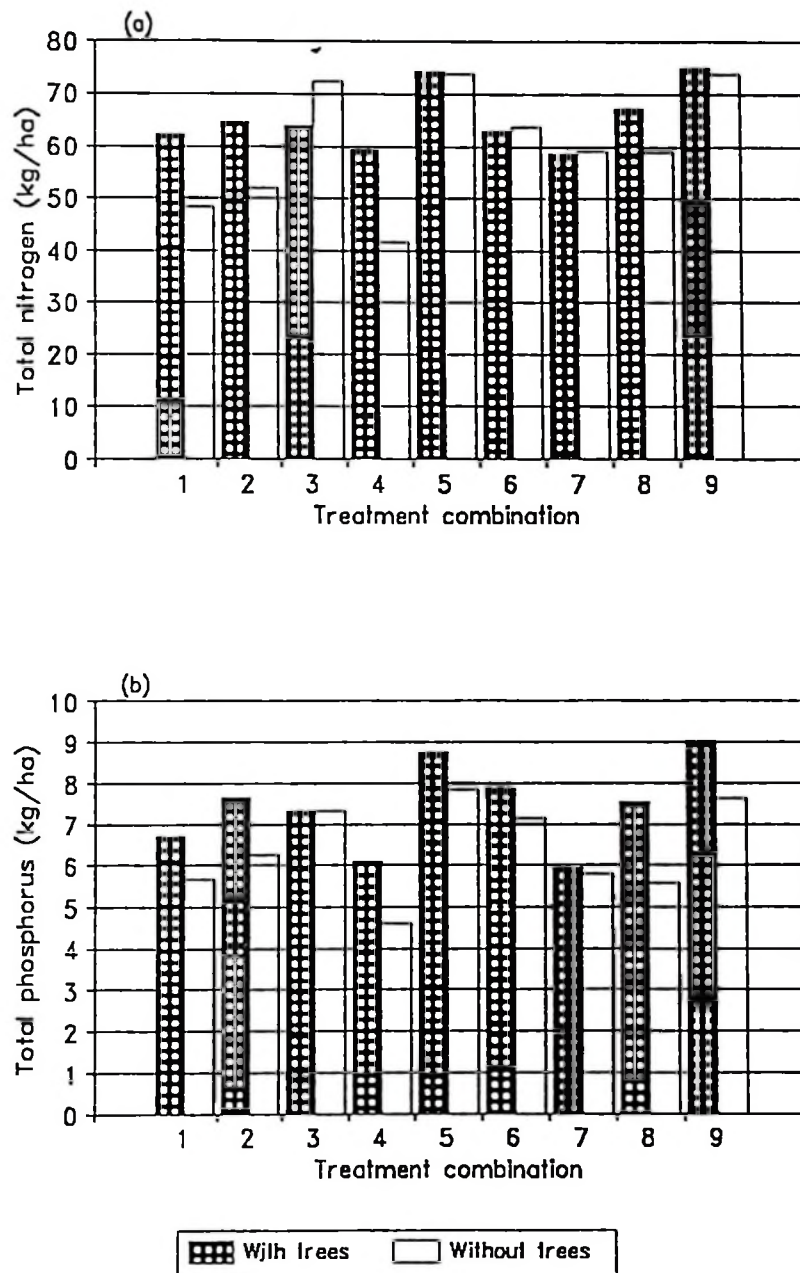


Figure 9: Nutrient uptake: total nitrogen in grain plus stover (a) and total phosphorus in grain plus stover (b) under relay intercropping of *Sesbania sesban* with maize at SUA Farm, Morogoro, Tanzania. Note: Treatment combination as defined in figure 7.

40 kg P ha⁻¹ increased grain N by 4%, grain P by 17%, and decreased stover N and P by 41% and 50% respectively when compared with control plots. Combined grain-stover N uptake was reduced by 11% and there was a negligible increase in combined grain-stover total P uptake in plots that were intercropped with *S. sesban* as compared with control plots (Fig 9). On the other hand, N fertilizer alone applied at the rate of 20 kg N ha⁻¹ in *S. sesban* intercropped plots, increased maize grain N by 70%, grain P by 47%, stover N by 8% and stover P by 2% as compared with control plots (Fig. 8). Combined grain-stover total N and P were increased by 43% and 33% respectively. In similar *S. sesban* intercropped plots, N fertilizer alone applied at the rate of 40 kg N ha⁻¹ increased grain P by 9%, stover P by 34%, stover N by 9% and had no effect on grain N as compared with control plots. Combined grain-stover total P was slightly increased by 3% while combined grain-stover total N reduced slightly by 0.96%.

CHAPTER 5

5. DISCUSSION

5.1 Green manure decomposition and nutrient release

5.1.1 Green manure decomposition

The results of green manure mass loss during decomposition (Figure 2) showed that mass loss percentage increased rapidly with an increase in decomposition time, particularly within the first four weeks. *Tephrosia vogelii* green manure decomposed most slowly, while *G. sepium* and *S. sesban* green manure decomposed faster than the green manure of the other two species. These results are in line with those of Lehmann *et al.* (1995) in which *Gliricidia* alone decomposed considerably faster in the first 18 days with 75% mass loss compared to *Senna* with 30%. Faster decomposition rates for *G. sepium* and *S. sesban* four weeks after green manure placement have been widely reported (Budelman, 1988; Mwiinga *et al.*, 1994; Mugendi and Nair, 1997; Nduwayezu, 1997). A much slower rate of decomposition of *T. vogelii* is related to the presence of certain poisonous compounds (Milne-Redhead and Polhill, 1971) which might have reduced microbial and fauna activity. This attribute may be very useful as *T. vogelii* could be used as a good fallow species as a sustainable source of nutrient

supply for a period of time (Drechsel et al., 1996).

However, it appears that green manure decomposition was greatly influenced by the rainfall pattern. The differences in mass loss among species stayed fairly consistent from week four to week 10 due to the dry spell (small amount of rainfall) during May and June (Table 3). This finding corroborates the report by Mugendi and Nair (1997) that in semi-arid areas of central Kenya where erratic rainfall and fluctuating temperatures are common, climatic factors become more important than plant quality factors in determining litter decomposition rates. Upadhyay et al. (1989) predicted monthly rainfall to be a more reliable factor regulating monthly weight loss of litter on individual sites in the central Himalayan forests as opposed to annual temperature. Vanlauwe et al. (1994) reported that the number of rainfall events gave a better correlation with the percentage dry weight loss than the the total amount of precipitation. Handayanto et al. (1994) reported that the rate of nitrogen release from pruning materials of *G. sepium* and *L. leucocephala* was considerably slower after 16 days due to inadequate moisture availability.

The results of this study may have also been affected by termite activity, accumulation of mud in litter bags, and the problem of removing mud completely from leaf fragments.

Similar problems have been reported by Budelman (1988) and Montagnini et al. (1993).

5.1.2 Green manure nutrient content and release

As indicated in Table 5, the MPTs showed a considerable variation in N and P mineral concentration, suggesting that they displayed a different ability to absorb minerals from soil. It appears that legumes showed a higher nitrogen content than the non-legume. Consequently, it may be assumed that the high N content of the green manure of legumes was due to nitrogen fixation and the low N content of *S. siamea* was due to the lack of the ability to fix nitrogen from air. *Tephrosia vogelii* showed the highest P content. This indicates that *T. vogelii* was able to take up soil P more efficiently than other common shrubs. Li et al. (1990) reported that some legumes can utilize non-available form of soil P and exhibit a different capacity in providing P.

The results of nutrient release (Figures 3 and 4, and Table 6) showed that most of the nutrients were released within the first four weeks after green manure placement and are consistent with those reported elsewhere (Yamoah et al., 1986; Budelman, 1988; Mwiinga et al., 1994; ; Lehmann et al., 1995; Mugendi and Nair, 1997; Nduwayezu, 1997).

The rapid nutrient loss of N (26-46%) and P (28-36%) during the first week after green manure placement (Tables 5 and 6) can be explained by the leaching of easily soluble fraction from the green manure. This suggests that an unusually high percentage of N and P was apparently held in soluble compounds such as polyphenols, possibly because of the leguminous nature of most of the decomposing substrate (Constantinides and Fownes, 1994). An initial "leaching phase" has been observed for mass and nutrient loss from fresh and dry leaves (Swift et al., 1981; Schroth et al., 1992). In sub-humid savanna of central Togo, Schroth et al., (1992) reported nutrient losses from mulch samples within the first 11 days in the range of about 50% for N and P. Maliondo et al. (In press) have observed an increase in soil mineral N up to 58 kg ha⁻¹ two weeks after amendment with green manure from *G. sepium* representing a sixfold increase over values measured one day before manuring. Mwiinga et al. (1994) reported the highest release of N kg ha⁻¹ ranging between 13-18% within the first one week after green manure placement. The processes of decomposition, besides leaching of an easily soluble fraction, are catabolism of decomposer organisms and comminution, mainly by animals feeding on the substrate (Swift et al., 1979; Prescott, 1997). The release of nutrients after leaching phase suggests that the export of fragments from the litter bags by soil animals was the dominating factor of decomposition. This is because high numbers of

invertebrates in and under green manure layer were observed.

Total amount of N and P released per hectare in this study ranged between 128 kg N ha⁻¹ (*S. siamea*) to 202 kg N ha⁻¹ (*S. sesban*) and 8 kg P ha⁻¹ (*A. lebbeck*) to 12.9 (*T. vogelii*) kg P ha⁻¹. These results are in agreement with those reported by Kang et al. (1985); Budelman (1988); Young (1988); Nair (1993); Mwiinga et al. (1994); Lehmann et al. (1995); Drechsel et al. (1996); Sanchez and Palm (1996). However, the initial percent N (2.3 - 2.9) and percent P (0.1 - 0.2) concentrations in green manure used for the decomposition study were generally lower than those reported in previous studies using tropical plant residues (Budelman, 1988; Montagnini et al., 1993; Mwiinga et al., 1994; Lehmann et al., 1995; Mugendi and Nair, 1997; Nduwayezu, 1997). The green manure applied at an equivalent of 7500 kg ha⁻¹ may have accounted for the short fall in initial N and P contents. It should be remembered that the quantity of nutrients mineralized depends on both the quality and quantity of biomass added to the soil.

5.2 Relay intercropping of *S. sesban* and maize

5.2.1 Firewood and green manure yield

Results for firewood and green manure yield are presented

in Table 8. Firewood yield of 3 t ha⁻¹ is lower than the 10 t ha⁻¹ reported by Kamara and Maghembe (1994) and Kwesiga and Coe (1994) with *S. sesban* species grown at high population density, but similar to those reported by Karachi et al. (1994) and Drechsel et al. (1996). Higher green manure yields have been recorded from *S. sesban* species grown either as fodder lots or in hedgerows (Evans and Rotar, 1987) but concluded that potential yields are dependent on fertility inputs, cutting regimes and environmental conditions. The low firewood and foliar biomass yield recorded in this study could be due to the failure of the short rains between October - December 1996 which resulted into massive litterfall. Defoliating insect attack may have also contributed. High death rates of smaller plants which were in the inner rows was also observed. This indicates the impact of intraplant competition suggesting that the intraplant spacing used was probably inappropriate for Morogoro. A similar observation has been reported by Karachi et al. (1994) in Central Tanzania.

High soil bulk density within 10-30cm soil depth and low available P (Table 4) may have also contributed to the low firewood and foliar biomass production. Schroth et al. (1992) reported that an unusually hardened subsoil of a sandy clayey soil can restrict root growth at a depth of between 10-70 cm. Yamoah and Burleigh (1990) reported that

the use of inorganic fertilization at the time of planting was indispensable for the establishment of leguminous shrubs, particularly on impoverished soils and that without starter fertilization several of the highest reported yields and residual effects would not have been possible. Burleigh and Yamoah (1997) reported a significant response of *Leucaena* and *Sesbania* to increased levels of P fertilizer on P deficient oxisols in Rwanda.

Another explanation for the low firewood and green manure yield may be attributed to the growth habitat preferred by *S. sesban*. Although *S. sesban* is commonly naturalized in regions that experience wet and dry seasons, it is reported to prefer habitats where there is sufficient moisture (Evans and Rotar, 1987; Bradbury, 1990, Nair 1993; Kwesiga and Coe, 1994). It has been observed that *S. sesban* never become leafless near a water source (Kwesiga and Coe, 1994) and that its mean relative growth can be depressed by 44% in a water-stressed environment (Bradbury, 1990).

5.2.2. Effect of *S. sesban* on seasonal field N status

The results of field mineral N status are presented in Figure 5. Nitrate-N and NH_4^+ -N of plots with and without *S. sesban* were not significantly different. This may be due to the fact that *Sesbania sesban* lost most of its leaves long before they were felled. Thus, most of the foliage might

have decomposed and lost most N even before soil sampling started.

The results of the present study indicate that the proportion of NO_3^- -N concentration was higher than that of NH_4^+ -N especially in the *S. sesban* green manured plots. This indicates that the system is predominantly nitrifying. The high mineralization rate (nutrient flush) observed during the first sampling might have been the result of decomposing materials like weed residues and litter from the *Sesbania* during the dry season.

Nitrate-N and ammonium-N patterns were highly influenced by rainfall pattern (Fig. 1 and Table 3). Within the first week, the site received 70.9 mm of rainfall leading to the leaching of the initially high concentration of NO_3^- -N. Under favourable conditions for mineralization, NH_4^+ -N is converted to NO_3^- -N. As a result, a decline in NH_4^+ -N lead to an increase in NO_3^- -N between weeks two and four. But as indicated in Fig. 1, for the past 27 years, April, 1997 had the highest total monthly rainfall (241 mm). The observed decline in NO_3^- -N within 0-10 cm soil depth and an increase in NO_3^- -N between 10-20 cm soil depth from week four and thereafter in both the *Sesbania* and control plots could be attributed to leaching of NO_3^- -N from the top soil horizon (0-10 cm). Loss of NO_3^- -N from top soil horizon through leaching has been widely reported (Alexander, 1977; Young,

1989; Nair, 1993; Tisdale et al., 1990; Nduwayezu, 1997; Maliondo et al., In press). In addition to leaching, mineralization rate may have declined between weeks six and 10 due to the low amount of rainfall during this period (Table 3). Prescott (1997) reported that soil moisture is a more critical factor for decomposition and mineralization than temperature. In Malawi, Maliondo et al. (In press) reported an average decline in soil mineral N within four weeks from 48 kg ha⁻¹ to 7 kg ha⁻¹ as average soil moisture content fell from 21% to 9%. Handayanto et al. (1994) reported that the rate of nitrogen release from pruning materials of *G. sepium* and *L. leucocephala* was considerably slower after 16 days due to inadequate moisture availability.

5.2.3 Effect of *S. sesban* green manure on nitrogen availability potential

Results for nitrogen availability potential are presented in Figure 6 and Table 9. Unlike NH₄⁺-N, NO₃⁻-N levels were relatively high, and this could be attributed to the presence of an active population of nitrifiers in the soil. It also showed that NH₄⁺-N in these soils is very unstable and once generated, is oxidized into NO₃⁻-N. These results confirm earlier findings that NO₃⁻-N is the dominant form of mineral nitrogen which is readily available and easily removed from agricultural soil as compared with NH₄⁺-N

(Alexander, 1977; Tisdale *et al.*, 1990; Nduwayezu, 1997; Maliondo *et al.*, In press). The rates of mineralization and nitrification are reported to be indicators of soil fertility (Allison, 1973; Pastor, *et al.*, 1987; Piccolo *et al.*, 1994).

Although not significant, plots in which green manure was applied showed higher levels of mineral N. This high concentration of mineral N in *Sesbania* plots is in agreement with earlier findings by Alexander (1977) and Nair (1993). During the initial soil sampling, the relatively high mineral N was probably coming from the already existing nitrogen in the soil as a result of *S. sesban* litterfall during the dry season, thus creating favourable conditions for decomposition and mineralization of added green manure.

Potentially available nitrogen level increased with an increase in sampling time up to week 8 after green manure placement in *Sesbania* plots. Probably this is due to the quality attributes of the green manure that ensured its fast rate of decomposition as reported by (Mwiinga *et al.*, 1994) and also confirmed in experiment 1 in this study where *S. sesban* green manure lost 98% of its initial-N content in eight weeks. The rapid loss of mineral-N within control plots (week 6) and more especially in *Sesbania* plots (week 8) may be due not only to mineralized N uptake

by weeds and maize crops but also to the completion of the decomposition process of the incorporated *Sesbania* green manure. Similar observations have been reported by Nduwayezu (1997) and Maliondo et al. (In press). The low level of $\text{NH}_4^+\text{-N}$ measured initially and during laboratory incubation (Fig. 6), indicates that microbial immobilization was important, since microbial assimilation prefer $\text{NH}_4^+\text{-N}$ to $\text{NO}_3^-\text{-N}$ (Recous et al., 1990).

It should be noted from these results that $\text{NO}_3^-\text{-N}$ can be used to predict the nitrogen availability potential in agricultural soils, not only because it is in higher concentration of the mineral-N but also because it is the last product of mineralization. The higher the concentration of $\text{NO}_3^-\text{-N}$, the higher will be the rate of nitrogen mineralization. The higher the $\text{NO}_3^-\text{-N}$ immobilization or loss the lower will be the level of mineral N in the soil.

5.2.4 Maize growth and yield

5.2.4.1 Effect of *S. sesban* green manure on maize yield

The magnitude of yield increment in both intercropped plots and those that were not as compared with the 1995/96 cropping season is very high in this experiment (Figure 7 and Appendix 3). A possible explanation could be the

outcome of hardpan breaking which may have enabled maize roots to penetrate further down enabling the capture of moisture and nutrients that were otherwise lost. Several authors have reported the effect of soil bulk density on root growth and development, soil water regime, and crop yields (Brady, 1984; Lal and Greenland (1979) cited by Young (1989); Landon (1991); Schroth et al., (1992).

The results in Appendix 3 and 5 show that relay intercropping of *S. sesban* and maize significantly increased maize grain yield with no fertilizer input. Increased crop yield after a 1 year fallow period has been widely reported (Palm et al., 1988; Nair, 1993; Kwesiga and Coe, 1994; Tonye et al., 1997). In this study, *S. sesban* without fertilizer increased maize grain yield (2.43 t ha^{-1}) by 16.3% as compared to control (2.09 t ha^{-1}). These results are in agreement with results of Kang et al., (1990); Singh (1992) and Kwesiga and Coe (1994) on the possibility of maintaining constant maize yield (around 2 t ha^{-1}) in maize\legumes intercropping systems. However, although this 16.3% increase in grain yield was statistically significant, it may be marginal to the farmer considering the big labour inputs required of such practice.

Trees can provide nitrogen inputs in agroforestry systems by two processes: Biological nitrogen fixation and deep nutrient capture (Sanchez and Palm, 1996). Although the

addition of *Sesbania* green manure was expected to significantly increase soil nitrogen availability, the amount of biomass and hence N added (21 Kg N ha^{-1}) was too low. *Sesbania sesban* lost most of its leaves long before they were felled and might have started to decompose before sowing of maize. This may also apply to fine roots. According to Sanchez and Palm (1996), for an African farmer, 4 t ha^{-1} maize crop require 100 kg N ha^{-1} . In order to obtain 2.43 t ha^{-1} of maize grain, $60.8 \text{ Kg N ha}^{-1}$ was supposed to have been added. This implies that the amount of N added through green manure in this study was less than half of what was supposed to be incorporated. But Rocheleau *et al.* (1988) reported that farmers in Kenya have observed that nitrogen derived from *S. sesban* is not cycled through leaf-litter but through the decomposition of the roots when the trees are felled.

5.2.4.2 Effect of fertilizer on maize yield

In this study, there were no significant differences between the three levels of N fertilizer but the effect of the three levels of P differed significantly (Appendix 5 and 6). An increase in N and P fertilizer application resulted into a further increase in maize yield to a certain extent in the presence of *Sesbania* green manure. The contribution of legume pruning to crop production do not entirely satisfy the crop N requirement and that

supplementary N fertilizer is often required to achieve maximum yield (Xu et al., 1992; Kwesiga and Coe, 1994; Mappaona et al., 1994; Sanchez and Palm, 1996) .

According to Landon (1991), soil total N between 0.1-0.2% is considered low for maize production. However, maize grain yield results obtained in this study though not significantly ($P > 0.05$) different showed that soil total N between 0.13-0.16% (Table 4) can not be considered low for maize production in Morogoro. Available P below 4 ppm is reported to be low for maize production (Landon, 1991). The highly significant response of maize to P fertilization indicated that P is a more limiting factor for maize production at SUA Farm when compared to N as initial available P results obtained from the experimental site was far less than 3 ppm (Table 4). Sanchez and Palm, (1996) observed that unlike N fertility, P fertility cannot be replenished by agroforestry alone. The highest maize grain yield of 3 t ha⁻¹ was obtained from plots in which 20 kg ha⁻¹ each of N and P fertilizer was applied in the presence of green manure.

Lack of statistically significant ($P > 0.05$) interaction effect between *S. sesban* green manure and fertilizer on the growth and yield of maize differ from results of other authors, who measured the effect of interaction between organic and inorganic sources of nutrients in agroforestry

systems (Xu et al., 1992; Kwesiga and Coe, 1994). This could be explained; firstly, by the low amount of green manure applied (Table 8) and secondly, by leaching of N and fixation of P. Fixation of large chunk of P by soils of relatively low pH with very low available P (Table 4) and high top soil clay content (Appendix 1) have been reported by Sanchez and Palm (1996).

5.2.5 Nitrogen and phosphorus uptake by maize

The results of N and P uptake obtained in this study are presented in Figures 8 and 9, and Appendix 4. The results showed that fertilizer applied at 20 kg ha⁻¹ each of N and P increased maize grain N and P uptake in the presence of *S. sesban* green manure. These results can be compared with those of Xu et al. (1992) in which N fertilizer affected mainly maize cob yield when N fertilizer was applied at 12.3 kg N ha⁻¹ in the presence of *Leucaena* prunings. The increase in maize grain N and P observed as a result of *S. sesban* green manure application differ from those reported by Mappaona et al. (1994) whereby N, P, potassium and magnesium concentrations in cabbage decreased by the incorporation of green manure while the calcium concentration increased.

However, fertilizer applied at 40 kg ha⁻¹ each of N and P in the presence of *S. sesban* resulted in a general decline in

uptake except that 40 kg P ha⁻¹ increased stover P by 34%. This may be due to nitrogen loss through denitrification as field observations showed that the experimental site was intermittently waterlogged in early wet season after application of N fertilizer (Table 3). Nitrogen loss and P fixation may have increased with an increase in application rate. This observation is in line with Xu et al. (1992) whereby 37% of N were apparently lost through denitrification from the plant-soil system when N fertilizer was applied at 40 Kg N ha⁻¹ or more in the presence or absence of plant residues. Kundu et al. (1991) reported that uptake efficiency of urea N decreased by 33%, whereas that of green manure sources of N increased by 19 to 39% in the wet, compared with those in the dry season. It was concluded that the observed decrease in the efficiency of urea N in the wet season was ascribed to increased loss of applied N, largely through ammonia volatilization, denitrification, run-off and leaching. Similar observations have been reported by several authors (Alexander, 1977; Young, 1989; Recous et al., 1990; Tisdale et al., 1990; Schroth et al., 1992; Becker et al., 1994, Piccolo et al., 1994) for nitrogen and (Sanchez and Palm, 1996; Tonye et al., 1997) for phosphorus.

CHAPTER 6

6. CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

These experiments indicate that the incorporation of green manure of legumes was to some extent effective for the maintenance of some plant nutrients like inorganic nitrogen and available phosphorus. The implications of the results presented in this dissertation are that there is still scope for relay intercropping improvement in the semi-arid areas. Nitrogen and P fertilizers are needed to achieve the optimum yield potential of maize although *S. sesban* green manure can improve both soil fertility and subsequent crop yield. The lack of significant interaction effect between fertilizer and *S. sesban* green manure in increasing maize yield in this study suggested that application of low amount of green manure could not improve the efficiency of use of fertilizer and similarly application of fertilizer could not also increase the benefit of green manure for maize production. Thus *S. sesban* is unsuitable for relay intercropping in semi-arid areas of Morogoro because of its low foliar biomass production and its inability to retain foliage during the dry season.

Appropriate agroforestry systems such as improved fallows

and relay intercropping may be able to maintain or even restore nitrogen fertility through BNF, deep nitrate capture and several cycling mechanisms. Soil phosphorus fertility, however cannot be replenished by agroforestry alone, but it can perhaps be made more available through cycling like in the case of *T. vogelii* observed in this study. Nitrogen levels at SUA Farm can be considered to be moderate for maize production but available P levels are critically low and it is being depleted at a fast rate. For long-term production, agroforestry systems must include the addition of phosphorus and, in some cases of nitrogen fertilizer as well in order to reverse nutrient depletion and ensure the efficient use of resources.

6.2 Recommendations

- (i) Since most of N released from *S. sesban* green manure was in the NO_3^- -N form which is very mobile in the soil, leaching losses are likely to be high unless the quantity and timing of N supply is carefully synchronized with crop demand as controlled by growth rate. Leaching of NO_3^- -N may have also reduced the amount of N available to the maize crops. Therefore, in some instances, it might be necessary to delay the first application, or apply in multiple small doses increased stepwise to match the maize growth stage.

- (ii) Fast decomposing plant material such as *Gliricidia* and *Sesbania* green manure should be applied where crops grow very fast and mature early in order to benefit optimally from nutrients supplied by decomposing plant materials. On the other hand, when slow growing crops are involved, slow decomposing green manure should be used like *T. vogelii*.
- (iii) Available P levels are very low in soils at SUA Farm as compared to N levels. Therefore the initiation of P fertilizer trials in maize production is strongly recommended. It could be an integrated research on soil fertility replenishment combining fallows or green manure and rock phosphate.
- (iv) It seems as if by just breaking hardpan within 10-30 cm soil depth, yield of maize could be increased to a certain extent in semi-arid areas with or without green manure and fertilizer. Research on effect of hardpan on crop production is recommended in future research work.
- (v) The rapid decline of mineral N after crop harvest may be compensated by leaving crop residues in the fields. These residues, once mulched may have advantage of protecting soil

from the heat of the sun and they may also contribute to soil moisture maintenance and nutrient conservation.

- (vi) I recommend a spacing experiment for *S. sesban* in order to determine the appropriate inter and intra plant spacing suitable for relay intercropping as trees tend to compete with each other for moisture and nutrient when left in the field after crop harvest.
- (vii) Research is needed to evaluate several MPTs in mixtures on multilocal sites in order to appreciate fully the contribution of relay intercropping in increasing the productivity of the land with reduced external inputs such as mineral fertilizers.
- (viii) Caution is required before selecting a green manure species as the 'best' as such other studies are needed (e.g. crop demand and nutrient uptake, time and rates of application, storage of leaves and, form in which nutrients are released by each species and nutrient budget).

7. REFERENCES

- Adesina, F.A. (1990) Soil management with cultivated fallows in humid and sub-humid Africa. *Canadian Journal of Soil Science* 71(2):147-154.
- Ahlback, A.J. (1994) Tree planting: Mobilization of the people of Tanzania. *Desertification Control Bulletin* No. 24:27-31.
- Alexander, M. (1977) *Introduction to soil microbiology*. 2nd Ed. John Wiley and Sons Inc, New York. pp 467.
- Allison, F.E. (1973) *Soil organic matter and its role in crop production*. Elsevier, New York. pp 637.
- Anderson, J.M. and Ingram, J.S.I. (1993) *Tropical Soil Biology and Fertility: A Handbook of Methods*. 2nd Ed. C.A.B. International. pp 221.
- Andriessse, J.P., Koopmans, T.T. and Schelhaas, R.M. (1987) A Monitoring study of nutrient cycles in soils used for shifting cultivation under various climatic conditions in tropical Asia. 111. *Agriculture, Ecosystems and Environment* 19:285-332.
- Armson, K.A. (1977) *Forest soils: properties and processes*. University of Toronto Press. Toronto. pp 390.
- Aweto, A.O. (1981) Secondary succession and soil fertility restoration in South west Nigeria. *Journal of Ecology* 69:601-607.
- Baskerville, G.L. (1972) Use of logarithmic regression in the estimation of plant biomass. *Canadian Journal of Forest Research* 2:49-53.
- Becker, M., Ladha, J.K. and Ottow, C.G. (1994) Nitrogen losses and lowland rice as affected by residue nitrogen release. *Soil Science Society of America Journal* 58:1660-1665.
- Becker, M., Ladha, J.K. and Ali, M. (1995) Green manure technology; potential, usage, and limitations. A case study for lowland rice. *Plant and soil* 174(1-2):181-194.
- Bouyoucos, G.J. (1962) Hydrometer method improved for making particle size analysis of soils. *Agronomy Journal* 54:464-465.

- Bradbury, M. (1990) The effect of stress on growth and dry matter distribution in juvenile *Sesbania sesban* and *Acacia nilotica*. *Journal of Arid Environment* 18:325-333.
- Brady, N.C. (1984) *The nature and properties of soils*. 9th Edition. Macmillan Publishing Company, New York. pp 750.
- Brady, N.C. (1994) Alternative to slash-and-burn: a global imperative. In: P.A. Sanchez and H. Van Houten (eds), *Alternatives to slash-and-burn Agriculture*. Proc. 15th International Soil Science Congress, Acapulco, Mexico, pp 3-14.
- Bremner, J.M. and Mulvaney, C.S. (1982) Total nitrogen. In: *Methods of Soil Analysis, Part 2. Chemical and Microbiological properties, Agronomy Monograph No. 9* (2nd Ed.). pp 159-165.
- Budelman, A. (1988) The decomposition of the leaf mulches of *Leucaena leucocephala*, *Gliricidia sepium* and *Flemingia macrophylla* under humid tropical conditions. *Agroforestry Systems* 7: 33-45.
- Burleigh, J.R. and Yamoah, C.F. (1997) Site factors associated with performance of *Leucaena leucocephala* (Lam.) de Wit and *Sesbania sesban* (L.) Merrill in pure and mixed stands in the northern highlands of Rwanda. *Agroforestry Systems* 37:121-131.
- Chamshama, S.A.O., Maliendo, S.M.S. and Mackengo, S.J. (1994) Early performance of *Faidherbia albida* intercropped with maize at Gairo, Morogoro. *Journal of Tropical Forest Science* 7(2):220-229.
- Constantinides, M. and Fownes, J.H. (1994) Nitrogen mineralization from leaves and litter of tropical plants: relationship to nitrogen, lignin and soluble polyphenol concentrations. *Soil Biology and Biochemistry* 26(1):49-55.
- Crossley, D.A. Jr. and Hoglund, M.P. (1962) A litter bag method for the study of micro arthropods inhabiting leaf litter. *Ecology* 43:571-573.
- Dhyani, S.K., Narain, P. and Singh, R.K. (1990) Studies on root distribution of five multipurpose tree species in Done Valley, India. *Agroforestry Systems* 12(2):149-161.

- Drechsel, P., Steiner, K.G. and Hagehorn, F. (1996) A review on the potential of improved fallows and green manure in Rwanda. *Agroforestry Systems* 33(2):109-136.
- Evans, O.D. and Rotar, P. (1987) *Sesbania in Agriculture*. Westview Tropical Agriculture Series No. 8. Westview Press, Boulder company. pp 192.
- FAO, (1988) *FAO/UNESCO soil map of the world*. 1:5 000 000. Revised legend. World Soil Resources report 60. Rome: FAO, pp 385.
- FAO, (1992) *Rural afforestation and natural forest management in Shinyanga*. FAO, Rome, pp 67.
- FAO, (1994) *Farming Systems Development: A participatory approach to helping small-scale farmers*. FAO, Rome pp 46.
- Handayanto, E., Cadisch, G. and Giller, K.E. (1994) Nitrogen release from prunings of legume hedgerow trees in relation to quality of the prunings and incubation method. *Plant and Soil* 160:237-248.
- ICRAF, (1993) *International Centre for Research in Agroforestry Annual Report*. ICRAF, Nairobi, Kenya. pp 208.
- Jonsson, K., Fidjeland, L. Maghembe, J.A. and Högberg, P. (1988) The vertical distribution of fine roots of five tree species and maize in Morogoro, Tanzania. *Agroforestry Systems* 6:63-70.
- Kaaya, A.K., Gerson, I.N. and Msanya, M.B. (1994) *Pedological studies and characterization of some benchmark soils in Morogoro district, Tanzania*. Soil Science Department, SUA, Morogoro. pp 116.
- Kamara, C.S. and Maghembe, J.A. (1994) Performance of multipurpose tree and shrub species 28 months after planting at Chalimbana, Zambia. *Forest Ecology and Management* 64:145-151.
- Kang, B.T. (1993) Alley cropping: past achievement and future directions. *Agroforestry Systems* 23: 141-155.
- Kang, B.T., Grimme, H. and Lawson, T.L. (1985) Alley cropping sequentially cropped maize and cowpea with *Leucaena* on a sandy soil in Southern Nigeria. *Plant and Soil* 85:267-277.
- Kang, B.T., Reynolds, L. and Atta-Krah, A.N. (1990) Alley farming. *Advances in Agronomy* 43:315-359.

- Karachi, M., Lema, N., Sabas, E. and Shirima, D. (1994) Growth, biomass production and plant mortality of seven *Sesbania sesban* Var. *nubica* and three *Sesbania macrantha* accessions at Tumbi, Tanzania. *Forest Ecology and Management* 64:153-159.
- Kundu, D.K., Rao, K.V. and Pillai, K.G. (1991) Agronomic efficiency of green-manure and urea nitrogen in wetland rice (*Oryza sativa*) as influenced by seasonal conditions. *Indian Journal of Agricultural Sciences* 61(6):422-424.
- Kwesiga, F.R. and Coe, R. (1994) The effect of short rotation *Sesbania sesban* planted fallows on maize yield. *Forest Ecology and Management* 64:199-208.
- Landon, J.R. (1991) *Booker Tropical Soil Manual*. A Handbook for soil survey and Agricultural Land Evaluation in the Tropics and Sub-tropics. Longman Group UK Ltd, Longman House. England. pp 474.
- Lehmann, J., Schroth, G. and Zech, W. (1995) Decomposition and nutrient release from leaves, twigs, and roots of three alley-cropped tree legumes in central Togo. *Agroforestry Systems* 29:21-36.
- Li, G.C., Mahler, R.L. and Everson, D.O. (1990) Effects of plant residues and environmental factors on phosphorus availability in soil. *Communication of Soil and Plant Nutrition* 21:471-491.
- Lowther, J.R. (1980) Use of single sulphuric acid-hydrogen peroxide digest for analysis of *Pinus radiata* needles. *Communication of Soil Science Plant Analyses*. 11:175-188.
- Maghembe, J.A. and Prins, H. (1994) Performance of multipurpose trees for agroforestry two years after planting at Makoka, Malawi. *Forest Ecology and Management* 64:171-182.
- Maliondo, S.M.S., Maghembe, J.A., Ikerra, S. and Smithson, P. (In press) Nitrogen mineralization in soils amended with green manure from *Gliricidia*. pp 15.
- Mappaona, A., Yoshida, S. and Kitou, M. (1994) Yield response of cabbage to several tropical green manure legumes incorporated in soil. *Soil Science and Plant Nutrition* 40(3):415-424.
- Milliken, G.A. and Johnson, D.J. (1984) *Analysis of messy data*. Vol 1. Design of experiments. Lifetime Publications. Toronto, Ontario. pp 180.

- Milne-Redhead, E and Polhill, R.M. (1971) *Flora of Tropical East Africa*. Crown Agents. pp 568.
- Montagnini, F., Ramstad, K. and Sancho, F. (1993) Litterfall, litter decomposition and the use of mulch of four indigenous tree species in the Atlantic lowlands of Costa Rica. *Agroforestry Systems* 33(1):39-61.
- Mugendi, D.N. and Nair, P.K.R. (1997) Predicting the decomposition patterns of tree biomass in tropical highland microregion of Kenya. *Agroforestry Systems* 35(2):187-201.
- Mugasha, A.G. and Nshubemuki, L., (1988) Soil conservation in Kondoa, Tanzania: the case of the Rangì people in the HADO area. *Forest Ecology and Management* 25:159-180.
- Mwiinga, R.D., Kwesiga, F.R. and Kamara, C.S. (1994) Decomposition of leaves of six multipurpose tree species in Chipata, Zambia. *Forest Ecology and Management* 64:209-216.
- Nair, P.K.R. (1990) The prospects for Agroforestry in the Tropics. World Bank Technical Paper No. 131, Washington, D.C. World Bank. pp 31.
- Nair, P.K.R. (1993) *An Introduction to Agroforestry*. Kluwer Academic Publishers/ICRAF. pp 499.
- Nduwayezu, J.B. (1997) Control of nitrogen mineralization from decomposing *Gliricidia sepium* leaves to optimize nitrogen uptake by maize crop. M.Sc. Dissertation, SUA, Morogoro, Tanzania. pp 82.
- Ong, C. (1994) Alley cropping-ecological pie in the sky. *Agroforestry Today* 6(3):8-10.
- Otsyina, R., Minae, S. and Cooper, P. (1996) A never-ending story: rotational woodlots for soil conservation, wood and fodder. *Agroforestry Today* 8(2):8-10.
- Palm, O., Weerakoon, W.L., Ananda, M., De Silva, P. and Rosswall, T. (1988) Nitrogen mineralization of *Sesbania sesban* used as green manure for lowland rice in Srilanka. *Plant and Soil* 108:201-209.
- Pastor, J., Stillwell, M.A. and Tilman, D. (1987) Little bleuestem litter dynamics in Minnesota old fields. *Oecologia* 72:327-330.

- Piccolo, M.C., Neill, C. and Cerri, C.C. (1994) Net nitrogen mineralization and net nitrification along a tropical forest-to-pasture chronosequence. *Plant and Soil* 162:60-70.
- Prescott, C.E. (1997) Effect of clearcutting and alternative silvicultural systems on rates of decomposition and nitrogen mineralization in a coastal montane coniferous forest. *Forest Ecology and Management* 95:253-260.
- Prins, D. (1986) Increasing productivity of smallholder farming systems by introduction of planted fallows. *Plant Research and Development* 24:31-56.
- Rao, M.R. (1989) Hedge-row intercropping and Rotational Agroforestry Systems. Paper prepared for ICRAF/DSO Training course. pp. 15.
- Rao, M.R., Kamara, C.S., Kwesiga, F. and Duguma, B. (1990) Methodological issues for research on improved fallows. *Agroforestry Today* 2(4):8-12.
- Recous, S., Mary, B. and Furie, G. (1990) Microbial immobilization of ammonium and nitrate in cultivated soils. *Soil Biology and Biochemistry* 22:913-922.
- Rocheleau, D., Weber, F. and Field-Juma, A. (1988) *Agroforestry in dryland Africa*. ICRAF, Nairobi, Kenya. pp 311.
- Sanchez, P.A. (1976) *Properties and management of soils in tropics*. New York. John Wiley and Sons. pp 376.
- Sanchez, P.A., Palm, C.A., Davey, C.B., Szott, L.T. and Lussel, C.E. (1985) Tree crops as soil improvers in the humid tropics In: Cannel, M.G.R. and Jackson, J.E. (eds). *Attributes of Trees as crop plant*. Institute of Terrestrial Ecology and Natural Environment Research Council, U.K. 327-358.
- Sanchez, P.A., Palm, C.A., Davey, C.B., Szott, L.T., Cuevas, E. and Lal, R. (1989) Organic input management in tropical agroecosystems. In: Coleman, D.C.; Oades, J.M. and Vehera, G. (eds). *Dynamics of Soil organic matter in tropical ecosystems*. Maui, Hawaii: NIFTAL pp.16-25.
- Sanchez, P.A. and Palm, C.A. (1996) Nutrient cycling and agroforestry in Africa. *Unasylva* 47:24-28.

- Sarrantonio, M. (1992) A protocol for screening legumes as soil-improving crop. In: Mulongoy, K., Gueye, M. and Spencer, D. S. C. (eds). *Biological Nitrogen Fixation and Sustainability of Tropical Agriculture*. pp 41-47.
- SAS Institute Inc. (1991) *SAS/STAT Guide for Personal Computers*. Version 8 Ed. SAS Inc. Cary, North Carolina. pp 672.
- Schroth, G., Zech, W. and Heimann, G. (1992) Mulch decomposition under agroforestry conditions in a sub-humid tropical savanna processes and influence of perennial plants. *Plant and Soil* 147:1-10.
- Singh, R.P., Ong, C.K. and Saharan, N. (1989) Above and below ground interaction in alley cropping in semi-arid India. *Agroforestry Systems* 9:259-274.
- Singh, G.B. (1992) Alley cropping for improvement in the tropics. *Agroforestry Abstract* 691.
- SseKabembe, C.K. (1985) Perspectives on hedgerow intercropping. *Agroforestry Systems*. 3:339-356.
- Swift, M.J., Heal, O.W. and Anderson, J.M. (1979) *Decomposition in Terrestrial Ecosystems*. Blackwell Scientific Publications. Oxford. pp 372.
- Swift, M.J., Russell-Smith, A. and Perfect, T.J. (1981) Decomposition and mineral-nutrient dynamics of plant litter in a regeneration bush-fallow in sub-humid tropical Nigeria. *Journal of Ecology* 69:981-995.
- Szott, L.T., Palm, C.A. and Sanchez, P.A. (1991) *Agroforestry on academic press of the humid tropics*. *Advances in Agronomy* 45:275-300.
- Tisdale, S.L., Nelson, W.L., and Beaton, J.D. (1990) *Soil Fertility and Fertilizers*. 4th Ed. Macmillan Publishing company, New York. pp 754.
- Tonye, J., Ibewiro, B. and Duguma, B. (1997) Residue management of a planted fallow on an acid soil in Cameroon: crop yield and soil organic matter fractions. *Agroforestry Systems* 37:199-207.
- United Nations (1993) *Population, environment, and development in Tanzania*. United Nations Department of Agriculture, Economic and Social Development on behalf of the Department of the Demographic Training Unit, University of Dar-es-salaam. pp 189.

- Upadhyay, V.P., Singh, J.S. and Meentemeyer, V. (1989) Dynamics and weight loss of leaf litter in central Himalaysan forests: abiotic versus litter quality influences. *Journal of Ecology* 77:147-161.
- Uriyo, A.P., and Singh, B.R. (1974) *Practical Soil Chemistry Manual.* University of Dar es salaam, Morogoro. Tanzania. pp 59.
- Vanlauwe, B., Vanlangenhove, G., Merckx, R. and Vlassak, K. (1994) Impact of rainfall regime on decomposition of leaf with contrasting quality under subhumid tropical conditions. *Biological Fertility and Soils* 20:8-16.
- Van Noordwijk, M., Spek L.Y. and Purnomosidhi, P (1995) Quantifying shallow roots: tree geometry makes root research easy. *Agroforestry Today* 7(2):9-11.
- Wani, S.P., Rupela, O.P. and Lee, K.K. (1995) Sustainable agriculture in the semi-arid tropics through biological nitrogen fixation in grain legumes. *Plant and Soil* 174(1-2):29-49.
- Waring, R.H. and Schlesinger, W.H. (1985) *Forest ecosystems: Concepts and management.* Academic press Inc. Harcourt Brace Jovanovich. pp 340.
- Xu, Z.H., Saffigna, P.G., Myers, R.J.K. and Chapman, A.L. (1992) Nitrogen fertilizer in Leucaena alley cropping. In: Maize response to nitrogen fertilizer and fate of fertilizer - ¹⁵N. *Plant and Soil* 147: 219-227.
- Yamoah, C.F., Agbooda, A.A. and Mulongoy, K. (1986) Decomposition, nitrogen release and weed control by prunings of selected alley-cropping shrubs. *Agroforestry Systems* 4:239-346.
- Yamoah, C.F. and Burleigh, J.R. (1990) Alley cropping *Sesbania sesban* (L) Merrill with food crops in the highland region of Rwanda. *Agroforestry Systems* 10:167-181.
- Young, A. (1989) *Agroforestry for soil conservation.* C.A.B. International U.K. pp 276.

Appendix 1: Soil particle size analysis of *Sesbania sesban*/maize relay cropping experimental site at SUA Farm, Morogoro, Tanzania.

Soil properties	Depth (cm)				
	0 - 10	10- 20	20 - 30	30 - 40	40- 50
	Soil particle size				
Sand %	35.48 ¹ (0.78)	32.76 (0.56)	30.90 (0.70)	30.63 (0.55)	30.23 (0.49)
Coarse silt %	8.48 (1.96)	6.06 (1.71)	5.80 (0.30)	5.48 (1.29)	7.12 (0.54)
Fine silt %	7.87 (1.24)	7.23 (1.40)	5.91 (0.59)	4.59 (0.97)	3.22 (0.50)
Clay %	48.16 (2.62)	53.89 (2.68)	57.36 (0.97)	59.30 (1.15)	60.10 (0.56)
Textural class	clay loam	clay loam	clay loam	clay loam	clay loam

¹Mean of three replications with standard error in parenthesis.

Appendix 2: Probability for F-ratio for significant differences between decomposition of five multipurpose tree/shrub species at SUA Farm, Morogoro, Tanzania

Retrieval date (weeks)	Mass remaining	Mass loss	N remaining	N loss	N released	P loss	P remaining	p released
1	0.009	0.009	0.011	0.382	0.001	0.048	0.001	0.048
2	0.014	0.014	0.036	0.381	0.001	0.186	0.001	0.130
4	0.004	0.004	0.032	0.238	0.186	0.527	0.001	0.577
6	0.025	0.025	0.035	0.075	0.009	0.256	0.001	0.015
8	0.029	0.029	0.001	0.001	0.240	0.293	0.001	0.086
10	0.001	0.001	0.001	0.001	0.017	0.034	0.001	0.112

Appendix 3. Growth and yield of maize grown under relay intercropping with *S. sesban* at SUA Farm, Morogoro, Tanzania

Presence of trees	Fertilizer application (kg ha ⁻¹)		Yield 1996	1997 Growth parameter		1997 Yield (t ha ⁻¹)		
	N	P		Height (m)	Root collar Diameter (cm)	Grain	Stover	
With	0	0	0.53 ¹	1.60	1.91	2.28	3.72	
				(0.05)	(0.23)	(0.16)	(0.37)	(0.96)
		20			1.72	2.10	2.47	3.99
		40			(0.12)	(0.13)	(0.24)	(0.89)
					1.87	2.21	2.00	3.68
					(0.05)	(0.07)	(0.20)	(0.20)
	20	0			1.51	1.82	2.55	3.04
					(0.08)	(0.03)	(0.30)	(0.87)
		20			1.85	2.07	2.98	4.08
					(0.05)	(0.08)	(0.65)	(0.87)
		40			1.81	2.22	2.38	3.88
					(0.09)	(0.09)	(0.19)	(0.98)
40	0			1.52	1.99	1.98	3.50	
				(0.09)	(0.06)	(0.06)	(0.72)	
	20			1.94	2.22	2.45	3.54	
				(0.07)	(0.02)	(0.14)	(0.28)	
	40			1.92	2.30	2.73	3.96	
				(0.12)	(0.03)	(0.22)	(0.40)	
Without	0	0	0.69	1.39	1.87	1.88	3.07	
				(0.08)	(0.11)	(0.11)	(0.08)	(0.32)
		20			1.66	2.06	2.11	4.17
		40			(0.09)	(0.09)	(0.41)	(1.39)
					1.64	1.98	2.36	5.09
					(0.06)	(0.01)	(0.22)	(1.33)
	20	0			1.28	1.73	1.45	2.99
					(0.13)	(0.14)	(0.11)	(1.38)
		20			1.58	2.11	2.20	5.86
					(0.08)	(0.06)	(0.26)	(1.10)
		40			1.82	2.15	2.48	4.13
					(0.04)	(0.02)	(0.15)	(0.56)
40	0			1.42	1.93	1.98	3.43	
				(0.11)	(0.07)	(0.09)	(0.58)	
	20			1.84	2.05	2.16	3.31	
				(0.30)	(0.14)	(0.60)	(0.85)	
	40			1.94	2.12	2.22	5.27	
				(0.06)	(0.03)	(0.16)	(1.50)	

¹Means of three replications with standard error in parenthesis

Appendix 4. Effect of *S. sesban* green manure on nitrogen and phosphorus uptake by maize at SUA Farm, Morogoro, Tanzania.

Presence of trees	Fertilizer application (kg ha ⁻¹)		N uptake (kg N ha ⁻¹)		P uptake (kg P ha ⁻¹)		Total uptake (kg ha ⁻¹)		
	N	P	Grain	Stover	Grain	Stover	N	P	
With	0	0	35.52 ¹ (6.69)	26.79 (6.58)	4.81 (0.99)	1.89 (0.77)	62.30 (8.22)	6.70 (1.28)	
		20	38.89 (3.66)	25.88 (5.77)	5.63 (0.46)	2.01 (0.57)	64.76 (4.85)	7.64 (0.96)	
		40	40.19 (5.02)	23.87 (2.41)	5.70 (0.25)	1.61 (0.23)	64.06 (3.19)	7.31 (0.09)	
	20	0	39.53 (5.36)	19.79 (5.89)	4.70 (0.44)	1.40 (0.50)	59.32 (7.07)	6.10 (0.48)	
		20	47.60 (11.51)	26.67 (5.59)	6.83 (1.42)	1.93 (0.48)	74.27 (13.20)	8.76 (1.62)	
		40	38.83 (2.53)	24.23 (6.11)	6.08 (0.88)	1.77 (0.39)	63.06 (6.63)	7.85 (1.08)	
	40	0	32.62 (1.47)	28.89 (6.97)	3.85 (0.12)	2.09 (0.29)	58.51 (6.39)	5.94 (0.37)	
		20	41.06 (0.94)	26.20 (2.07)	5.93 (0.16)	1.59 (0.28)	67.25 (2.32)	7.53 (0.42)	
		40	45.45 (4.32)	29.54 (4.73)	7.15 (0.70)	1.87 (0.25)	74.99 (8.78)	9.02 (0.96)	
	Without	0	0	30.04 (0.84)	18.21 (1.26)	3.69 (0.38)	1.98 (0.31)	48.24 (1.83)	5.67 (0.08)
			20	25.50 (5.92)	26.45 (8.57)	4.29 (1.25)	1.97 (0.74)	51.95 (14.47)	6.26 (1.07)
			40	38.61 (3.99)	33.55 (9.46)	4.89 (0.16)	2.41 (0.71)	72.16 (13.32)	7.30 (0.86)
20		0	23.21 (2.39)	18.33 (8.03)	3.20 (0.09)	1.37 (0.54)	41.54 (8.93)	4.57 (0.62)	
		20	34.18 (3.42)	39.52 (3.68)	4.55 (0.90)	3.27 (0.74)	73.70 (6.62)	7.83 (1.63)	
		40	39.66 (1.40)	24.01 (3.96)	5.44 (0.44)	1.68 (0.38)	63.67 (5.29)	7.13 (0.38)	
40		0	32.52 (0.73)	26.56 (4.87)	4.21 (0.40)	1.56 (0.59)	59.09 (4.35)	5.77 (1.00)	
		20	33.03 (8.82)	25.67 (7.70)	3.86 (1.17)	1.72 (0.44)	58.70 (16.32)	5.58 (1.61)	
		40	38.05 (4.89)	35.78 (7.00)	5.17 (0.51)	2.47 (0.76)	73.84 (7.83)	7.63 (0.74)	

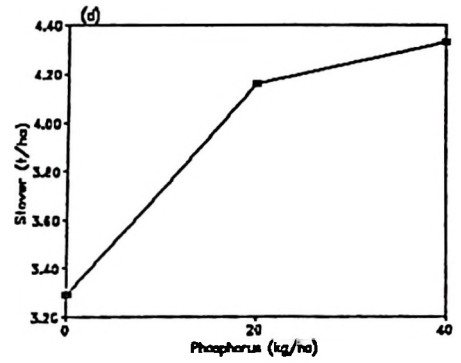
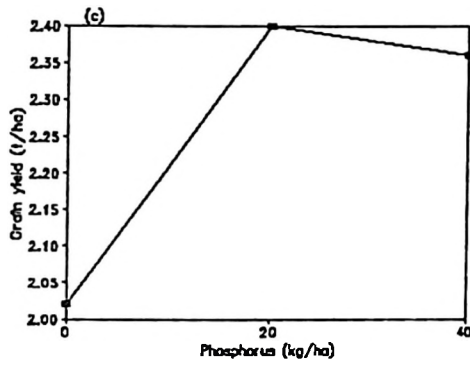
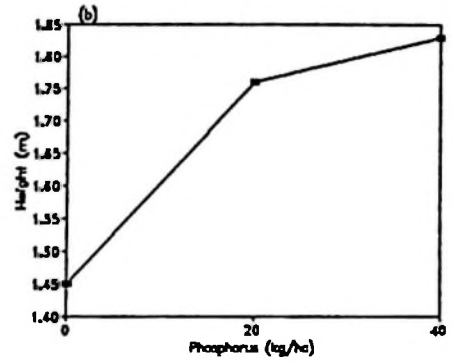
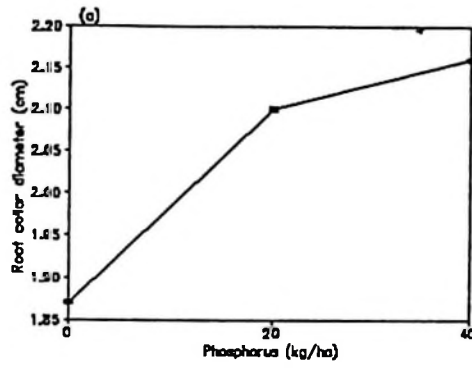
¹Mean of three replications with standard error in parenthesis.

Appendix 5: Probability of F-ratio for significant differences on the effect of *Sesbania sesban*, N and P fertilizer on maize growth and yield, and N and P uptake by maize at SUA Farm, Morogoro, Tanzania

Treatment	Rcd	Height	Grain	Stover	Grain-N	Stover -N	Grain-P	Stover-P
Block	0.0209	0.0052	0.0282	0.0083	0.1916	0.0152	0.0152	0.0016
Trees	0.0207	0.0143	0.0144	0.2682	0.0034	0.4887	0.0002	0.2447
N	0.1209	0.0976	0.6144	0.9399	0.6293	0.5153	0.7259	0.9313
P	0.0001	0.0001	0.0440	0.0791	0.0279	0.1631	0.0004	0.3653
Trees*N	0.5559	0.6196	0.3410	0.9212	0.7254	0.8676	0.8784	0.8007
Trees*P	0.4891	0.6240	0.2411	0.4217	0.2971	0.2777	0.3156	0.4130
Trees*N*P	0.6927	0.7316	0.4968	0.5870	0.6351	0.3916	0.5526	0.2476

Appendix 6: Probability of F-ratio for significant contrast on the effect of P fertilizer on maize growth and yield at SUA Farm, Morogoro, Tanzania

Parameters	Pr> F-ratio
Height	0.001
Linear	0.0001
Quadratic	0.0227
Root collar diameter	0.001
Linear	0.0001
Quadratic	0.0423
Stover	0.0791
Linear	0.0248
Quadratic	0.3786
Grain	0.0440
Linear	0.0353
Quadratic	0.1438



Appendix 7: Maize RCD (a), Height (b), Grain yield (c) and stover yield (d) response to P fertilization at SUA Farm, Morogoro, Tanzania