SYNCHRONIZATION OF NUTRIENT RELEASE FROM *GLIRICIDIA SEPIUM* MULCHES TO OPTIMIZE NUTRIENT UPTAKE BY MAIZE AT SUA FARM, MOROGORO, TANZANIA

BY

AGNES NSHEMELE IGNATUS

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT FOR THE DEGREE OF MASTER OF SCIENCE IN FORESTRY OF SOKOINE UNIVERSITY OF AGRICULTURE

2000

ABSTRACT

This study was conducted at the Sokoine University of Agriculture (SUA) Farm, Morogoro, Tanzania, to assess the effect of synchronized mulching of *Gliricidia sepium* on soil nutrient status; nutrient uptake by maize and field performance of maize. The experiment was laid out in a 4 x 4 split-plot arrangement in a randomized complete block design with three replications. The different factors and their levels were as follows: Major factors (mulch application dates) i.e just before sowing (T_1), two weeks after sowing (T_2), four weeks after sowing (T_3), six weeks after sowing (T_4). Minor factors (mulch application rates) i.e Control (0 kg ha^{-1}, dry wt per plot, M_1), 2.5 t ha^{-1} (2500 kg ha^{-1}, 4 kg $plot^{-1}$ M_2), 5.0 t ha^{-1} (5000 kg ha^{-1}, 8 kg $plot^{-1}$ M_3) and 10.0 t ha^{-1} (10000 kg ha^{-1}, 16 kg $plot^{-1}$ M_4).

Measurement and analysis included: net mineralization samples collected at 0, 1, 2, 4, 6, 8, 10 and 12 weeks after sowing of maize; height of maize plants at tasseling stage (i.e 6 weeks after sowing), and maize grain and stover yield at harvesting. Also nitrogen and phosphorus contents of maize leaves at tasseling and maize grain and stover at harvesting were determined.

Results on N mineralization at all sampling periods showed significant differences ($P<0.05$) between mulching rate treatments except at weeks 1 and 4 for nitrate-N and at weeks 1 and 2 for ammonium-N. Nitrogen mineralization was not affected by the time of mulch application. Nitrate dominated the system throughout the whole growing period.

Maize yield was not significantly ($P > 0.05$) affected by time of mulch application in terms of grain and stover, but it was significantly affected by mulching rates. The trend was the higher the mulching rate, the higher the yield. Mulching time had no significant effect on maize growth and yield, however its effect was significant on grain P and stover N uptake. The interaction between time and mulching rate had no significant effect on maize growth, yield and nutrient uptake, except stover yield and stover P.

It was concluded that, application of mulch 2 weeks after maize sowing or just before sowing should be adopted in order to optimise N uptake by the crop and thus increase yield. A mulching rate of 10 t ha^{-1} is recommended. However, mulching alone cannot sustain crop yield enhancement, and supplementation with fertilizers is necessary.

DECLARATION

I, Agnes Nshemele Ignatus do hereby declare to the Senate of the Sokoine University of Agriculture that this dissertation is my own original work and has never been submitted for a degree in any other university.

Signature ...Nignatus...

Date ...6 Nov. 2000...

COPYRIGHT

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude and appreciation to all those who, directly or indirectly contributed to the successful completion of this study. First of all, I would like to thank The Almighty God who strengthened me, and whom without I couldn't manage to finish and produce something valuable like this.

In particular, I am greatly indebted to the following:

- NORAD/SUA for sponsoring this study;
- Prof. S.A.O. Chamshama, of Forest Biology Department my supervisor for his invaluable guidance, criticisms and constant encouragement which made possible the development of the research proposal and subsequently the production of the dissertation;
- Prof. A. G. Mugasha also from Forest Biology Department for suggesting this topic and also his invaluable criticism throughout the research period;
- The Head, Department of Forest Biology, Dr. S.M.S. Maliondo for assistance in various ways during the conduct of this study;
- Departments of Animal Science and Production and Soil Science for allowing me to use their facilities during data collection and analysis;
- Ms Kafui of Soil Science Department for her assistance during laboratory work;
- All members of Forest Biology Laboratory for their warm company during laboratory work; and finally

- the whole of my family who encouraged and supported me financially during my extension period, I thank them sincerely.

DEDICATION

This work is dedicated to my sweetheart husband Emmanuel Mwambenja and our lovely daughter GLORY.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
a.s.l	above sea level
AvP	available phosphorus
CEC	cation exchange capacity
conc.	concentration
DAS	days after sowing
E	east
EC	electrical conductivity
e.g	for example
et al	and others
etc	and many more
GLM	general linear model
GM	green manure
Ht	height
ICRAF	International Centre for Research in Agroforestry
i.e	that is
IRRI	International Rice Research Institute
Mineral-N	mineral nitrogen
MPTs	Multipurpose trees
NaOH	sodium hydroxide

NAS	National Academy of Sciences
Nitrate-N	available nitrogen in terms of nitrate
NH_4^+	ammonium ion
NH_4^+-N	available nitrogen in terms of ammonium
NO_3^-	nitrate ion
NO_3^--N	available nitrogen in terms of nitrate
NO_2	nitrous oxide
NORAD	Norwegian Agency for Development Cooperation
OC	organic carbon
OM	organic matter
pH	hydrogen ion concentration
ppm	parts per million
S	south
SAS	statistical analysis system
SE	standard error
SUA	Sokoine University of Agriculture
TN	total nitrogen
TP	total phosphorus
TSP	triple super phosphate

SYMBOLS

cm	centimetre
cmol	centimole
°C	degree centigrade
°E	degree east
°S	degree south
g	gramme
>	greater than
=	equal to
<	less than
ha	hectare
kg	kilogramme
m	metre
mm	millimetre
mg	milligramme
N	nitrogen
Ca^{2+}	calcium
K^{+}	potassium
Na^{+}	sodium
Mg^{2+}	magnessium
P	phosphorus

t	tonne
t/ha	tonnes per hectare

CHAPTER 1

1.0 INTRODUCTION

The population of Tanzania is estimated at 33 million with an annual growth rate of 2.8% (Population Census, 1988). Tanzania is one of the most underdeveloped countries in the world and its economy is largely dependent on the agriculture sector. The main contributors to the economy are small-scale farmers who depend largely on simple farm inputs for crop production. In the traditional shifting cultivation systems, farmers mainly relied on long fallow periods to regenerate soil fertility exhausted during the cropping period. However, increasing land pressure due to rapid population growth in many parts of the country and other parts of the tropics, has led to the shortening of the fallow period. This has consequently caused the rapid decline of the soil fertility and depletion of the soil nutrients which in turn has led to poor crop production and finally low income (Rao *et al.*, 1990; Wangari, 1995; Young, 1997; Buresh and Tian, 1998). One of the greatest challenges facing Tanzania today is the production of adequate food to feed the rapidly increasing population.

Rao *et al.*, (1990) also added that when the fallow period becomes too short as it is observed in areas with high population densities, either artificial fertilizers have to be used to improve soil fertility or other alternatives which are economically attractive to small scale farmers have to be included in the production system.

Since most farmers in rural areas cannot afford to continue with traditional shifting cultivation fallows or use non-sustainable inorganic fertilizers, the productivity of farmlands has been declining with time. The decline in yield of maize which is the leading food grain in Tanzania, is a major problem resulting from fertility depletion. Although nutrient supply can be enhanced through application of fertilizers, the use of industrial fertilizers can be limited by high prices, unavailability in many developing countries, pollution problems and inefficient use caused by erosion, volatilization, leaching and denitrification (Palada *et al.*, 1992). Thus, alternative ways for supplying nutrients to the soil using low risk locally available low cost external inputs are needed.

In their efforts to maintain soil fertility using low cost external inputs, farmers in tropical areas incorporate trees in their farming systems in an agroforestry setting. They also widely use crop residues, composts, green manure (GM), sawdust, chicken manure and other animal wastes or practice crop rotation (Nair, 1993). Despite all these efforts, failures to restore soil fertility have been observed due to inadequate choice of agroforestry species, poor timing of GM application, poor quality or insufficient quantity of materials and inappropriate method of application (Nduwayezu, 1997).

Mulching has been reported to improve and maintain soil fertility since it can assure the slow and continuous release of nutrients (Budelman, 1988; Oglesby and Fownes, 1992; Nair, 1993). The synchronisation of nutrient released from mulch with nutrient uptake by crops is considered as vital for improving the efficiency of nutrient utilization by crops.

The agricultural crops have well defined critical periods of high nutrients demand (Nair, 1993). If nutrients could be made available to the crops during the period of high demand, the released nutrients would be used efficiently, leaching losses minimized and crop productivity increased. The effective use of organic fertilizers so as to meet the demand of agricultural crops requires an understanding of controls on nutrient release from these sources (Szott and Kass, 1993). In trying to address soil fertility problems using plant materials, many researchers have focused on mass loss and nutrient release patterns during the decomposition process (Budelman, 1988; Palm and Sanchez, 1990;). Studies on nitrogen mineralization are fewer (Fox *et al.*, 1990; Oglesby and Fownes, 1992; Constantinides and Fownes, 1993;).

The knowledge about the proper time of GM application and adequate amount of the materials used, in minimizing nitrogen (N) losses and nutrient release control so that they can be released and made available regularly throughout the critical stages of the crop growth is inadequate.

On the other hand, information about minimizing N losses from inorganic fertilizers using nitrification inhibitors (eg. nitrapyrin, halophenols, nitroanilines) is readily available (Tisdale *et al.*, 1990). Thus, establishment of proper timing of application of organic materials and optimum quantities of these materials to be applied could be an important soil management option to increase crop yield and increase the rate of N- recovery from these materials that are used as a source of N to crops.

The main objective of this study was therefore, to assess the effect of rate and time of mulching of *Gliricidia sepium* on nutrient uptake by maize; soil nutrient status and field performance of maize.

The specific objectives were:

- to determine the change in soil nutrient status due to the application of *G. sepium* mulch at different rates and dates;
- to assess the effect of mulching rates of *G. sepium* on growth and yield of maize;
- to assess the effect of time of mulching of *G. sepium* on maize growth and yield.
- to assess the nutrient uptake by maize plant as influenced by rate and time of application of mulch of *G. sepium.*

The following hypothesis was tested in this study:

There is a significant change in soil nutrient status and field performance of maize under different rates of *G. sepium* mulch applied at different times.

CHAPTER TWO

2.0 LITERATURE REVIEW.

2.1 Description and ecological requirements of *G.sepium* (Jac Q.) Walp

Gliricidia sepium belongs to subfamily papilionideae in Leguminoseae family. *G. sepium* has a wide ecological range. It can grow in dry and humid tropics (600 - 3000 mm rainfall per year at 500 - 1600 m a.s.l) and in saline soils. *G. sepium* is a fast growing shrub that can grow to 10 m height. It coppices and can be propagated by direct seeding, seedling and cuttings. *Gliricidia sepium* fixes N through root nodules that account for 30 – 60% of the plants' N uptake (Sanginga *et. al.*, 1989). It is used as fodder, fuelwood, wood for furniture, building materials, etc. In other areas, *G. sepium* is used for ornamental and live fencing (Nair 1993). *Gliricidia sepium* leaves have high N and other nutrient contents namely potassium (K), Calcium (Ca) and Magnessium (Mg) (Atta-Krah and Sumberg 1988; Budelman 1989 a, b) and low C: N ratio (Lehmann *et al.*, 1995) which results in high decomposition and nutrient release of forage and twigs at faster rate than most other legumes used in agroforestry trials (Budelman 1988). It has readily decomposable compounds, and low contents of lignin and polyphenols compared to other agroforestry species (Nduwayezu, 1997). Nduwayezu (1997) showed the chemical composition of *G.sepium* leaves as being N (31.8 g kg^{-1}), Phosphorus (P) (1.7 g kg^{-1}), K (13.9 g kg^{-1}), Ca (13.1g kg^{-1}), Mg (6.62 g kg^{-1}), polyphenols (4.1%), lignin (9.8%), cellulose (17.8%) and lipids (6.1%) with 14, 1.31 and 3.1 C: N, polyphenol: N and lignin: N ratios respectively. Kwesiga (1994) showed that *G. sepium* has high foliage productivity and vigorous tap root development.

2.2. Effect of tree/shrub prunings on soil fertility improvement and crop yield enhancement

Leguminous and non-leguminous tree prunings and shrubs, ferns and algae can all be used as GM. These materials are usually incorporated into the soil to improve its fertility status. Green manure plants can either be grown on farm and ploughed under, or brought in from somewhere else and incorporated into the soil as mulch. In a study on the N contribution of cowpea GM and residue to upland rice, the GM on average, accumulated 68 kg ha^{-1} and the aboveground residue after harvest of dry pods contained 46 kg N ha^{-1} (John *et al.*, 1992). Yamoah *et al.*, (1992) observed that in 120 days, Gliricidia cut-backs released 71% of the total N required by maize while Flemingia and Cassia released 26 and 77%, respectively, for the same purpose. Further, it appeared possible to supply the 29% N deficit in the Gliricidia plots from a second pruning at about 66 days after planting maize. These results were, however, based on the assumption that N from prunings was fully utilized by the crops which is contrary to what actually happens in nature.

Ordinarily, the N so released is subjected to other effects (reactions) such as immobilization by the soil microbial biomass, loss through leaching, volatilization etc. Kang and Duguma (1985) have also shown additions to soil of over 200 and 100 kg N ha^{-1} $year^{-1}$ from prunings of *Leucaena leucocephala* and *G. sepium* respectively.

Under favourable soil conditions, 1 ha of Leucaena bushes, cut at a height of 1 metre every three months, could provide foliage containing 500 – 600 kg N $year^{-1}$ (NAS, 1979).

Nutrient transformation patterns, determining release or otherwise, vary widely between different plant species and the nutrient in question. Considering N, for example, trends that have been identified include:

- Rapid net mineralization.
- Slow net mineralization.
- Net immobilization up to 12 months for some plants species, followed by slow but positive net mineralization (Palm and Sanchez, 1991). A majority of organic amendments showing trend (i) above i.e rapid mineralization release up to 50%

of the N by the third week of incubation (Budelman, 1988; Palm *et al.*, 1988; Nikokwe, 1992). Calcium release was shown to be highly related to N release for ten green manures, and after 7 weeks of incubation, a significant correlation coefficient was recorded between the percentage of N and Calcium released (Tian *et al.*, 1992 a). Nikokwe (1992) observed net N and P mineralization from two leguminous species, *Crotalaria ochroleuca* and *L. leucocephala* in an 84 day laboratory incubation study. Budelman (1988) using *L. leucocephala, G. sepium* and *F. macrophylla* species in a field experiment obtained similar results.

Organic matter (OM) improves the soil physical, chemical and biological characteristics. Organic matter build up was observed with *Azolla* and *Sesbania rostrata* GM in rice production in a long-term experiment. Organic matter so formed leads to improved soil structure which influences aeration, water holding capacity and temperature regimes (especially with surface- applied OM) of the soil. Boparai *et al.*, (1992) reported tremendous improvement of the soil physical properties in soils under wetland rice after using GM (*Sesbania aculeata*) over a period of three years. In this experiment, green manuring increased by 62%, water- stable aggregates of sizes between 0.1 and 0.5 mm, reduced the soil bulk density and increased infiltration rate.

Green manures also affect the soil chemical properties. Incorporating *Leucaena* prunings continually over a period of six years resulted in higher OM, exchangeable bases (K, Ca, and Mg) and also NO_3^- levels in soil solution (Kang *et al.*, 1986). In another situation, an increase in the cation exchange capacity (CEC), available P and exchangeable K contents of the soil was observed after the application of cattle manure and *Leucaena* leaves (Mkangwa, 1983). Use of *Lantana camara* Var *aculeata* as a green manure in wheat production in India also showed an increase in the total N, ammonium –N and available P contents in the soil (Bhardwaj and Kanwar, 1991).

The researchers however observed that nitrate –N was less in the treated than in the control plots.

Green manures also affect the soil biological properties. Organic amendments constitute one of the most widely distributed sources of energy for microbes in the soil environment. The amount, type and availability of these materials determine the size and composition of the microbial population in the soil. The nature of the flora will vary with the chemical composition of the added substrates, certain microbial groups predominate for few days while others maintain high population levels for long periods. In fermenting straw manure heaps, the fast growing bacteria and fungi are responsible for initial stages of degradation, involving the readily available carbohydrates and proteins (Allison, 1973). Then, actinomycetes begin to gain dominance since they can utilize resistant materials more readily than the fast growers can. Soils rich in OM generally have higher counts of microorganisms. Mulching also has been reported to prevent weed seed germination, and decrease soil erosion (IRRI, 1988; Tilander, 1993).

Some data exist that indicate the varied effects of GM (prunings) on crop yields. In different areas, the use of *G. sepium* in farms has been observed to improve soil fertility and hence increase in food crop yields (Nair, 1993;Yamoah *et al.,* 1992). For example Nyamai *et al.,* (1996) indicated that hedgerow intercropping system of *G. sepium* resulted in maize grain yield with a range of 1.6 to 5.1 t ha^{-1}. In Zambia, incorporation of *Leucaena* (alley-cropped) prunings without N-fertilizer application resulted in an increase of up to 95% in maize yields (Matthews *et al.*, 1992). In the same trial, prunings of other tree species namely *Gliricidia* and *Flemingia* did not result in maize yield increases, while *Albizia* prunings tended to depress yields. Using the same tree species but with soybean as a test crop, the prunings consistently depressed yields during the period of investigation except for *Flemingia* in 1988.

In this study it is apparent that the maize crop utilized properly the N mineralized from *Leucaena*. On the other hand, soybean showed depressed yields, probably because of competition for similar nutrients with the leguminous tree species. Yield increase of upland rice of 0.7 t ha^{-1} was observed with cowpea GM and residues, as the sole sources of N, when compared to the yield obtained in a pre-rice fallow. Nogueria *et al.*, (1989) obtained similar results of yield increases with *Crotalaria juncea* as GM source in garlic production of up to 1008 kg ha^{-1}. *Crotalaria zanziberica* (ploughed under, no fertilizer), has also been shown to improve maize yields tremendously from 1.4 t ha^{-1} to 6.8 t ha^{-1} at Uyole, Tanzania (Temu, 1986). Palada *et al.*, (1992) using four vegetables namely amaranth, celosia, okra and tomato, also observed higher yields in alley cropping with *Leucaena* (prunings incorporated as GM) than the control plots. In a study to evaluate the potential of *Sesbania bispinosa* leaves as a supplement to inorganic fertilizers, the dry matter yield of wheat was significantly increased (Hussain and Ibrahim, 1987). These results show the varied responses of different crop species to different GM sources.

This would be expected since GMs differ in their N contents, decomposition rates and their nutrient release patterns while the test crops also differ in their nutrient uptake trends.

In their experiment to evaluate the potential of alley cropping systems to restore crop productivity on a degraded site and maintain crop productivity on a non-degraded site, Aihou *et al.,* (1999) found that adding fertilizer containing N, P, K, and Boron (B) without prunings (as in the 'relative control' treatment) did not lead to increase in maize yields on both sites. As the P content in the soils of both sites was relatively high, N appears to be the main limiting nutrient to crop production. Organic matter additions may improve crop yield through direct supply of N, through improved usage of fertilizer N added in combination with the OM. And also through indirect effects related to the presence of a mulch layer on the soil surface. Maize yields averaged over all alley cropping treatments and years (1994 – 1996) were double the 1990 values on the degraded site and slightly lower than the 1990 values on the non-degraded site. In 1996, both the *Leucaena* and *Senna* treatments produced significantly higher grain yields (1393 and 2002 kg ha^{-1} respectively) on the degraded site than the 'relative control' treatment (109 kg ha^{-1}). In 1994, only the *Senna* treatment produced higher yields (1254 kg ha^{-1}) when compared to the 'relative control' treatment (27 kg ha^{-1}). On the non-degraded site, maize grain yield of 1996 in the *Leucaena* and *Senna* treatments was significantly greater (3150 and 3078 kg ha^{-1} respectively) than in the 'relative control' treatment (1346 $kgha^{-1}$).

In 1994, the same trend was observed only for *Senna* treatment.

Despite the advantages of GM, there is a range of disadvantages, which include the fact that, the control of the quantity and timing of nutrients is more complex than with inorganic fertilizers (IRRI, 1988).

2.3 Effects of prunings quality and environment (climate and soil) on decomposition and mineralization

Decomposition and mineralization (nutrient release) of biomass so added are key processes by which nutrients locked up in plant parts eventually become available to crops. The processes are regulated by a number of variables including physical and chemical properties (quality) of litter, climate, soil properties and decomposer communities (Mugendi and Nair, 1997).

The term litter (prunings) quality refers to nutrient content and comparative rate of decomposition of plant residues (Nduwayezu, 1997). Traditionally, high quality litter is one with high N and low carbon contents (eg. succulent materials rich in protein with narrow C: N ratio) are fast decomposing, whereas woody residues and other lignified materials (eg. cereal straw) or plant materials with high fats and wax contents which decompose slowly due to wider C: N ratio, are of low quality (Constantinides and

Fownes, 1993; Nair, 1993). Under field conditions in Cote d'Ivoire, Budelman (1988) showed an example of such close relation between decomposition rate and C: N ratio of different plant species. He reported that, half-life values of the fresh leaf biomass of *L. leucocephala, G. sepium* and *Flemingia microphylla* with C: N ratios 12:1, 12:1, 21:1 were 31, 22 and 53 days respectively. Buresh and Tian (1998) on the other hand, observed a rapid decrease in dry matter for Gliricidia and Leucaena prunings with losses up to 40% over a 2 months period. Additionally, they also found that the rate of dry weight losses of all prunings materials was considerably slower after 16 days due to inadequate moisture availability. In another experiment (Mugendi and Nair, 1997), observed that among the plant indices that were shown to be effective in determining the rate of decomposition, N, C: N, lignin: N and (lignin+polyphenol): N were best correlated with the rate of decomposition. When studying the decomposition pattern of Calliandra, Cordia and Grevillea with C: N of 15.9, 16.4 and 32.7 respectively, and lignin: N of 4.4,10.1, and 16.5 as well as N content of 2.9, 2.8, and 1.4 respectively, the decomposition rate was in the order Calliandra ≥ Cordia > Grevillea.

This observation was supported by a number of researchers (Tisdale *et al.,* 1990; Oglesby and Fownes, 1992; Nair, 1993 and Lehmann *et al.*, 1995). If the C: N ratio of the applied material is low, the decomposition is rapid releasing large amounts of N, while those with wide C: N ratio (eg. cereal straw) provide a source of energy (C) for the microbes, the microbes subsequently multiply and draw upon N reserves from the soil (Tisdale *et al.*, 1990; Nair, 1993).

Tisdale *et al.,* (1990), further reported that as decay proceeds, and since the added material is poor in N, this causes temporary N immobilization. In another experiment to assess the decomposition patterns of plant residues, plant materials that have contrasting chemical compositions were chosen for the field study (prunings of *Acioa barteri, G. sepium* and *L. leucocephala*, maize stover and rice straw) (Vanlauwe *et al.*, 1995). A rapid decrease in ash-free dry weight was observed for Gliricidia and Leucaena prunings during the first 41 days after incubation followed by rice straw and maize stover.

On the contrary, Acioa prunings showed slow decomposition. The extreme low decomposition rate for Acioa prunings may be due to their extreme low quality. Nitrogen release from plant residues followed the same pattern as decomposition of plant residues. The slower rates of N release from Acioa, maize stover and rice straw appears as that during decomposition. Some N was immobilized despite the decrease in total N in the remaining material. N immobilization was related with C: N ratio i.e N immobilization occurs if the plant residues has a C: N of $\geq$ 30. The C: N ratio of Acioa prunings, rice straw and maize stover were higher than this critical value (Vanlauwe *et al.*, 1995). Thus, the initial nitrogen content or C: N ratio of plant materials (litter quality) is a convenient tool for predicting the rates of decomposition and nutrient release (nitrogen mineralization).

Apart from the material specific aspects, there are environmental factors at work that co-determine decomposition. Under tropical conditions, where the temperature varies within a rather narrow range, rainfall can be expected to be the determinant climatological factor influencing the decomposition and nutrient release (mineralization) process. Synchronisation of the nutrients released, especially N, with demand by the growing crop is crucial for increasing the nutrient use efficiency, as it has been stated earlier. Correct timing of organic residue applications relative to the planting of the crop is essential for improved synchronisation, but this may be difficult to achieve because of the largely unpredictable rainfall events (Vanlauwe *et al.*, 1995).

Field studies suggest that decomposition rates in the tropics are generally higher compared to the rates found under temperate circumstances (Budelman, 1988). The optimum situation for fast decomposition is where average temperatures are found together with a continuous moisture supply. It follows that decomposition rates are highest in the continually humid lowland tropics. Vanlauwe *et al.*, (1995) found a better correlation of rainfall events with the percentage dry matter loss than with the total amount of precipitation in their study on the impact of rainfall regime on the decomposition of litter with contrasting quality.

Mugendi and Nair (1997) reported a significant correlation of rainfall and soil temperature with decomposition rate.

Decomposition patterns of the biomass were affected by both the region (environment) and the type of species (region by species interaction). Patterns of cumulative mineralised N (N released) of biomass was influenced by region and species.

Table 1: Cumulative N released at week 20 by biomass from different tree species in different regions of the central highlands of Kenya

	Season 1 (LR95)			Season 2 (SR95)			
	Reg1	Reg2	Reg3	Reg1	Reg2	Reg3	Reg4
Species	...........Nitrogen released (g 100 g^{-1})...........						
Calliandra	1.88a	3.07a	1.71a	1.97a	3.40a	1.68a	3.47a
Cordia	1.53a	1.68b	0.46a	1.78a	1.30b	0.98b	1.62b
Grevillea	0.43b	40c	0.44b	0.17b	0.30c	0.40c	0.44c

Source: Mugendi and Nair (1997)

Abbreviations: LR = long rains; SR = short rains

Literature is scarce on the combined use of climatic, plant and soil indices in the prediction of decomposition and nutrient release especially in agroforestry systems. However, in their study to predict the decomposition patterns of tree biomass in four micro-regions of tropical highlands of Kenya, Mugendi and Nair (1997) found that the combined effects of the three groups of factors (climate, plant quality and soil) on the influence of the rate of decomposition climate played a key role in regulating the rate of decomposition (Table 1). Soil factors played a minimal role in both seasons. This finding corroborates the work of Meentemeyer (1978) cited by Mungendi and Nair (1997) who indicated that climate was more important predictor of decomposition than litter quality when dealing with multi-locational sites that had differing climates.

However, when dealing with particular regions that had reasonably uniform microclimate and terrain, litter quality indices were excellent predictors of the rate of decomposition. They concluded that, during "good" seasons with average climatic conditions, biomass decomposition is governed predominantly by plant quality factors, whereas climatic factors (rainfall and temperature) are more important during seasons of uneven or irregular conditions.

Besides the amount of residue, its particle size, or its biochemical composition (C: N ratio, lignin: N ratio, polyphenol content) and climatic factors, the biological (microbial and faunal activity) and physicochemical soil environment are important modifiers of the decomposition process (Vanlauwe *et al* ., 1995). Soil fauna play an important role in enhancing and sustaining soil productivity through their effects on soil OM decomposition and availability of plant nutrients (Tian *et al.*, 1993 and Tian *et al.*, 1992b). Exclusion of macrofauna was reported to reduce decomposition rate and nutrient release from leaf litter. Earthworms are able to increase the decomposition of OM and availability of nutrients by comminuting residues and incorporating OM in the soil and by producing casts enriched with microflora.

Application of plant residues as mulch is known to attenuate the increase of soil temperature and to retain higher soil moisture contents in addition to providing food for soil animals. Soil aeration (following soil texture) can also influence decomposition as well as mineralization. Where the oxygen supply is inadequate for microorganisms, there will be little ammonium oxidation, and the reactions aiming at nitrates production ceases in the total absence of oxygen (Tisdale *et al.*, 1990).

More decomposition was reported to occur in the upper soil layers, because more OM is added there and furthermore aeration is more adequate than below. Mafongoya *et al.*, (1996 a) reported that the decomposition and N-mineralization rates of multipurpose tree prunings applied as a source of N to annual crops in agroforestry systems, are affected by the chemical composition and method and time of application of the prunings and the soil type. In a greenhouse study undertaken on two contrasting Zimbabwean soils (Alfisol and Psamment), there was a significant interaction of pruning quality with time and method of pruning application on nitrogen recovery by maize and residual effects on a subsequent maize crop on both soil types. Using three MPT species (i.e *Acacia angustissima, Cajanus cajan* and *Flemingia macrophylla*), *Flemingia macrophylla* showed prolonged N immobilization on an Alfisol (sandy clay loam) but not on the Psamment (sandy soil) (Mafongoya *et al.*, 1996 a). Low quality prunings such as *F. macrophylla* and *A. angustissima* applied 4 weeks after sowing gave a higher residual effect on N recovery on the Alfisol than on the Psamment.

2.4 Effect of mulch quantity on nitrogen recovery by crops and crop growth and yield

Tilander (1993) reported that higher leaf dosages gave higher grain yield than did lower dosages. The results showed that, leaf mulch from *Azadirachta indica* and *Albizia lebbeck* can enhance the yield of sorghum in a semi-arid Burkina-Faso. The degree of yield enhancement was positively related to the amount of leaves added. Nduwayezu (1997) also reported the same results that N uptake by maize crop decreased with decreasing rate of Gliricidia application. Nduwayezu (1997) suggested that under lower application rates of Gliricidia, N was not readily available to maize crop, due to immobilization by soil microorganisms, weeds or leaching. In an experiment to assess the effect of the quantity of leaves applied at the soil surface on the rate of decomposition, dry weight loss of Dactyladenia and Flemingia mulch was monitored by Henrot and Brussaard (1997). The litter tubes were filled with amounts of fresh leaves corresponding to 1, 2, 4 and 8 t ha^{-1} on dry basis and they were placed in the field. The amount of Flemingia or Dactyladenia leaves placed in the litter tubes did not affect the rate at which the mulch decomposed (Henrot and Brussaard, 1997). Visual observations in the field, suggested that decomposition occurred at a faster rate when only the thin layer of leaves was present on the soil surface, which could be explained by a better contact between the leaves and the soil (Henrot and Brussaard, 1997). The author concluded that decomposition rate constants are not affected by the quantity of mulch added at the soil surface.

However, additions of very high quantities of materials with high C: N ratios should be avoided, since as reported by Nair (1993), additions of high quantity of poor quality, reduces crop productivity due to high soil nitrogen immobilization by soil microorganisms (as explained in 2.3 above). This results in marked depression of nitrogen uptake by the plant and consequent decrease in yield.

In their experiment to evaluate the effectiveness of alley cropping systems, Aihou *et al.*, (1999), found that the net grain yields of the alley cropping plots relative to the grain yield of the 'relative control' plot were linearly related to the total amount of N added as prunings. The increase in grain production is related to the amount of pruning N added, up to a level where N supply meets the maximal demand (about 100-kg pruning-N ha^{-1}). The observed relationships do not necessarily indicate a direct contribution of pruning N to crop growth, but may partly be the result of an improved use efficiency of fertilizer or soil derived N due to the presence of OM. Basing on the fact that the organic inputs alone cannot supply adequate nutrients, Gachengo *et al.*, (1999) conducted a study in Western Kenya to observe the use of two organic resources, *Tithonia diversifolia* (Tithonia) and *Senna spectabilis* (Senna) leaves and their combination with inorganic P for improving soil fertility and maize yields. Treatments included control, 5 t ha^{-1} (dry matter) Tithonia leaves, 5 t ha^{-1} senna leaves, 5 t ha^{-1} tithonia leaves + 25 kg P ha^{-1} as TSP, 5 t ha^{-1} senna leaves + 25 kg P ha^{-1} as TSP and 25 kg P ha^{-1} of TSP.

Maize was used as test crop. The authors observed that, tithonia +TSP application tripled maize yields compared to the control, senna + TSP application and tithonia sole application doubled yields, while senna sole applications did not increase yields substantially. The control plots yielded a total of only 2.7 t ha^{-1} for the three crops compared to 8.6 t ha^{-1} for the tithonia + TSP treatment. The higher yields for the first crop with the application of the higher quality tithonia are due to a combination of more P and N added and faster release patterns of P and N for tithonia as compared to senna. The higher relative yield of crop 2 for the senna + TSP treatment compared to crop 1 suggests that nutrients became available later and resulted in a delayed crop response. The authors also found that, the maize crop recovered a high percentage of P and P added from tithonia GM compared to senna. This observation supports the idea that the quality of the organic input, not just the amount of nutrients added affect nutrient availability patterns and crop growth. The lower recovery of the P and N added as senna green manure in crop 1 might be a result of the late release of P and slower release of N from senna that resulted in a lack of synchrony between crop nutrient demand and supply by the soil. The P recovery values from the treatments with organic inputs are high compared to recovery levels of 10% for the first crop and 20 – 30% after several crops for inorganic fertilizers. The authors also added that the high recovery might be an effect of the organic additions on P availability on moderately P fixing soil. Nziguheba *et al.,* (1998) cited by Gachengo *et al.,* (1999), found that applications of 5 t ha^{-1} (15 kg P) of tithonia increased the sum of resin + NaOH inorganic extractable P when compared to additions of similar amounts of P added as TSP. The increase in P availability was related to a decrease in the P adsorption capacity of the soil with additions of tithonia.

The N recovery values from tithonia green manures were high compared to senna for the three crops. The authors explained that, since P was the primary nutrient limiting crop growth and nutrient uptake may also account for the high N recoveries. Once the P limitation was overcome the crop readily took up N this effect is shown by the dramatic increase in N recovery when P was added to the organic matter.

2.5 Effect of mulch application time on nutrient uptake by crops and crop growth and yield

The synchronization of nutrient release from mulch with nutrient uptake by crops is considered a vital point for improving the efficiency of nutrient uptake through the plant (Lehmann *et al.*, 1995). Yamoah *et al.*, (1986) cited by Njuki (1998) observed that for nutrients to be available to the plants during the growing season, the decomposition and release of nutrients by the prunings has to be synchronized with when nutrients are needed by the crop. Further, for effective nutrient conservation in the cropping systems, the release of nutrients from the organic mulches should be synchronized with crop growth demands (Henrot and Brussaard 1997).

To achieve this synchrony, adequate mulch must be applied in the field at an appropriate time during the cropping season. As it has been pointed out earlier, that agricultural crops have well defined critical periods of high nutrients demand (eg. 4 – 6 weeks for maize crop) (Nair, 1993). Thus, if nutrients could be made available to the crops during the period of high nutrient demand, therefore, the released nutrients would be used efficiently, leaching losses minimized, and crop productivity increased.

Mafongoya *et al.*, (1996b) suggested that, the time of pruning application and mixing prunings of varying qualities could be important management options to increase the rate of N recovery from multipurpose-tree prunings that are used as a source of N to crops. A field experiment was conducted in the semiarid zone of Zimbabwe to test this hypothesis, using a leaf prunings of Calliandra and Leucaena applied at 5 t ha^{-1} alone or in mixtures (2.5 t ha^{-1}), to plots with maize as a test crop at 0, 2, or 4 weeks after sowing. Time of pruning application significantly affected N uptake, N recovery and grain yield of maize. Applying prunings of Calliandra at the time of maize sowing was significantly better in terms of crop N uptake and recovery, and grain yield than applying them 4 weeks after sowing. However, with Leucaena, the time of pruning application had no significant effects on N recovery. Split application of available prunings at 0 or 4 weeks after sowing reduced N recovery and uptake in some cases, in comparison with one-time application of entire amount of prunings at sowing.

Tilander (1993) also observed that, the year by year statistical analysis of the three modes differing in application time suggested that timing influenced yield. Plots receiving Azadirachta leaves either at sowing or 4 - 6 weeks after sowing gave a higher response than plots receiving Azadirachta with straw or Albizia with straw.

When studying the decomposition and nutrient release from leaves, twigs and roots of three cropped tree legumes in Central Togo, Lehmann *et al.*, (1995) observed that mulch from *L.leucocephala*, *G.sepium* and *A.barteri* together with 45 kg N ha^{-1} seemed to increase nutrient uptake and maize grain yield in comparison to the control. The temporal pattern of N released was as important as the total quantity. Until the time of maximum N demand of maize (4 to 6 weeks), 86% of the N content of Gliricidia leaves had already been released compared to only 52% for Calliandra and 39% for Senna. They concluded that, this might indicate an advantage of applying Gliricidia prunings about two weeks after sowing of maize.

Studies conducted in the green house have revealed that N availability was higher when corn residues were applied 45 days before planting than when they were applied at planting (Ishuza, 1987). In another observation, Ishuza (1987) reported higher concentration of N in the soil when wheat straws were applied 4 or 6 weeks before planting than when the straws were applied just prior to planting. The author added that application of straw in the soil generally resulted in the immobilization of nitrogen.

Ishuza (1987) further reported higher availability of P in the soil when plant residues were allowed to stay in contact with the soil for longer periods than when residues were in contact with the soil for shorter periods (period was not specified). The author reported higher yields when straws were incorporated into the soil 4 or 6 weeks before planting than when straws were incorporated just prior to planting.

CHAPTER 3

3.0 MATERIALS AND METHODS

3.1 Study site description

The experiment was carried out at Sokoine University of Agriculture (SUA) farm (06°E 50'24.7"S, 37°E 38'59.8" S; 526 m asl). The area is located in a sub-humid tropical belt. It experiences a bi-modal rainfall pattern characterised by two rain peak seasons per year with a definite dry season separating the short rains (October to December) and long rains (March to May). The long term mean annual rainfall ranges from about 750 to 1050 mm, total annual evapotranspiration is about 1307 mm and the mean annual temperature is 24°C. The 1999 cropping season rainfall is presented in table 2. The original vegetation was mostly Miombo, which was cleared, cropped and fallowed. The soils are classified as acrisol or ultisol. These soils are deep and well drained, predominantly clay loam soils with very low N content (FAO, 1987). The pH ranges from 4.2 to 4.7 in the depth of 0 to 9 cm and 9 to 23 cm respectively. The mineralogy of the soils is purely kaolinitic, representing the red and relatively highly weathered soils. Some of the soil physical and chemical characteristics for SUA Farm are presented in table 3.

Table 2: Monthly total rainfall during the 1999-growing season at meteorological station, SUA Campus, Morogoro, Tanzania

Month	March	April	May	June
Rainfall (mm)	29.0	186.2	200.7	95.3

Source: Morogoro Meteorological station (SUA)

3.2 Experimental design and treatments

The experiment was laid out in a 4x4 split-plot experimental arrangement in a randomized complete block design with three replications. The different factors and their levels were as follows:

(a) Major factors (mulch application dates)

- Just before sowing = T_1
- Two weeks after sowing = T_2
- Four weeks after sowing = T_3
- Six weeks after sowing = T_4

(b) Minor factors (mulch application rates)

- Control (0 kg ha^{-1}, dry wt per plot) M_1
- 2.5 t/ha (2500 kg ha^{-1}, 4 kg plot^{-1}) M_2
- 5.0 t/ha (5000 kg ha^{-1}, 8 kgplot^{-1}) M_3
- 10.0 t/ha (10000 kg ha^{-1}, 16 kgplot^{-1}) M_4

There were 16 treatment combinations (treatments) as follows:

T_1M_1	T_2M_1	T_3M_1	T_4M_1
T_1M_2	T_2M_2	T_3M_2	T_4M_2
T_1M_3	T_2M_3	T_3M_3	T_4M_3
T_1M_4	T_2M_4	T_3M_4	T_4M_4

3.3 Experimental establishment and management

The experimental plot was ploughed and harrowed before planting in March 1999. The major plots measured 9.2 x 9.2 m, and minor plots 3.6 x 3.6 m. The block size was 20.4 x 20.4 m. The distance between major plots was 2 m, and the distance between minor plots was 2 m. Maize seeds variety Kito were planted at 0.6m spacing (within rows) and 0.75 m (between rows). The inner plots contained 9 by 5 rows of maize. Three maize seeds were planted per planting hole and after germination one weak maize seedling was thinned. All plots were weeded twice during the cropping season at 4 and 6 weeks after sowing of maize. The GM samples were randomly collected from *G. sepium* fodder banks in early March 1999, placed into paper bags and taken to SUA Forest Biology Laboratory. The GM were oven dried at 70°C to constant weight for nutrient content analysis and also for estimation of green weight to be applied in the field. Nitrogen concentration was found to be 2.85 ± 0.12% and P 0.14 ± 0.02%. GM leaves were collected and applied manually onto the soil in each minor plot at the times and rates indicated in 3.2 (a) and (b).

3.4 Data collection

3.4.1. Soil sampling

Soil samples were taken in two phases: for routine analysis and for determination of potentially available N. For routine analysis, soil samples were collected from three randomly selected points in a block at 0-10, 10-20, 20-30, and 30-50 cm soil depth before sowing of maize. Soil samples were then composited by block and sampling depth mixed thoroughly and then sub-sampled. Sub-samples were then taken to the Forest Biology Laboratory for analysis. For determination of soil N availability potential, soil samples were collected from both plots i.e plots with GM and without GM (control).

For each plot, soil samples were taken from three randomly selected points within the rows of maize at 0-15 cm depth at 0, 1, 2, 4, 6, 8, 10, and 12 weeks after sowing of maize. For each sampling date, the soils were bulked by sampling depth, mixed thoroughly and sub-samples taken to the laboratory, stored in a refrigerator at 4-5°C for N-mineralization studies.

3.4.2 Assessment of maize growth and yield

Maize height was measured using a scaled metric wood bar to the nearest 0.1 cm at the beginning of tasselling i.e 6 weeks after sowing. Also at this time, a 4th leaf from top was collected from five maize plants for determination of N and P contents.

Maize grain yield was determined by counting and harvesting all maize plants on 2nd, 3rd and 4th rows in each minor plot i.e three inner most rows. The harvested maize was partitioned into grain, cobs and stover and was separately weighed to determine the field weight. Sub-samples of maize grain, stover and cobs were weighed and oven dried (70°C) to constant weight for moisture content determination, maize grain and stover yields were later expressed on a t ha^{-1} basis.

3.4 .3 Laboratory Procedure

3.4.3.1 Analysis of soil samples

(a) Soil physical properties

Soil texture was determined by hydrometer method as described by Bouyoucos (1962). Soil bulk density was determined near field capacity as described by London (1991). Soil samples were collected with coring cylinder of 5-cm length and 5 cm diameter. Soil samples from the core were weighed and then dried in the oven at 105°C for 24 hours. Bulk density was calculated according to Blake and Hartage (1986).

(b) Soil chemical analysis

All soil samples were air dried and ground to pass through a 2 mm sieve. The 0.5g of soil sample was digested using concentrated sulphuric acid followed by oxidation by hydrogen peroxide as described by Anderson and Ingram (1993).

Total N in each digest was determined by semi-micro Kjedahl procedure according to Bremner and Mulvaney (1982). Total P was determined by ascorbic acid method. Available P was determined by Bray-1 method (Anderson and Ingram, 1993). Organic carbon was determined by the oxidation-titration method as described by Anderson and Ingram (1993). Soil exchangeable cations and CEC were determined by the saturation method (Urio and Singh, 1979). A 1:10 ammonia acetate at pH 7 was used to saturate the colloidal complex with ammonium. The displaced exchangeable cations K^+ and Na^+ were measured by flame emission spectroscopy while Ca^{2+} and Mg^{2+} were determined by atomic absorption spectroscopy. Soil pH was determined potentiometrically by a glass-electrode pH-metre using 1:2.5 soil:water suspension and in 0.01M Calcium chloride (London, 1991).

Table 3: Some selected soil characteristics at SUA Farm, Morogoro, Tanzania.

Soil depth (cm)	0 – 10	10 – 20	20 – 30	30 – 50
Soil pH(H_2O)	4.8 [a](0.28)	4.24 (0.03)	3.73 (0.43)	4.16 (0.04)
EC(dS mm^{-1})	66.47 (19.3)	80.03 (6.63)	54.23 (7.9)	45.0 (3.56)
OC (%)	0.99 (0.034)	0.84 (0.023)	0.14 (0.008)	0.12 (0.007)
Total N (%)	0.16 (0.014)	0.17 (0.014)	0.13 (0.008)	0.11 (0.006)
T P(mg kg^{-1})	312 (33.4)	320 (23.1)	338 (28.8)	330 (15.9)
AvP (mg kg^{-1})	2.93 (0.015)	1.94 (0.017)	0.58 (0.003)	0.37 (0.012)
Na^+	0.53 (0.015)	0.31 (0.006)	0.33 (0.009)	0.39 (0.003)
K^+	1.06 (0.006)	1.09 (0.003)	0.67 (0.019)	0.58 (0.009)
Ca^{2+}	4.49 (0.07)	3.67 (0.03)	2.91 (0.01)	2.44 (0.01)
Mg^{2+}	3.06 (0.007)	2.7 (0.003)	2.5 (0.007)	2.79 (0.007)
Texture	Clay loam	Clay loam	Clay loam	Clay loam

[a] Mean of three replications with standard error in parentheses.

c) Nitrogen mineralization assessment

Potentially available N was determined as described by Fasuluku (1998) as follows: For every sampling date, soil moisture content and disturbed bulk density were determined before further mineral N analysis. Soil samples were filled to brim in a well labelled crucible with known weight and volume. The soil filled crucibles were oven-dried (105°C) to constant weight.

Then moisture content and bulk density were calculated as described by Hillel (1982). After determining the moisture content and bulk density of each soil sample, the percentage of soil pore space was determined by using the following formula as adopted from Hillel (1982):

Porosity = (1 - (bulk density/2.65)) X 100

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

Fifty grammes of oven dry (105°C) soil were taken for aerobic incubation. Soil moisture for each sample was adjusted to 70% field capacity. The plastic bottles covered with polythene paper with small pores were used for keeping the soil samples for incubation.

The weight of the container and the sample was recorded before incubating at 26°C for 14 days. Every day, the incubator was opened for 5 minutes to allow aeration, meanwhile, moisture correction was made after weighing each bottle, by adding a corresponding amount of distilled water (Fasuluku, 1998). At time zero, i.e beginning of the incubation, a 5 g of oven dry (105°C) soil sub-samples were taken for determination of initial mineral nitrogen (Nitrate-N and Ammonium-N) content. The extraction was made using 1M of Potassium sulphate for nitrate and ammonium determination as described by Anderson and Ingram (1993).

Nitrate-N was determined by calorimetric procedure, while NH_4^+-N was determined by distillation-titration procedure as for total N (Anderson and Ingram, 1993). After incubation for 14 days, procedures of extraction and determination of NO_3^- - N and NH_4-N were done as at time zero.

3.4.3.2 Analysis of maize samples

Sub-samples for maize grain, leaves, stover and cobs were weighed and oven dried (60°C) to constant weight. The oven dried sub-samples were ground in a Wiley Mill to pass through a 1 mm sieve except cobs. Determination of N and P concentrations was done as described in section 3.4.3.1 b, but for plant samples, 0.2 g of ground material was digested.

3.4.3.3 Data analysis

Analysis of variance (ANOVA) was done on plot means using General Linear Model (GLM) procedure of SAS. Means separation was done by Duncan's Multiple Range Test for all parameters analyzed including N mineralization, as well as maize growth and yield according to the statistical software programs in SAS (1991) (Appendix 11).

For all statistical analyses a fixed model was fitted and a type III SS analysis was carried out.

$Y_{ijk} = \mu + B_i + D_{ij} + \alpha_{(ij)} + BD_{i(j)} + R_{ik} + \beta_{ijk} + DR_{i(jk)} + \chi_{(ijk)}$

$i = 1,2,3 \quad j = 1,2,3,4 \quad k = 1,2,3,4$

Where: Y_{ijk} = variable to be analysed

μ = overall mean

B_i = effect of the i^{th} block

D_{ij} = effect of the j^{th} mulching date (random) in the i^{th} block

$\alpha_{(ij)}$ = first restriction error (error I)

$BD_{i(j)}$ = effect of the interaction of the i^{th} block with the j^{th} mulching date

R_{ik} = effect of the k^{th} mulching rate in the i^{th} block

β_{ijk} = second restriction error (error II)

$DR_{i(jk)}$ = effect of the interaction of the k^{th} mulching rate with j^{th} mulching date in the i^{th} block

$\chi_{(ijk)}$ = residual effect (error III).

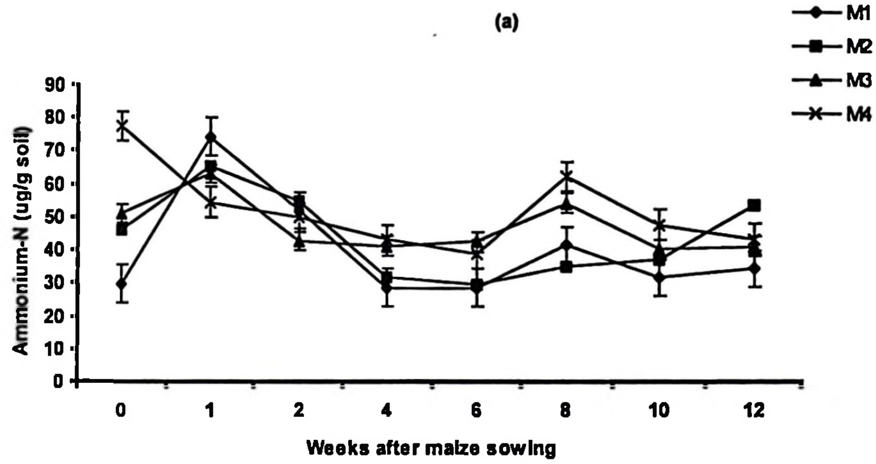
CHAPTER 4

4. 0 RESULTS

4.1 The effect of mulch application times and rates on field mineral nitrogen status

The results for field mineral nitrogen concentration i.e. NO_3^--N and NH_4^+-N are presented in figures 1, 2 and 3 and in appendices 1, 2 and 3. Nitrate-N and ammonium-N were significantly affected by mulching rates except ammonium-N at weeks 1 and 2 and nitrate-N at weeks 1 and 4. Overall, the higher the mulching rate, the higher the field mineral-N. At week 6 for example, nitrate-N ranged from 60.04 μg N g^{-1} soil (M_1) and 87.7 μg N g^{-1} soil (M_4) and ammonium-N ranged from 28.76 μg N g^{-1} soil (M_1) and 43.36 μg N g^{-1} soil (M_4).

Mulching application times had no significant effect on field mineral-N, except ammonium-N at weeks 4 and 12 and nitrate-N at week 12. At week 12 for example, nitrate-N ranged from 72.46 μg N g^{-1} soil (T_1) and 77.68 μg N g^{-1} soil (T_4) and ammonium-N ranged from 40.06 μg N g^{-1} soil (T_2) and 36.99 μg N g^{-1} soil (T_3). However, the results show that for all sampling dates, nitrate-N was the dominant form of the total extractable N.



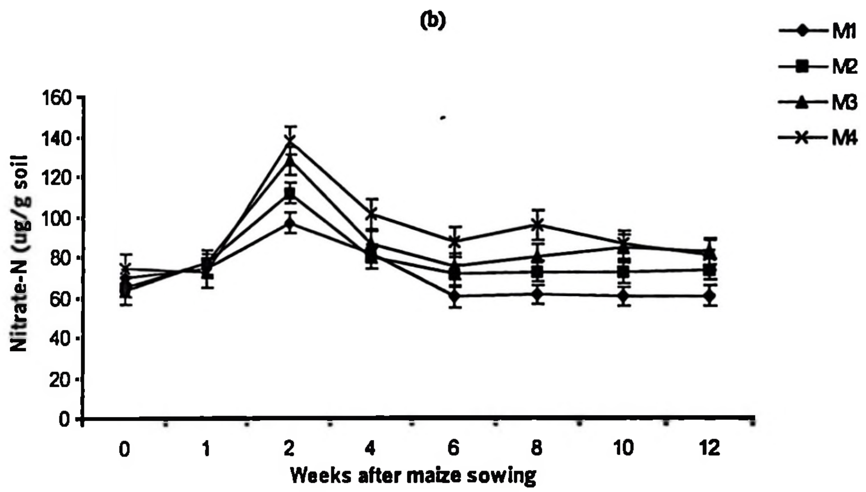
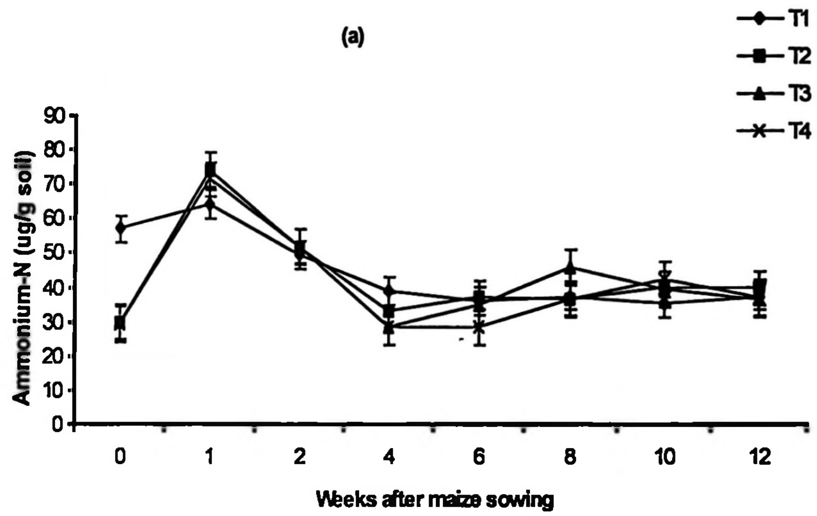


Figure 1: Effect of *G.sepium* mulching rates on field mineral nitrogen (a) ammonium (b) nitrate at SUA Farm, Morogoro, Tanzania.

M_1= 0 t ha^{-1} mulch, M_2= 2.5 t ha^{-1} mulch, M_3= 5 t ha^{-1} mulch and M_4= 10 t ha^{-1} mulch. Bars are the standard errors of the mean of three replicates.



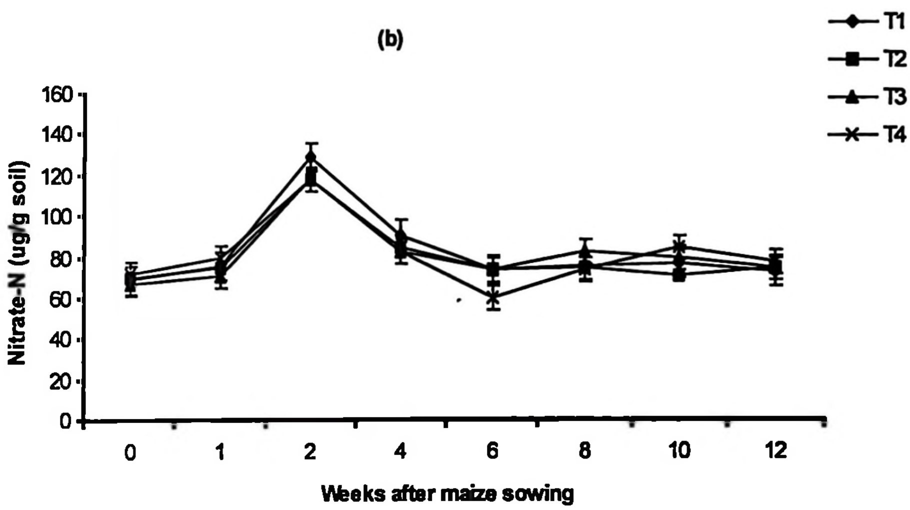


Figure 2: The effect of *G.sepium* mulching dates on field mineral nitrogen (a) ammonium (b) nitrate at SUA Farm, Morogoro, Tanzania.

T_1= Just before maize sowing, T_2= 2 weeks after sowing, T_3= 4 weeks after sowing and T_4= 6 weeks after sowing. Bars as defined in figure 1.

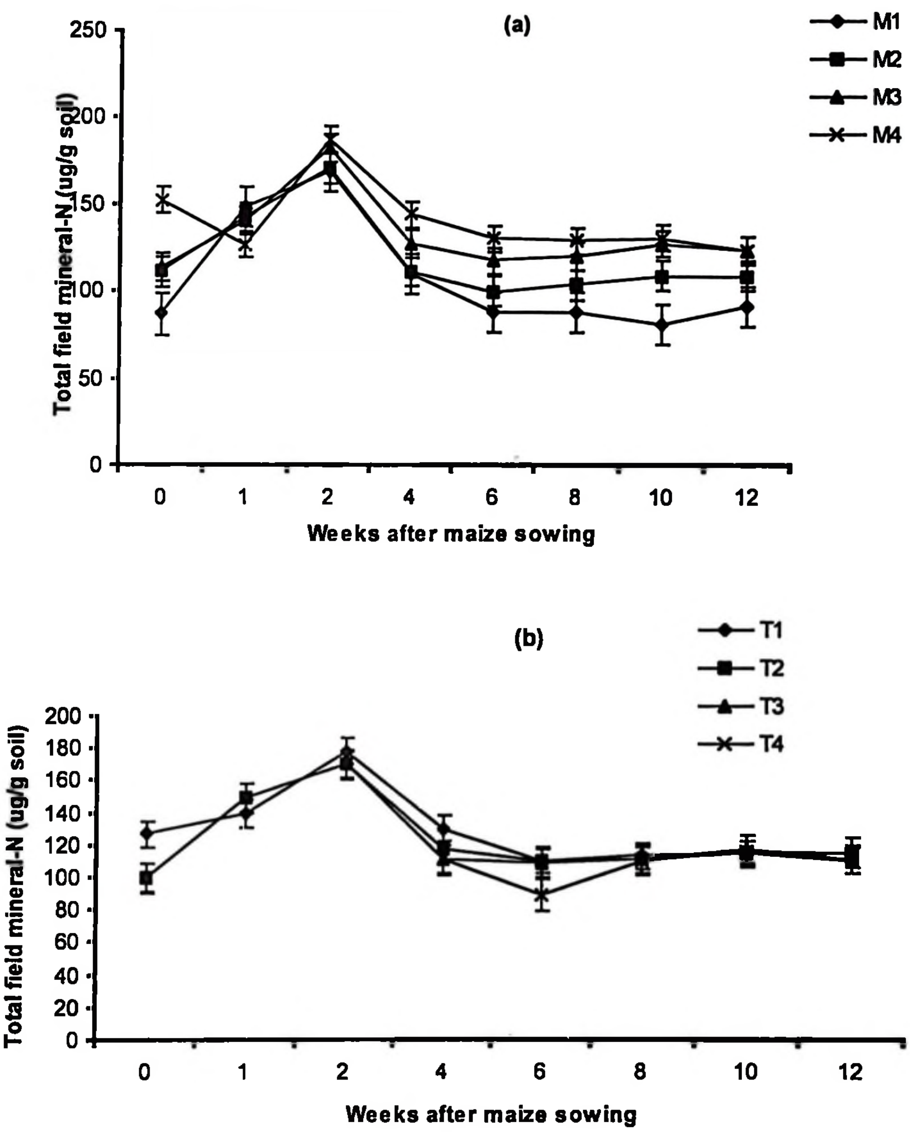


Figure 3: Total field mineral-N as influenced by (a) mulching rates (b) mulching dates at SUA Farm, Morogoro, Tanzania. Treatments as defined in figures 1 and 2 and bars are as defined in figure 1.

4.2 Maize plant leaf N and P contents and biomass 42 DAS

Nitrogen content was significantly affected by the mulch rates applied. The highest N content was observed from plots with highest mulch doses. For example, M_4 resulted in the highest leaf N content 5.54 mg leaf^{-1} (2.90%) compared with M_1 that resulted in the lowest leaf N content of 4.04 mg leaf^{-1} (2.22%) (Figure 4 and Appendix 6). Mulching rate however, had no significant effect on leaf P concentration.

Time of mulch application had no significant effect on leaf N content (Figure 4 and Appendix 6). Phosphorus content was significantly affected by the mulching times. Application of mulch four weeks after sowing i.e T_3 resulted in the highest leaf P content of 0.45 mg leaf^{-1} (0.22%). Whereas mulch application just before sowing of maize i.e T_1 resulted in the lowest P content of 0.44 mg leaf^{-1} (0.19%) as well as four weeks after maize sowing i.e T_4 0.22 mg leaf^{-1} (0.15%).

Neither mulching dates nor mulching rates had significant effect on maize leaf biomass.

There was more or less a significant linear relationship between leaf N and P contents and biomass with rates and times of mulch application. These parameters tended to increase with increase in mulching rates, but decreased following the delay in mulch application times.

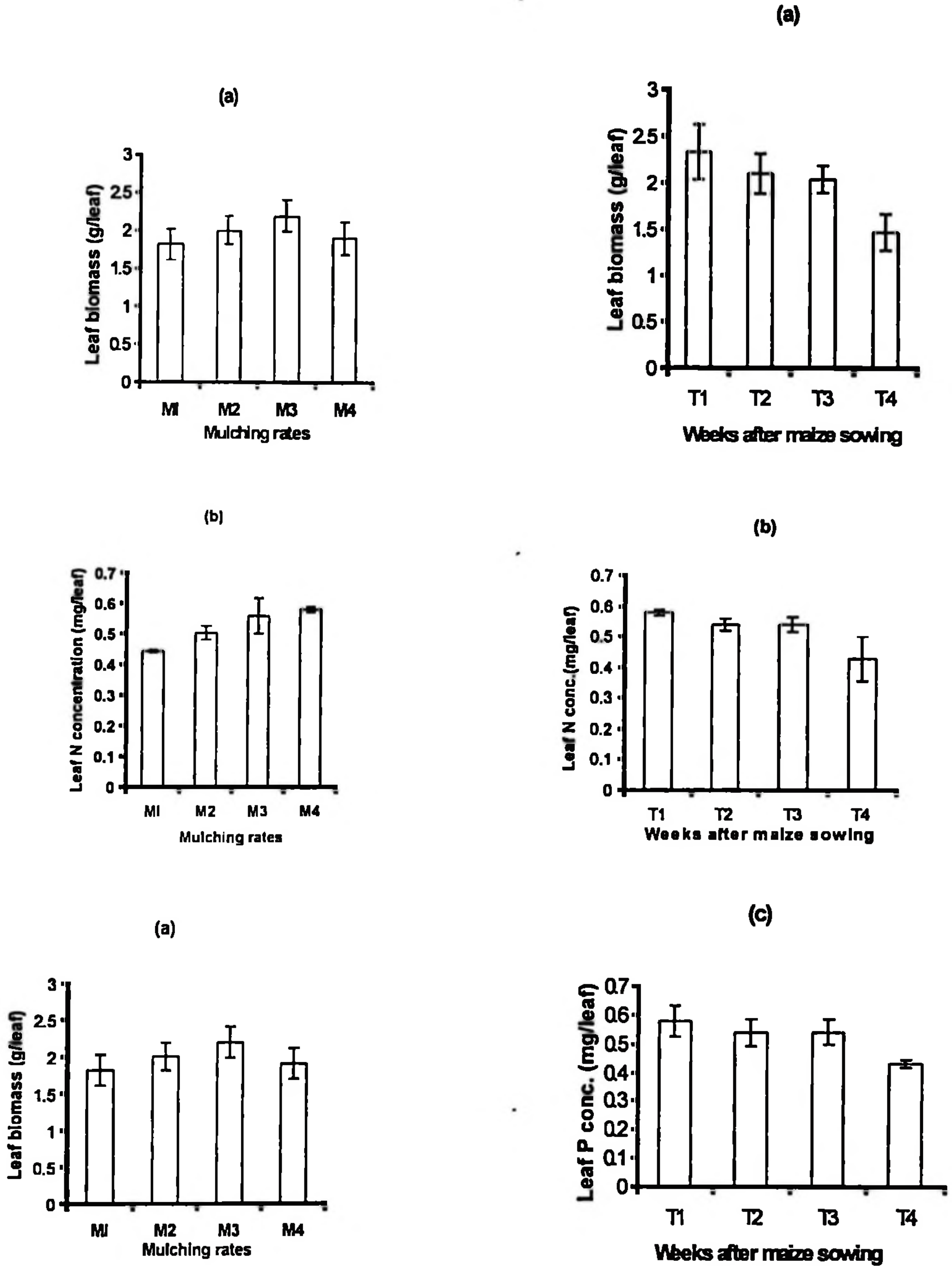


Figure 4: Effect of *G. sepium* mulching rates and dates on maize leaf biomass, leaf N and P contents at SUA Farm, Morogoro, Tanzania. Treatments as defined in figures 1 and 2 and bars are as defined in figure 1.

4.3 Effect of *G. sepium* mulching rates and times of application on plant height and yield

4.3.1 Maize plant height

The height of maize plants was not significantly ($p>0.05$) affected by mulch rates. However the height of maize increased more or less linearly with increase in mulching rates (Figures 5, 6 and appendices 4 and 5). Treatment M_4 (10 t ha^{-1} mulch) resulted in the tallest maize plants (99.9 cm) followed by M_3 (5 t ha^{-1} mulch) which resulted in 96.5 cm maize plants. On the other hand M_2 and M_1 resulted in shortest maize plants (91.9 and 94.3 cm respectively).

Time of application of mulch had no effect on plant height. However, relatively T_1 resulted in the tallest maize plants (105 cm) than T_4, which resulted in the shortest maize plants (85.7 cm).

The results of the interaction effects of mulch rates and mulching times on plant height are presented in Figure 7. Maize plant height was significantly affected by the interaction of mulching rates and dates. Combinations of T_1 and M_4 resulted in the tallest maize plants (120.2 cm) followed by T_2 and M_4, which resulted in 114.6 cm maize plants. The least combination, which resulted in the shortest maize plants, was T_4 and M_3 (79.3 cm).

4.3.2 Maize grain yield

The maize grain yield was significantly affected by mulch rates applied.
The highest mulch rate (dosage) resulted in the highest grain yield (Figure 5, and appendix 4). Treatment M_4 resulted in 2.52 t ha^{-1} followed by M_3 (2.08 t ha^{-1}), M_1 was the least grain producer (1.31 t ha^{-1}). Relative increase in maize grain yield ranged from 20% (M_2) to 34% (M_4) as compared to 18% (control).

Mulching time had no significant effect on maize grain yield. However, the trend was $T_1 \rangle T_2 \rangle T_3 \rangle T_4$ with corresponding maize grain yield of 1.98, 1.91, 1.9 and 1.63 t ha^{-1} respectively (Figure 6).

The interaction between mulch rates and mulching dates was significantly ($P<0.05$) different (Figure 7 and appendix 5). The combination of T_1 and M_4 resulted in the highest maize grain yield (3.02 t ha^{-1}) compared with T_2 and M_1 which resulted in the lowest maize grain yield (1.05 t ha^{-1}).

4.3.3 Stover yield

Stover yield was significantly ($P<0.05$) different among different mulch rates (Figure 5 and appendix 4). Plots with higher mulch rates gave highest stover yield.

Mulching rate of 10 t ha^{-1} mulch i.e M_4, gave the highest yield of stover (5.12 t ha^{-1}) when compared with the control treatment which gave the lowest yield of stover (3.43 t ha^{-1}).

Time of mulch application, had no significant effect on stover yield, but relatively T_3 gave the highest stover yield (4.23 t ha^{-1}) compared with T_1 (3.88 t ha^{-1}) (Figure 6).

The interaction effects of mulch rates and mulching dates on stover yield was significant ($P< 0.05$) (Figure 7 and Appendix 5). Combination of T_2 and M_4 gave the highest stover yield (6.135 t ha^{-1}). However, combination of T_1 with M_1 and M_2 resulted in stover yields of 2.51 t ha^{-1} and 2.1 t ha^{-1} respectively.

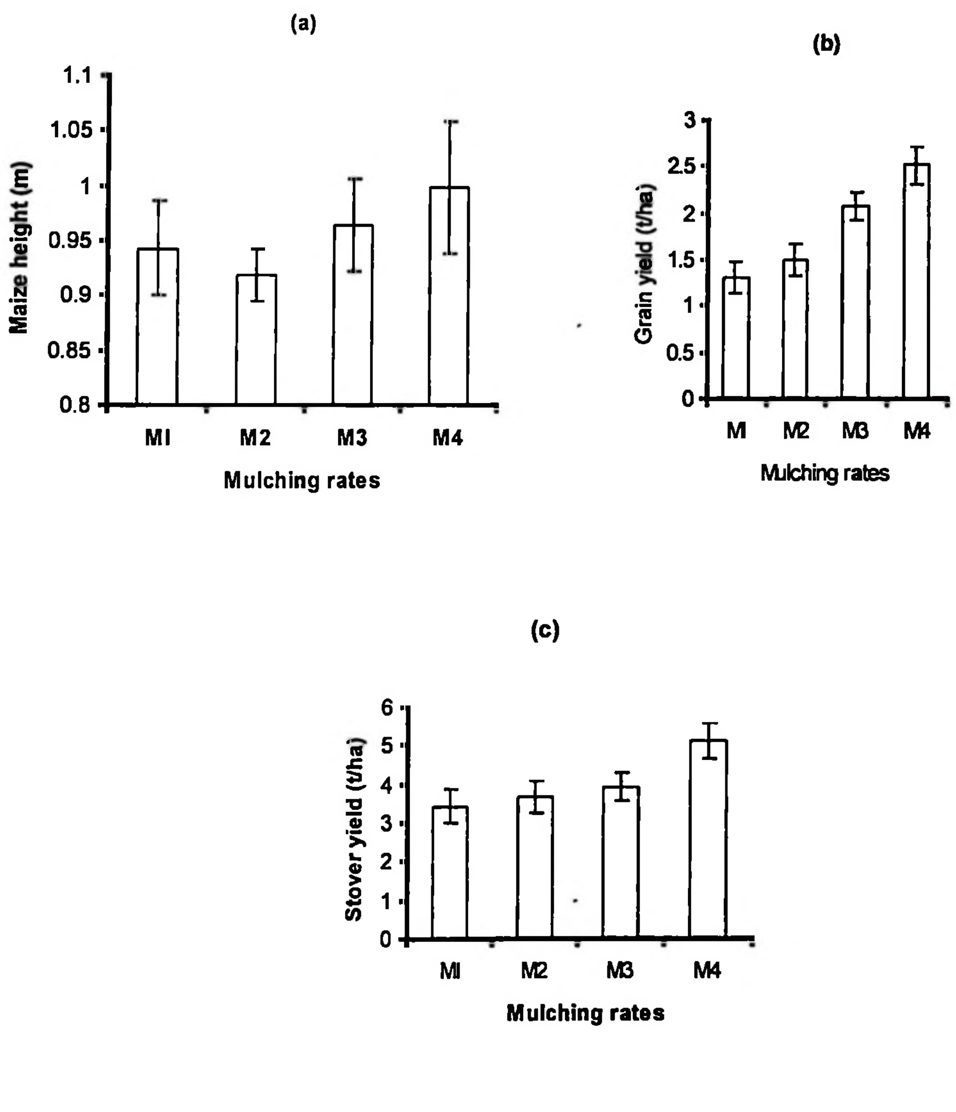


Figure 5: Effect of *G. sepium* mulching rates on maize growth and yield at SUA Farm, Morogoro, Tanzania. Treatments as defined in figure 1 and bars are as defined in figure 1.

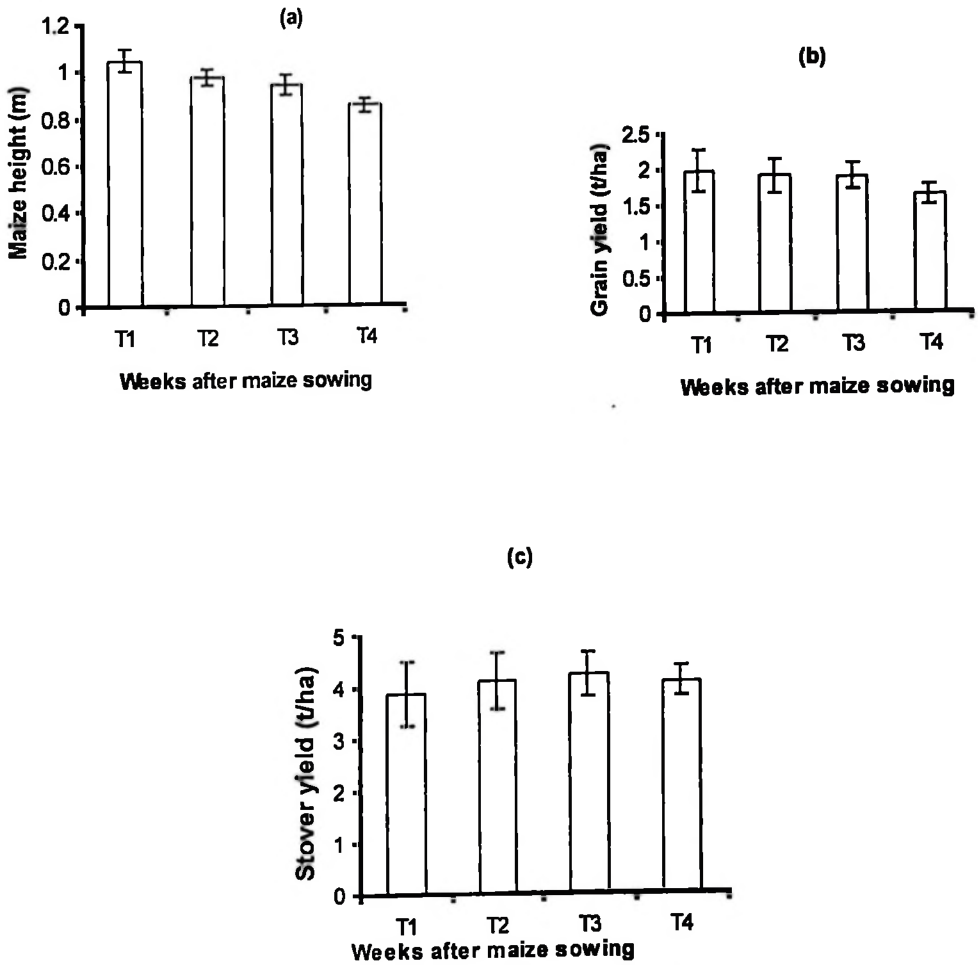


Figure 6: Effect of *G. sepium* mulching dates on maize growth and yield at SUA Farm, Morogoro, Tanzania. Treatments as defined in figure 2 and bars are as defined in figure 1.

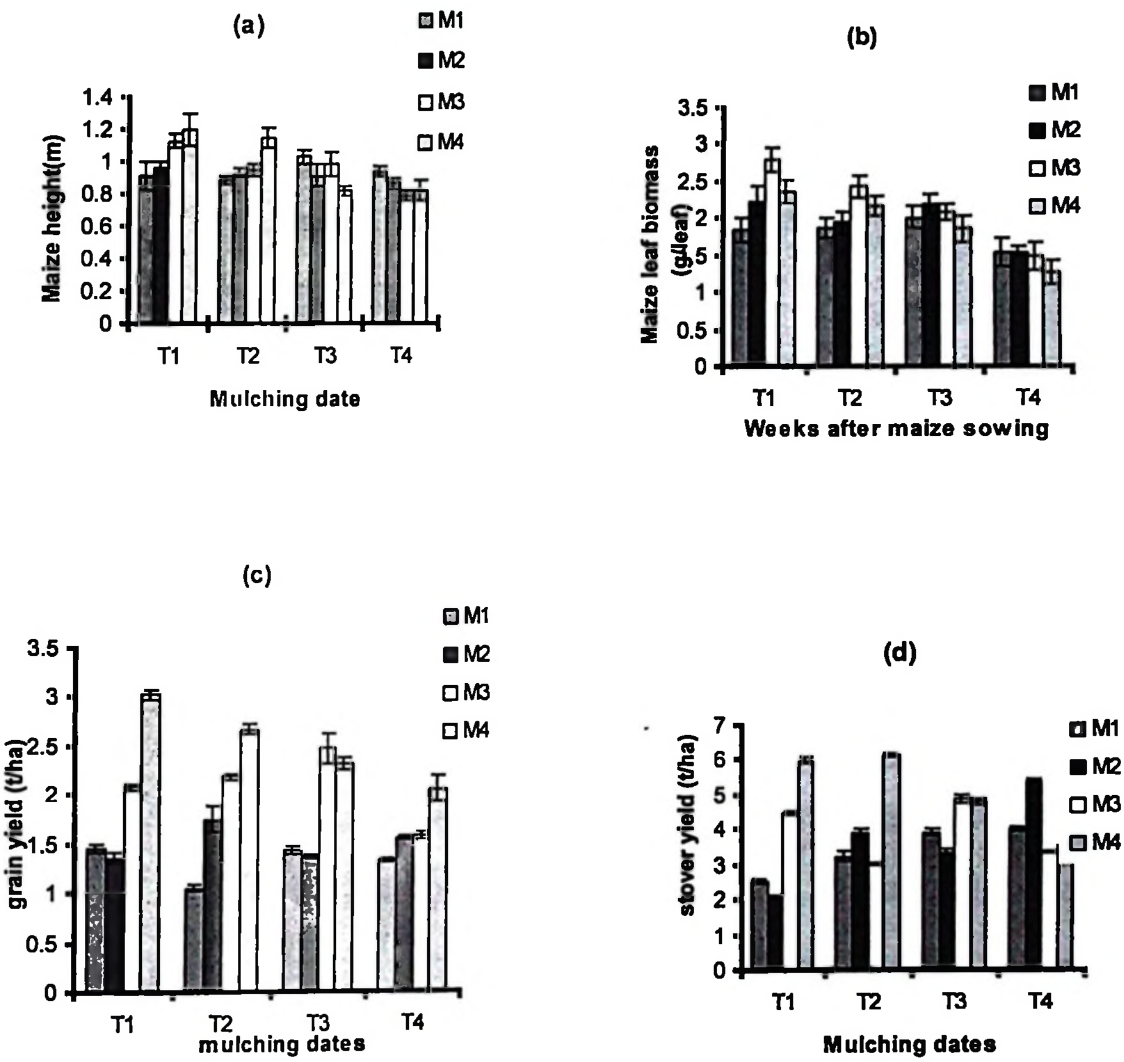


Figure 7: Effect of interaction of *G. sepium* mulching rates and dates on maize growth and yield at SUA Farm, Morogoro, Tanzania. Treatments as defined in figures 1 and 2 and bars are as defined in figure 1.

4.4 Nitrogen and P uptake by above ground maize component

Nitrogen and P content in maize grain and stover showed significant variation among mulch application rates and time of application (Figures 8, 9 and appendices 8, 9). Mulching with high doses resulted in the high concentrations of P as well as N in both maize grain and stover. Treatment M_1 for example resulted in 0.63% (21.6 kg N ha^{-1}) and 0.032% (1.112 kg P ha^{-1}) stover N and P contents respectively, while M_4 resulted in 1.46% (74.75 kg N ha^{-1}) and 0.04% (2.20 kg P ha^{-1}) stover N and P contents respectively. Grain N and P contents followed the same trend as for stover. Treatment M_1 resulted in 1.23% (16.2 kg N ha^{-1}) and 0.14% (1.83 kg P ha^{-1}) N and P contents respectively. While M_4 resulted in the highest contents of N and P i.e. 1.90% (47.87 kg N ha^{-1}) and 0.20% (4.99 kg P ha^{-1}) respectively.

The time of mulch application had no significant effect on stover P and maize grain N contents. However, it had a significant effect on stover N and grain P. Treatment T_1 resulted in 0.03% (34.42 kg N ha^{-1}) stover N and 0.161% (2.24 kg P ha^{-1}) grain P while T_4 resulted in 1.30% (52.83 kg N ha^{-1}) stover N and 2.61 kg P ha-1 grain P (Figure 9 and appendices 8, 9). The results for the total nutrient uptake and the interaction of mulching rates and time of application on nutrient uptake by grain and stover are presented in Figures 10, 11 and Appendix 10. There was a significant effect of the interaction of mulching rates and time of application on nutrient uptake by maize plant components.

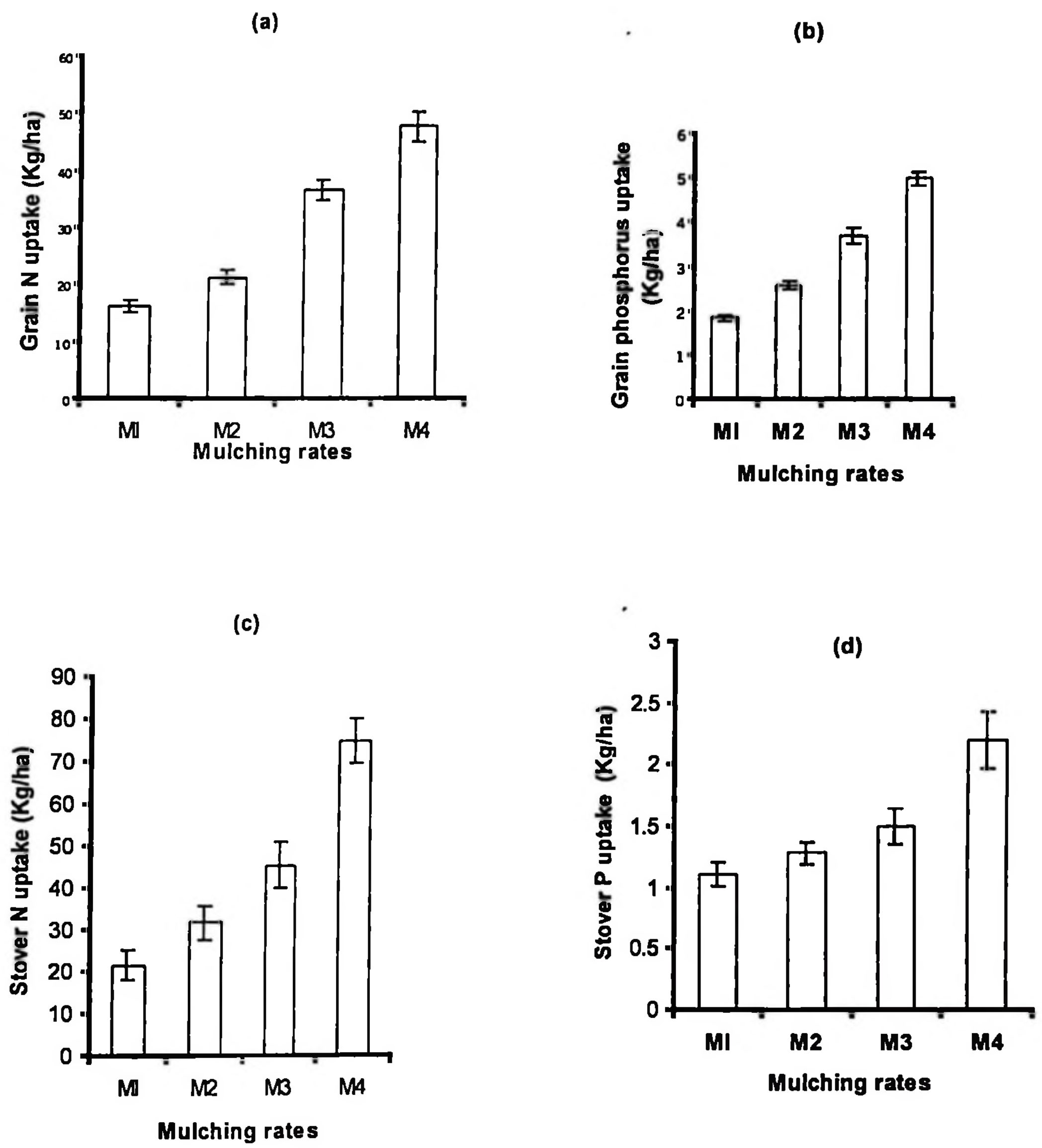


Figure 8: Effect of *G.sepium* mulching rates on nutrient uptake by above ground maize components at SUA Farm, Morogoro, Tanzania. Treatments as defined in figure 1 and bars are as defined in figure 1.

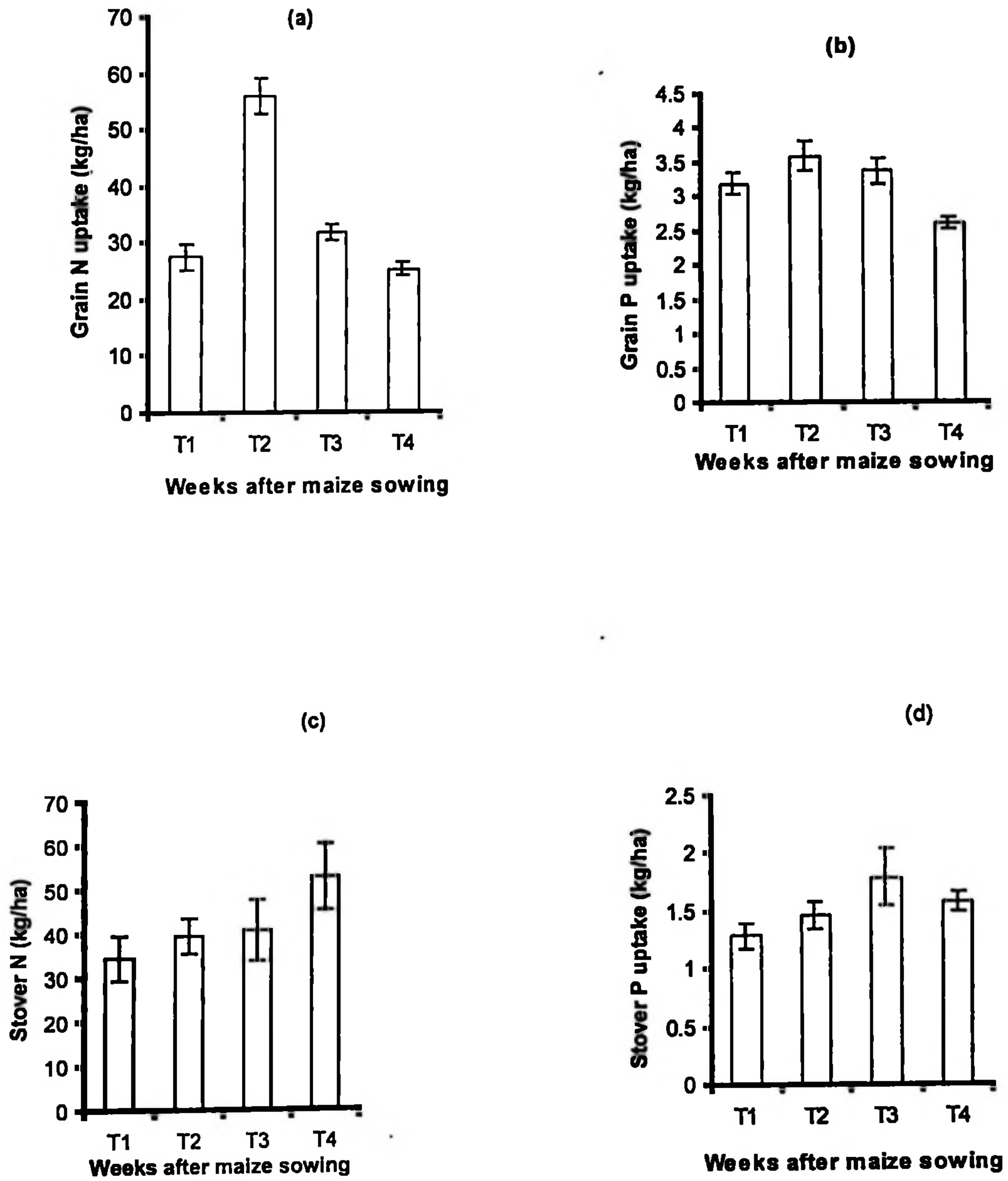


Figure 9: Effect of *G. sepium* mulching dates on nutrient uptake by maize plant components at SUA Farm, Morogoro, Tanzania. Treatments as defined in figure 2 and bars are as defined in figure 1.

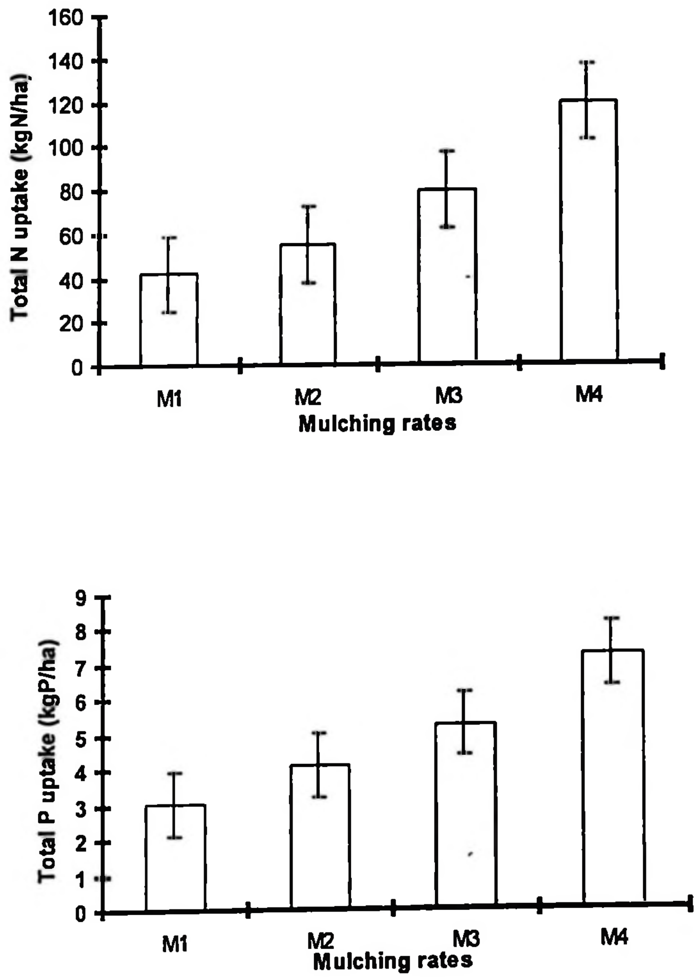


Figure 10: Effect of *G.sepium* mulching rates on total nutrients uptake at SUA Farm, Morogoro, Tanzania. Treatments as defined in figure 1 and bars are as defined in figure 1.

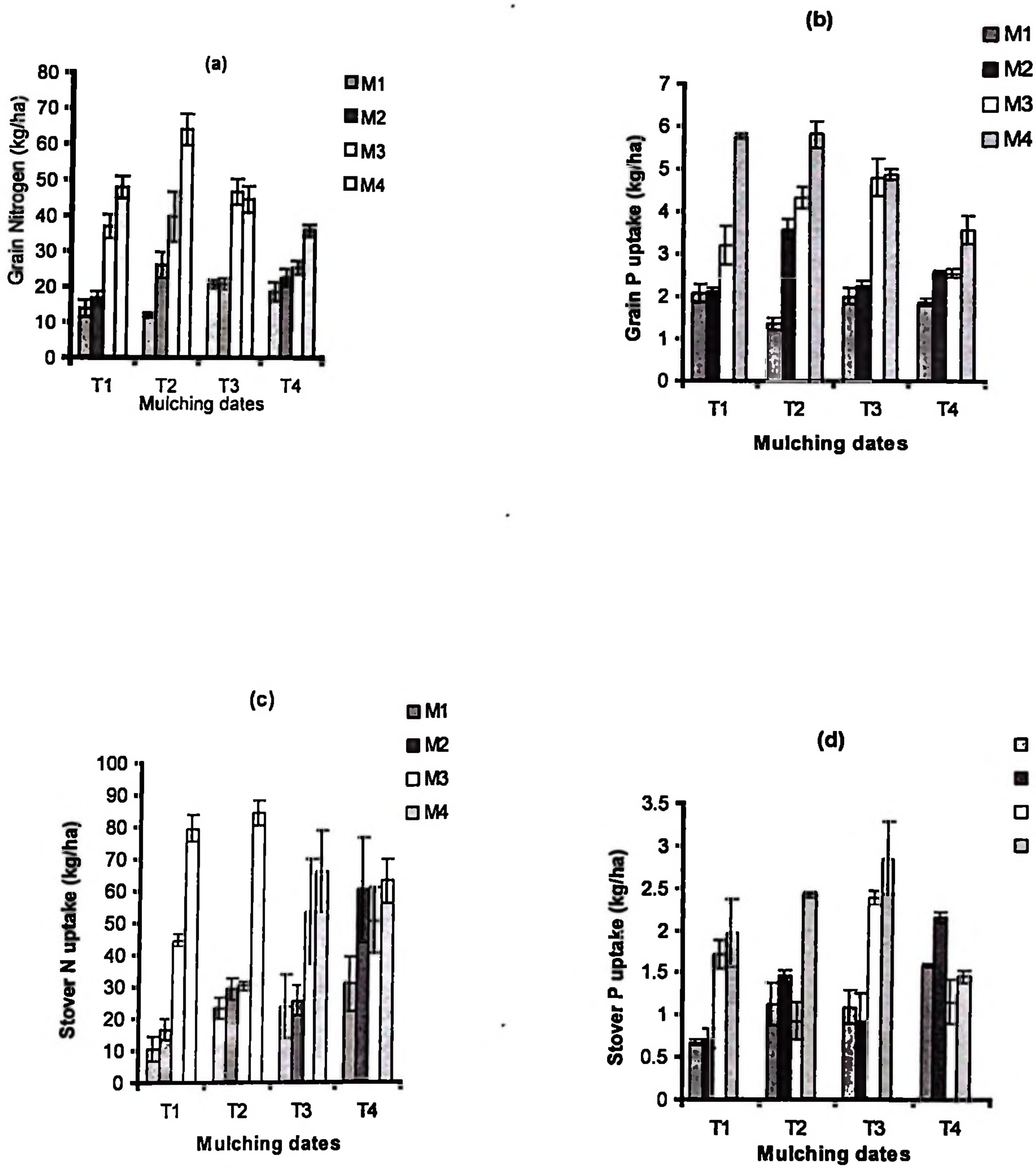


Figure 11: Effect of interaction of *G.sepium* mulching rates and dates on nutrient uptake by maize plant components at SUA Farm, Morogoro, Tanzania. Treatments as defined in figures 1 and 2 and bars are as defined in figure 1.

CHAPTER 5

5. 0 DISCUSSION

5.1 Nitrogen availability potential

The results for field mineral N are presented in figures 1, 2 and 3 appendices 1, 2, and 3. Nitrate-N and ammonium-N were significantly affected by mulching rates except ammonium-N at weeks 1 and 2 and nitrate-N at weeks 1 and 4. The overall trend was, the higher the mulching rate the higher the field mineral-N. These results are in agreement with those obtained by Tilander (1993) who reported a higher rate of ammonification following higher leaf dosages. The high rates of *Gliricidia* application (5 and 10 t ha^{-1} mulch) showed high mineral N, mineralization and nitrification. Probably this was due to the high quality attributes of *Gliricidia* that ensured fast rate of decomposition as reported by Yamoah *et al.*, (1986) cited by Njuki (1998) and Budelman (1988). Mineral N in terms of nitrate increased rapidly from 0 week to week 2, due to the completion of the decomposition of mulch incorporated just before maize sowing. This observation is in line with earlier findings reported by Budelman (1988) in which half of the applied fresh leaves of *G. sepium* was decomposed within 22 days. Similarly, Lehman *et al.*, (1995) found that *Gliricidia* decomposed considerably faster in the first 18 days.

The fast decomposition of *Gliricidia* manures was associated with rapid N release. However, the uptake of N released from mulch by crop may be influenced by the method of manure application (Mafongoya *et al.*, 1996a; Mafongoya and Nair 1996). The authors reported that the chemical composition and method and time of application of the prunings and the soil type affect the decomposition and N-mineralization rates of multipurpose tree prunings applied as a source of N to annual crops in agroforestry systems. Incorporating prunings into the soil at sowing gave higher N recovery than surface application at 2 or 4 weeks after sowing for all MPTs used. The results of the present study in which manure was surface applied, are in conformity with the later observation that all the parameters observed were lower compared with results of other studies.

Mulching application times had no significant effect on field mineral N except at week 12, where T4 resulted in higher mineral –N than T1. This might be due to the completion of mulch decomposition applied 6 weeks after maize sowing in which N released was not available to the crop. These results are in agreement with the time reported by Lehman *et al.*, (1995) that the critical period of nutrient demand by maize is 4 – 6 weeks.

It should be noted from the results that nitrate-N can be used to predict the N availability potential in agricultural soils, not only because of its higher concentration but also because it is the last product of mineralization.

The higher the concentration of nitrate-N, the higher will be the rate of nitrogen mineralization. The higher the nitrate-N immobilization or loss, the lower will be the level of mineral-N in the soil.

Unlike ammonium-N, nitrate-N levels were relatively higher and this could be due to the presence of an active population of nitrifiers in the soil. It also shows that ammonium-N in these soils is very unstable and once generated, is oxidised into nitrate-N. This indicates that the system is predominantly nitrifying. The decrease in NO_3^--N and NH_4^+-N during mineralization could be explained by maize N uptake and losses through either leaching or runoff or denitrification. Loss of soil N, outside what is withdrawn by growing plants, is primarily due to leaching since NO_3^--N compounds, are highly soluble in water and very little is adsorbed by soil colloids. Ammonium, on the other hand, is rather firmly adsorbed by the soil colloids and, in consequence, is only little exposed to leaching. Therefore, it represents a safe reserve from which the lost nitrate supply can be, and is, quickly replenished.

Also a further losses of N can result from the reduction of nitrate to nitrite and then to free N and ammonia which is caused by various bacteria under anaerobic conditions. These bacteria simply obtain the oxygen they need in order to utilise carbon compounds as a source of energy from the nitrate, which results in the reduction of the latter. The elemental N is lost as N_2 gas in the air.

This process (denitrification) is favoured by poor soil aeration that may be caused by high water content or by soil compaction. In this study there was high water contents due to seasonal high rainfall favouring the possibility of N loss through denitrification.

These results confirm earlier findings that nitrate-N is the dominant form of mineral N which is readily available and easily removed from the agricultural soil as compared with ammonium-N (Alexander, 1977; Tisdale *et al.*, 1990; Nduwayezu, 1997; Fasuluku, 1998).

The results of the present study are in contrast with those of Yobterik *et al.*, (1994), Lavelle *et al.*, (1994) and Boxman *et al.*, (1998) who observed that more than 70% of the system was dominated by ammonification activity.

The observed decline of nitrate-N levels from the second week towards week 8 is large due to crop uptake but may be also attributed to some leaching. Nitrate-N patterns are highly influenced by rainfall pattern (Presscot, 1997). During the first week there was little rain and rainfall increase from the second week may have led to the leaching of the initially high concentrations of nitrate-N. Loss of nitrate-N from topsoil horizon through leaching has been widely reported (Alexander, 1977; Tisdale *et al.*, 1990; Nair, 1993; Nduwayezu, 1997;Young, 1997; Fasuluku, 1998).

5.2. Effect of mulching rates and time of application on plant height, yield and nutrient uptake by above ground components

5.2.1 Maize plant height

Maize plant height in this study was not significantly affected by mulching rates or time of application. The values are also lower than those reported by Fasuluku (1998) in a relay intercropping experiment of *Sesbania sesban* treated with prunnings and fertilizers. According to Chirwa *et al.*, (1994) treatments fertilized with *Leucaena leucocephala* and *Flemingia* prunings increased maize height, dry matter and grain yield with increasing fertilizers rates. In fact, fertilized alleys produced twice as much grain yieldd as unfertilized alleys, suggesting that prunings alone were not an adequate source of nutrients. The results of the present study are in agreement with this observation. The lower values observed in maize height may be due to the fact that the experiment was not fertilized. Similar results were obtained by Powell and Webb(1974) in alley cropping trials with Cassia, where by application of fertilizer at the full recommended dose plus prunings produced the highest maize yields and growth as compared to unfertilized plots (control plots).

Lal (1989) concluded that high yields could not be sustained with prunings alone and that supplementation by mineral fertilizers was necessary.

According to London (1991), levels of total soil N between 0.1 – 0.2% as well as available P below 4 ppm is considered as low for maize production. The results for routine analysis (Table 2) show that soils at SUA Farm fall under this category, thus they need supplementation by inorganic fertilizers. The highly significant response of maize to P fertilization observed by Fasuluku (1998) and Chingonikaya (1999), indicate that P is a limiting factor for maize production in Morogoro. Sanchez and Palm (1996b) observed that unlike N , P fertility cannot be replenished by agroforestry alone.

5.2.2 Maize grain and stover yield

Mulching rates had significant effects on maize yield in terms of grain and stover. The mulching effect was more pronounced on the plots with higher leaf dosages. The results of the present study are also in agreement with studies conducted by Tilander (1993) which revealed that, higher leaf dosages gave higher grain yield than did lower dosages. The degree of yield enhancement was positively related to the amount of leaves added.

Mulching dates had no significant effect on maize grain and stover yield. However, plots that received mulch at sowing time resulted in higher maize yield. This is in agreement with Mafongoya *et al.*, (1996 a) who suggested that, the time of pruning application could be important management options to increase the rate of N recovery from multipurpose-tree prunings that are used as a source of N to crops.

Time of pruning application significantly affected N uptake, N recovery and grain yield of maize. Applying prunings of Calliandra at the time of maize sowing was significantly better in terms of crop N uptake and recovery, and grain yield than applying them 4 weeks after sowing. However, with leucaena, the time of prunings application had no significant effects on N recovery. Split application of available prunings at 0 and 2 or 4 weeks after sowing reduced N recovery and uptake in some cases, in comparison with one-time application of entire amounts of prunings at sowing. The strong positive correlation between N uptake by the maize crop and the crops subsequent growth and yield performance in the present study are in conformity with the patterns between nutrient uptake by the crop plants and their subsequent productivity reported by Nduwayezu (1997).

Application of 10 t ha^{-1} mulch just before sowing resulted in the highest maize grain and stover yield followed by application of mulch 2 weeks after sowing. Application of mulch 6 weeks after maize sowing resulted in the lowest grain and stover yield, suggesting that this amount of mulch applied was not utilised by the crop because the critical period of high nutrients demand was over. These results are in agreement with the results reported by Lehman *et al.*, (1995) that the critical period of maize is 4 – 6 weeks. However, this period differs with maize variety and environmental conditions. Maize crop for the present study was Kito variety of which its period of critical nutrient demand may be even shorter than 4 – 6 weeks.

The lower yielding value of maize grain influenced by mulching rates and time of application i.e 1.3 –2.5 t ha^{-1} and 1.98 – 1.63 t ha^{-1} respectively, may probably be caused by the lower N and P supply from mulch only. As reported earlier, prunings alone cannot sustain high crop yields. The N and P contents in maize plant leaves at early stages of growth can be used to predict the yield of the respective crop. For example, P is responsible for meristem development which influences the number of kernels to be initiated (Ussiri, 1992).

Tilander (1993) also observed that, the year by year statistical analysis of the three modes differing in application time suggested that timing influenced yield. Plots receiving Azadirachta leaves either at sowing or 4 - 6 weeks after sowing gave a higher response than plots receiving Azadirachta with straw or Albizia with straw.

5.2.3 Maize leaf N and P content and biomass 42 DAS

The results of the present study show that leaf N and P content were significantly influenced by mulching rates and time of application. The highest mulch doses resulted in the highest N and P contents. Maize plant leaf P in this study 42 DAS is less than that reported by Okalebo (1977) who observed that at 27 to 58 DAS, P uptake in maize seedlings ranged between 1.1 and 18.7 mg $leaf^{-1}$. Usually, nutrient concentration values less than the critical levels will result in deficient conditions on growing plants (Ussiri, 1992).

However, N and P content in maize plant leaves at early growth stage depends on other factors such as initial amount of soil nutrient, rate of leaching, levels of weed control and microbial activity.

5.2.4 Nitrogen and P uptake by above ground maize parts

Mulching rates and mulching times of application influenced N and P uptake in this study. The results show that N and P uptake by maize grain and stover increased linearly with the increase in mulching rates. Mafongoya *et al.*, (1996 a) observed that split application of available prunings at 0 and 2 or 4 weeks after sowing reduced uptake in some cases, in comparison with one-time application of entire amounts of prunings at sowing (high dosage).

Phosphorus uptake by maize grain and stover regardless of the effects of mulching rates in this study is lower i.e out of the range as that reported by Okalebo (1977). The author observed that P uptake was between 12.5 – 29.3 kg P ha^{-1} and 0.6 – 19.5 kg P ha^{-1} for maize grain and stover respectively. Lower range of P uptake in this study was related to lower yields.

The application of fast decomposition manures alone improves N availability temporarily. Possibly this may benefit short duration crops such as some varieties of legumes. Improvements in the yields of long duration crops like maize, however, would depend on the effective regulation of the decomposition rates of these high quality manures. They will require a gradual but sustained nutrient release pattern that would ensure that sufficient N is available throughout the crops' developmental stages, and maximize its overall uptake. When studying the decomposition and nutrient release from leaves, twigs and roots of three cropped tree legumes in Central Togo, Lehmann *et al.*, (1995) observed that mulch from *L.leucocephala*, *G.sepium* and *A.barteri* together with 45 kg N ha^{-1} as mineral fertilizer seemed to increase nutrient uptake and maize grain yield in comparison to the control. The temporal pattern of N released was as important as the total quantity. Until the time of maximum N demand of maize (4 to 6 weeks) 86% of the N content of Gliricidia leaves had already been released compared to only 52% for Calliandra and 39% for Senna. They concluded that, this might indicate an advantage of applying Gliricidia prunings about two weeks after sowing of maize. This is in agreement with the results obtained from the present study that the interaction of mulching date and rates had significant effect on grain and stover N uptake. Application of 10 t ha^{-1} mulch 2 weeks after maize sowing favours the highest N uptake by both grain and stover (i.e 64.08 and 84.53 kg N ha^{-1} respectively). Application of the same mulch quantity just before maize sowing also gave better results. These findings are in agreement with the major aims of maintaining and improving soil fertility reported by a number of workers on organic fertilizers (Budelman, 1988; Tisdale *et al.*, 1990;Yamoah *et al.*, 1992; Mafongoya *et al.*, 1996a).

The results are also in line with the suggestions of efficiently managing nutrients and especially N in order to improve crop yields (Nair, 1993; Lehnman *et al.,* 1995).

CHAPTER 6

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

From the results obtained from this study, it can be concluded that:

- High mulch dosages resulted in the high field mineral N changes in terms of nitrate and ammonium.
- Mulching application times had no significant effect on field mineral-N, except ammonium-N at weeks 4, 12 and nitrate-N at week 12.
- The system was dominated by nitrate implying that the system was highly nitrifying.
- High mulch dosage resulted in high maize growth in height and maize yield in terms of grain and stover.
- Mulching times had no significant effect on plant height growth and yield in terms of grain and stover.
- The interactions of mulching rates and times of application had significant effect on maize plant growth, yield and nutrient uptake by above ground maize components. This interaction was high when 10 t ha^{-1} mulch was applied just before sowing or 2 weeks after maize sowing.
- The nitrogen uptake by maize plants was found to be positively correlated with the maize growth and yield.

6.2 Recommendations

From the preceeding conclusions, the following recommendations can be made:

- The application of mulch should be well timed to ensure better synchrony between nutrient release from mulch and nutrients demand by the crops. Application of 10 t ha^{-1} mulch 2 weeks after maize sowing or just before sowing should be adopted in order to optimise N uptake by crops and thus increase their yields. However, the timing should be researched more to have the real time of mulch application for different maize varieties.
- Stover contains high N and P concentrations, and should therefore not be mined from the fields.

REFERENCES.

Aihou, K; Sanginga, N; Vanlauwe, B; Lyasse, O; Dcels, J. and Merckx, R (1999). Alley cropping in the moist savanna of West Africa:

1. Restoration and maintainance of soil fertility on 'terre de barre' soils in Benin Republic. *Agroforestry Systems* 42(3): 213 - 227.

Alexander, M. (1977). *Introduction to Soil Microbiology.* 2nd Ed. John Willey 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. CAB International. pp 221.

Attan-Krah, A.A and Sumberg, J.E (1988). Studies with *G.sepium* for crop/livestock production systems in West Africa. *Agroforestry Systems* 6: 97 - 118

Bhardwaj, K.K.R. and Kanwar, K (1991). Utilization of wild *sage (Lantana camara* var aculeata) as green manure and raw material for composting. *Indian Journal of Agricultural Sciences* 61: 898 - 903

Blake, G. R. and Hartage, K. H. (1986). *Bulk density. In*: Methods of Soil Analysis part 1: Physical and Mineralogical Methods. Agronomy Monograph No 9, (2nd Ed.) pp 363-376.

Boparai, B.S; Yadvinder, S. and Sharma, B.D (1992). Effect of green manuring with *Sesbania aculeata* on physical properties of soil and on growth of wheat in rice-wheat and maize-wheat cropping systems in a semiarid region of India. *Arid Soil Research and Rehabilitation* 6: 135 - 143

Bouyoucos, G. J. (1962). Hydrometer methods improved for making particle size analysis of soils. *Agriculture Journal* 54: 464-465.

Boxman, A.W; Van der Ven, P.J.M and Roelof, J.G.M (1998). Ecosystem recovery after a decrease in nitrogen input to a Scots pine stand at Yesselsteyn, the Netherlands, *Forest Ecology Management* 101: 155 - 164

Bremner, J. M. and Mulvaney, C.S. (1982). *Total nitrogen.* Methods of soil analysis part 2.Page and Mulvaney (eds.). Amer. Soc. Agron. Madson, Wisconsin.

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

Budelman, A. (1989a). The decomposition of the leaf mulches of *Leucaena leucocephala, Gliricidia sepium* and *Flemingia macrophylla* under humid tropical conditions. *Agroforestry Systems* 7: 33 - 95

Budelman, A (1989b). Nutrient decomposition of the leaf biomass of three selected woody leguminous species. *Agroforestry Systems* 8 : 39 - 51

Buresh, R.J and Tian, G (1998). Soil improvement by trees in sub-Saharan Africa. *Agroforestry Systems* 38(1-3): 51-76

Chingonikaya, E.E. (1999). Effect of improved fallows of selected leguminous shrubs on soil fertility and maize yield at Gairo, Morogoro, Tanzania. *MSc. Dissertation*. pp 134.

Chirwa, P.W; Nair, P.K.R. and Kamara, C.S (1994). Soil moisture changes and maize yield under alley cropping with Leucaena and Flemingia in semi-arid conditions in Lusaka Zambia. *Forest Ecology and Management* 64: 231 - 244.

Constantinides, M. and Fownes, J. H. (1994). Nitrogen mineralization from leaves and litter of tropical plants: relationship to nitrogen, lignin and soluble polyphenols concentration. *Soil Biology and Biochemistry* 26: 49 - 55.

FAO (1987). Fertilizer strategies. FAO Land and Water Development Series No. 10. Food and Agriculture Organization of the United Nations, Rome pp148.

Fasuluku, S.A.J.,(1998). Effect of relay intercropping of *Sesbania sesban* on soil fertility improvement and maize and firewood production at Morogoro, Tanzania. *MSc. Dissertation,* SUA. pp108.

Fox, R. H.,Myers, R. J. K. and Vallis I. (1990). The nitrogen mineralization of legume residues in soil as influenced by their polyphenol, lignin and nitrogen contents. *Plant and Soil* 129: 251 - 259.

Gachengo, C.N., Palm, C.A., Jama, B and Othieno, C (1999). Tithonia and Senna green manures and inorganic fertilizers as phosphorus sources for maize in Western Kenya. *Agroforestry Systems* 44 (1): 21 - 36.

Henrot, J and Brussaard, L (1997). Determinants of *Flemingia congesta* and *Dactyladenia barteri* mulch decomposition in alley-cropping systems in the humid tropics. *Plant and Soil* 191: 101 -107

Hillel, D (1982). *Introduction to soil physics.* Acadeic Press inc. Harcourt Brace Javanorch Publishers New York. pp 364.

Hussain, A and Ibrahim, M. (1987). Evaluation of *S. bispinosa* leaves applied as green manure supplement to inorganic fertilizer. *Nitrogen Fixing Trees Research Report* 5: 63 - 64

IRRI (1988). Green manure in rice farming. Proceedings of a Symposium on sustainable agriculture. International Rice Research Institute, Los Banos. The Phillipines.

Ishuza, I. L. R (1987). The effect of applying maize straw to soil on the availability of soil and fertilizer N and P and on maize yield. *MSc. Dissertation* pp 96.

John, P.S., Buresh, R. J. and Prasad, R. (1992). Nitrogen contribution of cowpea green manure and residue to upland rice. *Plant and Soil* 142: 52 – 61.

Kang, B. T. and Duguma, B. (1985). Nitrogen management in alley cropping systems. In: Kang, B. T. and Van der Heide, J. (eds.) *Nitrogen Management in Farming Systems in Humid and Sub-humid Tropics.* Haren, The Netherlands; Institute of Soil Fertility.

Kang, B. T., Van Derkruijs, A. C. B. and Cooper, D. C. (1986). Alley cropping for food crop production in the humid and sub humid tropics. *In*: Kang, B. T. and Reynolds, L. (eds). Alley Farming in Humid and Sub Humid Tropics. *Proceedings International Workshop*, Ibadan, Nigeria, March 1986. Ottawa, Canada: IDRC.

Kwesiga, F.R. (1994). Rotational agroforestry systems. *Paper prepared for the ICRAF Agroforestry Training Course* in Bogor, Indonesia, May, 1993. pp 26

Lal, R. (1989). Agroforestry systems and soil surface management of tropical alfisol. Effects on soil phsical and mechanical properties. *Agroforestry Systems* 8: 197 – 215.

Lavelle, P., Dangerfield, M., Fragoso, C., Eschenbrenner, D., Lopes- Hermandez, P. B. and Brussaard, L. (1994). The relationship between soil macrofauna and tropical soil fertility: *In* :Woomer, P.L. and Swift, M. J (eds). *The biological management of tropical soil fertility* 137 -169.

Lehmann, J., Schroth, G. and Zench, 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.

London, J. R. (1991). *Booker Tropical Soil Manual.* A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics. Longman Scientific and Technical, Longman Group UK, Longman House, Burut Mill, Harlow, England. pp 474.

Mafongoya, P.L. and Nair, P.K.R. (1996). Multipurpose tree prunings as a source of Nitrogen to maize under semiarid conditions in Zimbabwe. 1.Nitrogen recovery rates in relation to pruning quality and method of application. *Agroforestry Systems* 35(1): 31 – 46.

Mafongoya , P.L; Nair, P.K.R. and Dzowela, B.H. (1996a). Multipurpose tree prunings as a source of Nitrogen to maize under semiarid conditions in Zimbabwe. 3. Interactions of prunings quality and time and method of application on nitrogen recovery by maize in two soil types. *Agroforestry Systems* 35(1): 57 – 70.

Mafongoya , P.L., Nair, P.K.R. and Dzowela, B.H. (1996b). Multipurpose tree prunings as a source of Nitrogen to maize under semiarid conditions in Zimbabwe. 2. Nitrogen recovery rates and crop growth as influenced by mixtures and prunings. *Agroforestry Systems* 35(1): 47 – 56.

Matthews, R.B; Holden, S.T; Volk, J. and Lungu, S. (1992). The potential of alley cropping in improvement of cultivation systems in the high rainfall areas of Zambia. II. Maize production. *Agroforestry Systems* 17: 241 - 261

Mkangwa, Z.C (1983). Effects of inorganic fertilizers , Leucaena leaves and different rates of cattle manure on some soil properties, nutrient uptake and yield of maize (*Zea mays* L.) variety Ilonga composite. *BSc. Special project* , SUA .

Mugendi, D.N. and Nair, P.K.R (1997). Predicting the decomposition patterns of tree biomass in tropical highland microregions of Kenya. *Agroforestry Systems* 35: 187 – 201.

Nair, P. K. R. (1993). *An introduction to agroforestry*. Kluwer Academic Publisher/ICRAF. pp 499.

National Academy of Sciences (NAS) (1979). *Leucaena*. Promising forage and tree crop for the tropics. NAS, Washington, D.C. pp 115.

Nduwayezu J. (1997). Control of nitrogen mineralization from decomposing *G.sepium* leaves to optimize nitrogen uptake by maize crop. *MSc. Dissertation*. SUA pp 82.

Nikokwe, C.A (1992). Decomposition of Crotalaria and Leucaena green manures and their nutrient release pattern. *MSc. Dissertation*. SUA, Morogoro.

Njuki, M.W. (1998). Root distribution and below ground interactions in alley cropping of *Calliandra calothyrsus* and *L. leucocephala* with maize at Embu, Kenya. *MSc. Dissertation*. SUA pp 87.

Nogueria, F.D; Guimaraes, P.T.G and Faria, J.F. (1989). Gypsum rock phosphate and green manure on garlic growth in alluvial soil. *Revista Brasileira de Ciencia do Solo* (Brazil) vol. 13: 349 – 354.

Nyamai, D.O., Gathumbi, S., Juma, P. and Njuguna, J.C. (1996). Hedgerow intercropping technology for soil fertility improvement and management. A sythesis of various studies conducted in Kenya. In: Mugah, J.O. (ed.). *People and intuitional participation in agroforestry for sustainable development.* First Kenya Agroforestry Conference 25 – 29 March, 1996. Pp 231 – 258.

Oglesby, A. K. and Fownes, J. H. (1992). Effect of chemical composition on nitrogen mineralization from green manures of seven tropical leguminous trees. *Plant and Soil* 143: 127-132.

Okalebo, J.R. (1977). Maize response to three high analysis phosphate fertilizer in some soils of East Africa. II. Uptake and removal of phosphorus. *East African Agriculture and Forestry Journal* 43: 84 – 95.

Palada, M.C.; Kang, B.T and Claassen, S.L (1992). Effect of alley cropping with Leucaena on yield of vegetable crops. *Agroforestry Systems* 19: 139 – 147.

Palm, D; Weerakoon, M.A.P; De Silva and Rosswal, T (1988). Nitrogen mineralization of *S. sesban* used as green manure of lowland rice in Sri Lanka. ***Plant and Soil*** 108: 201 – 209.

Palm, C. A. and Sanchez, P.A. (1991). Nitrogen release from the leaves of some tropical legumes as affected by their lignin and polyphenolic contents. *Soil Biology and Biochemistry*. 23: (83) 77-88.

Population Census (1988). *Population Census of Tanzania* 1988. RPOT-Morogoro, Tanzania.

Powell, R.D and Webb, J.R (1974). Effects of high rates of fertilizer N, P and K on corn leaf nutrient concentrations. *Communications in Soil Science and Plant Analysis* 5 : 93 – 104.

Prescott, C.E. (1997). Effect of clear-cutting and alternative silvicultural systems on rates of decomposition and nitrogen mineralization in a coastal montane coniferous forest. *Forest Ecology and Management* 95: 253 - 260.

Rao, M. R., Kamara, C S. Kwesiga, F. and Bahiru Duguma. (1990). Methodological issues for research on improved fallow. "*Agroforestry Research for Development*" ICRAF. 11th-29th October 1993. pp 5.

Recous, S., Mary, B. and Furie, G. (1990). Microbial immobilization of ammonium and nitrate in cultivated soils. *Soil biology and Biochemistry* 22: 913 – 922.

Sanchez, P. A. and Palm, C. A. (1996 a). Nutrient cycling and agroforestry in Africa. *Unasylva 185, Vol.* 47: 24-28.

Sachez, P. and Palm, C. (1996 b). Nitrogen and phosphorus in African soils. *Agroforestry Today* 8(4): 14 – 16.

Sanginga, N., Mulongay, K. and Ayanaba, A. 1989. Nitrogen fixation of field inoculated *Leucaena leucocephala* (Lan) de wit estimated by the ^{15}N and different methods. *Plant and Soil.* 117:267-274.

Sierra, J. (1992). Relationship between mineral-N and N-mineralization rate in disturbed and undisturbed soil samples incubated under field and laboratory conditions. *Australian Journal of Soil Research* 30: 477 – 492.

Statistical Analysis Systems Institute Inc. (1991). SAS/STAT. Guide for Personal Computers. Version 8 Ed. SAS Inc. Cary, North Calorina.

Szott, L.T and Kass, D.C.L (1993). Fertilizers in agroforestry systems. *Agroforestry Systems* 23(2 &3) : 157-176

Temu, A.M.C (1986). Effect of *Crotalaria zanziberica* as a previous crop on grain yield of maize. *Uyole Agricultural Bulletin* 1: 7 - 14

Tian, G., Kang, B.T and Brussard, L. (1992 a). Biological effects of plant residues with contrasting chemical compositions under humid Tropical conditions: Decomposition and nutrient release. *Soil Biology and Biochemistry* 24(10): 1051 – 1060.

Tian, G., Kang, B.T and Brussard, L. (1992 b). Biological effects of plant residues with contrasting chemical compositions under humid Tropical conditions: Effects on soil fauna. *Soil Biology and Biochemistry* 25(6): 731 – 737.

Tian, G., Kang, B. T. and Brussard, L. (1993). Effect of chemical composition on Nitrogen, Calcium and Magnesium release during incubation of leaves from selected agroforestry and fallow plant species. *Biogeochemistry* 16: 103-119.

Tilander Y. (1993). Effects of mulching with *Azadirachta indica* and *Albizia lebbeck* leaves on the yield of sorghum under semi-arid conditions in Burkina-Faso. *Agroforestry Systems* 24(3): 277 - 293.

Tisdale, S.L., Nelson, W.L. and Beaton, J.D. (1990). *Soil fertility and fertilizers* 4th ed. Macmillan Publishing Company, New York pp 754.

Urio, A. P., and Singh, B. R., 1974. *Practical Soil Chemistry Manual.* Department of Soil Science and agricultural Chemistry. University of Dar es Salaam - Morogoro. pp 59.

Ussiri, D.A. N. (1992). Phosphorus status and availability in some benchmark soils of Morogoro district. *MSc. Agriculture dissertation*, SUA. pp 99.

Vanlauwe, B., Vanlangenhove, G., Mercks, R and Vlassk, K (1995). Impact of rainfall regime on the decomposition of leaf litter with contrasting quality under sub-humid tropical conditions. *Biology and Fertility of Soils* 20: 8 – 16.

Wangari, N. (1995). Decomposition and nutrient release patterns of *S. sesban* and *L. camara* and the use of Lantana as a green manure source in vegetable production. MSc. Dissertation. SUA. pp 90.

Yamoah, C.F., Burleigh, J.R. and Eylands, V.J. (1992). Correction of acid infertility in Rwandan oxisols with lime from an indigenous source for sustainable cropping. *Experimental Agriculture* 28: 417 – 424.

Yobterik, A. C., Timmer, V. R and Gordon, A. A (1994). Screening tree mulches for corn growth: a combined soil test, pot trial and plant analysis approach. *Agroforesty Systems* 25: 153 – 166.

Young, A. (1997). *Agroforestry for soil management*. CAB International, Wallingford, UK pp 320.

LIST OF APPENDICES

Appendix 1: Effect of *G. sepium* mulching rates on field mineral nitrogen at SUA Farm, Morogoro, Tanzania.

	Weeks after maize sowing							
Rates	0	1	2	4	6	8	10	12
				Nitrate-N				
M_1	70.0ba[1]	74.67a	117.6c	82.12a	60.04d	59.19d	60.6c	60.9c
	(2.33)	(2.41)	(3.23)	(2.88)	(1.69)	(0.15)	(0.32)	(0.34)
M_2	65.33b	77.0a	123.2bc	79.8a	71.24c	72.93c	72.44c	73.82b
	(2.33)	(2.04)	(3.23)	(3.41)	(1.06)	(0.32)	(0.68)	(1.29)
M_3	63.0b	77.0a	134.57ba	86.33a	75.6b	79.64b	84.63a	82.79a
	(1.67)	(2.31)	(4.33)	(1.93)	(1.41)	(1.02)	(0.85)	(1.31)
M_4	74.66a	72.33a	138.13a	101.73a	87.73a	86.78a	86.06a	81.3a
	(2.33)	(2.33)	(4.74)	(1.69)	(2.42)	(1.02)	(1.12)	(1.16)
				Ammonium-N				
M_1	29.87c	74.29a	52.19a	28.71b	28.76b	29.66b	31.86c	31.34c
	(0.63)	(1.83)	(4.38)	(1.85)	(0.35)	(0.29)	(0.21)	(0.34)
M_2	46.25cb	65.32a	47.95a	32.05b	29.45b	31.55b	37.17b	35.92b
	(3.12)	(0.92)	(4.82)	(2.10)	(1.04)	(0.97)	(1.06)	(1.16)
M_3	51.0b	63.2a	48.6a	41.37a	42.62a	41.59a	43.67a	41.32a
	(2.70)	(0.93)	(2.94)	(2.69)	(1.18)	(1.10)	(0.54)	(0.91)
M_4	77.52a	54.56a	50.1a	43.14a	43.36a	43.01a	45.42a	43.57a
	(1.85)	(2.55)	(2.08)	(1.48)	(1.24)	(0.26)	(0.71)	(0.50)

M_1=0 t ha^{-1} mulch, M_2= 2.5 t ha^{-1} mulch, M_3= 5 t ha^{-1} mulch and M_4= 10 t ha^{-1} mulch.

[1] Means that are followed by the same letter in a column are not significantly different.

In parentheses are standard errors of the mean of three replicates

Appendix 2: Effect of *G. sepium* mulching dates on field mineral nitrogen at SUA Farm, Morogoro, Tanzania.

	Weeks after maize sowing							
Dates	0	1	2	4	6	8	10	12
				Nitrate-N				
T_1	68.6a[1]	75.25a	128.38a	90.77a	73.97a	75.48a	76.16ba	72.46b
	(1.61)	(2.30)	(3.030	(6.30)	(3.57)	(3.20)	(3.21)	(2.50)
T_2	72.33a	74.67a	117.6a	84.23a	73.27a	74.14a	74.48b	74.24ba
	(2.33)	(3.41)	(3.23)	(4.50)	(3.40)	(3.32)	(2.93)	(2.79)
T_3	72.33a	74.67a	117.6a	82.12a	73.73a	75.43a	76.85a	74.43ba
	(2.33)	(3.41)	(3.23)	(2.88)	(2.97)	(3.26)	(3.38)	(2.96)
T_4	72.33a	74.67a	117.6a	82.12a	60.04a	73.49a	75.85ba	77.68a
	(2.33)	(3.41)	(3.23)	(2.88)	(1.69)	(2.77)	(3.15)	(2.84)
				Ammonium-N				
T_1	51.56a	64.34a	49.7a	39.09a	36.18a	37.67a	38.11a	37.52ba
	(5.60)	(5.26)	(2.20)	(2.17)	(2.45)	(1.97)	(1.77)	(1.66)
T_2	29.87b	74.29a	52.19a	33.54b	37.19a	36.89a	40.1a	40.06a
	(0.63)	(1.83)	(4.38)	(2.13)	(2.55)	(1.83)	(1.58)	(1.57)
T_3	29.87b	74.29a	52.19a	28.71b	34.79a	46.4a	39.95a	36.99b
	(0.63)	(1.83)	(4.38)	(1.85)	(1.64)	(1.86)	(1.95)	(1.33)
T_4	29.0b	74.29a	52.19a	28.78b	28.76b	36.62a	39.95a	37.57ba
	(0.63)	(1.83)	(4.38)	(1.85)	(0.35)	(2.01)	(3.15)	(1.79)

T_1=Just before maize sowing, T_2= 2 weeks after sowing, T_3= 4 weeks after sowing and T_4= 6 weeks after sowing. [1] as defined in appendix 1

Appendix 3:Effect of *G. sepium* mulching rates and dates on total field mineral – N at SUA Farm, Morogoro, Tanzania.

	Weeks after maize sowing							
	0	1	2	4	6	8	10	12
Rates								
M_1 [1]	102.73b[2]	148.96a	169.79a	110.82b	88.80d	88.85d	92.46c	92.23c
	(2.88)	(6.62)	(7.6)	(8.59)	(1.78)	(0.33)	(0.43)	(0.51)
M_2	111.58b	142.32a	171.15a	111.85b	100.7c	104.48c	109.61b	109.74b
	(2.31)	(5.96)	(6.47)	(2.80)	(1.87)	(1.00)	(1.36)	(1.65)
M_3	116.74b	140.2a	183.17a	127.71ba	118.2b	121.23b	128.30a	124.11a
	(3.69)	(3.27)	(1.98)	(9.55)	(2.02)	(1.4)	(0.96)	(1.16)
M_4	152.18a	126.89a	188.21a	144.87a	131.09a	129.78a	131.06a	124.78a
	(8.64)	(4.53)	(9.86)	(8.49)	(3.12)	(1.04)	(1.39)	(1.16)
Dates								
T_1	120.81a	139.59a	178.08a	129.86a	110.15a	112.64a	114.27a	109.98b
	(6.06)	(6.97)	(3.83)	(7.6)	(5.71)	(5.00)	(4.44)	(3.93)
T_2	102.73a	148.96a	169.79a	117.76a	110.45a	111.03a	114.58a	114.30ba
	(2.88)	(6.62)	(7.6)	(5.11)	(5.58)	(4.98)	(5.23)	(4.26)
T_3	102.73a	148.96a	169.79a	110.82a	108.52a	110.56a	116.80a	111.43ba
	(2.88)	(6.62)	(7.6)	(8.59)	(4.32)	(4.80)	(5.23)	(4.25)
T_4	102.73a	148.96a	169.79a	110.82a	88.80b	110.11a	115.78a	115.16a
	(2.88)	(6.62)	(7.6)	(8.59)	(1.78)	(4.58)	(4.71)	(4.25)

[1] and [2] as defined in appendix 1 and 2.

Appendix 4. The effect of *G. sepium* mulching rates and dates on maize plant growth and yield at SUA Farm, Morogoro, Tanzania.

	Height (cm)	Grain (t ha^{-1})	Stover (t ha^{-1})
Mulching rate			
M_1 [1]	94.3a[2] (0.043)	1.313c (0.169)	3.43b (0.43)
M_2	91.9a (0.023)	1.50c (0.163)	3.69b (0.41)
M_3	96.5a (0.042)	2.08b (0.155)	3.92b (0.349)
M_4	99.9a (0.06)	2.52a (0.2)	5.12a (0.45)
Mulching dates			
T_1	105a (0.047)	1.98a (0.29)	3.88a (0.61)
T_2	97.8a (0.035)	1.91a (0.23)	4.10a (0.54)
T_3	94.0a (0.044)	1.90a (0.19)	4.23a (0.41)
T_4	85.7a (0.03)	1.63a (0.14)	4.08a (0.29)

[1] and [2] as defined in appendices 1 and 2 respectively

Appendix 5: The effect of *G. sepium* mulching rates and dates on maize growth and yield at SUA Farm, Morogoro, Tanzania.

Date	Rate	Height (cm)	Grain (t ha^{-1})	Stover
T_1[1]	M_1[1]	91.2(0.088)[2]	1.45(0.47)	2.51(0.44)
	M_2	95.9(0.042)	1.36(0.60)	2.10(0.42)
	M_3	103.0(0.047)	2.08(0.33)	4.46(0.54)
	M_4	120.2(0.096)	3.02(0.58)	5.98(0.93)
T_2	M_1	88.5(0.024)	1.05(0.26)	3.24(1.25)
	M_2	93.0(0.036)	1.75(0.14)	3.93(0.81)
	M_3	95.0(0.036)	2.18(0.25)	3.02(0.45)
	M_4	114.6(0.061)	2.67(0.58)	6.14(0.60)
T_3	M_1	1.034(0.150)	1.43(0.45)	3.93(0.83)
	M_2	91.6(0.070)	1.37(0.27)	3.34(0.08)
	M_3	98.7(0.033)	2.47(0.15)	4.87(0.98)
	M_4	82.1(0.027)	2.32(0.06)	4.80(0.75)
T_4	M_1	94.0(0.064)	1.33(0.29)	4.02(0.45)
	M_2	87.0(0.036)	1.56(0.25)	5.39(0.34)
	M_3	79.3(0.076)	1.58(0.36)	3.35(0.03)
	M_4	82.5(0.057)	2.05(0.13)	3.56(0.65)

[1] and [2] as defined in appendix 1 and 2

Appendix 6: Effect of *G. sepium* mulching rates and dates on maize plant leaf N and P content and biomass at 42 DAS at SUA Farm, Morogoro, Tanzania.

	Leaf biomass (g leaf^{1})	Nutrient content (mg leaf^{1})		Nutrient conc^{n} (%)	
Mulching Rates		N	P	N	P
M_1[1]	1.82a[2] (0.21)	4.04b	0.29a	2.22b(0.14)	0.16a(0.02)
M_2	2.01a (0.19)	5.07ba	0.34a	2.51ba(0.16)	0.17a(0.01)
M_3	2.20a (0.21)	6.14 a	0.42a	2.79a(0.17)	0.19a(0.01)
M_4	1.91a (0.21)	5.54a	0.38a	2.90a(0.15)	0.20a(0.02)
Mulching dates					
T_1[1]	2.33a (0.22)	6.78a	0.47 b	2.91a(0.13)	0.20b(0.01)
T_2	2.10a (0.17)	5.63a	0.38 b	2.68a(0.06)	0.18b(0.02)
T_3	2.04a (0.22)	5.51a	0.45a	2.70a(0.16)	0.22a(0.02)
T_4	1.47a (0.21)	3.16	0.22b	2.15a(0.28)	0.15b(0.01)

[1] and [2] As defined in appendices 1 and 2

Appendix 7: Effect of interaction of *G. sepium* mulching rates and dates on maize plant leaf N and P content and biomass at SUA Farm, Morogoro, Tanzania.

Date	Rate	leaf biomass (g leaf^{-1})	Nutrient content (mg leaf^{-1})		Nutrient content(%)	
			N	P	N	P
T_1[1]	M_1[1]	1.845(0.165)[2]	4.06	0.30	2.20(0.03)	0.16(0.01)
	M_2	2.334(0.295)	6.49	0.47	2.78(0.12)	0.20(0.03)
	M_3	2.789(0.167)	9.45	0.06	3.39(0.30)	0.02(0.01)
	M_4	2.355(0.263)	7.70	0.49	3.27(0.03)	0.21(0.02)
T_2	M_1	1.863(0.133)	3.52	0.26	1.89(0.04)	0.14(0.02)
	M_2	1.944(0.156)	4.82	0.29	2.48(0.12)	0.15(0.00)
	M_3	2.430(0.246)	7.05	0.46	2.90(0.05)	0.19(0.03)
	M_4	2.163(0.131)	7.48	0.50	3.46(0.24)	0.23(0.02)
T_3	M_1	2.018(0.148)	5.32	0.40	2.64(0.13)	0.20(0.03)
	M_2	2.199(0.242)	5.61	0.44	2.55(0.10)	0.20(0.01)
	M_3	2.094(0.215)	5.82	0.46	2.78(0.10)	0.22(0.02)
	M_4	1.863(0.269)	5.22	0.47	2.80(0.29)	0.25(0.02)
T_4	M_1	1.559(0.389)	3.35	0.23	2.15(0.38)	0.15(0.02)
	M_2	1.558(0.071)	3.51	0.23	2.25(0.26)	0.15(0.01)
	M_3	1.488(0.197)	3.17	0.24	2.13(0.23)	0.16(0.00)
	M_4	1.277(0.166)	2.66	0.15	2.08(0.26)	0.12(0.01)

[1] and [2] as defined in appendices 1 and 2

Appendix 8: Effect of *G. sepium* mulching rates and dates on nutrient concentration in the above ground maize components at SUA Farm, Morogoro, Tanzania.

	Nutrient content(%)			
	Grain		Stover	
	N	P	N	P
Rates				
M_1[1]	1.23b[2]	0.14c	0.63c	0.032b
M_2	1.42b	0.17b	0.86c	0.035ba
M_3	1.77a	0.18b	1.16b	0.038ba
M_4	1.90a	0.20a	1.46a	0.043a
Dates				
T_1[1]	1.39a	0.16b	0.89b	0.033a
T_2	1.72a	0.19a	0.96b	0.036a
T_3	1.68a	0.18ba	0.96b	0.042a
T_4	1.55a	0.16b	1.30a	0.039a

[1] and [2] as defined in appendices 1 and 2.

Appendix 9: Effect of *G. sepium* mulching rates and dates on nutrient uptake by above ground maize components at SUA Farm, Morogoro, Tanzania.

	Nutrient uptake (kg ha^{-1})				Total uptake (kg ha^{-1})	
	Grain		Stover			
	N	P	N	P	N	P
Rates						
M_1[1]	16.67c[2](1.11)	1.80c(0.07)	24.02c(3.58)	1.14b(0.10)	41.86c	3.02c
M_2	21.92c(1.08)	2.65c(0.10)	32.92cb(3.96)	1.36b(0.10)	54.83c	4.11b
M_3	37.10b(1.84)	3.73b(0.18)	43.15b(5.52)	1.57b(0.15)	80.25b	5.30b
M_4	47.52a(1.24)	5.06a(0.17)	73.27a(5.36)	2.21a(0.23)	120.79a	7.27a
Dates						
T_1	27.48a(2.20)	3.19b(0.15)	34.40b(5.14)	1.29a(0.11)	61.88a	4.48a
T_2	56.01a(3.20)	3.59a(0.22)	39.46a(4.03)	1.46a(0.12)	95.47a	5.05a
T_3	31.92a(1.48)	3.37ba(0.18)	40.71b(6.95)	1.79a(0.25)	72.63a	5.05a
T_4	25.30a(1.24)	2.61b(0.09)	52.84a(7.5)	1.58a(0.08)	78.14a	4.19a

[1] and [2] as defined in appendices 1 and 2.

Appendix 10: Effect of interaction of *G. sepium* mulching rates and dates on nutrient uptake by maize plant components at SUA Farm, Morogoro, Tanzania.

		Nutrient uptake (kg ha^{-1}))			
		Grain		Stover	
Dates	Rates	N	P	N	P
T_1[1]	M_1[1]	13.87(2.37)[2]	2.1(0.21)	10.54(3.66)	0.68(0.04)
	M_2	16.82(1.98)	2.11(0.11)	16.65(3.53)	0.72(0.11)
	M_3	36.89(3.40)	3.21(0.44)	44.6(2.08)	1.72(0.17)
	M_4	47.9(3.07)	5.76(0.06)	79.53(4.19)	1.97(0.40)
T_2	M_1	12.0(0.65)	1.36(0.14)	23.43(3.30)	1.13(0.26)
	M_2	26.13(3.63)	3.6(0.23)	29.34(3.31)	1.46(0.07)
	M_3	39.68(6.99)	4.34(0.24)	30.3(1.4)	0.94(0.22)
	M_4	64.08(4.36)	5.82(0.32)	84.53(3.79)	2.43(0.03)
T_3	M_1	20.69(1.20)	2.02(0.18)	23.84(10.09)	1.1(0.19)
	M_2	20.78(1.60)	2.26(0.1)	25.78(4.87)	0.93(0.33)
	M_3	46.68(3.60)	4.81(0.43)	53.41(16.39)	2.39(0.08)
	M_4	44.6(3.71)	4.87(0.12)	66.08(12.62)	2.86(0.42)
T_4	M_1	18.62(2.69)	1.88(0.07)	30.95(8.6)	1.54(0.02)
	M_2	22.57(2.55)	2.51(0.05)	60.37(16.45)	2.16(0.07)
	M_3	25.44(1.92)	2.56(0.12)	50.81(10.34)	1.16(0.26)
	M_4	35.88(1.66)	3.59(0.32)	63.13(7.1)	1.46(0.08)

[1] and [2] as defined in appendices 1 and 2.

Appendix 11: Probability of F-ratio for significant differences on the effect of *G. sepium* mulching rates and dates on maize growth and yield, N and P uptakc and maize leaf N and P content and biomass 42 DAS at SUA Farm, Morogoro, Tanzania.

Source	Block	Dates	Block * Dates	Rates	Dates * Rates
Height	0.591	0.064	0.127	0.343	0.008
Maize grain	0.0002	0.253	0.033	0.0001	0.216
Stover	0.009	0.886	0.100	0.003	0.002
Grain-N	0.301	0.013	0.078	0.0001	0.079
Stover-N	0.003	0.002	0.010	0.0001	0.916
TN	0.0472	0.0008	0.0007	0.0001	0.3574
Grain-P	0.019	0.003	0.774	0.0001	0.078
Stover-P	0.075	0.183	0.726	0.031	0.037
TP	0.0226	0.0129	0.837	0.0001	0.079
Leaf biomass	0.026	0.121	0.762	0.101	0.719
Leaf-N	0.358	0.061	0.380	0.002	0.800
Leaf-P	0.832	0.0004	0.570	0.080	0.524