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The Second National Agroforestry and Environment Workshop: Partnerships and Linkages for Greater Impact in Agroforestry and Environmental Awareness

Editors

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FOREWORD

It is part of that trio which constitute the basic human needs namely; food, clothing and shelter. Napoleon aptly put it – an army walks on its stomach. The Nyankole have a saying that hunger fears no one even if impeccably dressed! This is however, part of the story. Food has to be produced. Thus the subject of food production, processing, and availability; is of arresting significance. In that regard, our soils and technology development among other things play a pivotal role.

Yet the bastion of our very existence, fertile top soil is being destroyed at alarming rates. This is mainly by erosion, continuous cropping without nutrient replenishment, and general poor husbandry. In central Tanzania, despite level topography in most parts, losses are estimated at 9 tones per hectare. Such losses are not confined to Tanzania. Alarming losses have been reported in the Ethiopian Highlands, Queensland – Australia, and in the United States. Such losses are well above the amounts which natural processes can crate annually. In most countries the top soil layer that is normally the most fertile, is hardly 30 cm deep and yet, it is this layer that feeds and clads the world. However, faced by human pressures on their fringes such as overpopulation overgrazing, deforestation, etc. Virtually all of Tanzania's marginal areas are expanding. Examples are stretches near Lake Eyasi, Hedaru, Ilkurot, Kisongo, and many more.

We as informed sources are not opposed to the science driven use of mineral fertilizers, however, it is regrettable to observe that fertilizer use has served as the hiding ground for faulty husbandry. Unsustainable yield increases have always been taken as success yardsticks. Also challenging, is the cost of fertilizers which even when subsidized is viewed high by resource poor farmers.

Agroforestry provides a promising alternative and or a supplement that can be used to go over these problems. It is gratifying to observe that the National Agroforestry Steering Committee – NASCO; has mounted a Second National Agroforestry and Environment Workshop to secure further insights and in-depth analysis of the challenges faced by our farmers, and the opportunities available, Evidently, the Workshop will not be a panacea. However, it is better to provide partial answers to pressing issues than providing complete answers to lesser problems.

The Workshop was made possible by a generous grant from the Norwegian Agency for Development Cooperation (NORAD) through support to the Management of Natural Resources Programme (MNRP) of the Ministry of Natural Resources and Tourism. On behalf of the Ministry I wish to thank NORAD for the support.

S. Pamba
PERMANENT SECRETARY,
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PREFACE

Tanzania has a population of 35 million people and a low per capita income. To reverse this situation, one of the major concerns of the Government is poverty alleviation and food security.

Agroforestry (AF) has a very important role to play in increasing food security and hence improving nutrition and alleviating poverty. This is due to the fact that AF is a dynamic, ecologically based natural resource management system that, through the integration of trees on farmlands and rangelands, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels.

Since the 1970's various institutions, organizations and farmers have been involved in research and development of AF in the country. As a result of this, various AF technologies have been developed with a great potential in improving the livelihood of farmers, particularly in the rural areas of Tanzania. These AF research and development efforts were presented during the first National AF and Environment workshop held at Sokoine University of Agriculture from 12th to 16th, October, 1993. The workshop brought together researchers, development institutions, trainers, extension workers, farmers and policy makers to exchange experiences, knowledge and document AF developments.

Recognising the need for coordination of AF research and development, and the importance and potential of AF in improving productivity and livelihoods of the local communities, the then Ministry of Agriculture (MA) and Ministry of Natural Resources and Tourism (MNRT) formed the National Agroforestry Steering Committee (NASCO) in 1993.

After the 1993 workshop, some advances have been made in research, capacity building, development and dissemination activities by different institutions, organizations, NGOs and farmers. There are also reports on adoption of AF technologies by farmers in various parts of the country. Such developments need to be shared by various partners, hence the need for a second workshop. This workshop was held from March 14 - 17, 2006 in Mbeya, Tanzania. The theme of the second workshop was: Partnerships and Linkages for Greater Impact in AF and Environmental Awareness. The main objective of the workshop was to exchange available knowledge on AF research and development activities and find ways to implement their scaling up and adoption. The specific objectives were:

(i) To review progress on AF research and development activities in Tanzania since the first workshop.
(ii) To review and strengthen mechanisms for collaboration, coordination and networking among stakeholders in AF research and development activities.
(iii) To identify research and development gaps and set priorities.
(iv) To find ways to implement strategies for scaling up AF.
(v) To review the current status of AF training in the country.

The workshop was attended by 72 participants from within and outside the country. Participants included scientists, development experts, administrators, and policy makers from Government Institutions, Non-Governmental and International Organisations. The list of participants is shown in Annex 1. The workshop was officially opened by the Minister for Natural Resources and Tourism Hon. Anthony M. Diallo (MP) and closed by the Permanent Secretary, Ministry of Agriculture, Food and Cooperatives Mr. P. M. Lymo. The opening and closing speeches are in Annexes 2 and 3 respectively.

The first three days of the workshop were dedicated to presentation of papers and a field trip to see AF activities in Mbozi District, Mbeya Region was held during the fourth day. A total of 35 papers were presented while 10 papers were exhibited as posters. There were keynote papers which covered the following topics: advances in AF research and development in Southern Africa; pathways to successful partnerships and networking: lessons from ICRAF Southern Africa and adoption; and impact of AF technologies in Southern Africa. One key note paper on training and capacity building in AF was not presented. The rest of the papers were in the following sub-themes: sustainable soil management; fodder production; wood production; adoption, impact of agroforestry/information and dissemination; and natural resources policies on AF.

All papers were reviewed by members of the technical committee of the workshop, for inclusion in these proceedings. A total of 23 papers were positively reviewed and appear in these proceedings by sub-themes. All the keynote papers were not submitted and are not included in these proceedings. The rest of the papers were rejected because they did not meet the requirements. The poster papers are not included in these proceedings.

A plenary session was held during the third day of the workshop. It focussed on AF and Environment research and development achievements, constraints, gaps in knowledge and the way forward. The workshop resolutions are summarised in Annex 4.

The workshop was organised by the Ministry of Natural Resources and Tourism and the Ministry of Agriculture, Food and Cooperatives through the National Agroforestry Steering Committee (NASCO) of which Tanzania Forestry Research Institute (TAFORI) is the secretariat. The workshop organising committee consisted of Dr. L. Nshubemuki (Chairman), Mrs. Mary Lutkamu, Dr. E. L. Ngatunga, Mr. G. Matiko, Mr. B. M. Gama and Mr. M.L. Mhando (Secretary), while the Technical Committee that reviewed all the papers consisted of Prof. S.A.O. Chamshama (Chairman), Mr. R.E. Swai, Mr. L. Mbwambo, Mr. M.A. Mndolwa, Mr. M.L. Mhando, Prof. S. Iddi, Mr. E. Sabas, Dr. E.L. Ngatunga and Mr. C. Balama (Secretary). It is with regret that Dr. Ngatunga who was a member of both the organising and technical committees passed away on 4th April 2006. May the Almighty God rest his soul in eternal peace. An obituary is attached as Annex 5.

Lastly, we are grateful to all those who contributed to the success of the workshop.

L. Nshubemuki
Chairman, Organising Committee

S.A.O. Chamshama
Chairman, Technical Committee

Morogoro, June, 2006

SUB-THEME: SUSTAINABLE SOIL MANAGEMENT

1. THE EFFECT OF *SESBANIA SESBAN* FALLOWS ON STRIGA INCIDENCES AND MAIZE YIELD IN TABORA REGION.

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Abstract

One of the major constraints to maize production in most farmers' fields in Tabora Region is nitrogen deficiency and Striga infestation. Trials were conducted on in farmer's fields in Tabora and Nzega Districts for a period of three years (1999-2001) to investigate the effect of *Sesbania sesban* improved fallow on Striga infestation and maize yield. The treatments were: Sesbania sesban, fertilized maize and control with no fertilizer and no Sesbania tree. Fertilized and unfertilized treatments were continuously cropped with maize but *Sesbania sesban* were cropped in the third year. Application of mineral fertilizer and incorporation of *Sesbania sesban* significantly ($P<0.05$) increased maize yield when compared to control. Maize grain yield (Kg ha^{-1}) was 1,013,425 and 1,345 for fertilized, unfertilized and *S. sesban* fallow. *S. sesban* fallow reduced Striga incidences considerably after cutting and incorporating the leafy biomass into plots in the third year of the trial.

Introduction

Maize (*Zea mays* L.) is an important staple cereal crop in Tabora region. One of the major constraints to maize production in most of the farmers' fields is declined soil fertility and Striga infestation (Berner *et al.,* 1995). Striga is endemic in African savannas which can cause serious devastation to maize production especially in fields of resource poor farmers (Parker, 1984; Lagoke *et al.,* 1991; Abayo *et al.,* 1997). Even under relatively good crop management conditions, about 79% reduction in crop yield has been reported from susceptible hybrid maize (Kureh *et al.,* 2000). Most of local maize cultivars are known to be susceptible to the parasitic weed Striga (Kim and Akintunde 1990). The value of total annual crop loss due to Striga in Africa has been estimated at USD 7-13 billion on cereal crops (Khan *et al.,* 2000; Yoder, 1999). It is reported that Strigas affects the livelihood of 300 million people in Africa with 17 countries seriously affected, and another 25 moderately affected (M'Boob, 1994). The effect of Striga is more pronounced on cereal crops grown under low agricultural inputs (Doggett, 1988; Parker, 1984; Parkinson; 1985, Ramaiah, 1987).

The most important Striga species infesting food crops in Africa are *Striga hermonthica* (Del.) Benth; *Striga asiatica* (L.) Kuntze, and *Striga gesnerioides* (Willd.) Vatke. Among the three dominant species, *Striga hermonthica* cause the greatest damage to cereal crops in Africa (Lagoke *et al*; 1991, M'Boob, 1989, Raynal-Rogue, 1991). The detrimental effects of this weed is well known to farmers who associate increasingly wide spread infestation with declining soil fertility (Ritchie *et al*, 1993). This is in agreement with research findings from trials in Malawi (Johnson, 1971; Ngwira and Nhlane, 1986) and other locations in Africa (Hassan *et al*; 1994). Traditional African cropping systems, which have included prolonged fallow, rotation and inter cropping were common management practices that were used in the past to improve soil fertility and keep the infestation of Striga at tolerable levels (Kureh *et al.,* 2000). However, increasing human population has resulted into intensive land use and shifting away from traditional cropping systems, which in turn has resulted in the depletion of soil fertility and increased Striga infestation (Berner *et al*; 1996).

Studies done at Tumbi Research Institute (Tanzania) and Southern Africa (Otsyina *et al*; 1994, 1995, 1997; Kwesiga and Coe, 1994) have shown that *Sesbania sesban* improved fallow can increase maize yield substantially and can give similar or even higher returns than mineral fertilizers. The N_2 – fixing tree legumes can replenish soil fertility within the shortest possible time (Kwesiga *et. al.,* 1999), although tree legumes differ in their effects on soil N availability (Barios *et al.,* 1997) and yield of subsequent maize crops (Kwesiga *et al.,* 1999).

Intercropping of maize with *S. sesban* has been reported to increase the efficiency of land use through improved productivity and reduction of *Striga hermonthica* soil seed bank. (Kwesiga and Beniest 1998), for example found that Striga densities were reduced when maize was intercropped with *S. sesban*. *S. sesban* controls Striga by stimulation suicidal germination of the striga seed (the seed germinates but then the seedlings do not find a host maize plant to attach to so they die), and it increases the soil fertility, making plants more resistant to attack. There has been some evidence of increased adoption of fast – growing, nitrogen fixing, multipurpose trees in tropical countries for land restoration and fallow improvement (Kwesiga and Beniest, 1998).

The objectives of this study were to investigate the effect of *Sesbania sesban* improved fallow on Striga incidence, soil fertility improvement and maize yield.

Materials and Methods

Trial sites

The trial was carried out in Tabora and Nzega Districts from 1999/2000 to 2001/2002 seasons. The trial was established in eight farmers' fields each in Tabora and Nzega Districts. In Tabora district the trial was carried out at Magiri and Itonjandas villages and in Nzega district at Isanzu, Shila and Mhembe villages. Selection of farmers was done on the basis of their willingness to participate after PRAs which were undertaken in the villages in 1998/99 where low soil fertility and Striga infestation were identified as major constraints to maize crop production. After the trial farmers assessment that involved discussions by using a checklist in homogenous groups was done.

Trial establishment and management

The experiment was laid out on farmer's fields in three plots each measuring 10 m x 10 m: a *Sesbania sesban*, fertilized maize and a control maize plot with no fertilizer and no trees. *S. sesban* seedlings were raised in the nursery for 45 days and transplanted in the field at a spacing of 1 m x 1 m on one-meter wide ridges.

On another plot, maize variety Kilima was planted at a spacing of 30 cm between plants on 1 m ridges. Nitrogen (N), Phosphorus (P) and Potassium (K) were applied at the rate of 100 kgN ha^{-1}, 40kg $P_2O_5ha^{-1}$ and 40 kg K_2Oha^{-1} in the form of NPK before planting. The maize was top dressed using urea one month after planting. Stalk borers were controlled by application of Thiodan dust. Tree growth parameters including root collar diameter, height, and survival were recorded at 12 and 18 months after planting.

Striga infestation was estimated by counting all Striga plants in an area of 8 m^2 within each plot at 63 days after planting. This measurement was taken on a unit area basis because it was not possible to accurately determine Striga infection on an individual maize plant. However, because weeds were judiciously controlled prior to Striga emergence, It is believed that Striga was not attached to plant hosts other than maize.

Maize was harvested when the crop was mature and dry. Plants in the net plot were cut and separated into stover (leaf + stem) and cob (grain + rachis). The weights of cobs and stover were recorded separately. A sample of 10 cobs was taken for dry matter determination. This was done by drying the sample in the oven at 70 °C to constant weight. Grain yield was recorded on oven dry weight basis after separating the grains from the rachis.

At the beginning of the third season 2001/2002 and before the rain season, the trees were cut and separated into their wood, leaf and twigs components. A sample of these components was taken, weighed and oven dried for dry matter determination. The remaining woody biomass was removed from the field and used by farmers for domestic fuel while the leaf and twig components were incorporated into the ridges before maize was sown in all plots and before the onset of rains.

All data were analyzed using Genstat 5, developed by Laws Agricultural Trust (Rothamstead Experiment Station) in the United Kingdom to compare treatment means. Before analysis raw data for Striga count were transformed to the square root to reduce the coefficient of variation often associated with the heterogeneity of distribution in the field.

Results and Discussion

Tree growth

There was marked variation in tree growth across sites. In Nzega, *Sesbania sesban* performed better at Shila than Isanzu and Mhembe village (Table 1). The differences in performance were probably due to variations in soil type and management of the fallows. Farmers in Shila village managed their fallows better than Isanzu and Mhembe by proper weeding in the first season leading to better establishment and growth of the trees there than the rest of the villages. In addition, soils at Shila were sandy loam to clay loam but those of Isanzu and Mhembe were very sandy. *S. sesban* is known to do well in relatively deep soils of medium texture and not very sandy soils (Kwesiga and Beniest, 1998).

Table 1. Growth of *Sesbania sesban* in Tabora and Nzega Districts after 18 months of growth

District	Village	Plant height (cm)	Root collar diameter (mm)
Tabora	Kigwa	228.8	35.4
	Magiri	320.9	42.9
Nzega	Isanzu	180.8	13.7
	Shila	317.4	35.9
	Mhembe	188.7	19.5

Striga incidences

Results showed that application of fertilizer decreased Striga incidences within seasons. *S. sesban* fallow reduced striga incidences considerably (Table 2) after cutting and incorporating the leafy biomass into plots in the third year of the trial. Similar observations were made in improved fallow studies in Zambia (Kwesiga and Coe, 1994). Reduction of Striga incidences was due to the use of green manure, which resulted to the increased of soil fertility. Nitrogen fixing legumes like cowpeas and Soya beans reduce Striga seed populations in the soil and increase cereal yields (Mbwaga *et al.,* 2000). *S. sesban* being a legume behaved in a similar manner and reduced striga and at the same time improved maize yield. This was most probably due to its high nitrogen content (2.2 - 3.0% Dry Matter) in the leaf + stem< 5 mm diameter component (Karachi and Matata, 2000).

Plots with Sebania were observed to have relatively low weed growth particularly in the second season of Sesbania growth when the tree canopy completely covered the plot. (Mbwaga *et al.,* 2000) reported that soil cover by legumes creates unfavorable conditions of optimum temperature and water for Striga germination thereby reducing production of Striga seed. *S. sesban* probably reduced striga populations in the same manner and hence the low Striga incidence in Sesbania plots in the third season when maize was cropped.

Table 2. Effects of *Sesbania sesban* and mineral fertilizer on Striga incidences in Tabora and Nzega Districts 1999/2000 seasons

Treatment	Striga count/8m²			
	1999/2000	2000/2001	2001/2002	Mean
Fertilized	2.6	3.9	4.8	3.8
Unfertilized	5.2	6.2	11.1	7.5
Sesbania sesban	*	*	0.8	0.8
SED	0.78	0.95	3.2	
CV (%)	48	59	142	

Mean Striga counts taken from a net plot 8-m² and transformed to square root.

* Sesbania fallow

Maize yield

Application of mineral fertilizer and incorporation of *S. sesban* leafy biomass significantly ($p<0.05$) increased maize grain yield as compared with the control (Table 3). Application of mineral fertilizer and Sesbania organic matter provided substantial amounts of nitrogen, which increased maize yield.

Table 3: Effect of *Sesbania sesban* and inorganic fertilizer on maize yield across Striga infested farmers' fields in Tabora District 1999/2000 – 2001/2002 seasons

Treatment	Maize grain yield ($kgha^{-1}$)			
	1999/2000	2000/2001	2001/2002	Mean
Fertilized	920	1080	1040	1013
Unfertilized	480	470	325	425
*Sesbania sesban***	*	*	1345	1345
SED	60	230	253	
CV (%)			56	

* Sesbania fallow

** Sesbania biomass incorporated = 3.29 t ha^{-1}

Farmers' assessment

Farmers indicated their interest in *S. sesban* as a fallow species and were willing to expand their fields after realizing the benefits in terms of maize yield increase. However, the farmers indicated their desire of having additional fallow species as drought, termites and nematodes affected Sesbania trees at some sites.

Conclusion and Recommendations

Results obtained confirmed earlier findings that *S. sesban* has the potential to improve soil fertility and maize production in Tabora. The study on the effect of this tree on reduction of Striga incidences has clearly demonstrated that application of S*esbania* manure can reduce Striga infestation on sandy soils of Tabora. It is therefore recommended that the technology be disseminated to more farmers in Tabora and else where with similar conditions.

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2. VECTOR ANALYSIS OF NUTRIENT INTERACTIONS IN MAIZE-BASE ROTATIONAL WOODLOT CROPPING SYSTEMS AT MKUNDI, MOROGORO, TANZANIA.

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Abstract

Earlier studies have shown that soil nutrient enrichment by trees during the fallow phase of rotational woodlot systems may be inadequate to improve crop yields due to short fallow period. This further implies that nutrient requirement for crops may be met by nutrients released from slash applied as green manure after wood harvests. Thus litter quality of tree fallow species may greatly influence soil nutrients availability to crops through their differential decomposition and nutrients release patterns. It was hypothesized that the type of fallow species would influence nutrient dynamics and maize yields after clearing the woodlot. Effects of tree species and fertilization on available nitrogen, maize yields and nutrient uptake in a split-plot experiment using Randomized Complete Block Design (RCBD) in order to compare species effects against fertilizer effects. Similarly, the RCBD experiment was adopted to assess species effects on leaf decomposition and nutrient release. Leaves of *Gliricidia sepium, Leucaena diversifolia* and *Acacia polyacantha* decomposed faster and released more N than leaves of Australian *Acacia* species which immobilized N; limiting its availability to maize. Mineralization of P and K occurred in all tree fallows with K exhibiting the highest release compared to other elements probably because it is neither structurally bound in plant tissues nor readily retranslocated prior to leaf senescence. Vector analysis depicted synergistic interactions between N and P on maize growth with N being the most limiting nutrient. This synergism was closely related to patterns of nutrients release from the decomposing leaf biomass. Maize growth responses in exotic *Acacia* fallows were mainly driven by P supply due to N immobilization while in other tree fallows both N and P were responsible for improving maize yields because of nutrient mineralization during green manure decompositions. Consequently, maize yields were highest after application of *G. sepium, L. diversifolia* and *A. polyacantha* fallows; ranging from 3.1 – 3.4 Mg ha^{-1} in the first cropping season. These yields were equivalent to full rates of N and P fertilizers. Maize yields and nutrients uptake in sequential cropping were consistent with synergisms and nutrient release patterns observed in different tree fallows. This study suggests that the type of fallow species plays a great role in influencing residual effects of rotational woodlots on maize production and *A. polyacantha* and *L. diversifolia* are suitable species.

Introduction

The rotational woodlot is an agroforestry technology developed recently to curb fuel wood deficit in semi-arid areas of Western Tanzania where intensive tobacco curing and livestock grazing have accelerated deforestation through forest clearing and high grazing pressure (Otsyina *et al.,* 1996; Ramadhani *et al.,* 2002; Nyadzi *et al.,* 2003a). The system consists of three interrelated phases of trees and crops grown sequentially in rotations of 4-5 years on the same land. The first phase is the establishment phase in which fast growing multipurpose trees are intercropped with crops for the first 2-3 years until canopy closure. This is followed by a tree-fallow phase in which trees are allowed to grow for another 2-4 years to produce wood and replenish soil fertility. The final phase is a post-fallow period in which trees are harvested and crops are either intercropped with coppicing tree stumps that later produce wood or grown with stumps uprooted, in the case of non-sprouting species. A fresh cycle starts after 2-3 years of sequential cropping (Otsyina *et al.,* 1996; Nyadzi *et al.,* 2003a).

Mechanisms of soil nutrients enrichments by trees in agroforestry systems have been reviewed extensively (Rao *et al.,* 1997; Buresh and Tian, 1998). These include biological nitrogen fixations, retrieval of nutrients from deep soil horizons (i.e. nutrients pumping) and their release on top soils through litter and root turnover, building of soil organic matter and reduction in nutrient losses from processes such as leaching and erosion. However, the ability of tree fallows to replenish soil nutrients and their impacts on site productivity is a function of many factors including type of fallow species, the length of the fallow period, types of management practices and climatic conditions (Rao *et al.,* 1997). For example, soil nutrient decline in young tropical plantations were attributed to nutrient immobilization in biomass of fast growing tree species at higher rates than replenishment through natural processes (Fölster and Khanna, 1997). This condition may limit ability of rotational woodlot to improve soil fertility due to its inherently short rotations. In a 4-year old rotational woodlot system in semi-arid areas of Tanzania, Nyadzi *et al*. (2003b) associated the small difference in soil inorganic nitrogen among tree fallow species with the short fallow period, proposing that the effects are likely to increase in the future. This implies that nutrient requirement for maize in post fallow phase may be met by nutrients released from slash applied as green manure. Consequently, the quality of foliage biomass retained on farm at clear felling will greatly influence availability of soil nutrients to crops as it affects the amounts and patterns of nutrients released during decomposition.

Theoretically, high quality litters decompose faster and release more nutrients than poor quality litters, which are often characterized by initial slow decomposition accompanied by immobilization of nutrients, particularly nitrogen (Zaharah and Bah, 1999; Mafongoya *et al.,* 1998). Currently, Australian *Acacia* tree species which have high wood production potential have poor litter quality (Nyadzi *et al.,* 2003a); implying limited ability to release nutrients and subsequently improve crop production. Ideally, appropriate tree species for sustaining crop productions in a rotational woodlot system should have high capacity to recycle nutrients during the fallow phase and improve their availability to crops in the post - fallow phase. Apart from soil inorganic dynamics (Nyadzi *et al.,* 2003a, 2003b) little information is available regarding the impacts of the tree fallow species and green manure on availability of soil nutrients to crops under this system. This information will contribute to the understanding of mechanisms driving crops responses to tree fallows during post fallow phase. The approach in this study was to examine the interactions of soil nutrients in stimulating maize growths to tree fallows of contrasting litter qualities in a maize-based rotational woodlot system as compared with nitrogen (N) and phosphorus (P) fertilizers.

The objectives of this study was to assess: (i) tree species effects on leaf decomposition and nutrients release and (ii) tree species effects and fertilization on soil inorganic N dynamics, maize yields and nutrients uptake.

Materials and Methods

Study site

The study was carried out at Mkundi Village located at 6° 40' S, 37° 39' E, about 20 km west of Morogoro, Tanzania, at an altitude of about 475 m. The area experiences a bimodal rainfall distribution characterized by two rainfall peaks per year with a dry spell separating the short rains (October to December) from the long rains (March to May). The mean annual rainfall and air temperatures are about 800 mm and 24°C respectively. The soils are fairly young, classified as Entisols (USDA soil taxonomy) with predominantly kaolinitic clay mineralogy (Msanya, 2003). Average soil physio-chemical characteristics of the top 0-15 cm soil depth were: pH = 6.7, organic carbon = 0.61%; total nitrogen (N) = 0.083 %; extractable Bray-1 phosphorus (P) = 8.5 mg kg^{-1}, exchangeable potassium (K) = 0.44 cmol kg^{-1}, exchangeable Calcium (Ca) = 4.30 cmol kg^{-1}, and exchangeable Magnesium (Mg) = 2.10 cmol kg^{-1}, effective cation exchange capacity = 7.26 cmol kg^{-1}; bulk density = 1.35 g cm^{-3} and sandy loamy texture. For agricultural production, total N and extractable P in the soil were considered deficient while exchangeable K was marginal (Msanya *et al.,* 2003). Natural vegetation at the study site is Miombo woodland dominated by scattered tree species of

Sclerocarya birrea, Dalbergia melanoxylon, Balanites aegyptica, Dichrostachys cinerea, Acacia species and *Albizia* species (Mugasha *et al.,* 2005). The rotational woodlot experiment was established on continuously cropped farmland acquired from local farmers.

Experiment establishment and management

The experiment was established in March 1999 in a Randomized Complete Block Design (RCBD) with three replications. The woodlot consisted of *Acacia crassicarpa* A. Cunn. ex Benth.*, Acacia mangium* Willd.*, A. polyacantha* Willd.*, Gliricidia sepium* (Jaqua)*, Acacia auriculiformis* A. Cunn. ex Benth*, Leucaena diversifolia* (Schldl.) Benth*.* and natural fallow. These species were selected from a wide array of trees and shrubs with potential to provide wood and fodder in Tanzania (Karachi *et al.,* 1997; Nyadzi *et al.,* 2003a). The *Acacia* species consisted of exotic *Acacia* species from Australia (*A. crassicarpa, A. mangium, A. auriculiformis*) and indigenous species (*A. polyacantha*). Tree seedlings were raised in pots for five months in a nursery at the Sokoine University of Agriculture. The seedlings were then planted at a 3 x 3 m spacing; giving 36 trees per plot measuring 16 x 16 m and separated by a 4 m-wide unplanted buffer strip. The distance between blocks was 5 m. Two years after establishment, a 0.5 m wide and 2 m deep trench was dug around each plot yearly during long-rain seasons to minimize below ground inter-plot interactions. Prior to the beginning of 2004 cropping seasons, trees in the woodlots were sampled to assess species effects on soil fertility, wood yields and nutrient use efficiency (Kimaro *et al.,* 2006). The remaining trees in each plot were felled and the site prepared using a hand hoe. The wood components (i.e. stem and branches) were removed from the plots while foliage biomass was incorporated into the soil during site preparation.

Maize yield assessments

A split-plot experiment with three replications was established to assess tree species effects on soil inorganic N, maize yields and nutrient uptake. The whole plot factor was tree species as listed above. The sub-plot factor was inorganic N and P fertilizers with four levels: Control (No fertilizer), full rate of N (80 kg N ha^{-1}), full rate of P (40 kg P ha^{-1}) and full rates of both N and P fertilizers according to recommended fertilizer rates in Morogoro (Ussiri *et al.,* 1998). Sources of N and P were Urea and triple super phosphate (TSP) respectively. Thereafter, maize variety *Kito* was intercropped between stumps at a spacing of 90 cm between rows and 45 cm within rows. Urea was split-applied on the 3rd and 5th weeks after maize planting, while TSP was applied once at the time of planting. Stumps of coppicing trees were regularly severed at two weeks interval to reduce competition for moisture and light (Otsyina *et al.,* 1996). At the end of each cropping season, all inner maize plants (leaving two surrounding rows) in each sub-plot were harvested, partitioned into grain, stover and cobs, weighed and sub-sampled for moisture content determinations at 70^0 C in the oven. The moisture content was used to estimate dry weight of each biomass component and the values were extrapolated to a hectare based on yield per sub-plot. The oven-dried samples of each biomass component were finely ground and wet-digested using hydrogen peroxide and sulphuric acid solution. Total N in the digests was determined using a Technicon II analyzer System (Schuman *et al.,* 1973), total P and K by stannous chloride method and atomic absorption respectively.

Determination of soil inorganic nitrogen

Soon after clear felling and prior to site preparations, soil samples from 5 randomly selected points within 4 x 4 m inner area of each sub-plot were collected at a 0 - 15 cm soil depth. The samples were bulked by sub-plots, mixed thoroughly and sub-sampled to get a composite sample for analysis of ammonium and nitrate N. Similarly, additional samples were collected during each cropping seasons at 0, 4, 6, and 8 weeks after maize planting. The samples were transported in a cooler and stored in deep freezers at 4^{o} C prior to analysis within one week. Soil inorganic N was extracted using 2 M KCl solution and the extracts analyzed for ammonium and nitrate N as described by Okalebo *et al.* (1993).

In-situ leaf decomposition

A RCBD experiment with three replications was established to evaluate rates of leaf decomposition and nutrients release under field conditions. The experiment was laid out adjacent to the rotational woodlot experiment so as to reduce site-to-site variation. The litterbag technique (Kuperman, 1999; Guo and Sims, 1999) was adopted for this study. The litter bags (20 x 20 cm) were constructed from nylon materials with 1mm mesh size. This size is considered small enough to prevent major losses of the small leaves but large enough to permit aerobic microbial activities (Guo and Sims, 1999). About 108 bags were prepared and filled with 10 grams of air-dried leaves of each species to obtain 18 bags per species. Out of these, leaves of three bags per species were oven dried to constant weight at 70^0C to determine initial moisture contents and concentrations of organic C, N, P, K, Ca, and Mg as described for maize samples. Organic carbon in the initial leaf samples was determined by the Walkley and Black method. Other litterbags were sealed with plastic bindings, kept in plastic bags to minimize losses while being transported to the field. Six bags per species were randomly placed horizontally at a 15 cm soil depth in 1 x 1m plots in each block located adjacent to field trails of the rotational woodlot. Eighteen bags, one from each species and block were randomly retrieved after 2, 4, 6, 8 and 12 weeks to assess dry mass and nutrients loss. The sampling dates were designed to reflect the entire growth period of maize. This allowed estimation of the potential amounts of nutrients released from decomposing foliage biomass applied as green manure after wood harvests from the rotational woodlot system. The retrieved litter bags were kept in plastic bags and transported to laboratory for analysis. Soil particles and extraneous plant materials in the retrieved leaf samples were removed manually and any remaining materials were removed by washing the leaves with distilled water and decanting through a 0.2 mm sieve. Apparently, such brief washing may allow nutrients leaching (Anderson and Ingram, 1993) but does not affect relative comparisons of treatments. The samples were placed in envelopes and oven dried to constant weight at 70^0C to determine dry weight and nutrient concentrations. Due to fast decomposition rates, *G. sepium* and *L. diversifolia* samples retrieved after 6 and 8 weeks respectively were too little to be processed for nutrient analysis. Therefore, only dry weights of these samples were recorded. The decay constant was calculated from data on the dry weight of residual materials remaining using a single negative exponential decay model (Olson, 1963):

$$W_t = W_o e^{-tk}$$

Where: W_t = dry weight of leaves in grams at time t (g)
W_o = the initial leaf weight (g)
e = Natural logarithm
t = time elapsed (week)
k = the decay constant ($week^{-1}$)

The specific decomposition constant (k) was estimated from the slope of the line of the regression between natural logarithms of the remaining leaf dry weight (W_t) against time. The amounts of nutrient remaining in the retrieved leaf samples (W_t) were calculated as described by Guo and Sims (1999) and expressed as a percent of the initial amounts.

Vector diagnosis analysis

Vector diagnosis analysis has been used to identify nutrients driving seedlings and crops growth responses to soil nutrients supply in both forestry and agroforestry systems (Imo and Timmer, 1997; Imo and Timmer, 2000; Salifu and Timmer, 2001). Compared with other diagnostic techniques such as critical nutrient concentrations and optimum ratios, nutrient diagnosis using vector analysis closely correspond with actual growth responses and vector nomograms simplify ranking and comparisons of relative importance of nutrients in stimulating plant growths, facilitate discriminations of single and multiple nutrient deficiencies, sufficiency or toxicities, synergism and antagonisms, luxury consumptions and dilution effects (Timmer, 1991). Detailed description on the development and the use of this technique can be found in Timmer

(1991), Hasse and Rose (1995) and Imo and Timmer, (1997). The vector diagram (Figure 1) reflects the function that nutrient content (or amount) in a plant (bottom horizontal axis) is the product of its nutrient concentration (vertical axis) multiplied by its biomass (upper horizontal axis). The diagonals of this graph are isopleths representing change of maize nutrients concentrations and contents where biomass remains (Timmer, 1991; Hasse and Rose, 1995). Changes in these parameters relate to plants responses to nutrient supply associated with treatments (i.e. tree species and fertilizations). Responses are expressed relative to the control set as a reference (that is normalized to 100) to facilitate comparisons between various treatments. These responses were depicted by vectors (arrows) that may differ in length and direction. Vector length represents response magnitude, and vector direction identifies specific nutritional responses (Table 1 and Figure 1). Thus, **shift A** in which both nutrient uptake and dry mass increased with decreased nutrient concentration would reflect a growth dilution of nutrients due to hastened growth. A similar response without change in concentration (**Shift B**) is associated with sufficiency since both growth and nutrient uptake increased without changes in concentration. **Shift C** in which biomass, nutrient concentration, and nutrient content increase depicts deficiency response of plant species because both growth and nutrient uptake improved. A similar shift without changing biomass (**Shift D**) signifies luxury consumption since nutrient uptake was enhanced without growth increase. Increased concentration with or without changes in both biomass and nutrient uptake (**Shift E**) would suggest concentration effects of less efficient species due to toxic nutrient accumulation. Decrease in nutrient concentration with or without change in biomass (**Shift G**) would suggest depletion response due to nutrient retranslocation (Salifu and Timmer, 2001). This analysis facilitated simultaneous assessments of nutrient use efficiency and its relationship with nutrient dynamics and wood production for different tree fallow species. This analysis facilitated identification of principal nutrients driving maize growth responses to tree fallows and fertilization treatments in sequential cropping because relative changes depicted by vectors relate to two key processes driving plant growth: nutrient uptake and dry matter production that characterize differing treatment responses.

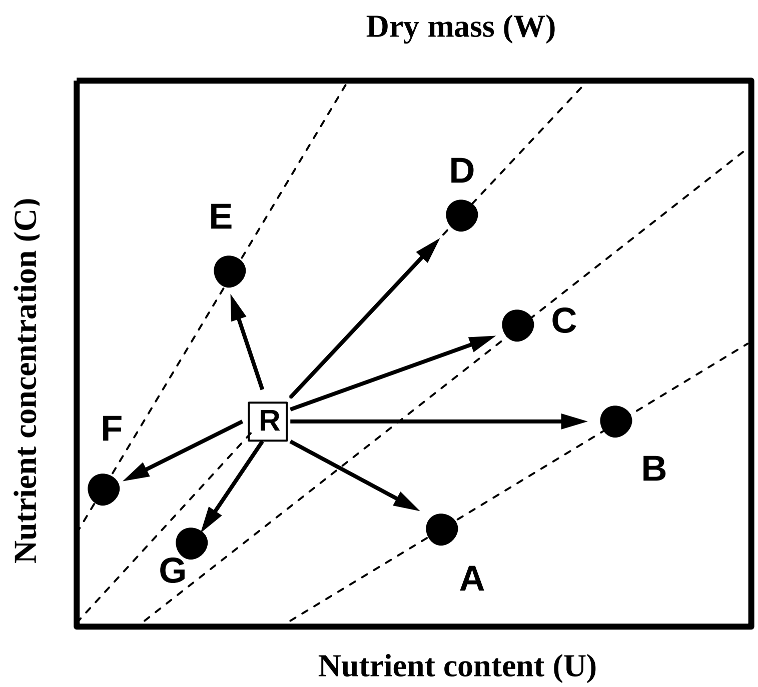


Figure 1: Interpretation of directional changes in relative dry mass and nutrient status of maize plants. The reference condition (R) is normalized to 100. Vectors directions (A to G) indicate increase [+], decrease [-] or no change [0] plant's nutrient concentration, nutrient content and dry mass in response to nutrient supply by tree fallows or fertilizations. Vector length depicts the magnitude of difference of plant parameters (Timmer, 1991; Salifu and Timmer, 2001).

Table 1. Change in relative Vector length in respose to magnitude with identified specific nutritional responses

Vector shift	Change in relative W	U	C	Interpretations	Possible diagnosis
A	+	+	-	Dilution	Non-limiting
B	+	+	0	Sufficiency	Non-limiting
C	+	+	+	Deficiency	Limiting
D	0	+	+	Luxury consumption	Non-toxic accumulation
E	-	-,+	+	Excess	Toxic accumulation
F	-	-	-	Excess	Antagonistic
G	+	-	-	Depletion	Retranslocation

Data analysis

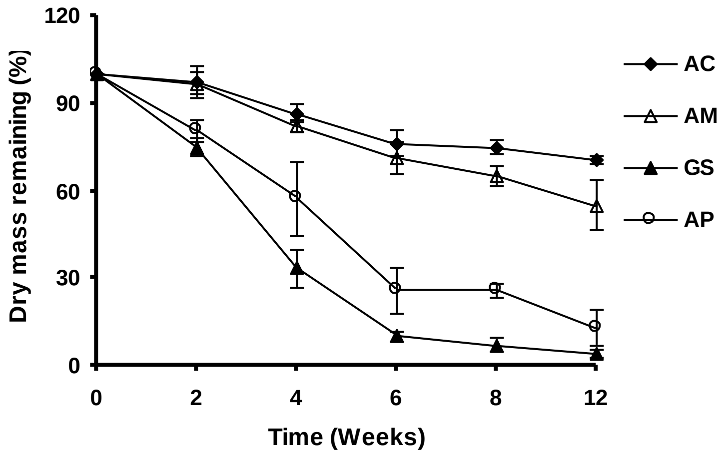
Data were tested for normality and homoscedasticity (i.e. constant variance) of residuals using statistical analysis system (SAS) procedures. Thereafter, analysis of variance (ANOVA) was carried out accordingly to assess effects of tree fallows species and fertilizations on soil inorganic N, litter decomposition and nutrient release, maize yields and nutrient uptakes using the generalized linear model procedure (SAS, 1987). Following ANOVA, significant means were separated using Tukey's Studentised Range Test at 5% level of significance.

Results and Discussions

In-situ leaf decomposition

Changes of leaf dry weights over the twelve week decomposition period are depicted in Figure 2. Values of instantaneous decay constant (k) which is commonly used to compare decomposition rates between treatments are summarized in Table 2. Coefficient of determination (r^2) showed a good fit of the data to the single negative exponential model probably due to a short duration of the experiment at which conditions such as leaf chemistry, moisture and temperature were similar. Leaf decomposition differed significantly among tree species. Decomposition was higher and rapid in leaves of *G. sepium, L. diversofolia* and *A. polyacantha* reflecting low C: N ratios and low concentrations of lignin and polyphenols (Zaharah and Bah, 1999; Mafongoya *et al.,* 1998). The initial C: N and C: P ratios in leaves of these species ranged from 14 to 16 and 223 to 305 respectively. These ratios are within the range at which net mineralization of N and P from decomposing leaves is expected (Brady and Weils, 2004). On average, leaves of fast decomposing tree species lost about 40 – 70 % of the initial mass within the first four weeks of field exposure. The decomposition of leaves of Australian *Acacia* species proceeded slowly losing only 30 – 55 % of initial dry mass by the end of decomposition period mainly due to poor quality (Jamaludheen and Monhan Kumar, 1999; Dutta and Agrawal, 2001). The decomposition rates of leaves of the Australian *Acacia* species were similar until after 8 weeks when leaves of *A. mangium* and *A. auriculiformis* decomposed relatively faster; probably due to changes in leaf chemistry (Figure 3).

Generally, contents of N in residual leaves declined in leaves of *G. sepium, L. diversofolia* and *A. polyacantha* over the decomposition period and increased slightly in other tested species. Phosphorus and K contents decreased relative to initial values in all species (Figure 3).



Key: AC = *A. crassicarpa*, AM = *A. mangium*, AP = *A. polyacantha*, LD = *Leucaena diversifolia*, GS = *G. sepium*, and AA=*A. auriculiformis.* Vertical bars indicate standard errors of the sample means of the 3 replicates.

Figure 2: The percentage remaining mass of air-dry leaves of tree fallow species of a five-year old rotational woodlot over a twelve week in-situ decomposition period at Mkundi, Morogoro, Tanzania.

Table 2: Decay constants (Week^{-1}) and half life ($t_{(0.5)}$, weeks) of leaves of different tree species in a litterbag experiment at Mkundi, Morongo, Tanzania.

Tree species	k (Week^{-1})	R^2	$t_{(0.5)}$, weeks
A. crassicarpa	- 0.0305	0.8752	22.7
A. auriculiformis	- 0.0382	0.9326	18.1
A. mangium	- 0.0516	0.9717	13.4
A. polyacantha	- 0.1527	0.9798	4.5
L. diversifolia	- 0.1912	0.9566	3.6
G. sepium	- 0.304	0.9351	2.3

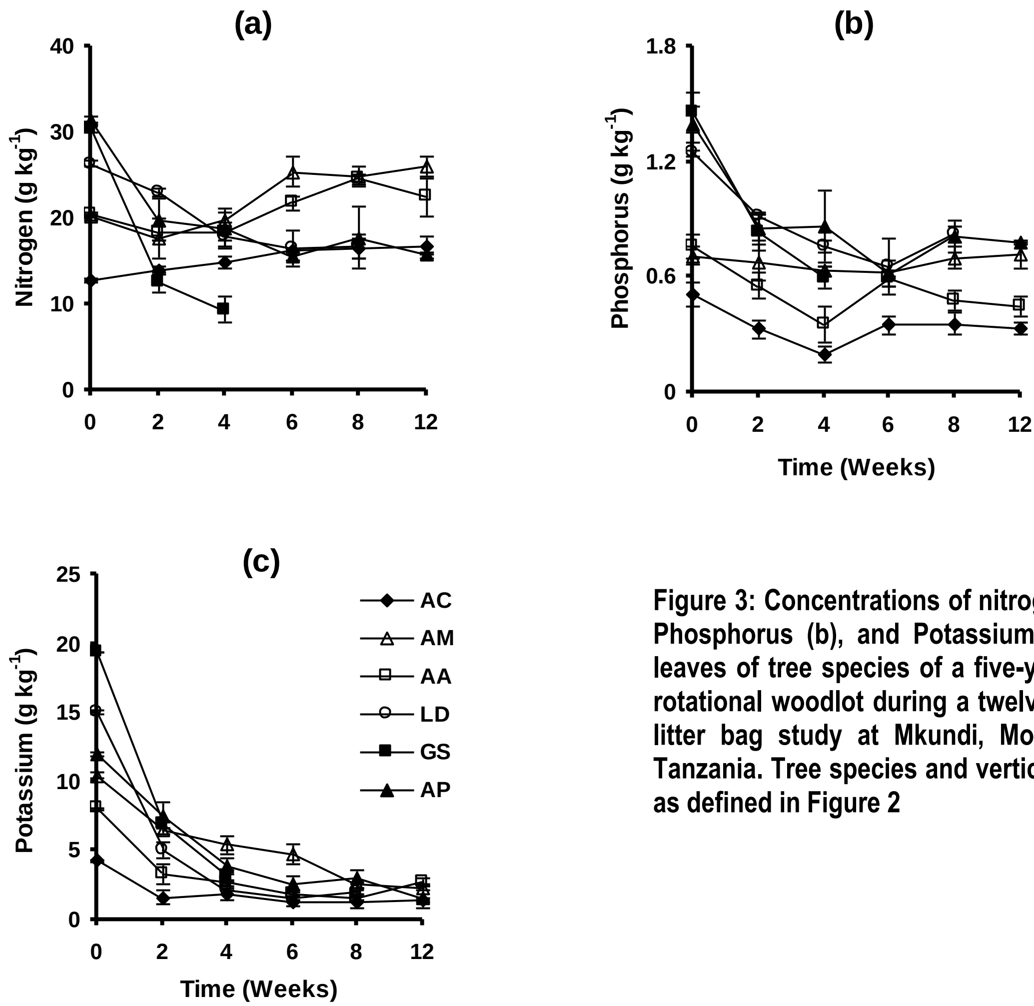
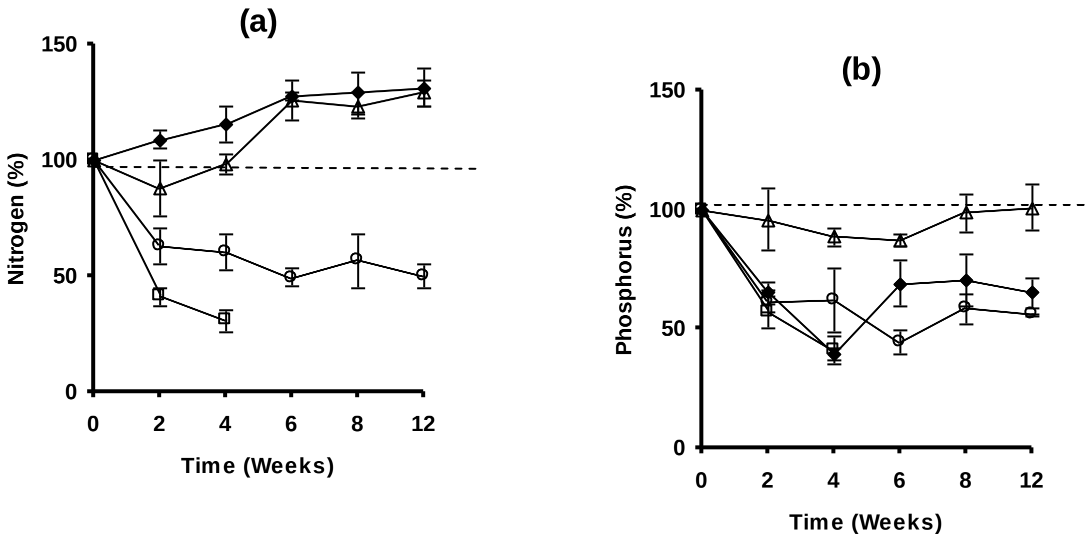


Figure 3: Concentrations of nitrogen (a), Phosphorus (b), and Potassium (c), in leaves of tree species of a five-year old rotational woodlot during a twelve-week litter bag study at Mkundi, Morogoro, Tanzania. Tree species and vertical bars as defined in Figure 2

To quantify nutrient dynamics during decomposition period, the N, P, K, concentrations in the residuals leaves were expressed in percentage of the initial nutrients amounts (Figure 4). There was net mineralization in leaves of *L diversofolia, A. polyacantha* and *G. sepium* averaging 40, 50 and 70 % respectively at the termination of the experiment. Nitrogen immobilization was observed throughout the decomposition period in leaves of *A. crassicarpa, A. mangium* and *A. auriculiformis*. This could also be associated with poor litter quality (Jamaludheen and Monhan Kumar, 1999). Slow decomposition and apparent N immobilization by leaves of these species imply limited nutrients release, particularly N to maize grown after wood harvests. There was mineralization of both P and K in all species indicating potential availability to crops (Figure 4). Comparatively, Potassium was the most abundant element with the highest release probably because this element is neither structurally bound in plant tissues nor readily retranslocated during leaf senescence. Thus, disintegrations of cell membranes result in easy leaching from organic materials (Zaharah and Bah, 1999; and Agrawal, 2001).



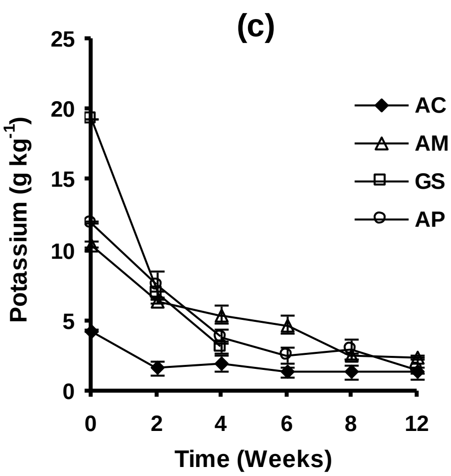


Figure 4: Concentrations of Nitrogen (a), Phosphorus (b) and Potassium (c), (expressed as a percent of initial nutrient concentration) in leaves of tree species of a five-year old rotational woodlot experiment during a twelve-week litter bag study at Mkundi, Morogoro, Tanzania. Values below and above 100 respectively indicate mineralization and immobilization of nutrients. Tree species and vertical bars as defined in Figure 2

Soil inorganic nitrogen

Changes of soil inorganic N during the cropping seasons are indicated in Figure 5. Soil inorganic N increased significantly and reached a peak between fourth and sixth weeks after maize planting. The peak N release coincided with the active growth period of maize (i.e. 4 – 8 weeks after planting) in the tropics (Lehman, 1995; Nduwayezu, 1997). The increase was rapid in plots of *G. sepium, L. diversifolia* and *A. polyacantha*. Higher amounts of soil inorganic N in plots of *G. sepium, L. diversifolia* and *A. polyacantha* probably reflect high decomposition rates (Figure 2). Patterns of N release and availability during the cropping seasons, suggest that most Australian *Acacia* species did not synchronize N release with crops demand (Figures 4 and 5); probably due to slow decomposition and N immobilization resulting from poor quality of litter (Jamaludheen and Monhan Kumar, 1999). In the second cropping season, available N declined in all species presumably due to loss of un-decomposed foliage biomass mainly through termite attack during the off season (Sileshi *et al.,* 2005); since no residual green manure from the last cropping season was evident at the start of 2005 cropping season. This, in turn, may have limited contributions of residual foliage biomass to soil nutrients, particularly N, in the second cropping season. Apart from *G. sepium* and to some extent *L. diversifolia* which sprouted after wood harvest, tree species effects on N availability in the second cropping season was presumably through mineralization of the active fractions of soil organic mater accumulated during the fallow period (Brady and Weils, 2004; Palm *et al.,* 2001).

Nutrients exported in harvested maize grain at the end of 2004 cropping season partly contributed to the N availability decline in the second season.

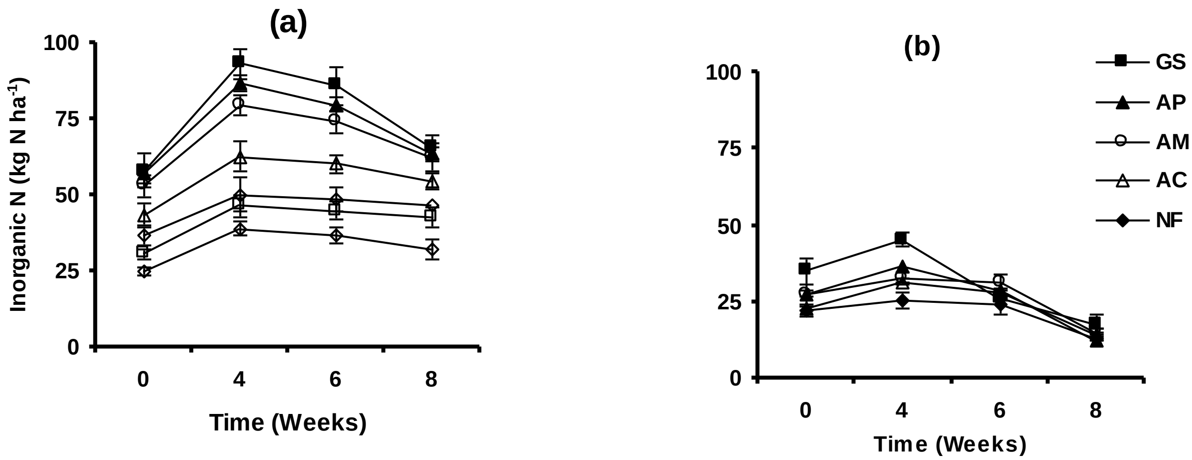


Figure 5:Total inorganic N (NO^-_3 - N and NH^+_4 - N) during the 2004 (a) and 2005 (b) cropping seasons after clear felling rotational woodlot system at Mkundi, Morogoro, Tanzania. Error bars indicate standard error of the sample means. Tree species and vertical bars as defined in Figure 2.

Maize yield and nutrients uptake

Tree species significantly improved maize grain yields in both cropping seasons (Figure 6) probably due to large amounts of nutrients, particularly N, P and K, released from decomposition of foliage biomass applied as green manure (Figure 4 and 5) and improved soil fertility during the fallow period (Nyadzi *et al.,* 2003b). The interaction of tree species and fertilizer treatments on maize yields was not significant implying that tree species effects on maize yields were independent of fertilizer applications. Maize grain yields were highest in *A. polyacantha*, *L. diversifolia* and *G. sepium* fallows probably reflecting highest amounts of nutrients, particularly N, released from green manure (Figure 5). In the first cropping season, maize grain yields from these species (3.10 - 3.35 Mg ha^{-1}) were equivalent to 3.50 Mg ha^{-1} recorded in plots receiving full rates of both N and P fertilizers (Figure 6b). Among exotic *Acacia* species, *A. mangium* fallow produced relatively high maize grain yields (Figure 6) probably due to comparatively more nutrients released during the cropping seasons (Figure 5) as predicted by the *in-situ* leaf decomposition study (Figure 4). Declining maize yields in the second cropping season was probably due to reduced residual effects of green manure on soil nutrients supply because most of the un-decomposed foliage biomass, applied as green manure at clear felling, was attacked by termites during off seasons. Virtually, there were no observable residuals of un-decomposed green manure in all tree fallows at the beginning of the second cropping season. Other studies (Sileshi *et al.,* 2005) have also associated 50 – 75% reduction in maize yields due to termite damage. Additionally, low and sporadic rainfall during the second cropping season may have contributed to this decline (Figure 6). Although, tree species effect on maize yields appear to diminish with time, our results suggest that selecting *A. polyacantha, G. sepium* and *L. diversifolia* tree fallows for rotational woodlot systems may be a practice that can replace fertilizer use by farmers, at least in the first cropping season.

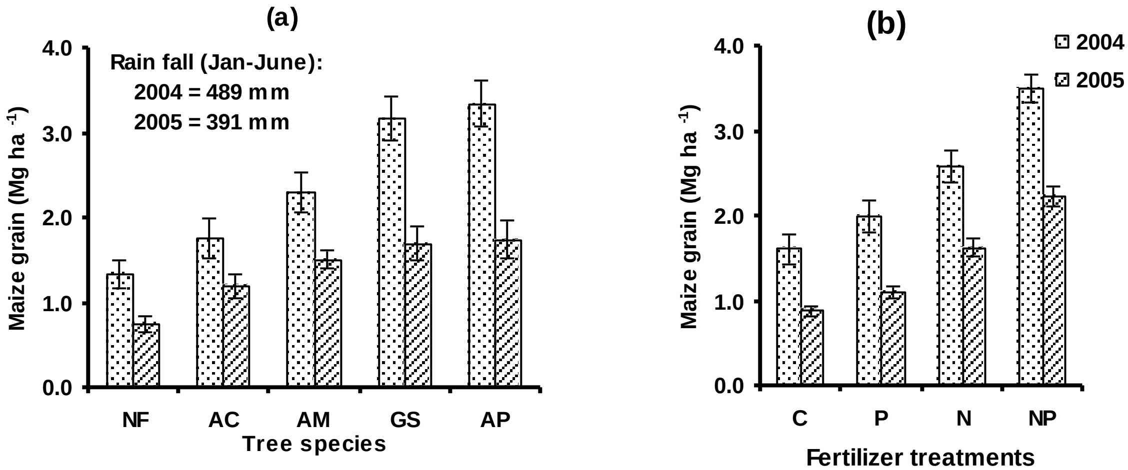


Figure 6: Effects of tree species (a) and N and P Fertilizers (b) on maize yield in a five-year old rotational woodlot at Mkundi, Morogoro, Tanzania. C=Control (No fertilizer). P= 40 kg P ha^{-1}, N= 80 kg N ha^{-1} and NP = Combined application of N and P fertilizer at 40 kg P ha^{-1}soil and 80 kg N ha^{-1}). Tree species and vertical bars as defined in Figure 2.

Vector diagnosis of nutrient interactions

Figure 7 is a vector nomogram showing the relationships between nutrient concentrations, content and above ground biomass yield of maize under different fertilizer treatments. Maize data from unfertilized plot (i.e. control) were set to 100% and compared with other treatments to depict fertilizer effects on maize growth. Similarly, vector nomograms of tree species effects on maize yields and nutrients uptakes were constructed with values of natural fallow normalized to 100% to assess principal nutrients driving growth response after tree fallows. It seems that both N and P were required for maize growth in the study site because additions, either singly or combined, increased maize biomass productions and nutrients uptakes (Figure 7). Vector diagnosis indicated that N and P were the most limiting nutrients for growth as they were associated with the longest right-pointing vectors (Shift C, Figure 2).This synergism is probably due to inherently low levels of these nutrients in the soil and is consistent with previous soil survey reports in Morogoro, which identified deficiency of soil N and P for crop production (Msanya *et al.,* 2003). Relative to control, combined application of these nutrients improved maize biomass yields and nutrients uptakes by 131 and 180 % respectively (i.e. 231 – 100 vs 280 - 100). The vector analysis further revealed that N was probably the primary limiting nutrients followed by P as demonstrated by relative vector lengths (Figure 7). Despite increase in maize K uptake and biomass growth due to fertilizations, K concentration did not change; exemplifying sufficiency status (Shift B, Figure 2). This response probably reflects highest K mineralization from the decomposition of applied green manure (Figure 4), since soil K supply is categorized as marginal for crop production (Msanya *et al.*, 2003).

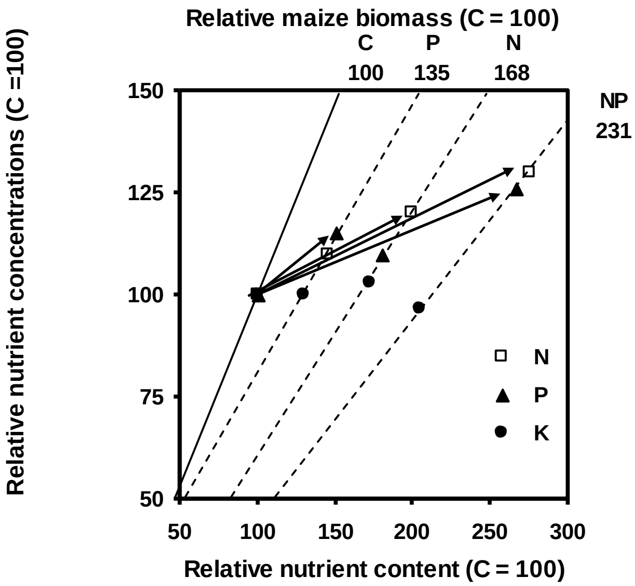


Figure 7:Relative nutrient concentrations, nutrient contents and maize biomass a five-year old rotational woodlot at Mkundi, Morogoro, Tanzania. C=Control. Treatments as defined in Figure 6b.

Similarly, tree fallows with the longest right-pointing N and P vectors, such as *A. polyacantha*, *G. sepium* and *L. diversifolia*, recorded the highest maize biomass yields; ranging from 127 to 141 % relative to control. Corresponding values of N and P uptake in these species were between 170 - 200% (Figure 8). Relative to natural fallows, K uptake by maize was also improved by these species (Shift C, Figure 2) probably due to high K mineralization from green manure decomposition (Figure 4). As depicted in the nomogram of fertilizer treatments (Figure 7), these results further affirm that maize growth responses were limited by availability of both N and P in the soils. Presumably, these elements were adequately available in fallow soils of *G. sepium, L. diversifolia* and *A. polyacantha* fallows and stimulated growth response of maize because vectors magnitudes were similar (Figure 8). This diagnosis tends to corroborate results from leaf decomposition study where green manure of these species released the largest amounts of N and P during the first 4 – 8 weeks (Figure 4 and 5). However, for maize grown in fallows of Australian *Acacia* species, P vectors were consistently longer than N vectors; suggesting that these species supplied more P than N. Apparently, these P "fertilization" effects were associated with initial P mineralization and immobilization of N by the green manure during the active growth period of maize (Figure 4). Our results suggest that maize growth responses following woodlots of Australian *Acacia*s species were mainly driven by P supply while in other tree fallows both N and P were responsible for increased maize yields relative to control. This suggests comparative advantages of the latter fallows under rotational woodlot systems since *A. polyacantha* and *L. diversifolia* have shown high potential to produce wood yields (Nyadzi *et al.,* 2003a; Kimaro *et al.,* 2006). Apparently, the patterns of nutrients interactions in stimulating maize growth responses to tree fallows were mostly determined by quality of foliage biomass applied as green manure after wood harvests.

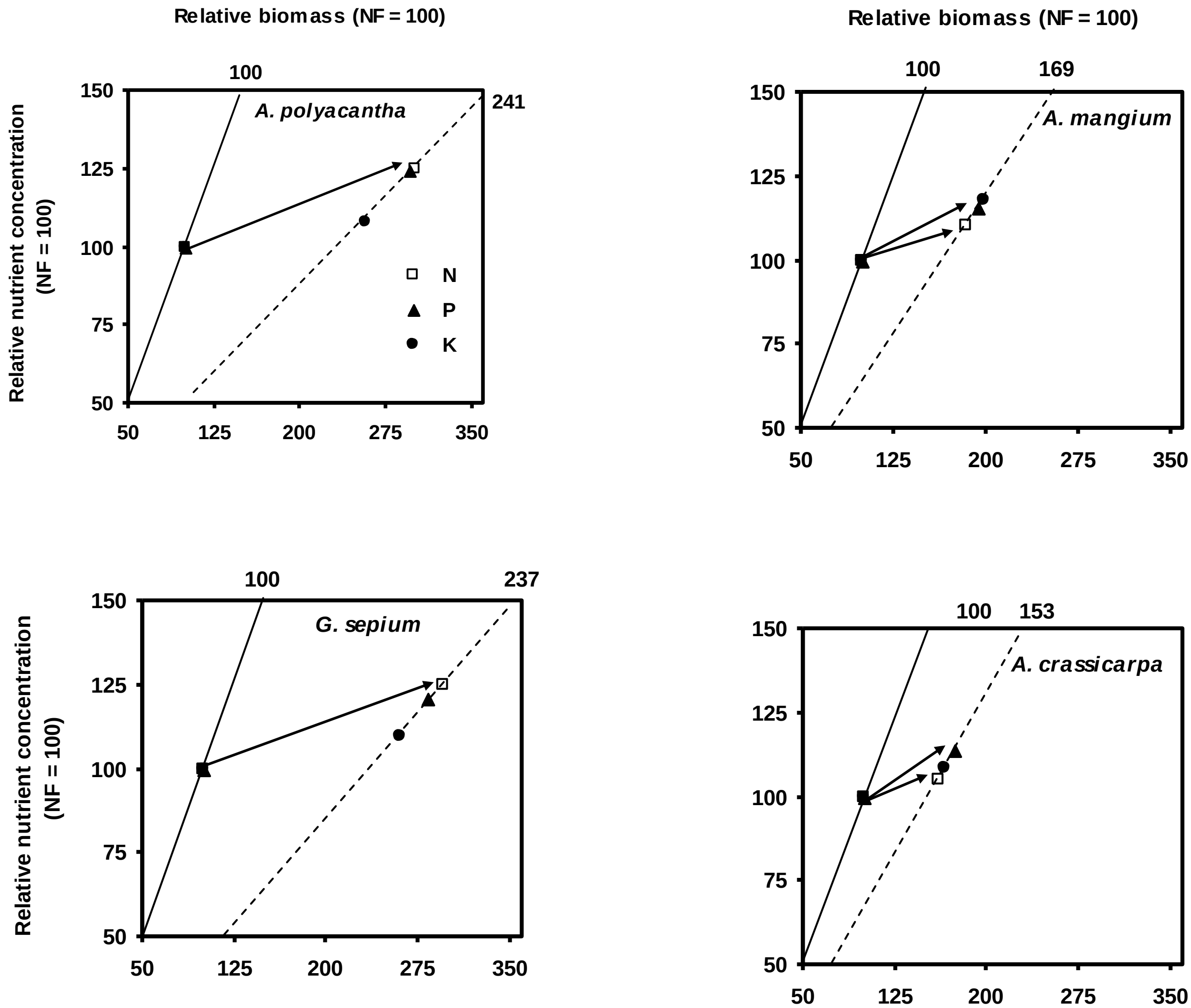


Figure 8: Vector nomogram on the effect of tree species on relative nutrient concentrations, nutrient contents and maize biomass in a five year old rotational woodlot at Mkundi, Morogoro, Tanzania. Natural fallow (NF) is normalized to 100 and compared with other tree fallow species.

Conclusions and recommendations

Our results suggest that foliage biomass of *G. sepium, L. diversifolia* and *A. polyacantha*, applied as green manure after wood harvests, decomposed rapidly and released large amounts of nutrients, particularly N, whereas those of exotic *Acacia* species immobilized N, limiting its availability to maize in sequential cropping under rotational woodlot system. As expected, this was due to high litter quality of the former and poor litter quality of the latter. Generally, mineralization of P and K was observed in fallows of all tree species. Comparatively, more K were released than other elements in green manure; probably because this element is neither structurally bound in plant tissues nor readily retranslocated prior to leaf senescence. The patterns of litter decompositions and nutrients release greatly influenced availability of soil nutrients during cropping season and residual effects of tree fallows on maize yields. Consequently, maize yields and nutrients uptakes were consistently higher in fallows of *G. sepium, L. diversifolia* and *A. polyacantha* and lower in Australian *Acacia* species.

Vector diagnosis depicted synergistic interactions between N and P on maize growth with N being the most limiting nutrient. This synergism was also closely related to patterns of nutrients release from the decomposing leaf biomass. Generally, maize growth responses following woodlots of Australian *Acacia* species were mainly driven by P supply while in other tree fallows both N and P were responsible for increased maize yields relative to control. This indicates a comparative advantage of the latter in terms of crop production since N and P are the most limiting nutrients in the study site. Consequently, where farmers' interest is to maximize production of both wood and crops, as in areas with scarcity of arable land, *A. polyacantha* and *L. diversifolia* would be appropriate for rotational woodlot system because of high potential to produce wood and improve soil nutrient availability to crops in sequential cropping. This paper, suggests that type of fallow species plays great role in influencing productivity of this system

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3. EFFECT OF *GLIRICIDIA SEPIUM* GREEN MANURE PLACEMENT ON MINJINGU PHOSPHATE ROCK SOLUBILITY AND MAIZE YIELDS IN ACIDIC PHOSPHORUS DEFICIENT SOILS OF MOROGORO, TANZANIA

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Abstract

Organic matter is known to improve dissolution of phosphate rocks and increases soil phosphorus (P) availability by releasing organic acids during decomposition and reducing soil P-fixing capacities. While incorporation of green manure into soil is known to be superior to mulching in terms of maize yield and nitrogen (N) recovery, the information regarding effects of these placement methods on Minjingu Phosphate Rock (MPR) dissolutions is scanty. Therefore, a factorial experiment, laid out in a Complete Randomized Block Design (CRBD) with three replications, was carried out at Sokoine University of Agriculture (SUA) farm to assess the effects of surface applied and soil incorporated *Gliricidia sepium* (Jaqua) green manure and MPR application rates on soil P availability and maize yields. Green manure significantly improved extractable P, maize yield and nutrient uptake with higher values observed in incorporation than mulching treatments. Four weeks after maize planting, these treatments had respectively improved Bray 1 P by 43 and 27 % over the control. Corresponding maize grain yield were 2.6 and 2.3 Mg ha^{-1} respectively. Higher performance of soil incorporated green manure than its application as mulch was attributed to fast decomposition and enhanced soil contact. Vector analysis indicated that P was the most limiting nutrient for maize production. Bray 1 P and maize yields and nutrient uptake increased with MPR applications rates; affirming P deficiency revealed by the vector analysis. Our results suggest that incorporation of green manure in combination with MPR is more effective in improving soil P availability than its application as mulch.

Introduction

Phosphorus (P) deficiency is a widespread constraint to crop production in tropical soils (Le Marre, 1991; Sahrawat *et al*, 1995) and this is also true for soils of Tanzania (Msanya *et al.,* 2003). According to Sanchez *et al*. (1996), P replenishment strategies are mainly inorganic fertilizer based with biological supplementations probably because agroforestry systems cannot supply most of the P required by crops (Palm, 1995). Limited P amelioration by most agroforestry technologies is partly because unlike nitrogen (N), P is not biologically fixed from the atmosphere and the P content of plant residues and manure is normally insufficient to meet the requirements for sustained crop production (Palm, 1995). This implies that mineral sources of P must be applied to soils where this element is depleted. But most smallholder farmers cannot afford use of commercial fertilizers. Alternatively, Phosphate Rocks (PR) have received considerable attention as a relatively low-cost P fertilizer sources in acid soils (Chien and Menon, 1995). Generally, use of PR in combination with plant organic materials enhances its dissolution and P availability in the soil (Zaharah and Bah, 1997). This has been ascribed to the following four mechanisms: i) enhanced dissolution of the PR due to the action of organic anions produced during the decompositions of organic matter, ii) reduction of the P absorption capacity of the soils, iii) contribution of P from decomposing plant biomass, and iv) enhanced microbio activities in the soil that influence P mineralization (Hammond *et al.,* 1986; Sale and Mokwunye, 1993; Nziguheba *et al.,* 1998). In agroforestry systems, green manure (GM) from tree pruning is either incorporated in soils or applied on the surface as mulch (Kang *et al.,* 1981; Wilson *et al.,* 1986). While the incorporation of GM into soil is known to be superior to its application as mulch in terms of maize yield and N-recovery (Mafongoya and Nair, 1996, Mafongoya *et al.,* 1996). Information regarding the effects of these two placement methods in combination with Minjingu phosphate rock (MPR) on soil P dynamics is scanty. This information is useful in improving crop productivity in acidic P deficient soils which are often characterized by high P fixations. Therefore, this study was carried out to assess the effects of *Gliricidia sepium* (Jaqua) green manure placements and MPR applications on soil P availability, maize yield and uptake of N and P.

Materials and Methods

Study site description

The study was carried out at Sokoine University of Agriculture (SUA) farm (6^0 50' 24.7" S; 37^0 38' 59.8" E; 526 m a s l), Morogoro, Tanzania during the 1999 cropping season. The area has a sub-humid tropical climate with a bimodal rainfall distribution and a definite dry season. The long term mean annual rainfall is 870 mm, total annual evapotranspiration is about 1307 mm and the mean annual temperature is 24^0 C. The rainfall data for the 1999 long rain season were 29.0, 186.2, 200.7, and 95.3 mm for the months of March, April, May and June respectively. The soils are classified as Ultisol according to USDA soil taxonomy (Msanya *et al.,* 2003). They are highly weathered with clay loam texture containing low soil pH, extractable P and total N contents, low organic carbon (OC) and high exchangeable Al (Table 1).

Table 1: Soil physio-chemical properties at the SUA Farm, Morogoro, Tanzania

Soil parameters	Soil depth (cm)			
	0-10	10-20	20-30	30-50
Total nitrogen (%)	0.11*	0.100	0.092	0.080
	(0.0001)	(0.0001)	(0.0002)	(0.0002)
Extractable phosphorus (mg kg^{-1})	1.392	1.386	0.754	0.603
	(0.06)	(0.32)	(0.27)	(0.21)
Soil organic carbon (%)	0.91	0.83	0.63	0.42
	(0.02)	(0.01)	(0.02)	(0.10)
Exchangeable acidity (c mol (+) kg^{-1} soil)	1.78	2.22	2.58	2.25
	(0.03)	(0.09)	(0.10)	(0.06)
Exchangeable hydrogen (c mol (+) kg^{-1} soil)	0.95	0.65	0.68	0.42
	(0.03)	(0.06)	(0.03)	(0.07)
Exchangeable Al (c mol (+) kg^{-1} soil)	0.83	1.57	1.90	1.83
PH	4.26	3.91	3.75	3.86
	(0.05)	(0.18)	(0.18)	(0.03)
Sand (%)	37.07	34.73	32.73	29.40
	(0.88)	(1.45)	(0.88)	(0.58)
Silt (%)	11.2	10.17	8.40	12.10
	(0.58)	(1.20)	(1.0)	(0.33)
Clay (%)	51.70	55.10	58.87	58.23
	(0.33)	(1.15)	(0.29)	(1.46)

Textural class	Clay loam	Clay loam	Clay loam	Clay loam

*Mean of three replications followed by standard error in parenthesis.

Foliar P and N concentrations of *G. sepium* leaves used as GM in these experiments were 0.14 and 2.85 % respectively.

Experimental treatments, establishment and management

A 3 x 5 factorial experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications to assess the effect of *Gliricidia sepium* (Jaqua) GM placement methods and MPR on extractable P, maize yield and nutrients uptakes. The site was disc ploughed, harrowed and divided into three blocks of 40 x 29 m separated by 3 m unplanted buffer strips. The blocks were further subdivided in to 18 plots of 3.6 x 3.6 m with 2 m distances between plots. Before ploughing, three pits were randomly dug in each block and soil samples were collected at 0 – 10, 10 – 20, 20 – 30 and 30 – 50 cm soil depths for site characterization. The collected samples were bulked by depth and sub sampled for analysis in the laboratory. The MPR was applied at six rates to give the following levels of phosphorus: 0, 10, 20, 40, 60, 80 kg P ha^{-1} and manually incorporated into 0 –15 cm soil depth using a hand hoe. The *G. sepium* GM was split applied at weeks zero and four after maize planting at an equivalent rate of 2.5 Mg ha^{-1} on dry matter basis, either incorporated into the soil using a hand hoe to 15 cm depth for incorporation treatments or surface applied for mulching treatments; giving the final rate of 5 Mg ha^{-1}. Source of the GM was a nearby even aged planted fallow of *G. sepium*. During the cropping season, soil samples were collected from each plot at 0, 1, 2, 4, 6, 8, 10, and 12 weeks after maize planting at 0 – 15 cm depth from three randomly selected points, mixed thoroughly and sub-sampled for Bray -1 P analysis.

Analysis of soil and plant samples

Soil samples for site characterizations were air dried, ground and sieved thorough a 2-mm sieve. Soil samples were block digested using hydrogen peroxide and sulphuric acid solution and total N in the digest was determined using the semi-Macro Kjeldahl method. Soil particle analysis was determined by the hydrometer method and soil organic carbon (OC) by Walkley-Black method. Bray -1 method was used for analysis of extractable P. Soil pH in 1:2.5 soil water suspensions were measured using pH-Ec meter. Total N and P in maize and *G. sepium* samples were determined using the semi-Macro Kjeldahl method after digestion with hydrogen peroxide and sulphuric acid solution. Nutrient analysis of all samples was carried according to standard laboratory procedures described by Anderson and Ingram (1993) and Okalebo *et al.* (1993).

Statistical analysis

Analysis of Variance (ANOVA) on the effects of green manure and MPR on extractable P, maize yields and nutrient uptakes was carried out using general linear model (GLM) procedure provided within SAS software package (SAS, 1987). Following ANOVA, significant means were compared using least significant difference.

Results and discussion

Soil P availability

Green manure treatments significantly improved extractable P during the cropping season as depicted in Figure 1. The interaction of green manure placement methods and MPR application rate on soil P availability was significant at weeks 4 and 6 after maize planting (Figure 1 b and c). Extractable P increased and reached a peak in the 4^{th} week after maize planting and decreased thereafter; corresponding to decomposition rates of *G. sepium* reported in previous studies (Zaharah and Bah, 1999). Four weeks after maize planting, incorporation and mulching treatments increased extractable P by 43 and 27 % respectively over the control. This increase is partly attributed to enhanced dissolution of MRP and improved availability of P in the soil following GM application. Low soil pH, low exchangeable Ca and low soil P are the major soil factors that increase dilution and subsequent P release from phosphate rocks (Hammond *et al.,* 1986). These factors may have accounted for improved dissolution and P release with MPR application rates (Figure 1b and c) as the soil was acidic with very low Bray 1 P (Table 1).

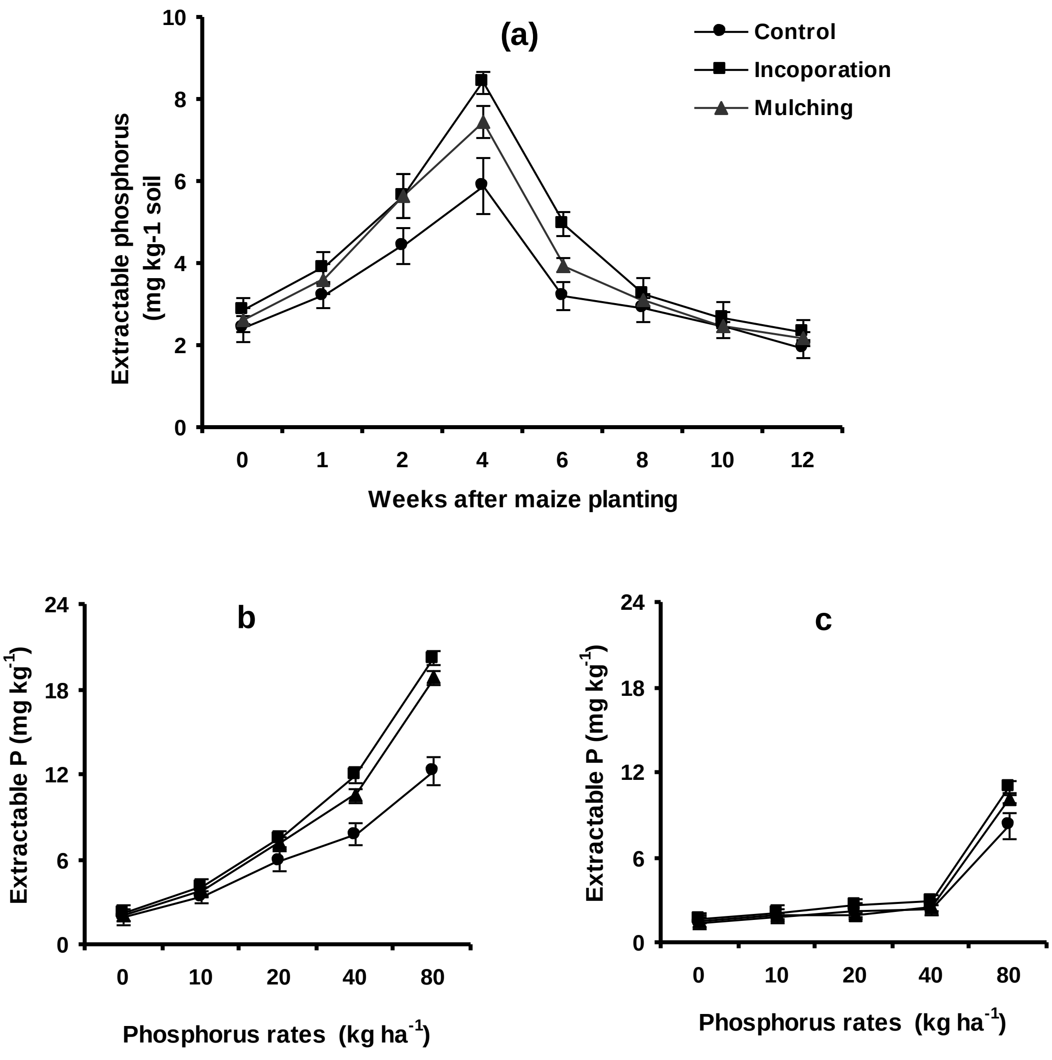


Figure 1: G. sepium green manure effects (a) and its interactions with Minjingu phosphate application rates on soil phosphorus availability on fourth (b) and sixth (c) week after maize planting at Sokoine University of Agriculture farm, Morogoro, Tanzania. Vertical bars indicate standard error of the mean of the three replicates.

Decomposition of GM is expected to enhance dissolution of rock phosphates through a number of mechanisms related to production of organic acids, which lower soil pH, chelating Al and Fe ions and providing energy source to microorganisms involved in mineralization process (Hammond *et al.,* 1986;

Zaharah and Bah, 1997; Nziguheba *et al.,* 1998; Brady and Weils, 2004). Although low soil P and pH might have limited GM effects on dissolution of MPR but high soil exchangeable Al indicates high potential for soil P fixations (Table 1). Therefore, increased soil P availability in GM treatments may largely be associated with reduction of soil P fixing capacity by organic acids produced during decompositions. These acids are negatively charged and therefore may compete with P ions for exchange site on the soil colloids; thus reducing soil P fixations and hence increasing soil P availability (Zaharah and Bah, 1997; Brady and Weils, 2004). Certain carbonic acids, particularly carboxylic groups produced during microbial decay of GM may chalete Al and Fe ions rendering them unavailable for reaction with phosphorus ions in soil solution (Brady and Weils, 2004). Furthermore, additions of green manure is known to enhance mineralization of recalcitrant fractions of soil P by providing food energy to soil microorganisms responsible for P mineralization (Nziguheba *et al.,* 1998), thereby contributing to higher extractable P in *G. sepium* green manure treatments (Figure 1). The observed increase of soil P during the cropping season is also associated with the contribution of P from decomposing *G. sepium* GM (Zaharah and Bah, 1999; Brady and Weils, 2004).

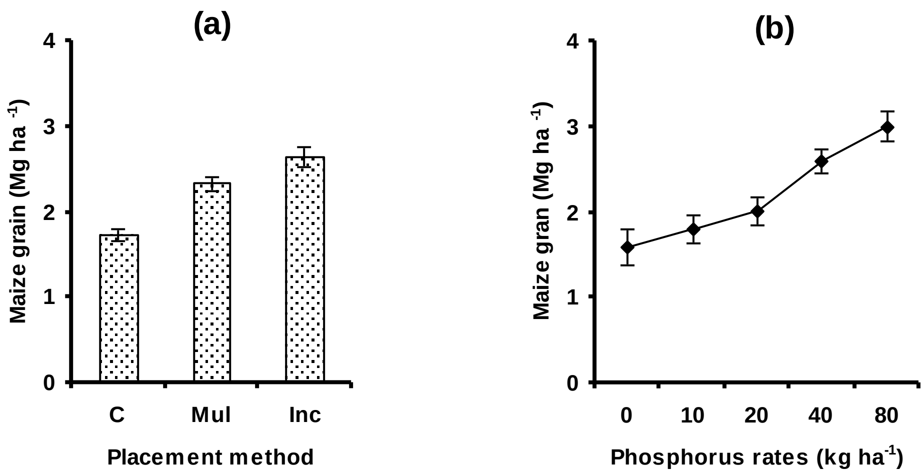
Soil extractable P was higher in soil where GM was incorporated than when surface applied at the fourth and sixth weeks after maize planting (Fig 1a); coinciding with peak decomposition period of *G. sepium* green manure (Zaharah and Bah, 1999). During these weeks the interaction of GM placement methods and MPR applications was also significant (Figure 1b and c). These patterns indicate the influence of the applied GM in increasing dissolution of MPR and soil P availability. Interactions also showed that differences in soil P availability due to green manure placements was significant at higher MPR application rates probably due to more P release. Higher extractable P in incorporation than mulching treatments is probably due to faster decomposition of green manure and the enhanced contacts between green manure and soil particles (Wilson *et al.,* 1986). Decrease in extractable P levels observed between 4 to 8 after maize plating is attributed to maize uptake due to high nutrient demand during this period (Lehman *et al.,* 1995; Nduwayezu, 1997) and partly due to P fixations by soil constituents, particularly Al ions (Table 1) and other losses such as particulate P in surface runoffs (Brady and Weils, 2004).

Maize yield

GM and MPR applications significantly improved maize grain yield (Figure 2). However, treatments interaction on maize yield was not significant. Relative to control, Incorporation of GM into soil improved maize production (2.6 Mg ha^{-1}) more compared to mulching (2.3 Mg ha^{-1}). This increase is associated with higher soil P availability (Figure 1) in incorporation than mulching treatments because the soils were P deficient (Table 1). Nutrients contribution, particularly N, through decomposition of G. *sepium* GM may have also contributed to maize response to GM application (Palm, 1995; Zaharah and Bah, 1999). Faster decomposition and mineralization of soil incorporated with GM probably accounted for high maize yields under this treatment whereas lower yield of mulching treatment may be due to high N losses from volatilization during decomposition (Wilson *et al.,* 1986). Improved maize yield following MPR application (Figure 2 b) is attributed to increased extractable P (Figure 1b and c) and its ameliorating effects on soil acidity and increased exchangeable Ca (Utumo and Sunyoto, 1995; Weil, 2000).

Nitrogen and phosphorus uptake

The relationships between maize biomass yield, N and P uptakes as influenced by GM placement methods and MPR rates are presented in Figure 3. In both treatments improved maize yields was accompanied by increased uptake of P and N with P being the most limiting nutrients as demonstrated by longer P vectors. This is probably due to high soil P fixing capacity resulting from low soil pH and high soil exchangeable Al limiting its availability to plants (Table 1). Relative to control, incorporation of green manure and its application as mulch improved maize P uptake by 140 and 70% respectively and N uptake by 130 and 60% respectively (Figure 3). This increase may be attributed to improved P availability in incorporation treatments than in mulching (Figure 1) and improved soil physical properties and nutrients, particularly N.



Key: C = Control, Mul = Mulching and Inc = Incorporation.

Figure 2: Effects of G. sepium green manure (a) and Minjingu phosphate rocks application rates (b) on maize grain yields at Sokoine University of Agriculture farm, Morogoro, Tanzania.

Vertical bars indicate standard error of the mean of the three replicates of manure application (Zaharah and Bah, 1999). Similarly, significant variation of maize N and P uptakes with MPR application rates is associated with improved soil P availability (Figure 1 b and c). The treatments effects on N and P contents in maize grain yield (Figure 4) were similar to those of total uptakes by maize biomass yield (Figure 3).

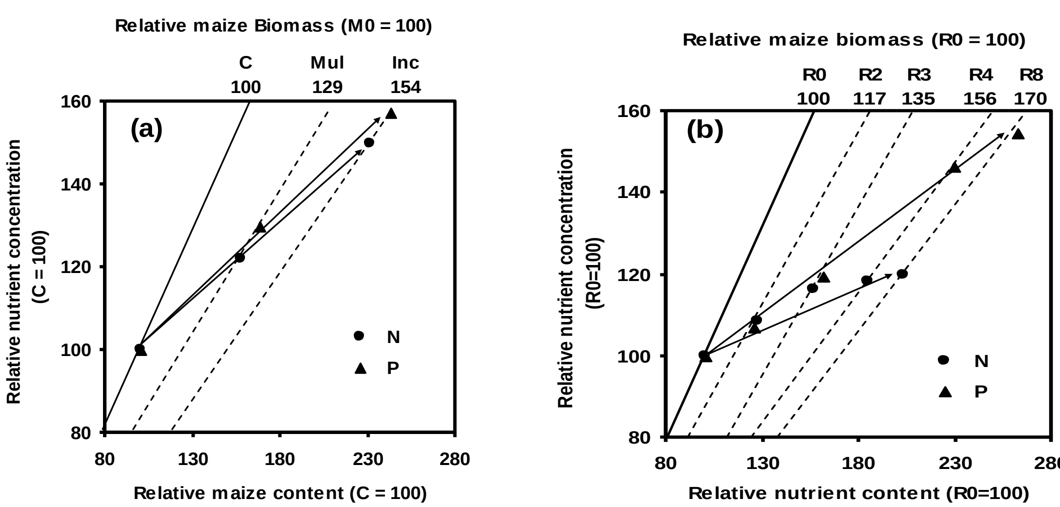


Figure 3: Relative nutrient concentrations, nutrient contents and maize biomass for different green manure (a) and Minjingu phosphate rock treatments at Sokoine University of Agriculture farm, Morogoro, Tanzania. Terms as defined in Figure 2.

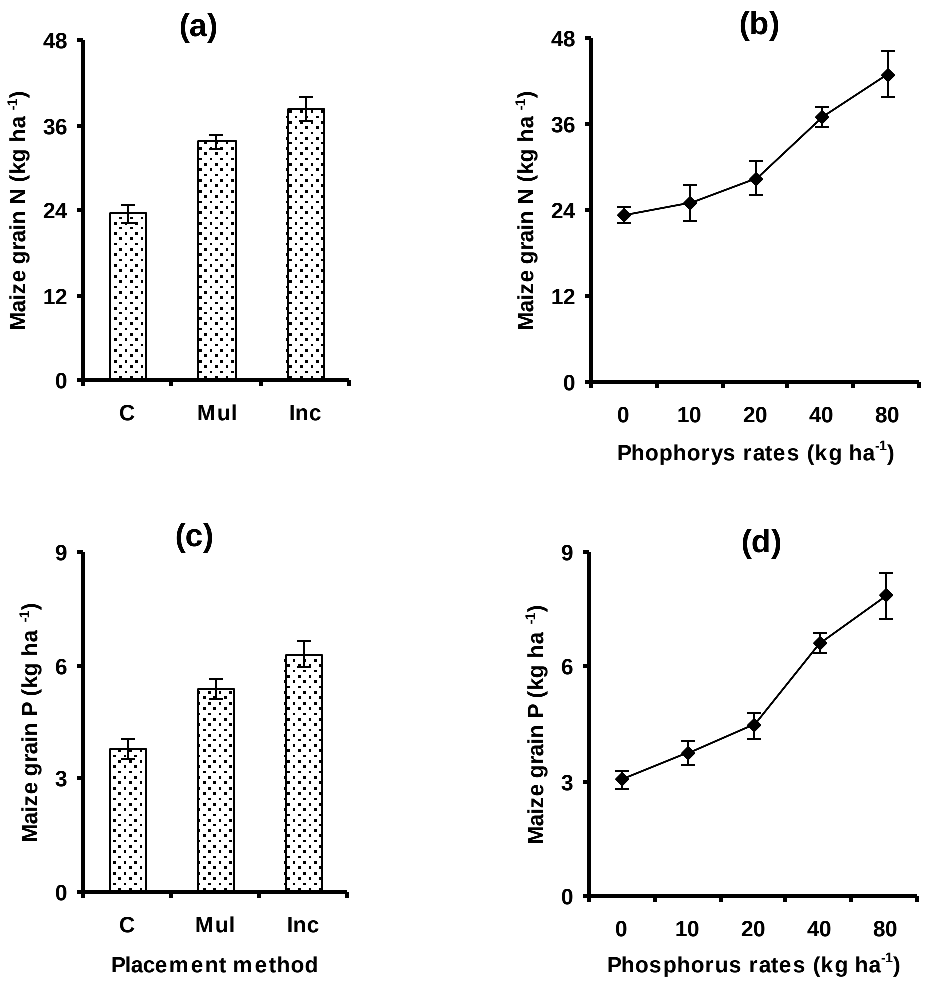


Figure 4: Maize nitrogen uptake for different green manure placement methods (a) and Minjingu rock phosphate application rates (b) and their corresponding maize P uptakes (c and d) at Sokoine University of Agriculture farm, Morogoro, Tanzania. Terms as defined in Figure 2.

Conclusions and recommendations

Gliricidia sepium GM application increased soil P availability partly through enhanced MPR dissolutions and reduction of soil P fixing capacity. This effect was much higher in soil-incorporated GM than surface applied mulch presumably due to fast decomposition and improved contacts with soil particles. Improved soil P availability due to GM and MPR applications were reflected in maize yields and nutrients uptakes. Consequently, maize grain yields and N and P uptakes were consistently higher in incorporation than mulching treatments. These parameters also increased significantly with MPR application rate; affirming P deficiency revealed by vector analysis. This study suggests that crop performance in acidic soils with P fixing potentials may be improved when green manure and MRP are incorporated into the soil rather than surface applied as mulch.

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4. EFFECT OF ROTATING *TEPHROSIA VOGELII* FALLOW AND MAIZE ON MAIZE YIELD AND SOIL FERTILITY REGENERATION IN SUB-HUMID CLIMATE OF EASTERN TANZANIA

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Abstract

A field experiment was conducted on acidic N and P deficient Ferralsol to determine the effect of *T. vogelii* fallow-rotation with maize on soil fertility regeneration. The experiment was conducted sequentially for four years, with 22-month old *T. vogelii* fallows followed by two subsequent sole maize cropping. The 22-month old *T. vogelii* fallows were applied with 0 or 80 kg P ha^{-1}, while the following maize crop was applied with *T. vogelii* biomass or sulphate of ammonia alone as N sources, co-applied with TSP or Minjingu Phosphate Rock (MPR). Soil pH, and exchangeable K, Mg and Ca were monitored both in the fallows and in the maize crop. Incorporation of accumulated litter and foliar biomass alone into the soil increased soil pH towards neutrality and exchangeable Ca, Mg and K significantly. The contribution of Natural fallow in increasing exchangeable Mg was much higher than that of plots amended with *T. vogelii* biomass. These results suggest that medium duration *T. vogelii* fallows-in rotation with maize can substantially regenerate soil fertility in acidic, N and P deficient Ferralsol in sub-humid climate of eastern Tanzania.

Introduction

Declining soil fertility especially in major nutrients is one of the major problems limiting crop production in the tropics (Eswaran *et al.,* 1997). Continuous cultivation on the same piece of land without using adequate amounts of fertilizers and mismanagement of soils, water and forests, are some of the factors which further aggravate soil fertility declining problem. In most cases, farmers rely on deep tillage up to 30 cm in 3 to 4-year cycles, recycled nutrients through progressively small amounts of crop residues, crop rotation and natural fallowing of up to 6 seasons. However, these approaches have not been able to provide amounts sufficient to compensate for the deficits. Hatermink and Van Kekem (1994) observed that about 1000 kg N ha^{-1} and 150 kg P ha^{-1} were lost in the last 30 years in some farming systems of eastern Tanzania. The major task ahead is to reverse the trends, increase and maintain adequate soil fertility levels on sustainable basis.

One of the potential entry points of reversing declining soil fertility trends could be sequential or simultaneous planting of cereal crops and an indigenous N_2-fixing leguminous plant (Gachene *et al.,* 2000). Species like *Sesbania sesban, Tephrosia vogelii, Tephrosia candida, Gliricidia sepium, Cajanus cajan* and *Crotalaria ochroleuca* have the advantage of accumulating large quantities of high quality biomass, and could be a source of nutrients in subsequent cropping (Balasubramanian and Sekayange, 1992; Rutunga *et al.,* 1999). In areas with favourable biophysical conditions such species accumulate 1-6 t ha^{-1} of foliage, 3-7 t ha^{-1} of litter, 187-203 kg N ha^{-1}, 13-17 kg P ha^{-1}, 80-90 kg K ha^{-1}, 58-98 kg Ca ha^{-1} and 9-13 kg Mg ha^{-1} (Drechsel *et al.,* 1996). However, in sites with suboptimal soil and climatic conditions, the quantity of biomass and nutrients accumulated by these species are generally low to have significant effect on soil fertility regeneration and on subsequent cropping. Evaluating the performance of these species in various agro-ecozones in fallow, rotational or intercropping situations is important before extending the use of such species in the farmers' fields. With this background, a field experiment using *T. vogelii* was conducted on a site with sub-humid climate, acidic, N and P deficient soil with the following objectives:

i. To evaluate the impact of fallow period on biomass and N accumulations
ii. To assess the effect of *T. vogelii*-maize rotation on maize yield
iii. To monitor the influence of *T. vogelii*-maize rotation on soil pH, Ca, K and Mg.

Materials and Methods

Site description

The experiment was conducted in the SUA Farm, (37°39′12.4″E, 06°50′24.5″S), in eastern Tanzania, at an elevation of 540 m a.s.l and slopes of 1.5 to 2%. The soil was classified as Hyperdystri-Umbric Ferralsol and Typic Haplustox using FAO Soil Classification (FAO, 2001) and the USDA Soil Taxonomy (Soil Survey Staff, 1999) systems, respectively. Parent material of the experimental site is colluvium derived from mafic metarmorphic rocks (Fe and Mg containing rocks) originating from the Uluguru Mountains. The soil was clay (54% clay), acidic (pH-H_2O-5.1), had low P (Bray-1 P-2.1 mg kg^{-1}) and deficient in N (0.07%). Grasses such as *Andropogon gayanus, Launaea conuta, Panicum maximum, Oxygonum sinuatum* and *Commelina beghalensis* dominated the site.

The climate is sub-humid tropical with short rains starting from mid November ending in end of January and long rains start in March and end in May. However, the onset and distribution of both short and long rains is irregular and unreliable. In the 10-year period (1987/88-1996/97), the total annual rainfall ranged from 711 to 1044 mm with an average of 850 mm. In the same period, the monthly total evaporation varied from 74.3 mm in May to 176.9 mm in December. Moisture surpluses are in March to May, and the remaining months are characterized by moisture deficits (Figure 1).

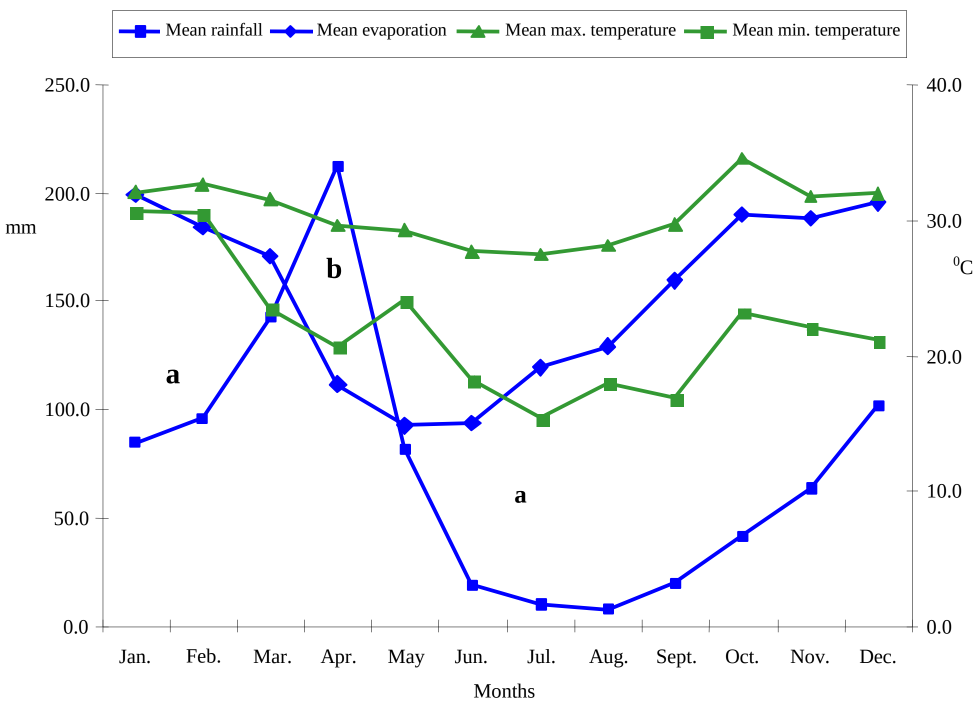

Figure 1. Ten year mean monthly rainfall distribution, evaporation, and mean maximum and minimum temperatures at SUA Farm, Morogoro.

Field activities

The field experiments were conducted sequentially starting with fallow establishment, first post-fallow maize response to fallow biomass, *T. vogelii* relay and second-post fallow maize response to *T. vogelii* relay biomass and to residual MPR applications. Table 1 gives the sequence of these activities and fertilizer application schedule.

Following land preparation using tractor, the experiment was laid as randomized complete block design, replicated three times with plot size of 4 x 8 m. *T. vogelii* was direct seeded at 1 - 2 cm depth in back filled (starting with topsoil) planting holes measuring 20 x 20 cm and a depth of 30 cm that were spaced at 50 x 50 cm. In each replication, 6 plots were under natural fallow (Nf), 4 plots under *T. vogelii* fallow with 0 kg P ha^{-1} and 2 plots under *T. vogelii* fallow applied with 80 kg P ha^{-1}. In P treated plots, Minjingu phosphate rock (MPR) was mixed with the soil back filled and *T. vogelii* seed sown. *Tephrosia vogelii* fallows were weeded and flowers removed regularly, while Nf was left to grow without any management for 22 months.

At 22 months, *T. vogelii* plants were uprooted and leaves separated from stems, followed using land preparation. Residues from Nf were incorporated in the soil during land preparation. The *T. vogelii* biomass at 80 kg N ha^{-1} comprised mainly litter (75%) and a small proportion of leaves (25%) was incorporated into the soil by hand hoe 2 days before maize planting. Table 2 gives total amounts of N, P, K, Ca and Mg applied in the *T. vogelii* biomass in the first and second post-fallow maize cropping. Both MPR and TSP at 80 kg P ha^{-1} were broadcasted and incorporated to about 15-cm depth and maize (var. TMV-1) planted at 30 x 75 cm spacing. Sulphate of ammonia was applied at 80 kg N ha^{-1} in two equal halves, at 2 and 6 weeks after maize planting.

Table 1. Sequence of field experiments and schedule of fertilizer application, SUA Farm, Morogoro Tanzania

Treatments	Fallow establishment (1999/00-2001/02)		First post fallow maize cropping (2001/02)		Fertilizer applied in the Second post fallow maize cropping (2002/03)
	Fallow type	MPR use	Fertilizers applied	*T. vogelii* relay	
T1	Natural	Nil	Nf biomass	Nil	Nf biomass
T2	Natural	Nil	TSP+S/A	Nil	S/A
T3	Natural	Nil	S/A	Nil	S/A
T4	Natural	Nil	MPR+SA	Nil	S/A
T5	*T. vogelii*	Nil	*T. vogelii* biomass	Nil	Nil
T6	*T. vogelii*	Yes	*T. vogelii* biomass	Nil	Nil
T7	*T. vogelii*	Nil	*T. vogelii* biomass+MPR	Nil	Nil
T8	*T. vogelii*	Nil	*T. vogelii* biomass	Yes	*T. vogelii* biomass
T9	*T. vogelii*	Yes	*T. vogelii* biomass	Yes	*T. vogelii* biomass
T10	*T. vogelii*	Nil	*T. vogelii* biomass+MPR	Yes	*T. vogelii* biomass
T11	Natural	Nil	MPR+SA	Yes	*T. vogelii* biomass
T12	Natural	Nil	Nf biomass	Yes	*T. vogelii* biomass

Table 2. Amounts of N, P, K, Ca and Mg applied in *T. vogelii* biomass

Nutrient	Amount added in 2001/02 (kg ha^{-1})		Amount added in 2001/02 (kg ha^{-1})	Total applied (kg ha^{-1})
	Leaves	Litter	Leaves	
N	20	60	30	110.0
P	0.78	3.2	1.2	5.2
K	10.9	60	16.4	87.3
Ca	9.1	88	13.6	111.4
Mg	2.4	10	3.6	16.0

At 4 weeks after planting *T. vogelii* was introduced as relays in treatments 8 to 12. Recommended agronomic practices such as timely weeding and pest control were strictly adhered. At maturity maize cobs were harvested on a net plot of 3.4 x 6.5 m, sun dried and shelled. After harvest, *T. vogelii* plants were left to grow for 11 months, up to the beginning of 2002/03 main rain season.

At 11 months, relayed *T. vogelii* plants were uprooted and leaves separated from stems, followed by land preparation. Residues from Nf were incorporated in the soil during land preparation. The *T. vogelii* biomass at 30 kg N ha^{-1} comprised of leaves was incorporated into respective plots using hand hoe 2 days before maize planting. Sulphate of ammonia was applied at 30 kg N ha^{-1} in two equal halves, at 2 and 6 weeks after maize planting. Both MPR and TSP were not applied in the second maize crop. *Tephrosia vogelii* biomass was supplemented from the nearby fields to reach the 80 or 30 kg N ha^{-1} in the first and second post fallow maize crops, respectively.

The data collected included total DM of litter, leaves and stems, N and P accumulations in *T. vogelii* plant materials, and maize grain yield. The soil parameters monitored were pH, Ca, K, and Mg. Litterfall was collected only from the first *T. vogelii* fallow in a 1 m^2 quadrat for 10-months, commencing at 12 ending at 22 months, and were analyzed for N and P concentrations. The litterfall outside the 1 m^2 quadrat was also collected and stored for subsequent application as organic fertilizer material. The foliar and stem N and P concentrations were determined from samples collected from harvested *T. vogelii* plants. A portion of litter, leaves and stems were dried in an oven at 70° C to constant weight, and used to calculate their dry weight on aerial basis. For relayed *T. vogelii* plants, only leaves and stems were used to obtain the dry matter weight. Maize grain yield for first post fallow crop was determined at 12.5% moisture and calculated on per ha basis. Prolonged drought up to tasselling stage led to failure in grain formation, and this necessitated measuring DM as an index of maize yield. Maize flag leaf was sampled from 10 randomly selected plants and analysed for N and P. Soil parameters were monitored by initial and final soil sampling.

Laboratory procedures as described by Okalebo *et al.* (2002) were used for determination of soil pH, available P (Bray-1 method), particle size analysis. Plant total N was determined using the macro-Kjeldahl digestion-distillation-titration method, and P was determined using the dry-ashing method. The data were analysed by MSTAT-C statistical package and significant means were separated using Duncan's New Multiple Range Test or student t-test at 5% level.

Results and Discussion

Dry matter production in 11- and 22-months old rotational *T. vogelii* fallow

Table 3 gives the total amounts of litter, leaves and stem DM production in the 22 months period. Application of MPR significantly ($P \leq 0.05$) increased litter and stem DM but not leaf DM. Relative to 0 kg P ha^{-1}, litter DM increased by 129 due to application of 80 kg P ha^{-1}. The data further indicate that at 22-months, litter DM was higher than leaf DM by contributing an average of 86.1% of the total biomass accumulated which is comparable to 82% of the two-year *T. vogelii* fallow reported in Rwanda by Drechsel *et al.,* (1996). This is contrary to observations obtained by Mkangwa *et al.,* 2003 for 12-weeks old *T. vogelii* seedlings. In 12-weeks old *T. vogelii* seedlings. The observed significant ($P \leq 0.05$) increase in shoot biomass by 94.4% due to MPR application. However, relative to other sites, the total litter DM and leaf DM obtained in this experiment are low, suggesting that in addition to P, other factors were also limiting to production.

The leaf and stem DM accumulated in 11-months old plants compared to that in 22-months old plants were very low (Table 4), suggesting that much biomass is accumulated in the age of above 11-months. MPR application significantly ($P \leq 0.05$) increased both leaf and stem DM. These observations indicate that *T. vogelii* responds to P fertilizers only at young ages, but as the age progresses, the P responses diminish. Sanginga *et al.,* (1995) observed similar decrease in P responses with time in field-grown trees. They found that *Gliricidia sepium* and *Senna spectabilis* responded to P applied at planting up to 168 days after planting, but not at 336 days.

Table 3. Effect of MPR application and fallow period (22-months) on total litter, leaf and stem production of *T. vogelii* fallows

Plant component	P rate (kg P ha^{-1})	Total DM (t ha^{-1})	Total N and P accumulation (kg ha^{-1})	
			N	P
Litter	0	2.5b	34.5b	1.2b
	80	5.7a	82.5a	3.7a
Leaves	0	0.39a	12.6a	0.5a
	80	0.44a	14.6a	0.6a
Stems	0	4.1b	18.6b	1.8b
	80	6.8a	36.5a	7.1a

Means bearing the same letter within a column and plant component are similar using t-test at $P \le 0.05$.

Table 4. Influence of fertilizer application on biomass, and foliar N and P accumulations of 11-months *T. vogelii* plants

Treatments	Biomass (t ha^{-1})		Foliar N and P accumulations (kg ha^{-1})	
	Leaves	Stem	N	P
Control	0.095b	1.25b	2.79a	0.13a
T. vogelii biomass	0.140ab	2.33ab	2.21a	0.10a
T. vogelii biomass+MPR[1]	0.220a	2.88a	3.26a	0.20a
T. vogelii biomass+MPR[2]	0.213a	2.55ab	4.82a	0.22a

Means bearing the same letter within a column are similar using DMRT at $P \le 0.05$, [1] MPR applied at maize planting in 2001/02 season, [2] MPR applied on fallow in 1999/00 season.

Nitrogen accumulations in 11- and 22-months old rotational *T. vogelii* fallow

The N and P accumulated in the litter, leaf and stems of 22-months plants as influenced by MPR application is given in Table 3. The N and P accumulated in the litter and stems but not in leaves were significantly ($P \le 0.05$) increased by MPR application. Lack of significant N and P accumulations in the leaves could be due to decreased P responses in 22-months old plants. Among the three plant components, litter provided more nutrients than the two components, by accounting up to 62% of the total N accumulated. The trend of P accumulation was similar to that of N, but P accumulated was very low. Rutunga *et al*. (1999), Hagedorn *et al*. (1997) and Mgangamundo (2000) also observed low P accumulations in the biomass of *T. vogelii* in other sites.

Both N and P accumulated in 11-months old plants were very low and were not influenced by different fertilizers applied (Table 4), suggesting that one season rotation can not provide sufficient nutrients for subsequent cropping.

Maize grain yield following 22 months old *T. vogelii* fallow

The maize grain yield following 22-months fallow as influenced by application of MPR, biomass from natural fallow or *T. vogelii* is given in Table 5. Application of different fertilizer materials significantly ($P \le 0.05$) increased maize grain yield. Application of MPR to *T. vogelii* fallows gave significantly highest maize grain yield whereas control plots gave the lowest yields. Application of *T. vogelii* biomass alone or co-applied with MPR, MPR+S/A and TSP+S/A gave similar maize grain yield. Relaying *T. vogelii* with maize plants had no effect on maize grain yield, possibly due to age. At tasselling, the relayed *T. vogelii* plants were 15 days old.

Relative to natural fallow plots, maize yield increased by 147% in plots applied with *T. vogelii* biomass that were amended with MPR at fallow establishment, by 105% where *T. vogelii* biomass was co-applied with

MPR and by 100% where *T. vogelii* biomass was applied alone. Compared to application of Sulphate of Ammonia (S/A) alone, maize grain yield was significantly ($P \leq 0.05$) increased by 39.6% due to application of *T. vogelii* biomass alone.

Improvement of maize grain yield subsequent to *T. vogelii* fallows is widely reported. In most cases longer *T. vogelii* fallow period led to more grain yield than short duration fallows. Relative to natural fallow, maize grain yield planted after *T. vogelii* fallows of 2 years was greater than 150% (Gichuru, 1991), after 1-year was between 70-100% (Drechsel *et al.,* 1996) and after 6-months was 33% (Niang *et al.,* 1996).

Table 5. Maize leaf N and P concentration and grain yield due to fallow biomass and N and P application, SUA Farm, Morogoro, Tanzania

Treatment	Flag leaf N and P conc. (%)		Grain Yield (t ha^{-1})
	N	P	
1. Control (natural fallow)	2.28c	0.228c	1.64d
2. SA	2.84ab	0.268bc	2.35cd
3. TSP+SA	2.72ab	0.319a	3.45ab
4. MPR+SA	3.02a	0.299ab	3.27ab
5. *T. vogelii* biomass	2.78ab	0.281ab	3.28ab
6. *T. vogelii* biomass+MPR	2.68ab	0.313ab	3.36ab
7. *T. vogelii* biomass+MPR (1999/2000)	2.7ab	0.313ab	
			.05a

Means with the same letter and within a column are not statistically different at $P \leq 0.05$

Changes in soil pH, exchangeable Ca, Mg and K

The change in soil pH and exchangeable bases (K, Mg and Ca) in the trial site were obtained by differences between the initial and final properties as induced by fallows, fertilizers used and maize cropping.

The changes in soil pH between initial and final sampling is given in Table 6. The change in soil pH was significantly ($P \leq 0.05$) increased by all the treatments. The highest and significant increases ranging from 8.1 to 11.9% were observed in plots applied with MPR and *T. vogelii* biomass. High Ca contents applied caused highest increments in soil pH in MPR co-applied with *T. vogelii* biomass plots. The biomass of *T. vogelii* applied in 2001/02 contained 71 kg K-, 97.1 kg Ca-, and 12.1 kg Mg-ha^{-1} (Table not shown). This observation suggests that co-application of *T. vogelii* biomass with MPR is more effective than S/A in increasing Ca availability, hence soil pH. George *et al*. (2002) also reported increases in soil pH by 1.0 pH unit in 18 months old *T. vogelii* fallows with litter retained in a Ferralsol in western Kenya.

The change in exchangeable Ca are given Table 6. The change in exchangeable Ca was increased in all the treatments, with significantly ($P \leq 0.05$) higher values in plots applied with TSP+S/A, MPR+S/A, and MPR co-applied with *T. vogelii* biomass. The lowest increases were in plots under natural fallow with one time application of *T. vogelii* biomass. Application of MPR at *T. vogelii* fallow establishment was more effective in increasing exchangeable Ca than co-application of the two materials at maize planting. *T. vogelii* biomass alone had significant effect on changes of exchangeable Ca. These results suggest that *T. vogelii* biomass increases exchangeable Ca by increasing solubility of MPR and Ca release from applied *T. vogelii* biomass.

Table 6. The change in soil pH and exchangeable K, Mg and Ca

Treatments	Soil pH	Exchangeable bases ($cmol_c$ kg^{-1})		
		Ca	Mg	K
Natural fallow+*T. vogelii* biomass[3]	+0.29c	+1.8e	+0.58a	+0.18cde
S/A	+0.25c	+0.9f	0.23e	+0.17cdef
TSP+S/A	+0.47b	+12.8c	0.48b	+0.193bcd
MPR+S/A	+0.50b	+8.5d	0.37c	+0.13ef
vogelii biomass+*T. vogelii* biomass[3]	+0.48b	+8.5d	0.36c	+0.25b
vogelii biomass+MPR[1]+*T. vogelii* biomass[3]	+0.54ab	+15.4a	0.30d	+0.31a
vogelii biomass+MPR[2]+*T. vogelii* biomass[3]	+0.65a	+14.4b	0.50b	+0.25b

Means with the same letter in the same column are similar using DMRT $P \leq 0.05$. [1] MPR co-applied with *T. vogelii* biomass at maize planting in 2001/02 season. [2] MPR applied on *T. vogelii* fallow at establishment in 1999/00 season. [3.] *T. vogelii* biomass applied at 30 kg N ha^{-1}.

The changes of exchangeable Mg were significantly ($P \leq 0.05$) increased in all the treatments. Highest values were observed in natural fallow plots and lowest in plots applied with S/A alone. Relative to natural fallow, application of MPR, TSP and *T. vogelii* biomass had significantly low effect on the changes of exchangeable Mg. Low contents of Mg in the *T. vogelii* biomass could account for low levels of induced exchangeable Mg.

The changes in exchangeable K were increased in all the treatments, ranging from 16.3 to 45.6%. Exchangeable K was significantly ($P \leq 0.05$) higher in plots applied with *T. vogelii* biomass either alone or co-applied with MPR. The percent increase in exchangeable K due to application of *T. vogelii* biomass alone or with MPR was 21.4 to 45.6%. Significant increases in exchangeable K were also observed in plots applied with MPR or TSP, with percent increase of 16.3 to 25.7%. High K concentration in *T. vogelii* biomass contributed to increased exchangeable K contents in plots applied with this material.

The results obtained in this study indicate that incorporation of accumulated litter and foliar biomass alone into the soil is able to improve soil pH towards neutrality and exchangeable Ca, Mg and K significantly. Co-application of *T. vogelii* biomass with MPR further increases these parameters. Natural fallow on the other hand, had also increased soil pH, exchangeable Ca, and K though at relatively lower level compared to improved fallow of *T. vogelii*. The contribution of Natural fallow in increasing exchangeable Mg was much higher than that of plots amended with *T. vogelii* biomass.

Conclusions

The biomass and N accumulations in *T. vogelii* fallow-rotation with maize are more influenced by fallow period and soil fertility status. Longer the fallow period led to more fertile soil and more biomass and N accumulations. The technology of *T. vogelii*-maize rotation has potential of increasing soil pH, K and Ca, and consequently maize grain yield.

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5. COMPONENTS PERFORMANCE AND RESIDUAL EFFECT IN RELAY INTERCROPPING OF *TEPHROSIA VOGELII* AND MAIZE IN SEMIARID GAIRO, TANZANIA

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Abstract

Producing sufficient shrub biomass to enhance soil fertility and maize yield in subsequent season without compromising yield of current crop in simultaneous agroforestry system was the main task of this research work in land scarce semi arid Gairo. A split plot design with main plot factor as time of planting having levels 0, 2 and 4 weeks after maize planting and spacing as minor plots factor with levels 30 (Tv30), 60 (Tv60) and 90 (Tv90) cm intra-row spacing (intercrop and monoculture *Tephrosia vogelii)* plus control (maize monoculture), was laid in the first season. For second and third seasons, a split- split-plot design was laid, where spacing treatment was split to two levels of fertilizer (without and with half and full recommended doses of N and P respectively). Maize height and stover yield were assessed at tasselling while grain yield was assessed at maturity. *Tephrosia* biomass yield was assessed at three, six and eleven months. In the second and third seasons, field mineral nitrogen and maize yield were assessed. Highest maize yield was maintained with Wk2Tv60 in the first season. At three months in intercrops, total shrub biomass was significantly higher ($P<0.05$) in Wk2Tv30 than the rest. Total shrub yields at eleven months in monoculture plots were 2-6 times higher than intercrops. Mean shrub biomass increment, and mean shrub diameter increment were significantly higher ($P<0.05$) in Wk0Tv90 than the rest between six and eleven month assessments for intercrops. Soil properties after eleven months did not consistently differ, but monoculture *Tephrosia* showed superiority in most cases over intercrops. Maize yield was maximized with fertilized monoculture *Tephrosia*, but unfertilized intercrops recorded 50 and 58 percent increase over unfertilized maize monoculture in second and third seasons, respectively. The study concludes that *Tephrosia* relay-intercropped with maize can enhance sustainable maize production in land-scarce semi arid areas and recommends further study on continuous intercropping involving various provenances of *Tephrosia vogelii*.

Introduction

Competition for limited growth resources between food crops and trees/shrubs is perhaps the greatest hindrance to the practice of simultaneous agroforestry in semiarid tropics, where low soil moisture availability is the most serious common problem for agricultural production. Inspite of this, the fundamental hypothesis of Agroforestry (AF) is that different plant life forms such as trees/shrubs and herbaceous crops or pastures occupy to some extent different soil strata with their root systems when grown in association, leading to a degree of complementarity in the use of soil resources (Schroth, 1999). In light of this hypothesis, the success of any simultaneous AF system therefore largely depends on the careful selection and manipulation of the woody component of the system. In this regard, the selection of species would usually consider such factors as growth rate and vigour in addition to rooting pattern, soil fertility improvement and range of other uses.

In Tanzania, the popular AF shrub species used for soil fertility improvement include *Sesbania sesban, Gliricidia sepium, Cajanus cajan* and *T. vogelii* (Chamshama *et al.,* 2000). The first two species and some varieties of the third are noted for high growth rate and biomass production; characteristics that render them less suitable for simultaneous AF in semiarid areas. The less vigorous varieties of *C. cajan* on the other hand have insufficient biomass production to improve crop yield in the subsequent year (Fasuluku, 1998;

Mgangamundo, 2000). Hence there is a need to find alternative species with less vigour to minimise competition, but enough biomass yield to improve soil properties and hence crop yield in one year of intercropping.

T. vogelii has been reported to improve crop yield in short fallows and intercropping systems in tropical Africa (Rocheleau *et al.,* 1988, Balasubramanian and Sekayange, 1992; Niang *et al.,* 1996, Rutunga *et al.,* 1999, Mgangmundo, 2000). *T. vogelii* has rapid growth vigour and fast maturing, flowering in one year, but hardly exceeding 2 m in height. Although the shrub is not edible by human as well as animals, farmers in many parts of Tanzania have realized the great potential of this species in AF for soil fertility improvement and pest control in field and storage. The species is also known to be drought tolerant, less susceptible to root knot nematodes that highly limits the propagation of *Sesbania* species (Rutunga *et al.,* 1999, Mgangmundo, 2000) and can be cultivated by direct seeding, thus making its use less labour demanding. It also has fewer pests than most common AF shrubs probably due to its pesticidal properties. In contrast with *Sesbania* especially, *T. vogelii* does not need inoculation with specific rhizobia strains, as it nodulates with native rhizobial population on wide range of soils (Mafongoya *et al.,* 2003).

T. vogelii has moderate growth vigour, when grown in close spatial association with fast growing annual crops however, some level of competition for limited resources is most likely (Rao *et al.,* 1998). The degree of competition is a function of several factors including inherent effectiveness in capturing growth resources, which in turn is a function of *Tephrosia* shoot growth, rooting pattern and root biomass (Ong *et al.,* 1996). *Tephrosia* shoot growth and root biomass may be affected by plant density as well as the time of planting in relation to planting of annual crop. It is therefore hypothesised that with appropriate time of planting and spacing of *Tephrosia*, competition for soil moisture, sunlight and growth space can be minimised and thus optimising maize growth and yield without jeopardizing the potential of *T. vogelii* to produce sufficient biomass to influence soil fertility and yield of crops in subsequent seasons.

Although several authors have commented on relay intercropping technology as a good soil management system, as well as the shrub *T. vogelii* (Rocheleau, 1988, Balasubramanian and Sekayange, 1994), generally, there is no information on the performance of component species under this system for semi arid conditions, particularly in Tanzania. Specifically, records on the effect of shrub density and time of planting on maize and *Tephrosia* performance in relay intercropping are virtually unavailable.

Understanding how best *T. vogelii* (the woody perennial component of the system) can best be manipulated in time and space to minimise loss of crop yield and optimise *Tephrosia* biomass production in the intercropping year will help sustain increase arable crop production in already exhausted scarce arable land at profitable level. The objective of this study was to determine the effect of spacing and time of planting *T. vogelii* in relation to time of planting maize crop on *T. vogelii* and maize performance in land-scarce semi arid Gairo, Tanzania.

Materials and Methods

Study site description

The study was conducted at Gairo, located half way between Morogoro and Dodoma Regions along the Dodoma/Morogoro Main Road (36^0 45' E, 6^0 30' S; 1200 m.a.s.l.) in Morogoro Region, Tanzania. The natural vegetation mainly consists of shrubs and few widely scattered trees such as *Acacia*, *Brachystegia, Julbernadia* and *Isoberlinia.* The experimental site acquired from local farmers had largely been subjected to years of continuous cropping with no deliberate external inputs of fertilizer and yields are generally very low. The soil is generally classified as Haplic Lixisols (Msanya and Msaky, 1994). The initial site characterization revealed organic carbon content 0.24 - 0.84%, electrical conductivity 0.03 – 0.05 dS cm^{-1}, Bray1 available phosphorus 0.88 – 3.90 mg kg^{-1} and total nitrogen 0.10 – 0.18%. Soil texture to the 120 depth cm is sandy loam to sandy clay with pH ranging between 5.47 and 5.88. Rainfall is usually low and poorly distributed, varying from year to year. The long-term average annual rainfall is around 499 mm, most of which falls between November and May (Chamshama, *et al.,* 1994). Maize varieties grown in this area are harvested within five months, and are usually planted between December and January depending on the promptness of the rains.

Experimental design and Establishment

A split-plot layout was used to establish the experiment in December 2001 in three replications following ploughing and harrowing. Main plots treatments were three levels of time of planting shrub and seven levels spacing of shrub as minor plot treatments. Levels of main plot factor included 0, 2 and 4 weeks time of planting *Tephrosia* in relation to time of planting maize, designated as T1 (Wk0), T2 (Wk2) and T3 (Wk4). Levels of minor plot included 30 (Tv30), 60 (Tv60) and 90 (Tv90) cm intra-row spacing of Tephrosia (intercropped) plus control (Tv0 or no *Tephrosia*). Adjacent and concurrently with the first layout, was laid an extension of minor plots of *Tephrosia* monoculture stands, designated as Tvm30, Tvm60 and Tv90 representing similar spacing as in intercrop.

Main plot size measured 14.8 x 17.5 m laid along contours with 4 m distance between them. Minor plot size measured 4.5 x 9.2 m separated by 2 m distance, in which 6 rows of maize were planted at a spacing of 90 x 45 cm, between and within row spacing respectively. *Tephrosia* seeds were sown directly between rows of maize. *Tephrosia* remained on site up to November 2002, while maize was harvested in May 2002 in the first season and plots were weeded twice before harvesting maize and once during dry season before *Tephrosia* was cleared. In the second and third seasons, a split – split-plot design was used in which the minor plot of the first season was split to give two levels of fertilizer treatment as minor plot treatments, that is F0 (without) and F1 (with half recommended dose of nitrogen (20 $kgha^{-1}$) and full dose of phosphorus (20$kgha^{-1}$) for Gairo condition.

Assessment and data collection

Tephrosia and maize biomass assessments in first season

Biomass of *Tephrosia* was assessed at maize tasselling stage. Six plants were randomly selected from second rows from outside each minor plot, dug out and taken to laboratory in polythene bags where they were washed with distilled water, first air-dried and then oven-dried to constant weight at 65^oC. Similarly maize biomass yield was assessed by carefully digging out at random six plants from each minor plot, separated into leaves stem and roots, cut and placed into polythene bags and taken to the laboratory for determination of oven-dried biomass. At maize harvesting in May 2002, Tv growth and biomass were assessed by measuring height and root collar diameter of all shrubs in the two middle rows of each minor plot. These parameters were used to generate biomass data per tree and per hectare, using allometric equations developed in this study. Maize was also harvested at the same time from two middle rows of each minor plot, grain and shaft weighed and sub-samples taken and weighed before and after oven-drying at 65^o C in the laboratory. Just before *Tephrosia* was cut down to be incorporated into the soil for the subsequent cropping season, the height and root collar diameter of all shrubs in the two middle rows were measured for estimation of above ground biomass. Root collar diameter was measured at 10cm above ground using micro-calliper to the nearest 0.01cm, while height was measured using a digital height-measuring pole. Shrub biomass yield was determined using allometric equations developed in this experiment using the two parameters measured (Ngegba, 2005). At harvesting, all maize in the two middle rows were harvested, grain and shaft weighed bulk and sub-samples were oven dried at 65^oC to constant weight. From the middle two rows, all maize stover were cut, weighed bulk and sub-samples taken to the laboratory for determination of oven dry weight.

Soil sampling for field mineral nitrogen and organic carbon

In the second and third seasons before planting of maize and immediately following layout of experiment, the first soil samples for determination of mineral N were collected from all unfertilized (F0) plots using soil auger at 0 - 15 cm depth from four randomly selected spots between the two outer maize rows. This was continued at 2^{nd}, 4^{th} and 6^{th} weeks after maize planting with the aim of assessing the effect of *Tephrosia* in intercrop and monoculture systems on field mineral N.

Laboratory Procedure

Organic carbon was determined using the Walkey and Black wet oxidation method using concentrated sulphuric acid and aqueous potassium dichromate (Okalebo *et al.,* 1993). Electrical conductivity and pH were determined in 1:2.5 ratio of soil:distilled water paste (Anderson and Ingram, 1993) using electrical conductivity and pH meters respectively. Total nitrogen was analysed using the semi-micro Kjeldahl procedure described in Bremner and Mulvaney (1982) after digesting samples in concentrated sulphuric acid and hydrogen peroxide as oxidising agents. Soil texture was done according to improved Bouyoucus (1962) hydrometer method and International classification of diameter classes (Okalebo *et al.,* 1993). Soil samples for field available N (i.e. nitrate-N and ammonium-N) were analyzed by calorimetric method outlined in Anderson and Ingram (1993) after extraction with potassium sulphate solution, and colour read by spectrophotometer at 410 and 655 nm wave lengths respectively.

Statistical analysis

For both split plot and split- split plot designs, data were subjected to Analysis of Variance (ANOVA) in General Linear Mode (GLM) for split plot and split-split plot in Statistical Analysis System (SAS) and significant means separated by Duncans Multiple Range Test (DMRT) in SAS.

Results and Discussion

Growth and yield of Tephrosia at three months during intercropping phase

The interaction effect of time of planting and spacing on mean plant total biomass did not differ significantly ($P>0.05$), but total shrub biomass was significantly higher ($P<0.05$) for T. vogelii planted two weeks after maize sowing at 30 cm intra-row spacing than the rest of the treatments (Figure 1b). This increase probably reflects shrub density much more than time of planting, and confirms that total biomass per unit area increases with increase in tree density (Philip, 1983). Hence, the contribution of the factor of time of planting here may be attributed to either root orientation of plant in response to soil conditions prompted by time of planting, or climatic conditions at planting, affecting growth rate (Schroth, 1999). Keen observation over time has revealed that sunny weather other than heavy rain weather favours the establishment and growth of *Tephrosia* (Mugasha, personal communication). This high biomass yield of Wk2Tv30 to some extent reflects the moisture status of the soil, which was lowest among Wk2 and Wk4 treatments at that stage (Ngegba, 2005). Generally, high biomass yield reflects high soil water utilization when all other things are normal, as the process of photosynthesis demands sufficient water, which results into biomass production. Mean plant and total biomass were also highest for *Tephrosia* planted two weeks after maize sowing at 30 cm intra-row spacing and lowest in week 2 and 90 cm intra-row spacing plots.

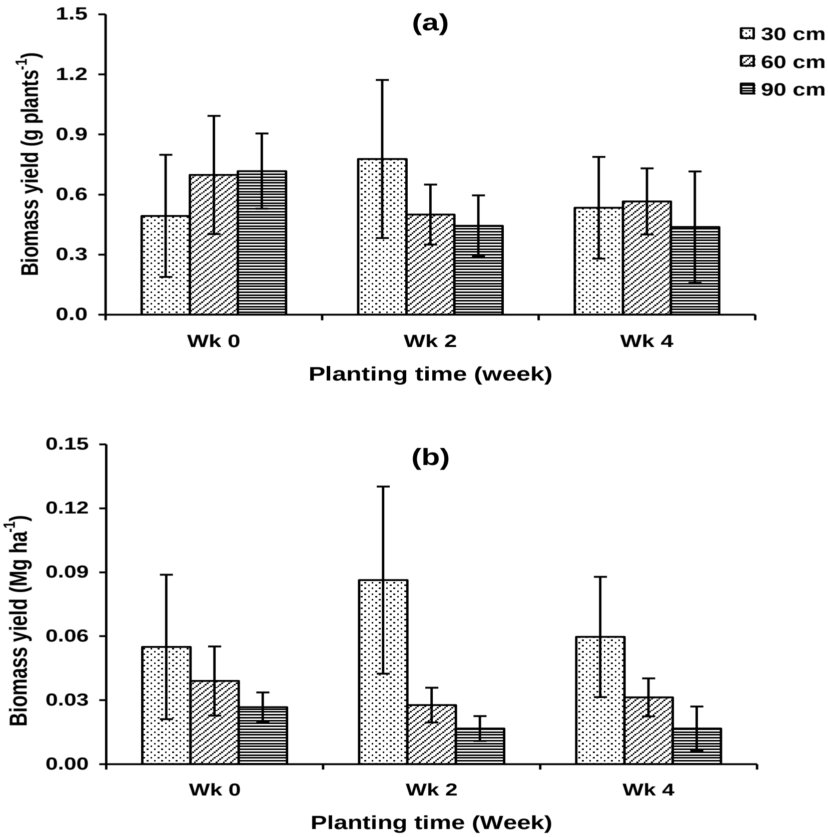


Figure 1: T. vogelii total biomass yield per plant (a) and per hectare (b) as affected by the interaction of time of planting and spacing at three month of growth in relay intercropping experimented at Gairo, Tanzania (±=standard error, n=3).

Maize growth and yields during intercropping phase

Maize grain and stover yield as well as height growth did not differ significantly (P>0.05) with time of planting and spacing of *Tephrosia* (Figure 2 and 3); suggesting that two-week difference in time of planting is insufficient to cause appreciable differences in resource use by the shrub component especially, or the system as a whole or the resource in question is not limited in supply at the time (Ngegba, 2005). However, week 2 time of planting and 60 cm intra-row spacing maintained highest grain yield. Intercropping *T. vogelii* two weeks after maize sowing resulted into 6 and 7 percent increase on maize yields compared with planting at week zero and week four respectively (Figure 2). Intra-row spacing of 60 cm recorded up to 11 percent increase over control (Figure 3). The same two treatments (i.e., Week 2 and 60 cm spacing) maintained highest maize height within both time of planting and spacing. The slight differences with week2 time of planting and 60 cm intra-row spacing and their interaction maintaining highest grain yield over others suggest that the higher moisture content maintained by these treatments (Ngegba, 2005) had some direct influence on maize yield. This then affirms the suggestions of earlier authors (McIntyre *et al.,* 1997; Ong *et al.,* 1996; Smith *et al.,* 1998) that soil water availability is indeed most limiting for the success of simultaneous AF systems in semi arid environments The fact that maize yield was still lowest in control plots (Figure 3), compared with intercropped plots, suggests that *Tephrosia* has positive effect on maize grown in closed association (in simultaneous system), with carefully selected spacing. From Figures 1, 2 and 3, biomass accumulated by maize in the form of stover was by far greater than that by *Tephrosia*, the highest being 0.07 t ha^{-1} and 6.22 t ha^{-1} of *Tephrosia* and maize biomass respectively. This implies that maize has higher growth vigour and would heavily suppress *Tephrosia* growth in a simultaneous system.

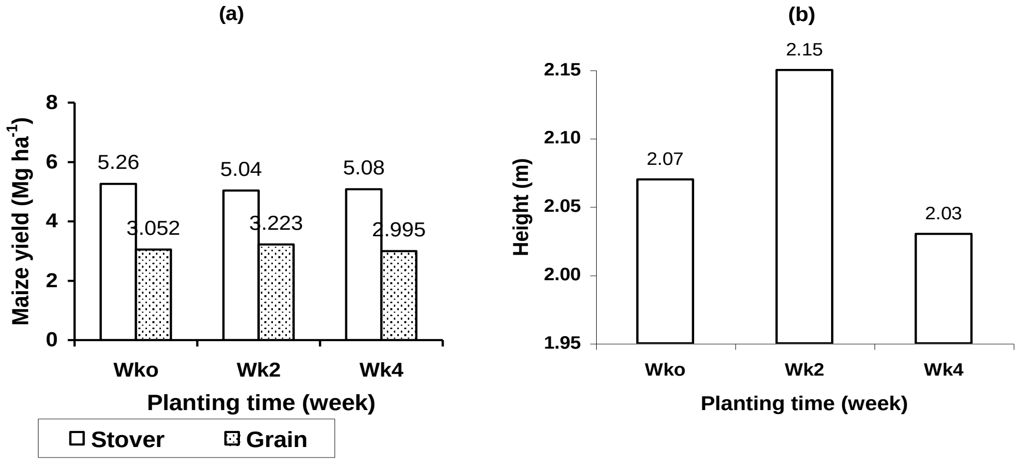


Figure 2: Effect of time of planting *T. vogelii* on maize yield (a) and height (b) during intercropping phase in relay intercropping experiment at Gairo, Tanzania

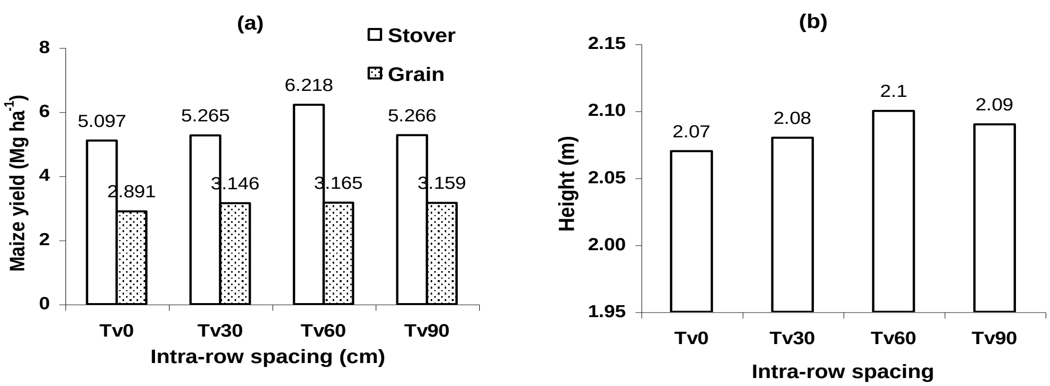


Figure 3: Effect of spacing *T. vogelii* on maize yield (a) and height (b) during intercropping phase in relay intercropping experiment at Gairo, Tanzania

Off-season growth and yield of Tephrosia

The interaction effect of time of planting and spacing on *Tephrosia* biomass, height and diameter at maize harvest (i.e. six months) is given in Figure 4. Generally, these parameters varied inversely with planting time with the lowest values obtained by *Tephrosia* planted four weeks after maize sowing, probably due to inherent short rain season in semi-arid areas where delays of planting time for four weeks would slow down growth. Consequently, biomass yields per plant and Root Color Diameter (RCD) were less affected by planting time and spacing except for week 4. Poor growth and yield of *T. vogelii* planted four weeks after maize sowing is probably associated with maize shading effects because corresponding maize height at tasselling for each treatment combination were higher than the height of *T. vogellii* at maize harvest; implying that the shrub dominated lower canopy through out the growing period (Ngegba, 2005). Interactions with intra-row spacing revealed that height, foliar, wood and total biomass yields of *Tephrosia* planted at 90 cm were significantly lower than those planted at 30 and 60 cm for week 0 and week 2 time of planting (Figures 4 c, d, e and f); indicating that this spacing is unsuitable for Relay Intercropping (RI) as it results into lower yields of both wood and foliage biomass. Foliar, wood and total biomass of *Tephrosia* planted at 30 cm intra-row spacing were significantly higher than those planted at 60 cm only for week 2 time of planting (Figures 4 d, e and f), suggesting that the former spacing is useful only when intercropping of *Tephrosia* is delayed for two weeks. The two-week delay probably caused compensatory root growth vertically to tap moisture from lower depth as maize root might have dominated the upper horizon due to high plant density (Schroth, 1999). This high biomass yields possibly reflects high moisture utilization because soil moisture was lowest in a treatment combination consisting of week 2 and 30 cm intra-row spacing (Ngegba, 2005) and photosynthetic processes demand sufficient water. The interaction effects of time of planting and spacing on biomass yields are given in Figures 5, 6 and 7. Generally, biomass yields in monoculture plots were 2 to 5 times higher than in intercropped plots (Figures 5 – 7); suggesting that shrub growth in RI plots was suppressed by maize. This suppression was most likely associated with shading effects of maize rather than competition for moisture and nutrients because prolonged observation revealed that sunny weather rather than heavy rain weather favors the establishment of *Tephrosia* (Mugasha, personal communication). Overall, the interaction of time of planting and intra-row spacing shows that biomass yields per unit area declined with increase in time of planting and spacing, emphasizing how early planting and narrower spacing can maximize biomass yield per unit area in both intercrop and monoculture (Figures 4, 5, 6 and 7).

Mean shrub biomass increment and mean shrub RCD increment were significantly higher (P<0.05) in the interaction of week 0 time of planting and 90 cm spacing treatment than others (Figure 8). In contrast, biomass yield per unit area and mean shrub biomass increment between six and eleven months growth were increasing with increase in spacing. This trend emphasises that increased spacing of trees/shrubs favours individual diameter growth and biomass yield while per unit area performance is decreased (Philip, 1983).

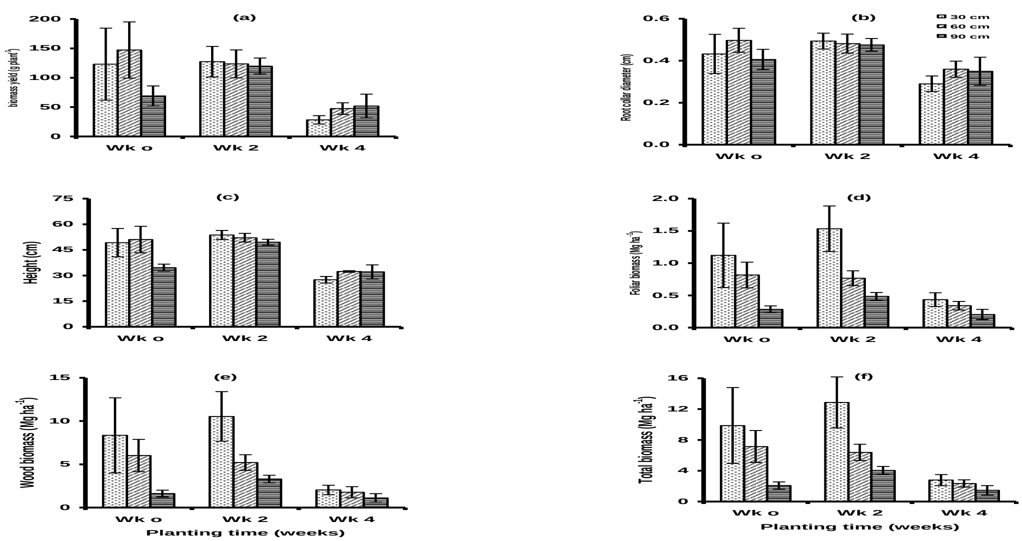


Figure 4: Effect of the interaction of time of planting and spacing on mean shrub biomass (a), mean shrub root color diameter (b), mean shrub height (c), foliar biomass (d), wood biomass (e) and total biomass (f) of *T. vogelii* at six months of growth in relay intercrpping at Gairo, Tanzania (± standard error, n=3)

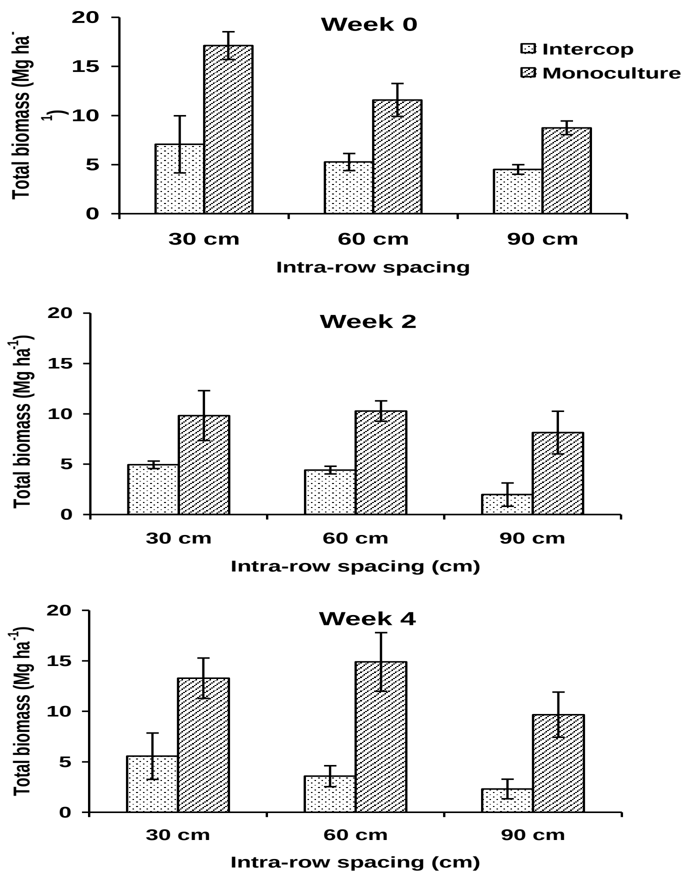


Figure 5:The interaction effect of time of planting and spacing on total biomass of *T. vogelii* at eleven months growth in relay intercropping experiment at Gairo, Tanzania (± standard error, n=3)

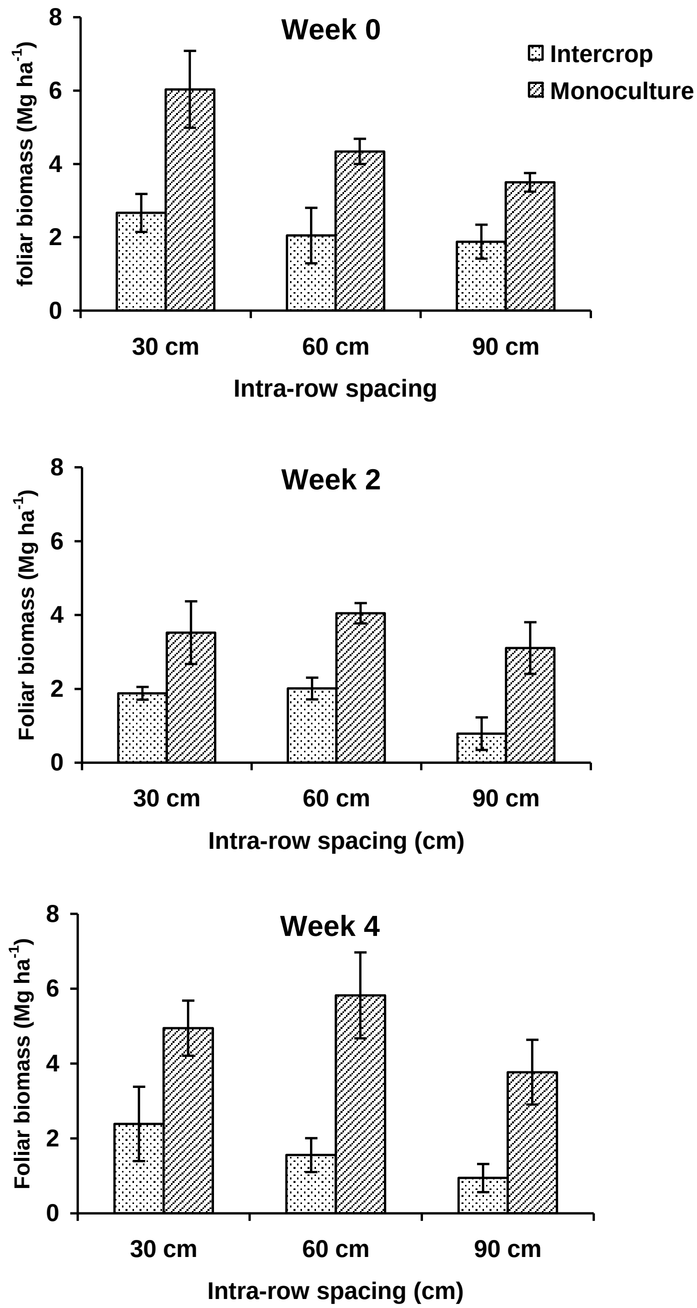


Figure 6: The interaction effect of time of planting and spacing on foliar biomass of *T. vogelii* at eleven months growth in relay intercropping experiment at Gairo, Tanzania (± standard error, n=3)

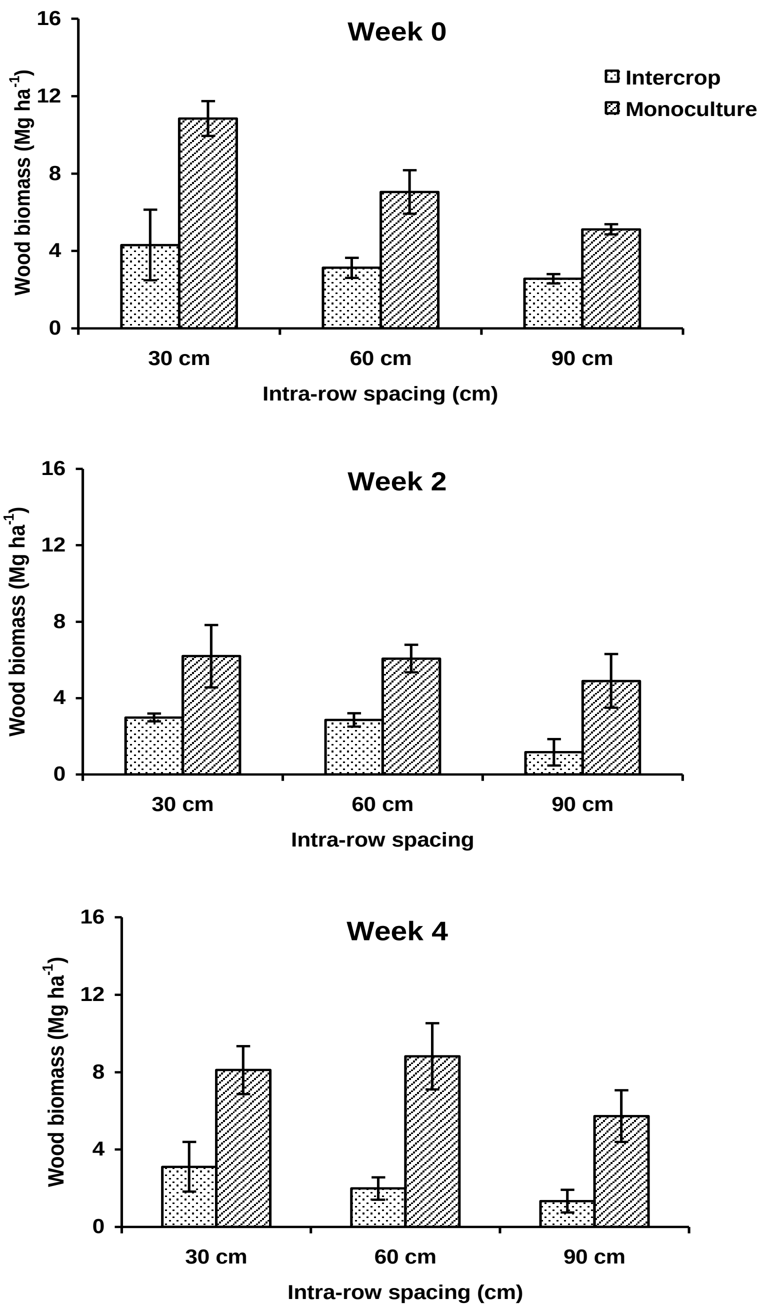
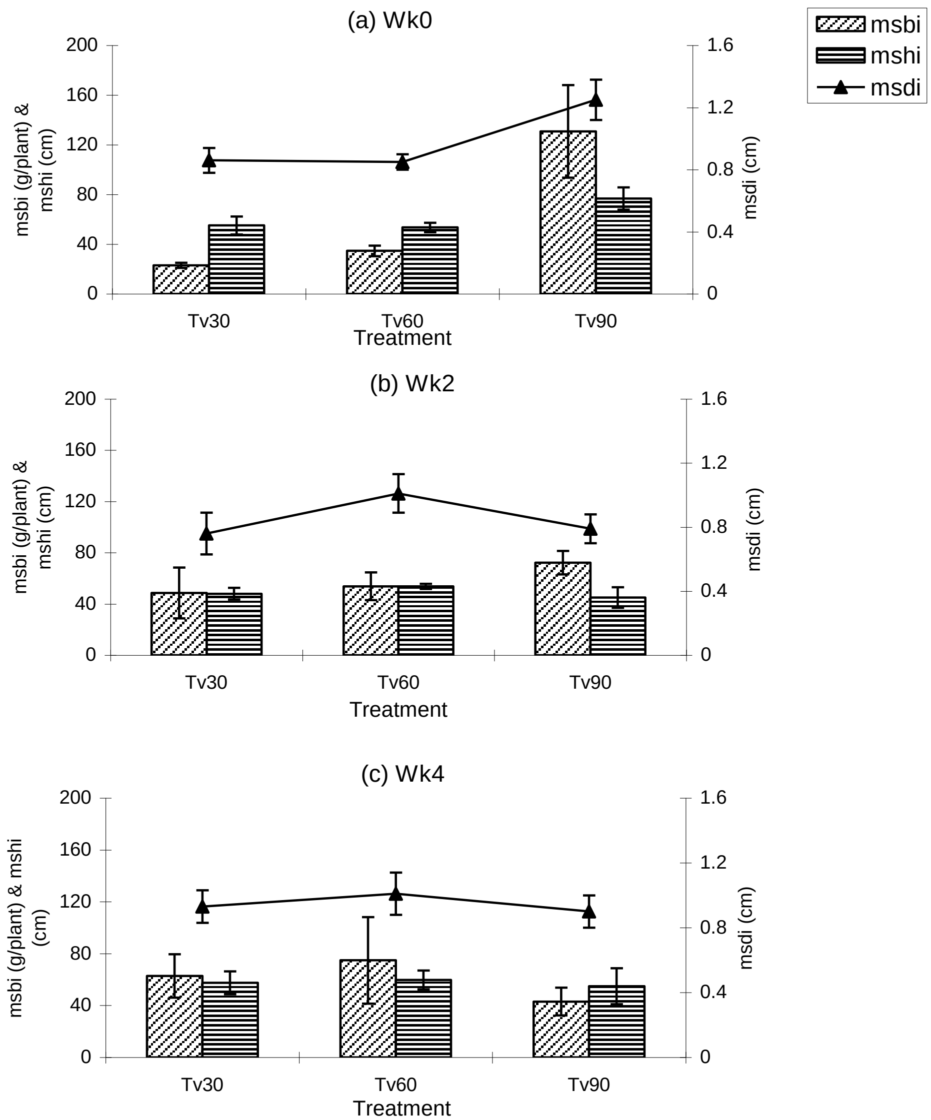


Figure 7: The interaction effect of time of planting and spacing on wood biomass of *T. vogelii* at eleven months growth in relay intercropping experiment at Gairo, Tanzania (± standard error, n=3)



Key: msbi= mean shrub biomass increment, mshi= mean shrub height increment and msdi= mean shrub diameter increment.

Figure 8: Interaction effect of time of planting and spacing on mean shrub biomass increment, mean shrub height increment and mean shrub diameter increment between sixth and eleventh month's assessments for intercrops in relay intercropping at Gairo, Tanzania.

Mineral nitrogen dynamics following intercropping phase

The residual effect of time of planting on field mineral N showed no particular trend (data not presented). Data for the residual effect of spacing of *Tephrosia* on field mineral N (Min-N) in the form of nitrate (NO_3-N), ammonium (NH_4-N) and total mineral N (Total Min-N) for first and second residual seasons are presented in Figure 10. Within spacing in the first residual season, no particular trend was observed in soil collected just before maize sowing (i.e. week 0 sampling time) and differences were not significant (P>0.05). This suggests that *Tephrosia's* ability to replenish soil nutrient during intercropping and off-season growth periods was not affected by spacing and time of planting. However, significant differences (P<0.05) were recorded at two weeks after maize sowing. Nitrate-N and total mineral-N were significantly lower (P<0.05) in control (i.e. maize monoculture) plots compared to *Tephrosia* intercropped and monoculture plots (Figures 10 a1 and a3). Similar results were also observed on the forth and sixth weeks after maize sowing, except that monoculture plots of *Tephrosia* maintained slightly higher levels of mineral-N more frequently over intercropped plots, and maize monoculture plots have sometimes shown higher levels of mineral-N over some treatments plots. Although a gradual decline in ammonium and total mineral-N from initial sampling to week 6 was noted, a sharp upsurge at week 4 was also observed (Figures 10 a2 and a3) probably reflecting nutrient up take by maize since the active growth period, which is associated with high nutrient demand, between 6 to 8 weeks (Lehman *et al.,* 1995; Nduwayezu, 1997). In the second residual season, significant differences ($P<0.05$) were recorded but without any specific trend, except that at sampling time zero, monoculture plots showed slightly higher levels of mineral-N over most intercropped plots, but the trend was reversed at week six, which also showed a sharp rise of mineral-N.

In spite of the very high amount of biomass recorded in monoculture plots over intercrops, and the consistently increasing total biomass yield with decreasing spacing, the trend of field mineral-N (Figure 10) did not reflect the above trend this much. The possible reason may be the irregular rainfall in amount and distribution. Among the factors that influence N mineralization in soil, moisture content is most paramount (Swift *et al.,* 1979). Moisture content equally affects the uptake of available nutrients. The high mineral-N, especially NO_3-N recorded under control plots sometimes equals treatment plots or is higher at sampling time zero in the first residual season may be due to three main reasons: First the treatment may not have yet affected the soil in terms of chemical properties as biomass was not yet incorporated. Second, the shrub may have taken up some of the initial available N and third, the presence of phenolic compounds in *Tephrosia* biomass that have regulatory effect on mineralization rate at different concentrations (Palm *et al.,* 2001; Mafongoya *et al.,* 1998, 2003). In the first residual season especially, the level of mineral-N was frequently higher in monoculture plots than intercrops; this may be due to differences in C: N and/polyphenol + lignin: N ratios. *Tephrosia* foliar biomass without either woody biomass or straws of maize, sorghum and the like is considered as high quality material, while those mixed are considered as medium quality. These two may obviously have different rates of decomposition and N release (Mafongoya *et al.,* 1998, 2003; Rutunga *et al.,* 2001).

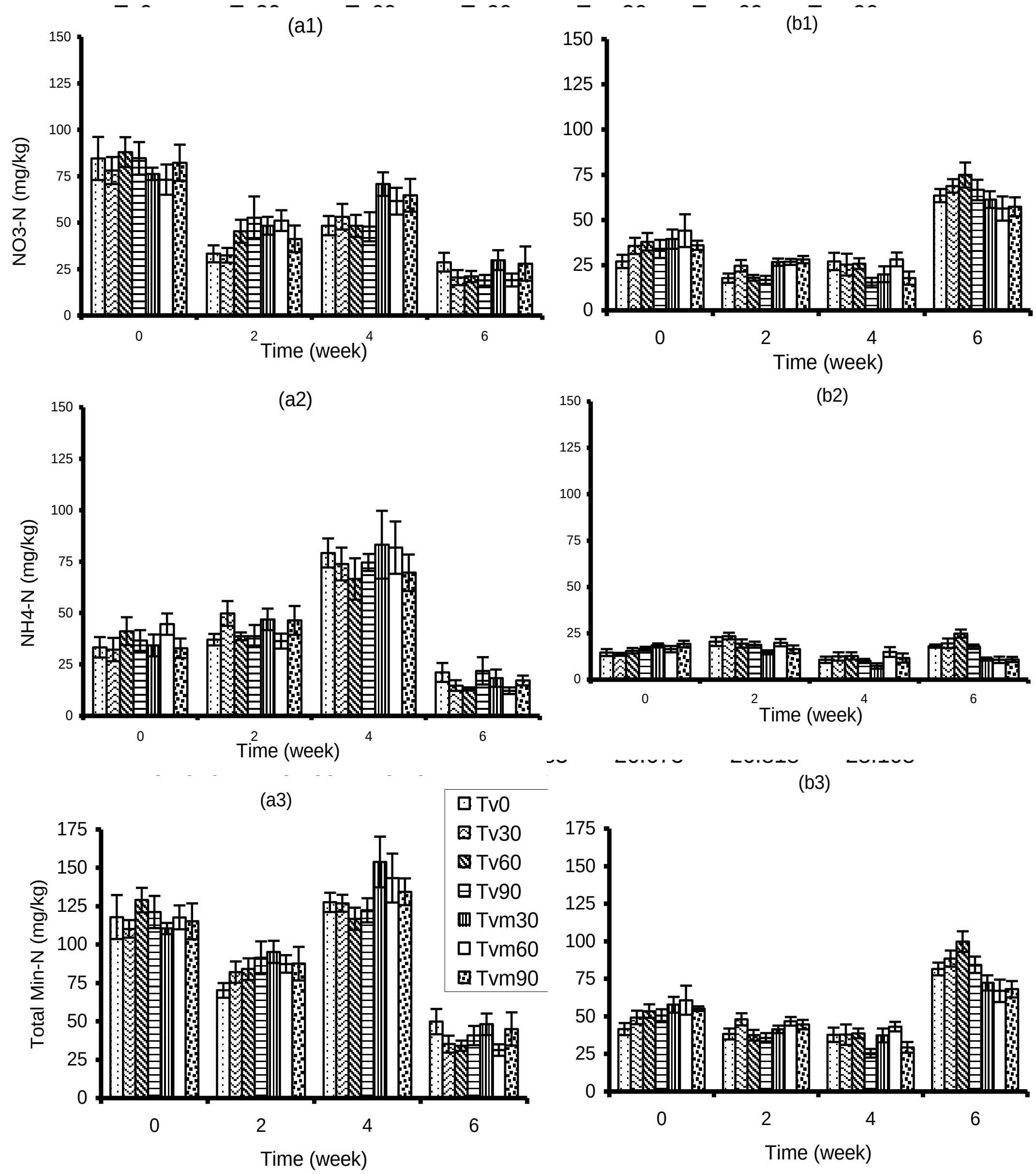


Figure 9: Soil nitrate nitrogen, ammonium nitrogen and total mineral nitrogen as affected by spacing of *T. vogelii* in first (a) and second (b) subsequent seasons following relay intercropping at Gairo, Tanzania (± standard error).

Maize growth and yields following intercropping phase-

The response of maize stover and grain to the interaction of time of planting, spacing and fertilization for both first and second residual seasons are summarized in Table 1. Highest stover yields in both first and second residual seasons were obtained in fertilized intercropped plots with the following treatment combinations: week 0 and 30 cm spacing (6.15 Mg ha^{-1}) and week 4 and 90 cm spacing (6.70 Mg ha^{-1}) while the least stover yields were obtained especially from *Tephrosia* fertilized monoculture plots in the first residual season, gave as low as 2.34 t ha^{-1} (Wk2Tv30F1).

On the other hand, highest grain yields were obtained with fertilized monoculture plots, but which were not necessarily significantly different (P>0.05) from some unfertilized monoculture plots. In the first residual season the treatment Wk4Tvm90F1 was highest in grain yield (4.33±0.27 t ha^{-1}), a fertilized monoculture plot followed by Wk2Tvm60F0 (4.22±0.14 t ha^{-1}) and Wk2Tvm90F0 (4.05±0.14 t ha^{-1}), both unfertilized monoculture plots, while the least was obtained with unfertilized maize monoculture plots (Wk0Tv0F0= 2.70±0.89 t ha^{-1}). However, an unfertilized intercrop plots (Wk2Tv30F0) attained grain yield of 4.04±0.48 t ha^{-1}.

In the second residual season, highest grain yield was obtained from the treatment Wk2Tvm90F1 (5.25±0.59 t ha^{-1}), a fertilized monoculture plot, followed by Wk0Tvm30F0 (4.68±0.58 t ha^{-1}), an unfertilized monoculture plot, while the least grain yield was obtained with unfertilized control plot (Wk0Tv0F0= 2.56±0.42 t ha^{-1}). Similarly, like in the first residual season, an unfertilized intercrop plots of Wk2Tv30F0 and Wk4Tv30F0 obtained grain yield of 4.04±0.27 t ha^{-1} and 4.05 ±0.64 t ha^{-1} respectively.

In the interaction of all three factors (time of planting and spacing of *Tephrosia* and fertilization), although maize grain yield was maximized with fertilized *Tephrosia* monoculture plots with the highest being Wk4Tvm90 (4.33 t ha^{-1}) and Wk2Tvm90 (5.25 t ha^{-1}) for first and second residual seasons respectively, unfertilized intercropped plots yielded 50 % and 58 % more than unfertilized maize monoculture plots (Tv0) in first and second residual seasons respectively (Table 1). Since unfertilized *Tephrosia*-maize intercrop would save money from fertilization and labour as *Tephrosia* is cultivated by direct seeding as well as maximize the use of land, the system may be still preferable to higher yield of fertilized sole *Tephrosia* in land scarce situations (Drechsel *et al.,* 1996).

Table 1: The effect of time of planting and spacing of *T. vogelii* and fertilization on mean maize stover and grain yield (± standard error) in relay intercropping experiment at Gairo, Tanzania

Treatment			First residual season		Second residual season		N
			Stover (t ha^{-1})	Grain (t ha^{-1})	Stover (t ha^{-1})	Grain (t ha^{-1})	
Wk0	Tv0	F0	3.97 ±0.07	2.70 ±0.89	4.15 ±0.79	2.56 ±0.42	
		F1	3.98 ±0.66	3.13 ±0.49	2.86 ±0.84	3.19 ±0.42	
	Tv30	F0	5.46 ±0.80	3.17 ±0.54	2.57 ±0.24	3.48 ±0.45	
		F1	6.15 ±0.70	3.49 ±0.90	4.28 ±0.20	3.71 ±0.44	
	Tv60	F0	4.36 ±0.27	3.27 ±0.52	5.22 ±1.06	3.18 ±0.39	
		F1	4.02 ±0.11	3.31 ±0.38	3.10 ±0.34	4.58 ±0.54	
	Tv90	F0	3.51 ±0.81	3.36 ±0.41	3.40 ±0.75	2.86 ±0.30	
		F1	5.04 ±1.27	4.05 ±0.64	5.33 ±1.01	3.74 ±0.19	
	Tvm30	F0	2.93 ±0.19	3.55 ±0.44	4.79 ±0.06	4.68 ±0.58	3
		F1	2.69 ±0.53	3.60 ±0.28	5.06 ±0.11	4.65 ±0.40	
	Tvm60	F0	3.26 ±0.18	3.02 ±0.66	5.33 ±0.48	4.24 ±0.14	
		F1	2.66 ±0.33	3.47 ±0.40	5.17 ±0.30	3.91 ±0.32	
	Tvm90	F0	3.21 ±0.42	3.38 ±0.39	3.98 ±0.85	4.06 ±0.66	
		F1	3.19 ±0.46	3.59 ±0.47	5.24 ±0.56	4.34 ±0.35	
Wk2	Tv0	F0	4.50 ±0.93	3.11 ±0.31	5.91 ±1.40	3.94 ±0.86	
		F1	4.77 ±0.67	3.24 ±0.52	4.05 ±0.50	4.24 ±0.90	
	Tv30	F0	4.73 ±0.17	4.04 ±0.48	4.54 ±1.37	4.04 ±0.27	
		F1	4.07 ±0.40	3.38 ±0.20	4.61± 0.70	3.54 ±0.29	
	Tv60	F0	4.29 ±0.83	3.34 ±0.24	3.33 ±1.60	3.10 ±0.40	
		F1	5.78 ±0.66	3.72 ±0.73	5.02 ±1.17	3.76 ±0.76	

Table 1: Continued

Treatment			First residual season		Second residual season		N
			Stover (t ha^{-1})	Grain (t ha^{-1})	Stover (t ha^{-1})	Grain (t ha^{-1})	
Wk2	Tv90	F0	3.82 ±0.61	3.37 ±0.57	3.72 ±0.46	3.18 ±0.70	
		F1	4.52 ±1.41	3.85 ±0.75	3.07 ±1.29	3.39 ±0.29	
	Tvm30	F0	2.89 ±0.58	3.34 ±0.25	4.63 ±0.05	3.65 ±0.40	
		F1	2.37 ±0.52	3.33 ±0.58	4.51 ±0.57	3.57 ±0.30	
	Tvm60	F0	2.65 ±0.21	4.22 ±0.14	4.61 ±0.70	3.55 ±0.53	
		F1	2.99 ±0.70	3.76 ±0.23	5.90 ±0.70	4.38 ±0.82	
	Tvm90	F0	3.25 ±0.53	4.05 ±0.29	5.38 ±0.28	4.51 ±0.45	
		F1	3.47 ±0.53	3.49 ±0.14	4.39 ±1.36	5.25 ±0.59	
Wk4	Tv0	F0	3.72 ±0.29	2.89 ±0.88	5.01 ±0.94	3.55 ±0.49	3
		F1	4.36 ±0.93	3.38 ±1.01	4.23 ±1.32	4.16 ±0.52	
	Tv30	F0	4.53 ±1.09	2.77 ±0.11	2.09 ±1.16	4.05 ±0.64	
		F1	3.94 ±0.90	3.10± 0.58	3.15 ±1.45	3.76 ±0.19	
	Tv60	F0	4.66 ±0.71	2.83 ±0.57	3.67 ±0.84	3.48 ±1.00	
		F1	4.56 ±0.67	3.15 ±0.51	3.86 ±0.58	4.09 ±0.52	
	Tv90	F0	4.28 ±0.64	3.11 ±0.66	4.23 ±1.09	3.25 ±0.13	
		F1	4.27 ±0.90	3.22 ±0.65	6.70 ±1.47	3.63 ±0.89	
	Tvm30	F0	2.31 ±0.42	3.46 ±0.35	4.38 ±0.59	3.69 ±0.23	
		F1	3.04 ±0.17	3.60 ±0.10	4.20 ±0.26	3.61 ±0.46	
	Tvm60	F0	2.79 ±0.13	3.34 ±0.41	5.44± 0.25	4.58 ±0.70	
		F1	3.40 ±0.66	3.18 ±0.17	3.87 ±0.41	3.49 ±0.35	
	Tvm90	F0	3.11 ±0.21	3.23 ±0.61	4.25 ±1.02	4.25 ±0.50	
		F1	3.36 ±0.37	4.33 ±0.27	4.79 ±0.70	4.46 ±0.08	

Conclusion

In light of the main objective of utilizing less land-demanding AF technology that enhances sustainable increase in crop yield in land-scarce semi-arid Gairo in Tanzania, for ensuring household food security and improved income of resource-poor farmers, the following conclusions were made from this study:

(a) Shrub and maize performance at intercropping phase

- The shrub-crop interaction in this association has no negative effect on crop yield; rather it improves it over sole maize system.
- Optimum maize yield is obtained with Wk2Tv30, considering that there is no significant difference ($P>0.05$) in maize yield between the treatment and Wk2Tv60 which was highest.
- There is competition in the *Tephrosia*-maize association, which delayed *Tephrosia* growth and it is most likely for sunlight and growth space (shade effect) rather than for soil moisture, which favoured maize crop at the expense of the shrub. However, the slight variation in maize grain yield is most likely from competition for soil moisture as the treatment with highest soil moisture also recorded the highest maize grain yield.

*(*b*) Tephrosia* performance and its effect on the soil following removal of maize:

- The shrub growth which is suppressed during cropping period has the potential to recover remarkably and influence soil properties after harvesting maize.
- With intercropping, six months is hardly sufficient to observe any significant differences in *Tephrosia* performance that would have any significant effect on soil properties, but monoculture *Tephrosia* might do.
- Total *Tephrosia* biomass production per unit area at both six and eleven months of growth can be optimized with narrower spacing of week2 time of planting in both intercrop and monoculture systems.
- *Tephrosia* biomass production can be maximized with monoculture system over intercrop, which should be preferable where arable landholding is not limiting.

(c) Residual effect on maize yield

- In the face of scarce arable land and resource-poor agriculture, unfertilized *Tephrosia* intercrop treatment has more potential to optimize maize production with week2 time of planting and 30 cm intra-row spacing , with insignificant difference from half and full recommended doses of N and P fertilizer treatments respectively at Gairo.

Against this background and in consideration of other beneficial properties of the shrub, this study concludes that *Tephrosia* relay-intercropped with maize has potential for sustainable maize production in land-scarce semi arid areas on well drained soils with good water holding capacity and where sustainable increase in crop yield at optimum profitability is the main goal.

Recommendations

(a) Relay intercropping maize with *Tephrosia* is recommendable in land scarce semi arid areas.
(b) Planting *Tephrosia* two weeks after maize at 30 cm intra-row spacing is recommended for moderate competition effect and optimum crop yield at both intercropping and residual phases.
(c) To realize any significant increase in crop yield in the subsequent years from the residual effect of *Tephrosia,* the intercropping phase should be done for at least two consecutive seasons in order to ensure sufficient biomass accumulation.
(d) Further studies to determine the effect of continuous relay intercropping of various species and/or provenances of *Tephrosia* and maize on soil properties and crop yield in semi arid areas are recommended.

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6. WATER USE AND NUTRIENT SUPPLY BY TREES IN WOODLOTS SYSTEM IN WESTERN TANZANIA

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Abstract

Farmers in western Tanzania are establishing rotations of trees and crops in an attempt to overcome the shortage of wood, reverse deforestation of natural forests and improve soil fertility for food security enhancement. However, over-exploitation of soil water resources and immobilization of soil nutrients have been suggested as possible negative effects of growing trees on farms in the semi-arid tropics. Such possible pitfalls undermine and even threaten a successful implementation of the woodlot technology at larger scale. The study presents results based on field trials that were established with five-year rotational woodlots in Tabora Region. There was no evidence that trees were over-exploiting the water reserves after four years. Transpiration was greatest in *A. crassicarpa* and was related to stem diameter, size of the tree canopy and soil water availability. The benefits of tree fallows compared to natural fallows were obvious, in terms of maize yield increases. Non-fertilized maize yielded more after Acacias than after the other trees and natural fallow. N ha^{-1} and P ha^{-1} were the most limiting nutrients in the study area. Application of 50 to 100 kg N and 20 kg P h^{-1} will suffice to get maize yields of about 3 to 4 t ha^{-1} after woodlots, and the fallow type has little effect on it. There was no need to apply fertilizer K in the study area. This could mean that the Acacias are mining the soil for P and K. Therefore long-term trials are needed to examine the sustainability of the system of rotational woodlots.

Introduction

The system of rotational woodlots using suitable tree species is a promising agroforestry technology in southern Africa for enhancing productivity on smallholders' farms (Nyadzi *et al.,* 2003; Ramadhani *et al*., 2002). In this system, a 5- to 7-year-old woodlot planted with a suitable tree species is rotated with annual crops. The trees can be intercropped with food crops during the first 2 to 3 years and thereafter are left to grow as a pure tree-fallow or woodlot until harvest. After harvesting the woodlot, either food crops are grown as intercrops between the coppicing tree stumps or a new cycle is initiated by a fresh planting of trees after 2 to 3 years of cropping (Otsyina *et al.,* 1996). The rotational woodlots provide fuel wood which can be used as a substitute for the wood from forests, and thus contribute to the conservation of forest areas.

Impressive results have been reported with rotational woodlots in which Australian *Acacia* species have been used to increase soil fertility improvement, wood yields (Nyadzi *et al.,* 2003) and smallholders' income (Ramadhani *et al.,* 2002). Many farmers have realized the importance of this technology for alleviating fuel wood shortage as well as to avoiding deforestation. Although farmers, research and development institutions, and other stakeholders in western Tanzania have expressed considerable enthusiasm for the technology, they also have serious concerns regarding the long-term environmental impacts (Nyadzi, 2004). The two main concerns are that the trees may over-exploit soil water resources and that the tree litter may immobilize soil nutrients, as the case is with eucalyptus plantations. *Eucalyptus* plantations have been criticized on the grounds that they consume excessive amounts of water (Calder *et al*., 1992) and compete strongly with crops for this resource. *Acacia*, *Leucaena* and *Senna* species used in rotational woodlots in western Tanzania may also create serious long-term problems in semiarid areas. However, little information is available concerning water use by most of the tree species used for agroforestry in semiarid environments.

Tree species differ in their ability to use soil water and modify nutrient cycling for the benefit of simultaneous and sequential crops (Nyadzi, 2004). An understanding of the water use patterns of trees is essential for developing sustainable rotational woodlot systems. The objectives of the present study were to determine the influence of different tree species on soil water dynamics during the woodlot or tree-fallow phase in Tabora region, western Tanzania, where the rotational woodlot technology has great potential for adoption. In the current study, we also compared the effects on maize of rotational woodlots of various agroforestry trees with those of natural fallow and continuous maize.

Materials and Methods

Study area

The study was conducted at Tumbi Agricultural Research Institute (5.03` S, 32.41` E, altitude 1190 m), which is located within the miombo woodlands of western Tanzania. Long-term (44-years) average annual rainfall is 928 mm, of which 94% occurs between November and April (Nyadzi, 2004). Mean maximum and minimum air temperatures are 28 °C and 18 °C, respectively. The soil in the study area is classified as a Ferric Acrisol (FAO–UNESCO system). Detailed soils characteristics of the sites have been discussed by Nyadzi et al. (2003b).

Experimental design and establishment of trees

The experiment was set up as a randomized complete block design with three replications in 16 m by 20 m plots. The seven treatments included five woodlots containing different tree species (*Acacia crassicarpa* A. Cunn. ex Benth., *A. julifera* Berth., *A. leptocarpa* A. Cunn. ex Benth., *Leucaena pallida* Britton & Rose, and *Senna siamea* (Lamarck) Irwin et Barneby), natural fallow and continuous sole maize (*Zea mays* L. var. Kilima). The woodlots were established using 8-week-old seedlings planted at 4 ×4 m spacing (625 trees ha^{-1}). The young trees were intercropped with maize during the first three years. In the subsequent two years, maize was grown only in the continuous sole cropping treatment. Maize was planted at a spacing of 0.25 × 1.00 m. During the rain season all plots except the natural fallow were weeded whenever necessary. After 1.5 years, a 1.5 - m deep and 0.5 - m wide trench was dug around each plot to prevent interference from the roots of trees in adjacent plots. This process was repeated annually.

Soil water

Soil water content was measured at monthly intervals using a Wallingford neutron probe (Bell, 1987). Five aluminium 44.5 mm diameter access tubes were installed to a depth of 185 cm within the net area (six trees covering 96 m^2) of each plot. Four tubes were installed at distances of 4 m from each other and the fifth was installed at the centre of the net plot. Soil water content was determined at 20 cm intervals between 35 and 175 cm. The details on access tubes installation and calibration of neutron probe readings over a range of soil water contents across eight soil horizons is summarized by Nyadzi *et al.* (2003b). Soil water content was measured during the last ten days of each months over a 17-month period.

Transpiration

Heat pulse sap flow gauges manufactured at ICRAF (Nairobi, Kenya) based on the version described by Khan and Ong (1996) were used. Continuous sap flow measurements on individual trees was done for periods not exceeding 14 days to avoid long-term damage to the stems. Probes were greased before inserting them into holes drilled radially into the trunk, correctly spaced and aligned along the trunk axis (Burgess *et al*., 1998). The sensor probes were embedded in the trunks 5 mm upstream and 10 mm downstream from the heater probe. The sensor probes were constructed from stainless steel needles 1.3 mm in diameter and 3 cm long. The copper and constantan (a nickel and copper alloy) thermocouples were placed inside probes at distances of 0.5, 1.5 and 2.5 cm from the tip (Khan and Ong, 1996). The positioning of sensors at different depths within the trunk allowed any variation in sap flux density across its cross-section to be taken into account (Hatton *et al*., 1995). The diameters of the trunks at breast height (1.3 m aboveground level) were measured in two perpendicular directions at the position of gauge installation. These diameters were then used to calculate the trunk cross-sectional area for each species. The section of trunk selected for probe insertion was straight, smooth and free from structural, pest or pathogen-induced defects. Three holes were drilled into the trunk with the help of a steel guide jig with holes pre-set at the required distances, which was held firmly in place against the trunk while the holes were drilled. Heat pulse velocity was recorded at 30-minute intervals, averaged over 1 h (Swanson and Whitfield 1981) and stored in an electronic data logger (model CR 21X, Campbell Scientific, Logan, UT), before being downloaded to a laptop computer. Heat pulse velocity (cm h^{-1}) was converted to sap flux density (volume of sap moving in the transpiration stream per unit cross-sectional area per unit time) by multiplying sap flow velocity by the trunk cross-sectional area for each tree. Trunk cross-sectional area was calculated based on stem diameter at breast height. Transpiration was measured during a 60-day period between Julian Day (JD) 304 to 363. The measurement duration differed between species due to the lack of a reliable laptop computer to download the data during the measurement period. Transpiration by *A. crassicarpa* was measured over a 25-day period (JD 304 to 328), *S. siamea* for 10 days (JD 330 to 339), *L. pallida* for 10 days (JD 345 to 354), *A. julifera* for 5 days (JD 354 to 358) and *A. leptocarpa* for 6 days (JD 358 to 363). Due to the predominantly diurnal pattern of sap flow (Jara *et al*., 1998), only daytime observations, i.e. between 06.00 am and 19.30 p.m. (EAT) were used for sap flow analysis. Cumulative water uptake was calculated for all tree species.

Experimental design of the NPK fertilizer trials

Results on maize yields, trees performance and wood production in the woodlots have been reported by Nyadzi *et al*. (2003a). Detailed analysis of the effects of rotational woodlots on the nutrition and yield of maize following trees is reported in Nyadzi (2004). After harvest of the trees, an NPK fertilizer trial was imposed in each of the seven fallow treatments (*A. crassicarpa*, *A. julifera*, *A. leptocarpa*, *S. siamea, L. pallida*, natural fallow, and continuous sole maize) and in all three replicates. The experimental design was a 3^3 factorial, i.e. 27 different combinations of fertilizer N, P and K in each plot of the 21 plots of Figure 1. Hence the total number of experimental units was 567. The factors investigated were nitrogen, phosphorus and potassium. Application rates were 0, 50 and 100 kg N ha^{-1} as urea; 0, 20 and 40 kg P ha^{-1} as triple superphosphate and 0, 20 and 40 kg K ha^{-1} as muriate of potash. The fertilizer N application was split into two equal parts, at sowing time and at 8 weeks after sowing. Triple superphosphate and potash fertilizers were applied once, at maize sowing.

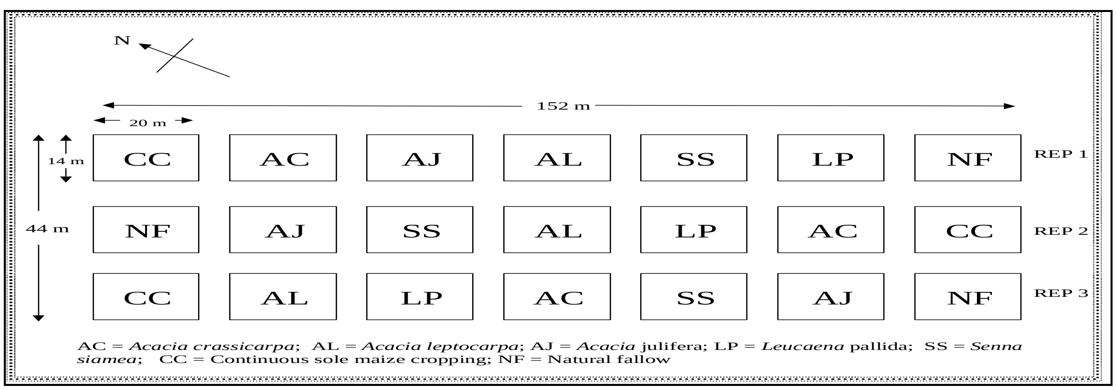


Figure 1. The field layout, randomisation and replications of main treatments (fallow types)

Statistical analysis

All data were tested for normality before subjecting to analysis of variance (ANOVA) procedure of the GenStat®program. The soil water data obtained from the five neutron probe access tubes located in each plot were averaged for each soil horizon and subjected to ANOVA. Treatment differences for soil water data were tested using the standard error of difference between means (*SED*). Grain yields at different fertilizer rates for each fallow type were subjected to ANOVA.

Results and Discussion

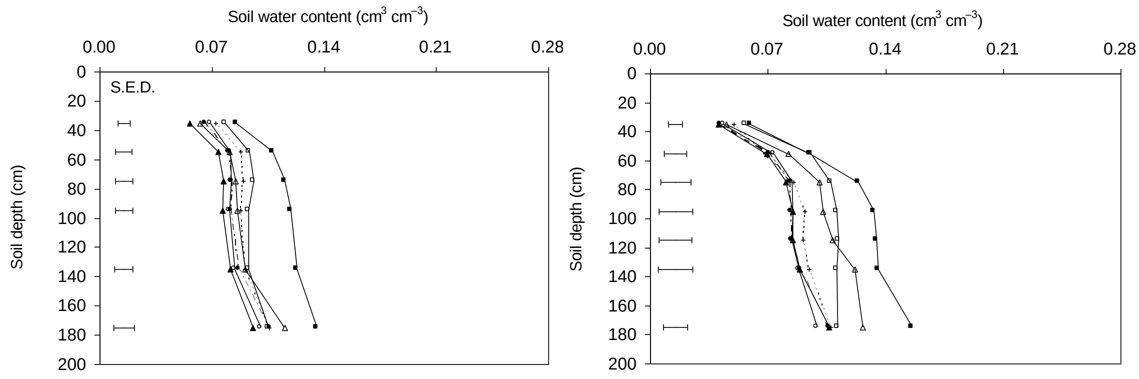
Soil water distribution in soil horizons

The treatments differed significantly ($P < 0.05$) in soil water content measured in all months except the dry months of May and September 2000 ($P = 0.23$) (Figure 2). In November 1999, the soil was dry, with water contents ranging between 0.05 and 0.07cm^3 cm^{-3} in the topsoil and between 0.10 and 0.12 cm^3 cm^{-3} at depths of 60 to 80 cm and 175 cm, respectively (Figure 2a). The bare soil of the continuous maize treatment contained significantly more soil water than the fallow system. Water contents were lowest in the *A. crassicarpa* and *A. leptocarpa* woodlot systems. Following rainfall during the period from January to March 2000, soil water content increased, particularly in the 80 to 140 cm horizon of the sole maize, *S. siamea* and natural fallow treatments (Figure 2b). Treatment differences were small in the horizons above 80 cm; below 80 cm, the treatments were ranked in the following order: continuous maize > *S. siamea* = natural fallow > *L. pallida* = *A. crassicarpa* = *A. julifera* = *A. leptocarpa*. Interestingly, soil water content was lowest in treatments containing the Australian *Acacia* species.

In May and September 2000, during the dry season, no major treatment differences in soil water content were detected (Figures 2c and 2d). Soil water content varied between 0.05 and 0.12 cm^3 cm^{-3} under continuous maize, 0.04 and 0.11cm^3 cm^{-3} under *S. siamea* and *A. crassicarpa*, and between 0.03 and 0.09 cm^3 cm^{-3} under *L. pallida*, *A. julifera*, natural fallow and *A. leptocarpa*. The small differences probably reflect the low rainfall during the preceding rain season and the prolonged dry season. Following the onset of the rains in November 2000, soil water content increased sharply at all depths (Figure 2e). The greatest increase in soil water content was in the 60 to 140 cm horizons, although the differences between treatments were not significant. As high and regular rainfall occurred throughout the season, soil water content continued to increase at depths below 60 cm in all treatments. The soil water distribution pattern observed at the end of March 2001 showed a complete reversal of those obtained during the previous season (Figures 2b and 2f) as all woodlot treatments exhibited higher soil water contents than the continuously cropped and natural fallow treatments.

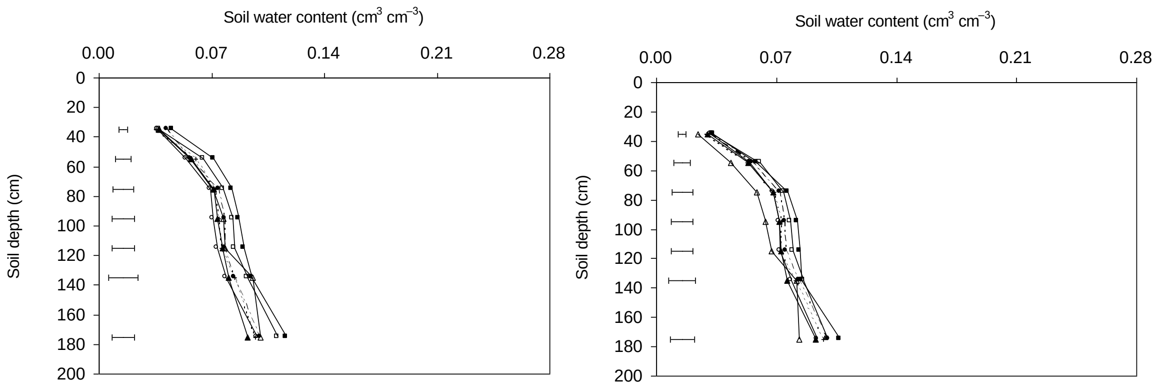
Trees appeared to deplete water to a greater extent than sole maize or natural grass/herb fallow during the dry season, when there was no rainfall, and conserve more during the wet season. Le Maitre et al. (1999) also reported greater depletion of soil water by plantations as compared to grasslands during the dry season. Soil water depletion from the deep soil layers was due to water uptake by trees during the dry season. Soil water content did not increase under trees following rainfall in December 1999 and January 2000 because rainfall was low (< 60 mm) and a substantial proportion of this may have been lost as a result of canopy interception. Canopy interception losses have been reported to be high for small rainfall events (Wallace, 1996). In contrast, soil water content under trees increased substantially following the high rainfall (> 300 mm) received in December 2000 and January 2001. These results are also consistent with those reviewed by Rao et al. (1997), who concluded that trees increase water availability by improving soil structure and infiltration and thereby reducing run off.

(i) Rainy season 1999-00 (November 1999–April 2000)



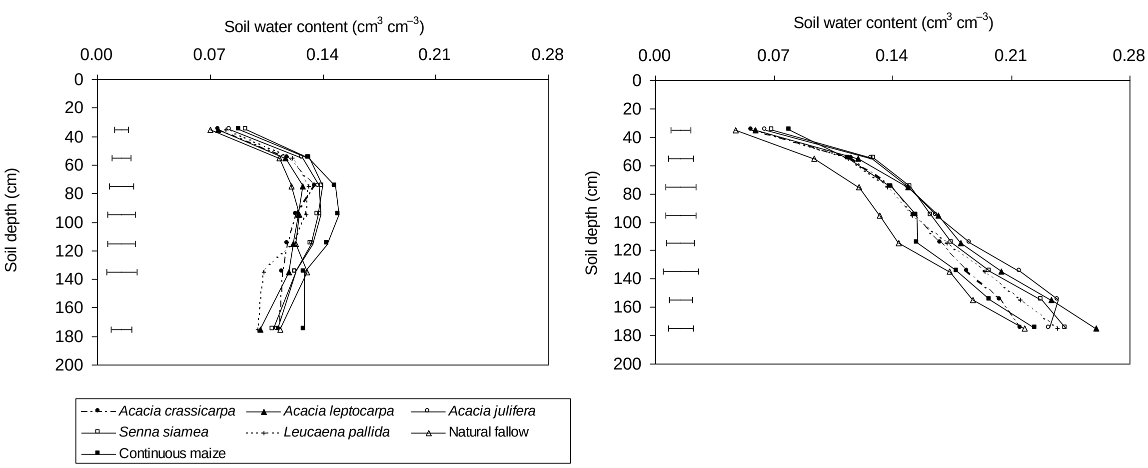
(a) 27 November 1999 **(b) 25 March 2000**

(ii) Dry season (May–October 2000)



(c) 26 May 2000 **(d) 26 September 2000**

(iii) Rainy season 2000-01 (November 2000–April 2001)



(e) 28 November 2000 **(f) 27 March 2001**

Figure 2. Soil water distribution patterns under woodlots of five tree species, natural fallow and continuous maize. Measurements began when trees were three years old. No crop was present in the continuous maize treatment in November 1999 and from May to November 2000. Horizontal bars show standard errors of difference between means (SED) for comparing soil water between treatments per depths.

Transpiration by trees

Figure 3 shows the mean diurnal trends of sap flow velocity recorded by heat pulse sensors positioned at depths of 0.5, 1.5 and 2.5 cm beneath the cambium for *A. crassicarpa* (Days 1 to 10, JD 307 to 316), *L. pallida* (Days 1 to 10, JD 345 to 354), and *A. leptocarpa* (Days 1 to 6, JD 358 to 363). The diurnal trends for the different tree species were similar, although the velocities differed substantially between species. Mean sap flow velocity increased from a minimum at 0600 h to a maximum between 1000 h and 1700 h, and then gradually decreased to a minimum at 1930 h. Sap flow was greatest in *A. leptocarpa*, with a maximum of 38.2 cm h^{-1} measured on Day 1 (JD 358); peak values remained relatively constant (28.1 to 30.7 cm h^{-1}) for the remaining five days of measurement. By contrast, *A. crassicarpa* had the lowest sap flow velocity during the first four days of measurement, and increased over time (Figure 3). Following rain on Days 4 and 5 (JD 310 and 311), the maximum sap flow velocity increased progressively from 14.2 cm h^{-1} to 29.4 cm h^{-1}over the subsequent six days indicating that soil water content was limiting transpiration initially.

The diurnal patterns of *A. julifera* and *S. siamea* are not shown in Figure 3 as their sap flow rates were similar to *L. pallida*. Sap flow velocity was generally greatest at a depth of 0.5 cm below the cambium and lowest at 2.5 cm depth in all species except *A. crassicarpa*, in which there was little difference in sap velocity at depths of 0.5 and 1.5 cm (data not shown). This implies that younger xylem near to the surface of the trunk was more active in transporting water than the older xylem tissues. Any changes in either soil water content or atmospheric demand during each day are likely to cause changes in transpiration rate, particularly in the younger xylem in which sap flow velocities are greatest. Sap flow velocity was lowest and least sensitive to soil and atmospheric changes at a depth of 2.5 cm below the cambium.

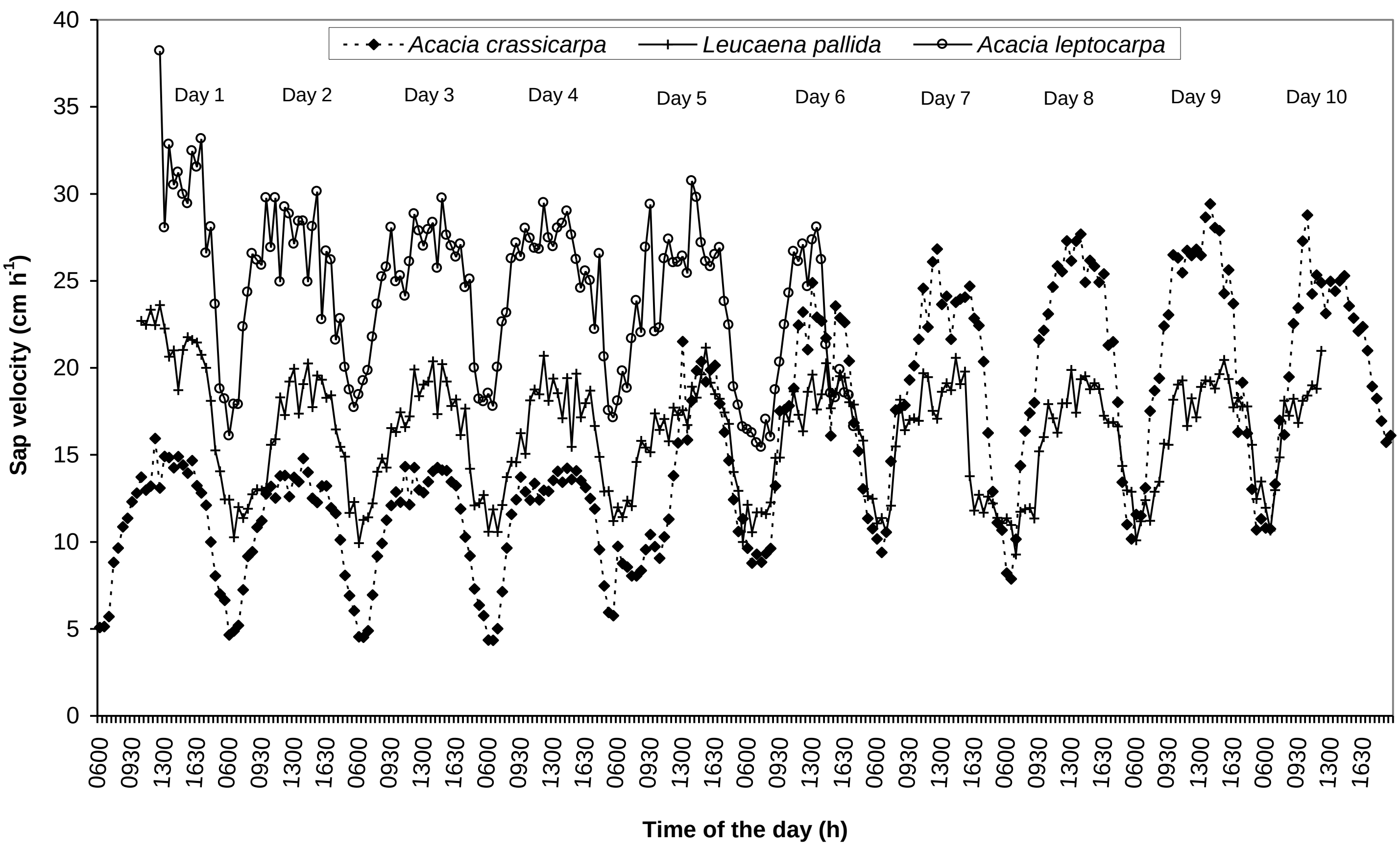


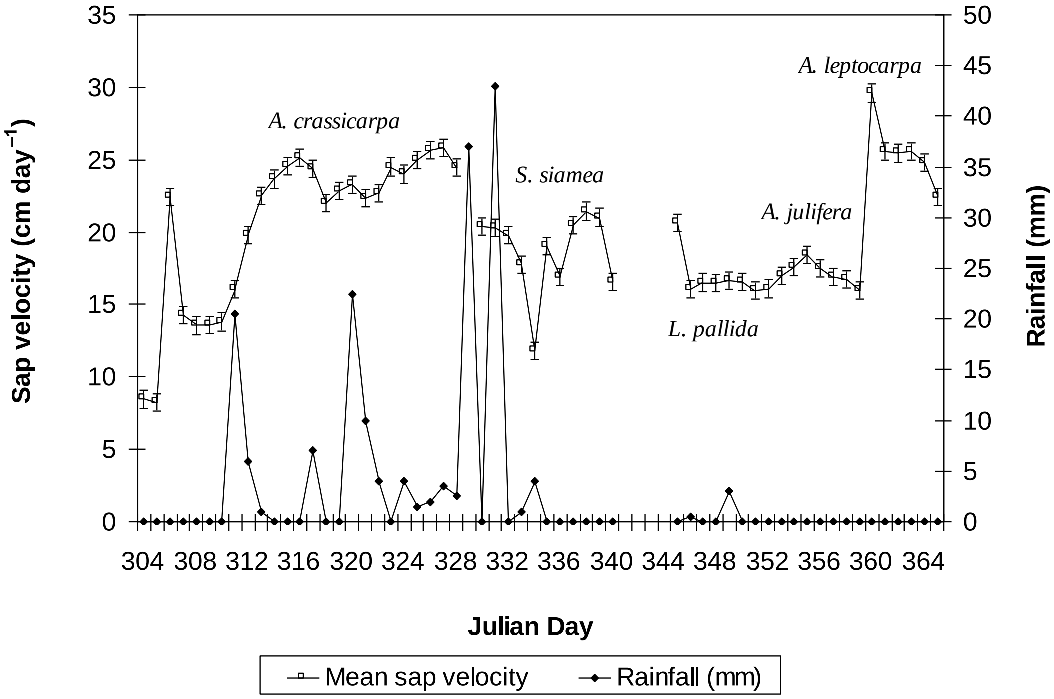
Figure 3. Mean diurnal sap flow velocity patterns in the trunks of three tree species measured continuously over 10 day periods at different Julian Days (JD) during the 1999-2000 season (*A. crassicarpa* JD 307–316; *L. pallida* JD 345–354 and *A. leptocarpa* JD 358–363). The values are means of sap flow velocities measured at depths of 0.5, 1.5 and 2.5 cm below the trunk surface.

Sap flow velocities calculated per day of 13 hours are shown in (Figure 4a). *Acacia leptocarpa* had the highest daily mean value (30.0 cm d^{-1}) while *S. siamea*, *A. julifera* and *L. pallida* had similar but lower values (mean of 17 cm d^{-1}). The mean daily sap flow velocity in *A. crassicarpa* was lower (7 to 14 cm d^{-1}) than in *A. julifera*, *S. siamea* and *L. pallida* (16 to 21 cm d^{-1}) when soil water content was limiting, but was greater (22 to 23 cm d^{-1}) when soil water content was not limiting. The mean daily sap flow velocity in *A. leptocarpa* measured when water was limiting was similar to that in *A. crassicarpa*.

The daily total transpiration rate is shown in Figure 4b. The mean values for *A. crassicarpa* ranged between 540 and 1680 g d^{-1} over a 25-day period when there was frequent rains. By comparison, daily transpiration rates ranged between 620 and 1090 g for *S. siamea*, 660 and 780 g for *A. julifera*, 540 and 700 g for *A. leptocarpa* and 360 and 470 g d^{-1} for *L. pallida* during periods when there were little or no rain. *Acacia crassicarpa* exhibited the greatest cumulative water uptake and *L. pallida* the lowest (Figure. 5).

The order of cumulative water use within the various woodlots was as follows: *A. crassicarpa* > *S. siamea* > *A. julifera* = *A. leptocarpa* > *L. pallida*. The rate of transpiration was related to stem diameter (greatest in *A. crassicarpa* smallest in *L. pallida* and *A. leptocarpa*), size of the tree canopy and soil water availability. Other environmental factors such as water vapour pressure gradient, wind speed, air temperature, relative humidity and the quantity of incident solar radiation are also likely to have influenced transpiration rate (Allen *et al*. 1998). *Leucaena pallida* had the lowest transpiration rate due to its relatively small stem and crown diameters (Nyadzi *et al*. 2002).

(a) Sap flow velocities



(b) Sap flux densities

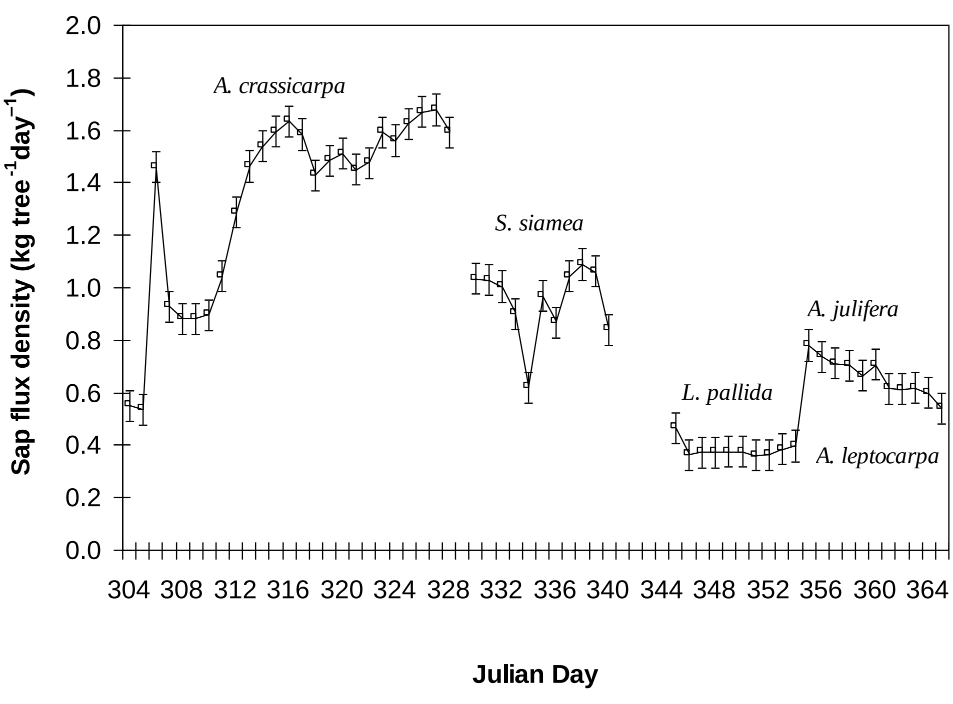


Figure 4. Mean daily sap velocities (a) and sap flux densities (b) in the stems of three-year-old trees in woodlots at Tabora, Tanzania. Error bars = ±S.E.

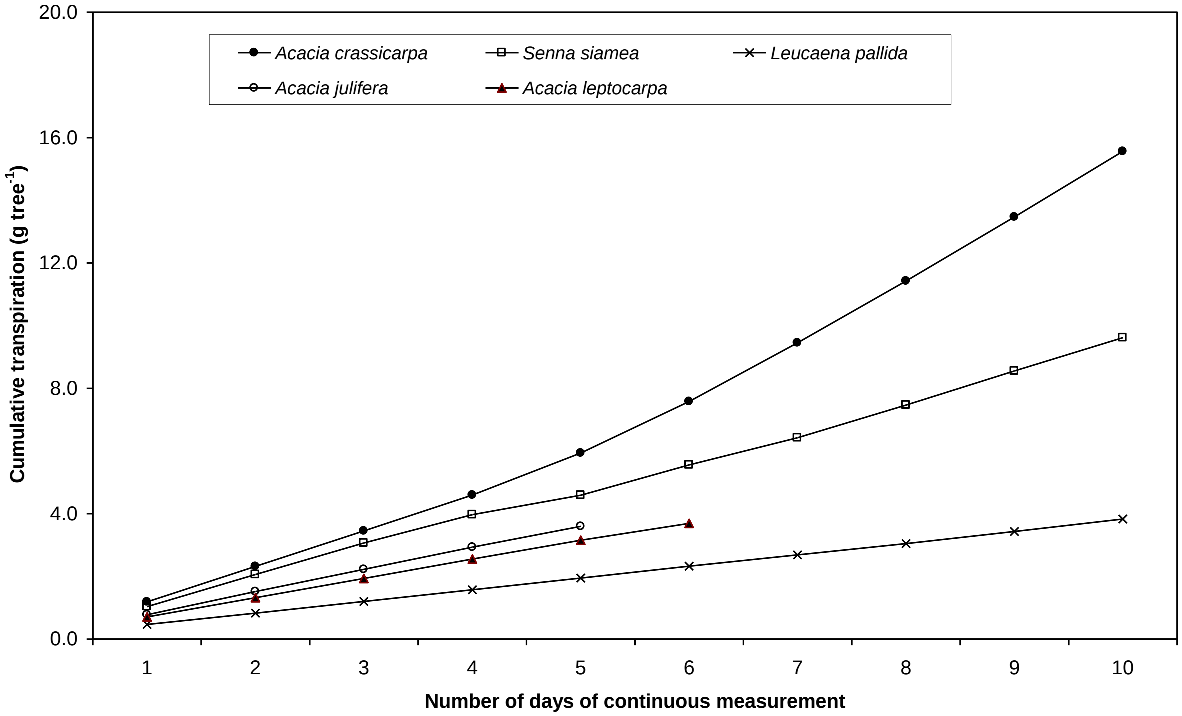


***Figure 5*. Cumulative water uptake (transpiration) by tree species measured at different times during the 1999-2000 season (*A. crassicarpa* JD 307–316; *S. siamea* JD 330–339; *L. pallida* JD 345–354; *A. julifera* JD 354–358 and *A. leptocarpa* JD 358–363).**

Yields and evaluation of soil fertility in the area

Table 1 presents, for each fallow type, the grain yields of Treatment 000 (averages of 3 values), the average yields of all fertilizer treatments (averages of 81 values), and the yields averaged per level of N, P or K (averages of 27 values). Mean 000 grain yields varied from 0.6 (CM) to 2.0 (AC), and yields averaged over all 27 fertilizer treatments varied from 2.36 (SS) to 2.91 (AJ) Mg ha^{-1}. This study has shown that N and P are the most limiting nutrients in the study area and that N and P must be applied to get high yields of maize after clearing woodlots. This was reflected by the high values of recovery fractions. The results confirm the study by Kato *et al* (1999) who also indicated that incorporation of the fallow vegetation, as a fire-free alternative cannot supply sufficient nutrients to the subsequent crops in the short run. There is no need to apply fertilizer K in the study area. Application of 50 to 100 kg N and 20 kg P per hectare will generally suffice to get maize yields of about 3 to 4 tons per ha after woodlots.

Table 1. Grain yields as function of fallow types and NPK treatments (Mg ha $^{-1}$).

		(Fallow types*)							
Nutrient	Level	AC	AJ	AL	LP	SS	CM	NF	Mean
None	0-0-0	2.01	1.70	1.09	0.89	0.83	0.60	0.81	1.13
NPK	Mean	2.38	2.91	2.58	2.60	2.36	2.49	2.60	2.56
N	0	1.29	1.67	1.35	1.23	0.80	1.40	1.61	1.33
	50	2.42	3.05	3.16	2.75	2.76	2.92	2.63	2.81
	100	3.42	4.02	3.23	3.82	3.52	3.49	3.22	3.53
P	0	1.89	2.66	2.05	2.13	2.21	2.24	2.07	2.18
	20	2.52	2.92	2.62	2.69	2.40	2.73	2.58	2.64
	40	2.72	3.16	3.06	2.99	2.48	2.84	2.82	2.87
K	0	2.50	2.66	2.78	2.43	2.20	2.67	2.16	2.49
	20	2.45	3.01	2.49	2.65	2.42	2.55	2.76	2.62
	40	2.18	3.07	2.47	2.73	2.46	2.57	2.54	2.57

*) AC = *Acacia crassicarpa;* AJ = *A. julifera*; AL = *A. leptocarpa*; LP = *L. pallida*; SS = *Senna siamea*; CM = continuous maize; NF = natural fallow.

Conclusions

Soil water dynamics were different in woodlots, natural fallow and continuous maize treatments. Trees depleted soil water more than the natural fallow and continuous maize systems during the dry season. By contrast, in presence of trees, greater proportion of rainfall was stored in the soil than in the other systems. *Acacia crassicarpa* exhibited the greatest mean transpiration rate during the measurement period, while *L. pallida* had the lowest values and the other species were intermediate. However, there was no evidence that trees were over-exploiting the water reserves after three to four years.

Clearly, N and P are the most limiting nutrients in the study area. Application of 50 to 100 kg N and 20 kg P per hectare will suffice to get maize yields of about 3 to 4 tons per ha after woodlots, and the fallow type has little effect on it. There was no need to apply fertiliser K in the study area. The best fallow type for soil fertility improvement was *Acacia julifera,* but all three acacia fallows were better than the other fallows. This could mean that the acacias are mining the soil for P and K. Therefore, long-term trials are needed to examine the sustainability of the system of rotational woodlots.

These results have implications regarding the benefits of woodlot technology in conserving water resources for sustainable development. Before wide scale dissemination of this technology is undertaken, integrated economic and environmental assessments are essential. Such an assessment should also include an appraisal of the impact of large-scale tree planting on landscape hydrology.

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7. AGROFORESTRY TECHNOLOGIES FOR SEMI-ARID AND SUB-HUMID AREAS OF TANZANIA: AN OVERVIEW

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Abstract

Agroforestry (AF) research at Sokoine University of Agriculture up to the mid 90s had concentrated largely on the testing of the potential of mixed cropping and alley cropping for semi-arid areas. Later on it was realized that crop failure was severe under these systems due to competitions for growth resources, particularly moisture between tree and crop component. Consequently, alternative technologies were considered for semiarid conditions. From 1995 to date, a number of technologies such as improved fallow (IF), relay intercropping (RI) and rotational woodlot (RWL) have been tested for suitability in semi-arid and sub-humid areas. Along with these technologies, trials were established to screen appropriate provenances/species and improve soil phosphorus (P) availability in P deficient soils with high P-fixing capacity. This paper reviews progress made so far with the objectives of providing information on findings that are available for scaling up and identifying gap(s) for future research. Results of provenances trials indicated that growth and yield differences among provenances were attributed to differences in climatic conditions, altitude and edaphic factors between native range and study sites affirming the need for screening tests prior to final selection of provenance and/or species to plant. Generally, *G. sepium* provenances showed highest survival, biomass yield and nutritive values than other tested provenances and/or species in all three sites; demonstrating wide adaptability to different agro-ecological zones and high potential for use in AF systems. Of the evaluated *Leucaena* species/provenances, *L. diversifolia* Ex Veracruz had the highest *psyllid* resistance and would be appropriate for replacing *L. leucocephala*. Two-year old IF of *G. sepium* and *T. vogelii* at Gairo were sufficient to improve soil fertility and have potential to reduce costs of N and P fertilizer by 50 % without adversely affecting maize yields. One-year narrow-spaced IF of *T. vogelii* yielded 3 Mg ha^{-1} of maize grain which is close to 4.41 Mg ha^{-1} from a two-year wide-spaced IF of the same species; reflecting increased foliage biomass production per unit area at narrow spacing. This technology together with RI may be appropriate for optimizing land use and sustaining crop production in areas with scarcity of arable land. Appropriate design of planting space and time may minimize competitions for moisture under RI in semi-arid conditions, as demonstrated by highest maize and *T. vogelii* biomass yields in plots in which *T. vogelii* was planted two weeks after maize sowing at a spacing of 30 cm and 90 cm within and between rows respectively. Wood production from one hectare of RWL was sufficient to meet household firewood demand for 7 – 16 years; demonstrating the potential to be an alternative source of firewood and reduce utilization pressure to natural forests. *Acacia crassicarpa*, *A. leptocarpa* and *A. mangium* produced the highest wood biomass at the lowest nutrient costs reflecting low nutrient exports per unit biomass at harvests and would be appropriate for sustaining wood production under this system. Crop growth and yields in AF systems on acidic soils with high P fixing potentials may be improved when green manure and Minjingu phosphate rock are incorporated into the soil rather than surface applied as mulch. In order to improve crop productivity under AF systems in semi-arid and sub-humid areas, further research is needed in the following areas: (1) evaluation of biological nitrogen fixing capacity and site x interactions of tree/shrub species/provenances as strategies to refine selection criteria, (2) foliar nutrient analysis of tree/shrub species as a criterion for assessing the potentials for use as fodder and green manure, (3) screening of indigenous tree/shrub leguminous species with potential to use in AF (4) partitioning the effects of competitions for soil moisture, nutrient and light on growth and yields of tree/shrub and maize under RI.

Introduction

Semi arid zone has been defined as an area with a growing period ranging from 75 to 197 days (Deckers, 1993). These areas are characterized by a high mean annual temperature (>18°C) and low variable annual rainfall ranging from 400 to 900 mm (Swindale, 1982). In the dry semi arid tropics in particular, rainfall usually exceeds potential evapotranspiration for less than 4.5 months of the year. Under such conditions, except where the water-holding capacity is adequately good, water content would be most often inadequate in soil for effective plant performance. Hence, from plant physiology perspective, Taiz and Zeiger (1991) defined arid and semi arid zones as areas in which plant transpiration totals only 50% or less of the transpiration that would occur with unlimited water availability.

The major draw back of simultaneous agroforestry (AF) systems, particularly alley cropping in semi-arid conditions is declining crop yields relative to monoculture due to competitions, particularly soil moisture. This limitation served as incentive to research on alternative technologies more suitable in moisture limited environments (Szott *et al.,* 1991; Haggar and Beer, 1993; Chamshama, *et al*., 2000), where demand for arable land is high as well. From 1995 to 2005, research attention had shifted largely to sequential and semi-simultaneous systems in semi-arid Gairo and SUA Farm with the hope to transcend the problem of declining crop yield resulting from competition for limited soil moisture between crops and AF trees/shrubs (Chamshama *et al.,* 1998). During this period a number of trials were established to test technologies for improving soil fertility, crops and wood yields in semi-arid Tanzania (Chingonikaya, 1999; Mgangamundo, 2000, Ngegba, 2005). These include improved fallow (IF), relay intercropping (RI) and rotational woodlot (RWL). Along with these trials, species/provenances experiments were established in order to screen species and/or provenances for semi-arid and sub-humid conditions (Msemwa, 1997, Herbert *et al*., 2002, Edward *et al.,* 2006; Gerald, 2003). In addition Minjingu Phosphate Rock (MPR) in combination with green manure was evaluated for potential to enhance soil phosphorus (P) availability in acidic soils with high P-fixing capacity (Kimaro, 2000).

This paper reviews ten-year research efforts at Sokoine University of Agriculture (SUA) for developing AF technologies for semi-arid and sub-humid environments with the objectives to provide information on findings that are ready for scaling up and identify gap(s) for future research.

Methodology

The studies reviewed in this paper were carried out at Gairo, Mkundi, SUA Farm and Kibaha. Gairo (36^0 45' E, 6^0 30' S; 1200 m. a.s.l.) is about 140 km from Morogoro Municipality on Morogoro – Dodoma highway. Annual average rainfall ranges between 499 and 617 mm. Generally, rainfall is erratic and poorly distributed. Mean annual temperature ranges between 18 – 28^{o}C (Chamshama *et al.,* 1994). The soils are moderately acidic with very low organic matter content, very low available N and P, and bulk density is between 1.34 and 1.41 g cm^{-3} indicating some compaction (Ngegba, 2005). The SUA Farm (6^0 50' 24.7"S; 37^0 38' 59.8"E; 526m asl), has a sub-humid tropical climate with a bimodal rainfall distribution of about 870 mm per year, and annual temperature of 24^{o}C. The soils are acidic (pH < 5) classified as Ultisols (USDA soil taxonomy) with high P fixing capacity and inherently low fertility (Fasuluku, 1998; Kimaro, 2000). Kibaha site, located within Ruvu forest project (6°32' and 6^o 43' S, 38^o 48' and 39^o 02' E; 70 m a.s.l.), receives annual rainfall ranging from 700 to 1000 mm and annual temperature of 26.5°C. Mkundi (6^o 40' S, 37^o 39' E), is about 20 km west of Morogoro, Tanzania, at an altitude of about 475 m. It experiences a bimodal rainfall distribution with annual rainfall and air temperatures of 800 mm and 24^{o}C respectively. The soils are fairly young, classified as Entisols (USDA soil taxonomy) with predominantly kaolinitic clay mineralogy, sandy loamy texture and low soil nutrients. For agricultural production, total N and extractable P levels in the soil are considered deficient while exchangeable K levels are marginal (Msanya *et al.,* 2003). Details of research methodologies of studies reviewed in this paper may be found in Msemwa (1997), Chingonikaya (1999), Kimaro (2000), Mgangamundo (2000), Herbert *et al*. (2002), Gerald (2003), Ngegba (2005), Edward *et al*. 2006, Mnyonga (2005), Kimaro *et al.,* (2006 a and b), and Mugasha *et al.,* 2006.

Results and Discussion

Provenance trials

The success of any AF system depends on the choice of suitable tree/shrubs component that should offer diversity of benefits such as soil improvement, wood, fodder and show compatibility with crops (Edward *et al.,* 2006). Most trees/shrubs species and provenances show different growth patterns in their natural range which reflect genetic variations and different capacities to provide these functions. Generally, a suitable provenance for introduction is the one whose environmental conditions in the native range match as closely as possible those of the introduced sites. However, this generalization has to be verified experimentally under a given set of site conditions prior to final selection of suitable provenance for planting as some provenances also perform well in site conditions outside their natural range due to wide plasticity. Consequently, testing of appropriate AF technologies was carried along with screening of appropriate tree/shrubs species and provenances in order to broaden genetic base and select best species and provenances since most trees/shrubs species used in AF systems in the country are exotic. Trees/shrubs species and provenances evaluated included: *S. sesban, S. macarantha, G. sepium, Calliadra calothyrsus*, *Leucaena leucocephala* (Msemwa, 1997; Hebert *et al.,* 2002; Gerald, 2003; Edward *et al.,* 2006; Mugasha *et al.,* 2006).

Calliandra calothyrsus **provenances**

Nineteen provenances were established at Gairo (8 provenances) and SUA Farm (17 provenances) experimental stations (Herbert *et al.,* 2002). After 27 month growth period at SUA Farm, survival ranged from 33.3% to 97.7% for Lushoto Arboreturm and Babati provenances respectively while above ground biomass yields ranged from 4.81 to 17.26 Mg ha^{-1} for Lushoto Arboreturm and San Ramon respectively. The provenances survival at final assessment in Gairo varied between 50% for Apic Apac to 75 % for Fortuna and Cofradia. The final above ground biomass yield at this site was lowest (12.60 Mg ha^{-1}) for Apic Apac provenance and highest (22.35 Mg ha^{-1}) for Fortuna provenance. There was little variation in leaf N and P concentrations among provenances and between the two sites (Herbert *et al.,* 2002). These results indicate that survival and productivity of provenances were higher at Gairo than SUA Farm site probably due to soil compaction and acidic soil condition of the latter (Herbert *et al.,* 2002). Growth and yield differences among provenances were attributed to differences in climatic conditions, soil and altitude between native range and study sites. For example, poor survival and biomass yield of Lushoto provenance in the two sites was associated with higher rain and altitude (1060 mm and 1450 m asl) compared with SUA Farm (870 mm, 500 m asl) and Gairo (499 mm, 1299 m asl). At SUA Farm, the study recommends provenances San Ramon and Flores for fire wood production due to highest biomass yields and Flores and Union Juarez provenances for green manure and fodder productions due to high foliage biomass yields. Based on the two criteria, Fortuna and Cofradia provenances are the most appropriate for Gairo.

Lesser-known Leucaena provenances

Nineteen lesser-known *Leucaena* species/provenances were assessed for growth and *psyllid* resistsnace for 37 months at Gairo as described by Edward *et al.,* 2006. Of the tested species/provenances, *Leucauena diversifolia* Ex Mexico, *Leucauena pallida* Ex Oaxaca, *L. diversifolia* Batch (15551) and *L. diversifolia* Ex Veracruz showed high potential to provide fodder and firewood at Gairo due to their high survivals, height and diameter growths, biomass yields and *psyllid* resistance. For example, *L. diversifolia* Ex Veracruz recorded lowest *psyllid* infection (1.29) but highest survival (100 %), wood biomass (15.61 Mg ha^{-1}), height (4.87 m) and dbh (4.93 cm) growths; indicating high tolerance to pests attacks and semi-arid conditions (Edward *et al.,* 2006). This study recommended *L. diversifolia* Ex Mexico, *L. pallida* Ex Oaxaca, *L. diversifolia* Batch (15551) and *L. diversifolia* Ex Veracruz provenances for Gairo.

Gliricidia sepium **provenances**

Eleven *Gliricidia sepium* provenances/land races were evaluated for fodder and wood production at Kibaha, SUA Farm (Gerald, 2003) and Gairo (Gerald, 2003; Mugasha *et al.,* 2006). Significant variations in growth and yield performances were observed among provenances. However, provenances did not differ in terms of leaf concentration; implying that *G. sepium* provenances/land races can be selected for both fodder and wood production based on growth and yield performance (Mugasha *et al.,* 2006). Generally, survival (75 – 100%) and nutrient concentrations (3.48 – 4.24 % N; 0.16 – 0.26% P) were good for all *G. sepium* provenances/landraces

(Gerald, 2003; Mugasha *et al.,* 2006) and comparatively higher than other common exotic AF trees/shrubs species in Tanzania (Mgangamundo, 2000); indicating high potential for rehabilitation of degraded lands, improving soil fertility and crop productivity, supply of fuelwood and fodder in semi-arid conditions. Ranges of foliar and wood biomass yields after 19-month growth period at Gairo were: 18.52 and 43.30 Mg ha^{-1}; 21.61 and 42.07 Mg ha^{-1}; 15.52 and 42.20 Mg ha^{-1}; 17.19 and 41.98 Mg ha^{-1} for Fransisco, SUA, Pontezuela Bolivar and Volcan Suchitan provenances respectively. Mugasha *et al.,* 2006, recommended provenances Fransisco and SUA landrace for both fodder and wood production; Pontezuela Bolivar and Volcan Suchitan provenances for wood production and Makhanga provenance for fodder production at Gairo because of the highest biomass yield.

Gerald (2003) did not statistically compare site effects on growth and yields of provenances due to age and provenances differences. However, comparing the two provenances that occurred in all sites at selected ages, Gerald (2003) found variations in survival, biomass yields and foliar nutrient concentrations for the three sites; reflecting presence of provenance x site interactions in *G. sepium*. At ages ranging from 2 to 2.5 years (i.e. 24 – 30 months), survival and biomass yields of both provenances were generally lowest at Gairo and higher in other sites (Tables 1 and 2). This variation was associated with differences in rainfall, altitude and edaphic factors like soil pH and fertility (Gerald, 2003). *Gliricidia sepium* is known to grow well at an altitude ranging from 0 – 750 m (AFNETA, 1992), which are ranges found at Kibaha and SUA Farm. It is also known to tolerate acidic conditions and low exchangeable calcium levels in the soil (Szott *et al.,* 1991), conditions which occur at SUA Farm. Therefore, these factors probably accounted for higher survival and yields of *G. sepium* provenances at SUA Farm and Kibaha since Gairo receives relatively less rainfall and it is at higher altitude (Gerald, 2003). This study identified Cuyatenango and Jutiapa as suitable *G. sepium* provenances for both SUA Farm and Kibaha.

Table 1: Survival and biomass yield of Cuyatenango *G. sepium* provenance at Gairo, SUA Farm and Kibaha, Tanzania

Site	Age (months)	Survival (%)	Biomass (Mg ha^{-1}) Foliar	Wood	Total
Gairo	27	71.6	10.64	36.16	47.26
	42	71.6	13.75	55.69	69.47
	70	63.4	18.68	95.15	110.64
SUA Farm	24	82.0	17.20	57.65	75.09
	41	73.9	18.20	87.53	109.37
	69	73.9	23.41	104.16	124.92
Kibaha	29	85.1	17.89	45.05	92.34

Source: Gerald (2003)

Table 2: Survival and biomass yield of Taxisco *G. sepium* provenance at Gairo, SUA Farm and Kibaha, Tanzania

Site	**Age (months)**	**Survival (%)**	**Biomass (Mg ha^{-1}) Foliar**	**Wood**	**Total**
Gairo	27	67.5	9.58	30.70	40.86
	42	67.5	11.79	42.00	54.42
	70	67.5	16.87	76.22	91.20
SUA Farm	24	90.0	17.20	57.65	75.09
	41	90.0	18.20	87.53	109.37
	69	90.0	21.60	92.10	112.03
Kibaha	29	80.3	16.78	41.89	83.00

Source: Gerald (2003)

***Sesbania macarantha* provenances**

Results of *S. macarantha* provenances at Gairo indicated highest survival (83.3%) for the Andago (Arusha) provenance and the lowest survival for Miabeze (Mbeya) provenance. Biharamulo provenances recorded the highest biomass production (8.4 Mg ha^{-1}) while the least biomass yields was produced by Kangamo provenance. *Sesbania macarantha* with wide natural distributions is expected to have genetic variation which probably accounted for the observed differences in survival and productivity of provenances. Overall, Andago, Biharamulo, Chala, Kikomakoma, Kisabya and Banda were the best performing provenances and are recommended for planting at Gairo and other sites with similar climatic conditions.

Improved fallow

Improved fallow (IF) is defined as a technology where soils rejuvenating trees or shrubs are planted in a land going to fallow with the aim of improving soil fertility in a short time. Temporal arrangements of tree and crop component reduce competition for soil moisture and nutrients (Rocheleau *et al.,* 1988; Tiessen *et al.,* 1992) making the IF technology more appropriate to semi-arid sites compared with simultaneous AF systems such as alley cropping. The benefits of IF on soil fertility, crop and wood yield improvement depend on the species used, fallow duration and type of annual crop (Jama *et al.,* 1998; Buresh and Cooper, 1999). As a result, SUA initiated IF research in semi-arid Morogoro to assess the effects of fallow types/species and length of fallow period for improving soil fertility, crop and wood yields (Chingonikaya, 1999; Mgangamundo, 2000, Chamshama *et al.,* 2000).

Soil fertility improvements by improved fallow

A two-year IF increased soil pH, organic carbon, extractable P and total N relative to initial levels (Table 3). Generally, these parameters were consistently higher in soils under shrub fallows than in natural fallowed soils. For example, Bray 1 P and total N were highest in fallows of *G. sepium, S. macrantha* and *S. sesban* indicating differential soil replenishment abilities. Based on the mean soil bulk density (1.24 g cm^{-3}) of the plough layer (i.e. 0-20 cm), Bray-1 P levels were 60.4, 19.8, and 26.7 kg P ha^{-1} for *G. sepium, S. macrantha* and *S. sesban* respectively. Compared with recommended rates of P (60 kg P) for Gairo (Chingonikaya, 1999), the soil P levels in *G. sepium* and *S. sesban* fallows were equivalent to full and half rates respectively. Similarly, net mineral N levels during the cropping season were higher in shrub fallows than natural fallows averaging 279.0, 325.5, 232.5 kg N ha^{-1} for *G. sepium, S. macrantha* and *S. sesban* respectively. Compared with the recommended N fertilizer rates of 80 kg N ha^{-1}, these values suggest that IF has high potential to meet N requirement for maize production at Gairo. Besides fallow types, soil fertility improvement under IF varied significantly with fallow period (Table 4) presumably due to differences in the duration trees/shrubs recycle nutrients. Improved soil nutrients by N-fixing trees/shrub fallows are usually attributed to biological N fixation, nutrient pumping from lower soil horizons and nutrient retention by trees/shrubs roots through reduction of leaching and surface runoff (Rao *et al.,* 1991; Buresh and Tian, 1998). The IF studies at Gairo indicated that two years was the optimum period for replenishing nutrients, particularly N and P required for maize production (Chingonikaya, 1999; Mgangamundo, 2000, Chamshama *et al.,* 2000).

Table 3: Soil physio-chemical properties of the topsoil (plough layer) before and after a two year improved fallow at Gairo, Morogoro, Tanzania

Properties	Before		After				
	Soil depth		Fallow type[1] (0 -15 soil depth)				
	0-10	10-20	*C. cajan*	*G. sepium*	*S. macarantha*	*S. sesbania*	*NF*[2]
EC (dsm^{-1})	0.05	0.04	0.09b	0.29a	0.15ba	0.17ba	0.07b
pH (H_2O)	6.53	6.68	6.34b	7.28a	6.91ba	7.42a	6.97ba
Organic Carbon (%)	1.67	1.65	1.52bc	2.59a	2.23ba	2.03bac	1.29c
Bray -1 P (mg kg^{-1})	3.29	1.85	7.82ba	32.46a	10.64b	14.33b	2.07b
Total N (%)	0.11	0.09	0.08	0.28	0.16	0.20	0.07
CEC (cmol (+) kg^{-1})	6.67	6.50	-	-	-	-	-
BD (g cm^{-3})[3]	1.19	1.28	-	-	-	-	-

Source: Chingonikaya (1999). [1]based on soil properties at 0-15 soil depth, [2] Natural fallow [3]Bulk density. Means of fallow type followed by same letter along each row are not significantly different (P<0.05) according to Duncan Multiple Range Test (DMRT)

Table 4: Soil chemical properties of the topsoil (plough layer) as affected by fallow type and fallow period at Gairo, Morogoro, Tanzania

Properties	Soil depth (cm)	Soil properties/Fallow period (years)					
		pH (H_2O)			Organic Carbon (%)		
		1	2	3	1	2	3
S. sesbania	0 - 10	9.943	7.100	7.310	1.920	2.720	2.413
	10- 20	6.900	7.070	7.343	1.853	2.663	2.366
T. vogelii	0 - 10	6.963	7.143	7.290	1.713	2.526	2.256
	10- 20	6.900	7.133	7.173	1.586	2.503	2.416
C. cajan	0 - 10	6.556	6.366	7.133	1.460	1.556	1.290
	10- 20	6.496	6.350	7.060	1.373	1.476	1.233
Natural fallow	0 - 10	6.336	6.356	6.436	1.040	1.290	1.330
	10- 20	6.326	6.346	6.400	0.880	1.040	1.220
Continuous cropping	0 - 10	6.263	5.953	5.523	0.796	0.693	0.595
	10- 20	6.223	5.920	5.505	0.706	0.586	0.510
		Bray -1 P (mg kg^{-1})			**Total N (%)**		
S. sesbania	0 - 10	12.923	16.290	14.450	0.203	0.250	0.256
	10- 20	12.733	15.246	14.100	0.183	0.240	0.903
T. vogelii	0 - 10	11.056	13.683	13.830	0.187	0.210	0.210
	10- 20	10.566	13.183	13.530	0.170	0.193	0.200
C. cajan	0 - 10	12.136	14.406	13.723	0.133	0.216	0.153
	10- 20	11.956	14.293	13.066	0.930	0.120	0.143
Natural fallow	0 - 10	2.136	4.946	5.730	0.730	0.087	0.110
	10- 20	2.103	4.660	5.426	0.063	0.083	0.096
Continuous cropping	0 - 10	4.226	3.133	2.110	0.096	0.077	0.065
	10- 20	4.133	2.873	2.010	0.087	0.067	0.050

Source: Mgangamundo (2000)

Wood production under improved fallow

Wood and foliage biomass varied significantly with fallow type and fallow period (Tables 5 and 6). In a two-year IF, *G. sepium* produced the highest foliage biomass whereas wood yield was highest in *S. sesban* plots (Table 5). Generally, total above ground biomass increased with fallow period and was highest in *S. sesban* and lowest in *C. cajan* (Table 6). Declining biomass yields in the third year fallow of *S. sesban* is associated with increased mortality as reflected by 46 % drop in survival (Mgangamundo, 2000). The highest foliage biomass in *G. sepium* fallows was also accompanied by highest OC and Bray– P indicating the role of litter fall and decomposition in ameliorating soil nutrients (Table 3). Wood production ranged from 3.43 – 51.76 Mg ha^{-1} indicating high potential of the IF to provide fuelwood in addition to improving soil fertility. However, biomass yields of tree/shrub species in these studies were generally lower than values reported in the literature mainly due to influences of rainfall, soil and species types and planting density (Chingonikaya, 1999: Mngangamundo, 2000). Gairo experiences a semi-arid climate with mean annual rainfall of 499 mm (Chamshama *et al.,* 2000) and highly degraded nutrient poor soils (Msanya and Msaky, 1994). These results suggest that *S. sesban* and *G. sepium* are suitable species for IF in semi-arid conditions because of high foliage and wood biomass yield.

Table 5: Wood and foliar biomass yield in two year improved fallow at Gairo, Tanzania

	Biomass Yield (Mg ha^{-1})		
Shrub/tree species	Foliage	Wood	Total
C. cajan	1.63c	6.57c	8.20
G. sepium	7.34a	8.18bc	15.52
S. macrantha	4.83b	9.47b	14.30
S. sesban	6.08ba	19.20a	25.28

Source: Chingonyikaya (1999). Means followed by same letter within a column are not significantly different (P<0.05) according to DMRT.

Table 6: Biomass production (Mg ha^{-1}) by 1, 2, and 3 year improved fallow at Gairo, Tanzania

Tree/shrub Species	Fallow period (years)								
	1			2			3		
	Foliar	Wood	Total	Foliar	Wood	Total	Foliar	Wood	Total
S. sesban	1.92	6.13	8.00	18.05	51.79	69.84	11.73	34.21	46.02
T. vogelii	2.11	3.43	5.44	3.65	4.59	8.29	4.11	4.77	8.95
C. cajan	2.15	7.53	10.01	1.48	5.19	6.79	1.60	6.89	8.25

Source: Mgangamundo (2000)

Maize production under improved fallow

Split-plot and split-split plot designs were used to compare effects of fallow type and fallow period on maize yields with N and P fertilizers (Chingonikaya, 1999; Mgangamundo, 2000). Results of these studies are summarized in Tables 7 and 8. Tree/shrub fallows, either with or without fertilizer applications, significantly improved maize yields over natural fallow and continuous cropping probably due to improved soil nutrients under IF (Tables 3 and 4). After a two-year fallow period, maize grain yields were highest in *T. vogelii* (4.41 Mg ha^{-1}), *G. sepium* (3.61 Mg ha^{-1}), *S. sesban* (2.48 Mg ha^{-1}) and *C. cajan* (2.47 Mg ha^{-1}). A similar trend was also reported for maize N and P uptake (Chingonikaya, 1999; Mgangamundo, 2000). Apparently, poor maize yields in *S.sesban* fallows were attributed to increased mortality and unsynchronized nutrient release from green manure due fast decomposition. Relatively slow decomposition rates of *T. vogelii* green manure compared with *G. sepium* and *S. sesban* green manure probably provided better synchrony of nutrient release with maize nutrient demand leading to highest maize yields (Fasuluku, 1998; Mgangamundo, 2000). Higher maize yields in tree/shrub fallows compared to natural fallow and continuous cropping affirm the superiority of IF of fast growing N fixing species over traditional fallow systems and non use of fertilizer.

Table 7: Maize grain yield from two year improved fallows at Gairo, Tanzania

	Maize yields (Mg ha-1)	
Shrub/tree species	Without fertilization	With fertilization
C. cajan	1.91	4.91
G. sepium	3.36	5.19
S. macarantha	2.22	3.19
S. sesban	2.72	4.70
Natural fallow	1.56	3.17

Source: Chingonyikaya (1999)

Table 8: Maize grain yield (Mg ha^{-1}) from 1, 2, and 3 year improved fallows at Gairo, Tanzania

Tree/shrub species	Fallow period (years)					
	1		2		3	
	Without fertilizer	With fertilizer	Without fertilizer	With fertilizer	Without fertilizer	With fertilizer
S. sesban	1.96	3.28	2.48	4.26	3.24	5.04
T. vogelii	3.32	7.30	4.41	6.85	5.38	8.30
C. cajan	1.66	2.87	2.47	7.53	2.85	6.79
Natural fallow	1.02	2.16	1.25	2.21	2.47	3.59
Continuous cropping	2.16	3.21	1.80	2.87	1.16	2.01

Source: Mgangamundo (2000)

Fallow period significantly improved maize grain yields in all fallow types (Table 8) presumably due to increased capacity of tree/shrub fallows to replenish soil nutrient (Table 4). Maize grain yields from unfertilized plots of *T. vogelii* were 3.32, 4.41 and 5.39 Mg ha^{-1} for 1, 2, and 3-year fallows respectively. Without fertilizer application, *S. sesbania* and *C. cajanus* fallows would require a three – year fallow period to produce as much maize grain yields as one year fallow of *T. vogelii*; demonstrating the high potential of *T. vogelii* to improve maize production.

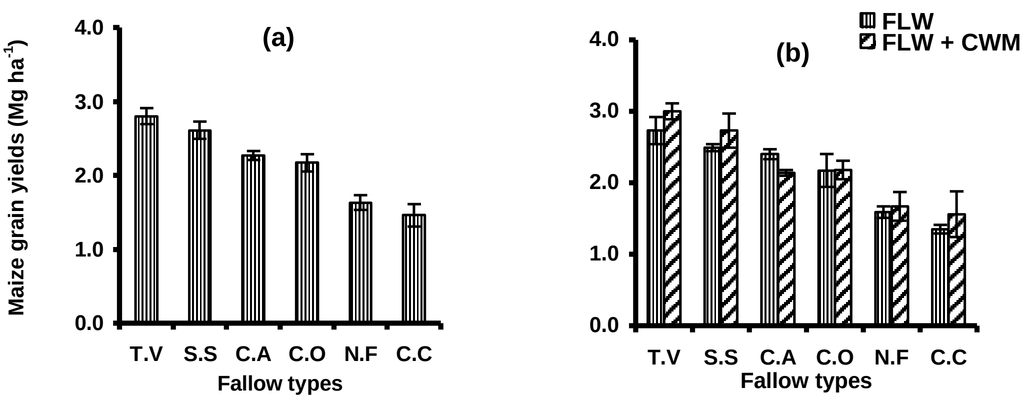
Fertilization with N and P further increased maize grain yields in all fallow types (Tables 7 and 8), suggesting that fertilizer supplement is necessary for optimizing crop yields because green manure alone is not an adequate source of nutrients, particularly P (Palm, 1995; Gachengo *et al.,* 1999). Interactions of fallow types and inorganic fertilizers on maize yields revealed that application of half rate of N with either half or full rate of P after 1-3 year fallow of the tested species is sufficient to optimize maize grain yields in Gairo (Chingonikaya, 1999; Mgangamundo, 2000). These results imply that IF has potential to cut down fertilizer costs by 50 % without compromising crop production.

Narrow-spaced one year IF and relay intercropping

Previous IF trials concluded that the optimum fallow period for *G. sepium*, *T. vogelii* and *S. sesban* is two years while for *C. cajan* is 3 years at the spacing of 2 x 2m and 2 x 1m under Gairo conditions (Chingonikaya, 1999; Mgangamundo, 2000). However, in places with high scarcity of arable land like Gairo, farmers can hardly afford to fallow their farms for 2 or more years. This problem may partly be addressed by using either one year IF at narrow spacing or RI of leguminous species. Crop production under RI in semi-arid areas may be adversely affected by competition for growth resources particularly moisture and nutrients between trees/shrubs and crops. However, with appropriate designs of spacing and time of planting trees/shrub components competitions among components may be reduced substantially. In order to address these problems, further studies were carried out to develop technologies that would optimize use of arable land and minimize growth resource competitions in AF systems (Mnyonga, 2005; Ngegba, 2005). Specific objectives of these studies were to evaluate the effects of: (1) narrow-spaced one year IF of selected AF shrubs and cow manure on soil fertility and maize yields improvements, (2) time of planting and planting space of *T.vogelii* and fertilization on soil moisture dynamics and maize yields under relay intercropping. Tree/shrub spacing in the one-year IF was reduced to 0.5 x 1 m within and between sowing lines respectively so as to increase foliage biomass produced per unit.

Maize yield in narrow-spaced one year improved fallows

Fallow types significantly improved maize yields over natural fallow and continuous cropping plots with the highest values obtained with *T. vogelii* and *S. sesban* (Figure 1a). This increase was attributed to higher potential available N in soils under AF shrub fallows (Mnyonga, 2005). There were no significant differences in maize yields between plots with and without cow manure (Figure 1b). Interestingly, *T. vogelii* gave maize yield close to 3 Mg ha^{-1}, which is close to yields of 4.41 Mg ha^{-1} from a 2 year fallow reported by Mgangamondo (2000) indicating high potential of narrow-spaced one year IF to replace longer fallows in land scarcity areas.



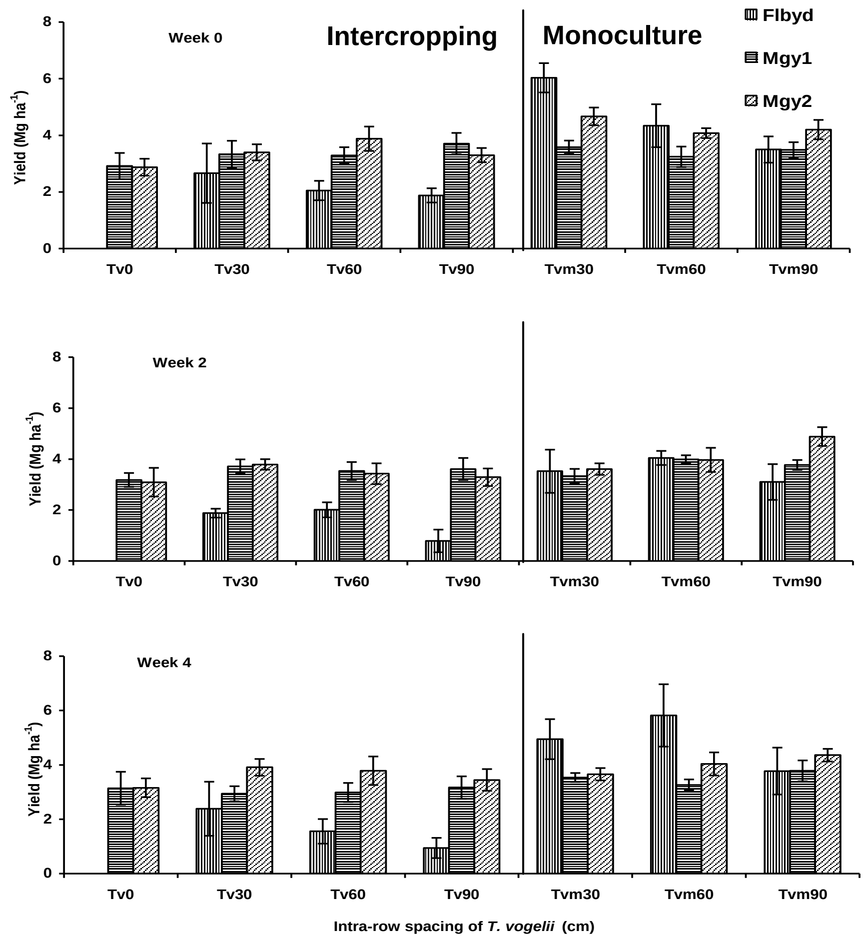
FLW = Fallow type, FWL + CWM = Fallow type and manure T.V = Tephrosia vogelii, S.S = Sesbania sesban, C.O = Crotaralia ochroleuca, N.F = Natural fallow and C.C = Continuous cropping. Vertical bars indicate standard errors of means of three replicates.

Figure 1: Effects of fallow types (a) and interaction effects of fallow type and cow manure (b) on maize grain yield under narrow-spaced one year IF at Gairo, Morogoro, Tanzania (Source: Mnyonga, 2005)

Shrub biomass and maize yields in Tephrosia-Maize relay intercropping

Apparently, the growth of *T. vogelii* in the RI was suppressed by maize because foliage biomass yields in the intercropped plots after one year were lower (2 – 3 Mg ha^{-1}) than yields (3.5 to 6 Mg ha^{-1}) from monoculture plots; implying that inter-specific competition negatively affected the shrub component (Figure 2). This suppression was associated with shading effects of maize rather than competition for moisture and nutrients because prolonged observation revealed that sunny weather rather than heavy rain weather favors the establishment of *Tephrosia* (Mugasha, personal comm.).

After six weeks growth period, biomass yield, diameter and height of *T. vogelii* planted four weeks after maize sowing were significantly lower than those of week zero and two (Figure 3). Poor growth and yield of *T. vogelii* planted four weeks after maize sowing is probably associated with maize shading effects because corresponding maize height at tasselling for each treatment combination were higher than the height of *T. vogellii* at maize harvest; implying that the shrub dominated lower canopy through out the growing period (Ngegba, 2005). Apparently, highest growth and biomass yields of *T. vogelii* planted two weeks after maize sowing at 30 cm intra-row spacing (Figure 3) possibly reflect high moisture utilization because soil moisture was lowest in this treatment combination (Ngegba, 2005) and photosynthetic processes demand sufficient water.



Key: Flbyd = Foliar biomass yield, Mgy1= Maize grain yield in first residual season and Mgy2= Maize grain yield in second residual season. Vertical bars indicate standard errors of means of three replicates.

Figure 2: The Interaction effect of time of planting and spacing of *Tephrosia* on and maize grain yield for first and second residual seasons along side the *Tephrosia* foliar biomass yields at eleven months growth in relay intercropping experiment at Gairo, Tanzania. (Source: Ngegba, 2005)

Maize yield did not differ significantly between intercrop and monoculture plots. Given higher *T. vogelii* biomass in monoculture plots this response is unexpected but it is mainly attributed to irregular rainfall and distribution patterns, which in turn did not cause significant variations in potential available N during the cropping season due to limited N mineralization (Ngegba, 2005). Interactions between fertilizer rates, planting time and spacing on maize yield revealed that unfertilized *Tephrosia* plots significantly improved maize production by 50 and 58% over control during the second and third cropping season respectively reflecting residual effects of *T. vogelii* one-year RI (Ngegba, 2005).

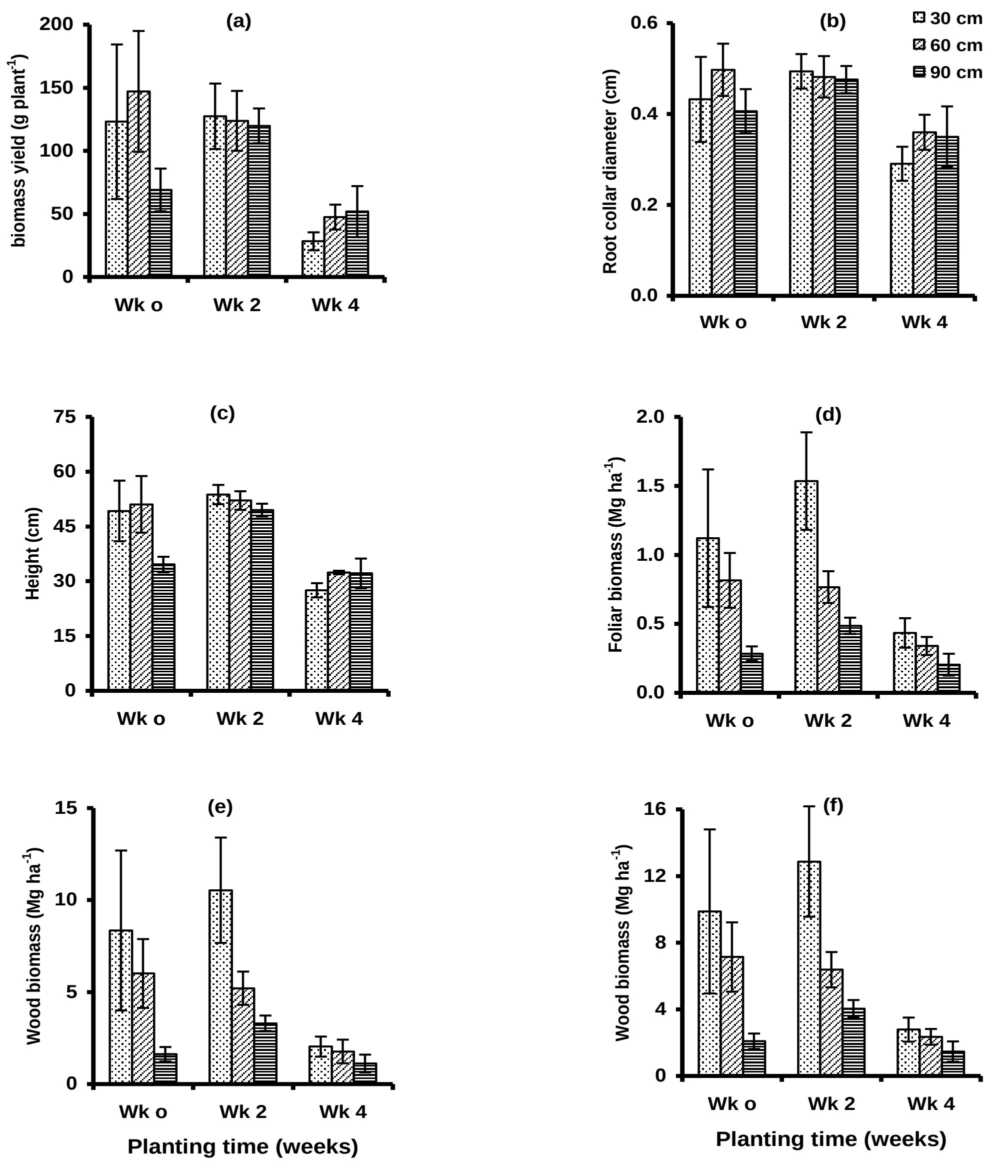


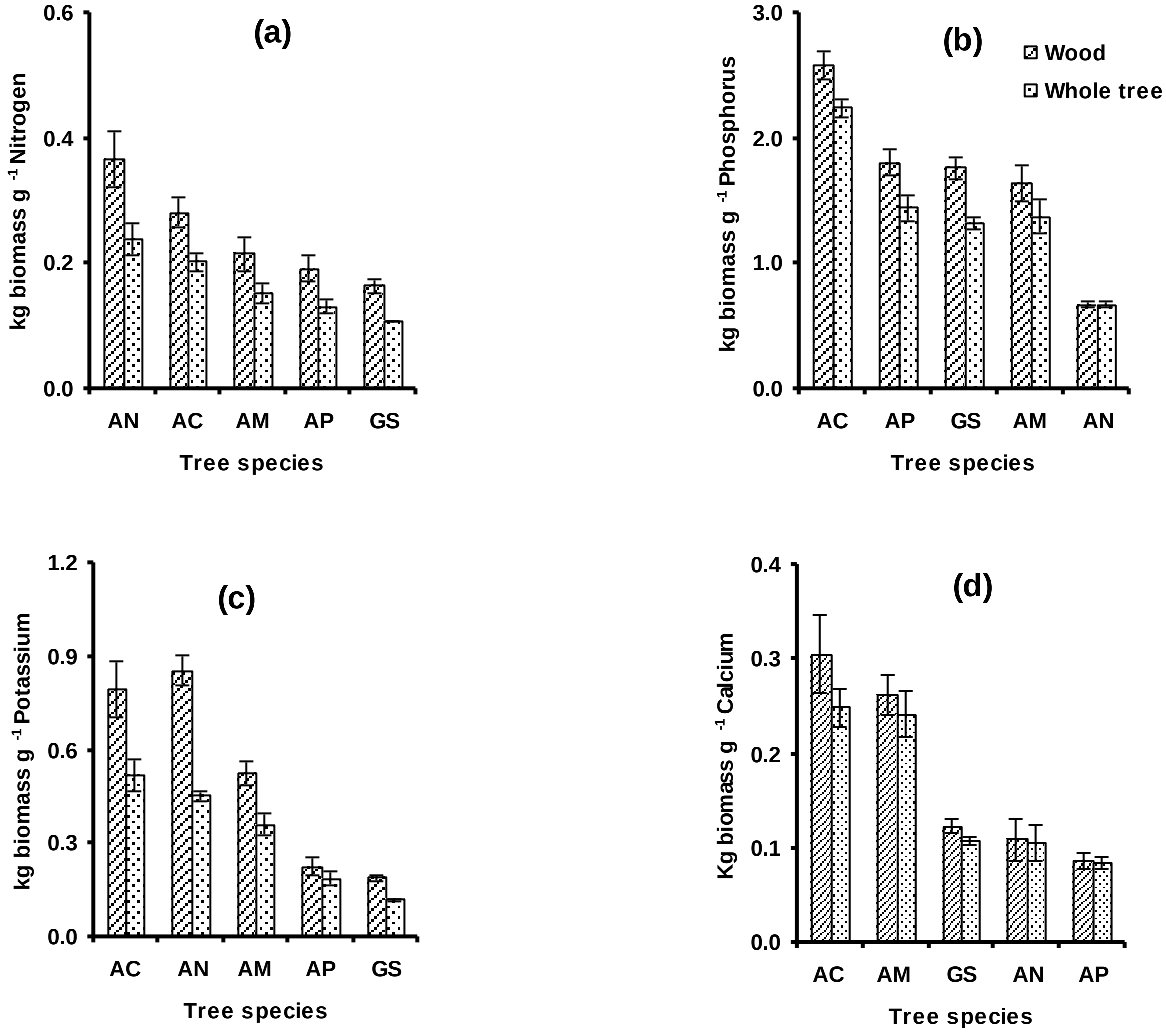
Figure 3: Effect of the interaction of time of planting and spacing of on mean shrub biomass (a), mean shrub diameter (b), mean shrub height (c), foliar biomass (d), wood biomass (e) and total biomass (f) of *T. vogelii* at six months of growth in relay intercropping at Gairo, Tanzania. Vertical bars indicate standard errors of means of three replicates. (Source: Ngegba, 2005)

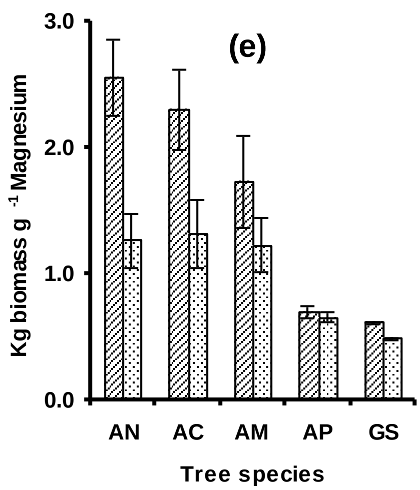
Rotational woodlot

Wood produced in IF and RI is usually low compared to rotational woodlot (RWL) because of inherently short growth period of trees/shrubs fallows. Consequently, RWL experiments were established primarily to address fuelwood deficit problems in semi-arid conditions. A number of tree species have been evaluated to assess their potential for wood production, maize yield, nutrient use efficiency and export (Kimaro *et al.,* 2006a and b).

Nutrient use efficiency, defined as the ratio of biomass productivity to nutrients uptake, is a measure of the efficiency with which tree species use soil nutrients for growth (Marschner, 1995) provides a basis for comparing nutrient "costs" of biomass production (Kumar *et al.,* 1998) and the potential of plant species to grow well under conditions of limited soil nutrients supply (Marschner, 1995). Generally, *A. crassicarpa* was the most efficient tree species. Its potassium use efficiency was four times higher than that of *G. sepium,* P - use efficiency was three times as high as that of *A. nilotica* exemplifying that *A. crassicarpa* produced the highest biomass at lowest nutrient "costs" (Figure 4). Low nutrient content per unit biomass produced (i.e. high nutrient use efficiency) implies that tree species will export less nutrient through wood harvests from the RWL; suggesting high potential for sustaining wood production under this system (Wang *et al.,* 1991; Kumar *et al.,* 1998). Similarly, wood production was highest in *A. crassicarpa* (51 Mg ha^{-1}) probably due to high nutrient use efficiency (Figure 5). Based on firewood consumption rates of 10 kg per week for an average family of six members in Miombo woodlands (Biran *et al.,* 2004), wood produced from RWL would be sufficient to meet the household fuelwood demands for about 7 to 16 years. The result indicates high potential of this system to contribute to firewood demand in the region, and would in turn reduce subsequent harvesting pressure on the natural forests (Kimaro *et al.,* 2006a).

Highest maize grain yields after wood harvesting were observed in *A. polyacantha*, *L. diversifolia* and *G. sepium* fallows (Figure 6) probably reflecting highest soil nutrients improvement during the fallow period and large amounts of nutrients, particularly N, released from slash applied as green manure (Kimaro *et al.,* 2006b). In the first cropping season, maize grain yields from these species (3.10 - 3.35 Mg ha^{-1}) were equivalent to 3.50 Mg ha^{-1} recorded in plots receiving full rates of both N and P fertilizers. Among exotic *Acacia* species, *A. mangium* fallow produced relatively high maize grain yields (Figure 6) probably due to comparatively high soil nutrient improvement and more nutrients released during the cropping seasons (Kimaro *et al.,* 2006b). These studies suggest that *A. crassicarpa*, *A. leptocarpa* and *A. mangium* are an appropriate species for wood production because of high wood produced at low nutrient costs while *A. polyacantha, G. sepium* and *L. diversifolia* would be appropriate species for improvement of soil fertility and maize yields under RWL system. Thus Australian acacias (i.e. the former group of species) are suitable for maximizing wood production in RWL.





Key: AC = *Acacia crassicarpa*, AM = *Acacia mangium*, AN = *Acacia nilotica*, AP = *Acacia polyacantha*, GS = *Gliricidia sepium*. Vertical bars indicate standard errors of means of three replicates.

Figure 4: Use efficiencies of nitrogen (a), phosphorus (b), potassium (c) calcium (d) and magnesium (e) in wood and aerial tree biomass of tree species in a five-year old rotational woodlot at Mkundi, Morogoro, Tanzania. (Source: Kimaro *et al.,* 2006a)

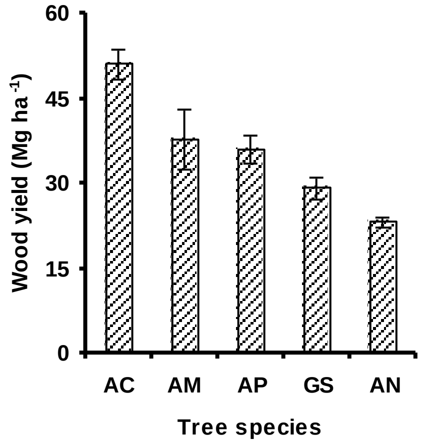
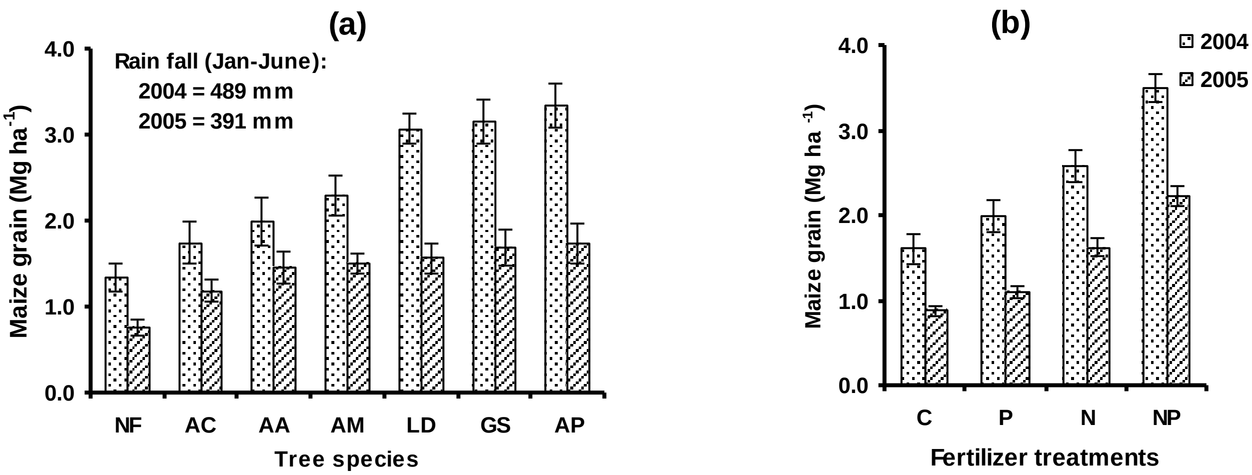


Figure 5: Wood biomass yields of tree species in a five-year old rotational woodlot at Mkundi, Morogoro, Tanzania. Tree species and vertical bars as defined in Figure 4. (Source: Kimaro *et al.,* 2006a)



Key: AC = *Acacia crassicarpa*, AA= *Acacia auriculiformis*, AM = *Acacia mangium*, AP = *Acacia polyacantha*, GS = *Gliricidia sepium,* LD = *Leucaena diversifolia*. Vertical bars as defined in Figure 4.

Figure 6: Effects of tree species (a) and N & P Fertilizers (b) on maize yield in a five-year old rotational woodlot at Mkundi, Morogoro, Tanzania. C=Control (No fertilizer). P= 40 kg P ha^{-1}, N= 80 kg N ha^{-1} and NP = Combined application of N and P fertilizer at 40 kg P ha^{-1}soil and 80 kg N ha^{-1}). (Source: Kimaro *et al.,* 2006b)

Green manure and Minjingu phosphate rock trails

Most AF technologies have limited abilities to ameliorate soil P because unlike nitrogen (N), P is not biologically fixed from the atmosphere and the P content of plant residues is normally insufficient to meet the requirements for sustained crop production (Palm, 1995). This implies that mineral sources of P must be applied to soils with deficiency of this element. Application of green manure and MPR is known to improve soil P availability through enhanced dissolution and reduction of P fixation capacity. This would be a promising approach to improve crop performance in AF systems in P deficient soils since MPR is an alternative affordable source of P readily available in northern Tanzania. In view of this fact, an experiment was established to assess the effects of *G. sepium* green manure and MPR application on soil P availability and maize yields on P deficient soils of Morogoro (Kimaro, 2000). Results of this study indicated that green manure application significantly improved extractable P, maize yields and nutrients uptakes with higher values observed in incorporation than mulching treatments. Four weeks after maize planting, these treatments had improved Bray 1 P by 43 and 27% respectively over the control. Corresponding maize grain yields were 2.6 and 2.3 Mg ha^{-1} respectively (Figure 7). Increased soil P availability following green manure application was higher in soil incorporated green manure than its application as mulch probably due to fast decomposition and enhanced soil contact.

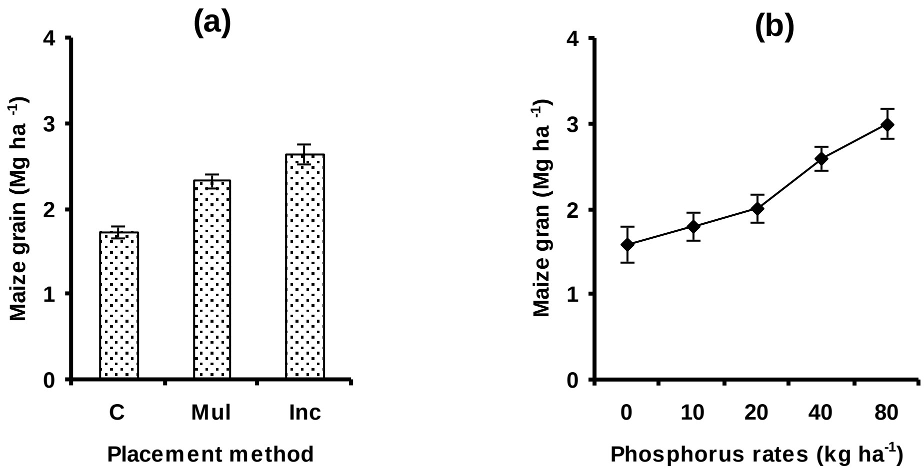


Figure 7: Effects of G. sepium green manure (a) and Minjingu phosphate rocks application rates (b) on maize grain yields at Sokoine University of Agriculture farm, Morogoro, Tanzania. C = Control, Mul = Mulching and Inc = Incorporation. Vertical bars indicate standard error of the mean of the three replicates (Source: Kimaro, 2000)

Conclusions

Species/provenance trials have demonstrated the need to test tree/shrub species and provenances under given site conditions prior to final selection of appropriate species/provenances for planting. Growth and yield differences among species/ provenances were attributed to difference in climatic conditions, altitude and edaphic factors like soil pH and exchangeable Ca between native range and study sites. Although the trials consisted of wide variations of age and species making statistical comparisons difficult, generally *G. sepium* provenances showed highest survival, biomass yields and nutritive values than tested species in all three sites demonstrating wide adaptability to different agro-ecological zones and high potential for use in AF systems and rehabilitation of degraded lands. Of the evaluated *Leucaena* species/provenances, *L. diversifolia* Ex Veracruz had the highest *psyllid* resistance and would be potential for replacing *L. leucocephala* in AF systems.

Two-year fallow period under IF at Gairo was sufficient to improve soil fertility, wood and maize yields with the highest improvement obtained with *G. sepium* and *T. vogelii* fallows. These fallows have potential to reduce costs of N and P fertilizer to farmers by 50 % without adversely affecting maize yields. However, where arable land is scarce, narrow-spaced one year IF or RI are alternative AF technologies for optimizing land use and sustaining crop production. For instance, one-year IF of *T. vogelii* planted at 0.5 by 1 m yielded 3 Mg ha^{-1} of maize grain which is close to 4.41 from a two-year IF of the same species planted at 2 and 1 m inter-row and intra-row spacing respectively; reflecting increased foliage biomass production per unit area at narrow spacing. Appropriate design of planting space and time may minimize competition for growth resources under RI in semi-arid conditions as demonstrated by highest maize and *T. vogelii* biomass in plots where *T. vogelii* was planted two weeks after maize sowing at a spacing of 30 cm and 90 cm within and between rows respectively. *Tephrosia* – maize RI improved maize yields by 50 and 58 % over control during the second and third cropping season respectively reflecting residual effects of one-year relay intercropping.

Wood produced in RWL was higher than in IF and RI. Australian *Acacia* spp., particularly *A. crassicarpa*, *A. leptocarpa* and *A. mangium* have high potential to sustain wood production under RWL systems because of the highest wood production at lowest nutrient "costs". Wood production per hectare of these species may meet household firewood demand for 7 – 16 years thereby reducing subsequent harvesting pressure on the natural forests. However, improvement of soil fertility and maize yields in fallows of Australian *Acacia* spp. are limited due to poor litter quality. Consequently, where farmers' interest is to maximize production of both wood and crops, as in areas with scarcity of arable land, *A. polyacantha* and *L. diversifolia* would be alternative species RWL because of high potential to produce wood and improve maize yield.

Crop growth and yields in AF systems on acidic soils with high P fixing potentials may be improved when green manure and Minjingu phosphate rock are incorporated into the soil rather than surface applied as mulch.

Recommendations

The following species/provenances are recommended for scaling up in AF system in areas with climatic conditions similar to the sites under which they were tested:

a) Gairo: *C. calothyrsus* (Fortuna and Cofradia provenances); *Leucaena spp. (L. diversifolia* Ex Mexico, *L. pallida* E x Oaxaca, *L. diversifolia* Batch (15551) and *L. diversifolia* Ex Veracruz; *G. sepium* (Fransisco and SUA landrace, P ontezuela Bolivar , Volcan Suchitan and Makhanga provenances); *S. macrantha* (Andago (Arusha) and Biharamulo provenances).
b) SUA Farm: *C. calothyrsus* (San Ramon, Flores Union and Juarez); *G. sepium* (Cuyatenango and Jutiapa);
c) Kibaha: *G. sepium* (Cuyatenango and Jutiapa);

Luecaena diversifolia Ex Veracruz is recommended for replacing *L. leucocephala* and other *Leucaena* spp. with low *psyllid* resistance. Two-year IF of *G. sepium* and *T. vogelii* is recommended for improvement of soil fertility, wood and maize yields at Gairo and other semi-arid areas. However, where arable land is scarce, narrow-spaced one year IF or RI are appropriate AF technologies if well designed to minimize competitions and increase tree/shrub foliage biomass production per unit area. Continuous RI rather than one year RC is recommended in order to build up soil nutrients. *Acacia crassicarpa*, *A. leptocarpa* and *A. mangium* are appropriate species for sustaining wood production under RWL whereas *A. polyacantha* and *L. diversifolia* would be appropriate areas with scarcity of arable land because of high potential to maximize production of both fuelwood and crops.

Future research agenda

The following areas need further research attention in order to improve productivity of AF technologies in semi-arid areas.

- Evaluation of biological N fixing capacity and site x interactions of tree/shrub species/provenances as strategies to refine selection criteria.
- Foliar nutrient analysis of tree/shrub species as a criterion for assessing the potentials for use as fodder and green manure.
- Screening of indigenous tree/shrub leguminous species with potential to use in AF.
- Partitioning the effects of competitions for soil moisture, nutrient and light on growth and yields of tree/shrub and maize under relay intercropping.

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8. COMBINING *TITHONIA DIVERSIFOLIA* AND MINJINGU PHOSPHATE ROCK FOR IMPROVEMENT OF P AVAILABILITY AND MAIZE GRAIN YIELDS ON A CHROMIC ACRISOL IN MOROGORO, TANZANIA.

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Abstract

1

A two-year field experiment was conducted to evaluate the effects of *Tithonia diversifolia* green manure combined with either Minjingu phosphate rock (MPR) or triple super phosphate (TSP) on soil chemical properties that influence P availability, P pools and maize grain yields, on a Chromic Acrisol in Morogoro, Tanzania. Leafy biomass of Tithonia was applied before maize planting for two consecutive growing seasons. Treatments compared were the control, MPR and TSP each at 80 kg P ha^{-1}; Tithonia alone at 2.5, 5.0, and 7.5 Mg ha^{-1} dry matter and Tithonia combined with MPR or TSP at 40 kg P ha^{-1}. Tithonia led to significant increases in soil pH, exchangeable Ca, labile (resin and $NaHCO_3$-Pi), and moderately labile inorganic P (NaOH-Pi). It reduced exchangeable Al and P sorption. Application of MPR alone had liming effects and resulted in increase in labile P. Combining Tithonia with MPR had similar but more intense effects. Triple superphosphate alone led to acidification and this was reversed when TSP was co-applied with Tithonia. Increasing the application rates of Tithonia either alone or in combination with TSP or MPR led to more pronounced liming effects but the differences between 2.5 and 5.0 Mg Tithonia ha^{-1} were not significant due to moisture stress that was experienced during the season. The P and Ca concentrations of the maize plants at tasselling increased with the application of Tithonia alone or combined with MPR or TSP, and were significantly correlated with maize grain yields (r = 0.75 and 0.64 for MPR and TSP, respectively). Tithonia added consecutively for two years increased total maize grain yields by 70% compared to that in the control. The relative agronomic effectiveness (RAE) of MPR increased from 46% in the first year of application to >142% in the second year, indicating that the initially slow dissolution of MPR improved by combined application of Tithonia and MPR, attributed to reduction of P sorption. It is concluded that Tithonia can enhance P availability from the Chromic Acrisol through modification of soil properties associated with P transformation and availability. In cases where Tithonia is found within the farmers' fields, its combined application with MPR can increase maize yields at a much-reduced cost associated with Tithonia procurement.

Introduction

In Tanzania, as elsewhere in Sub-Saharan Africa (SSA), continuous cropping without adequate fertilization has led to soil fertility depletion and subsequent low crop yields. For instance, N, P and K uptake from soils, and other losses and transformations have led to negative balances in arable lands to the magnitudes of 27 kg $ha^{-1}yr^{-1}$ of N, 4 kg $ha^{-1}yr^{-1}$ of P, and 18 kg $ha^{-1}yr^{-1}$ of K (Smaling *et al*., 1993). Phosphorus deficiency associated with P fixation is one of the major causes of declining crop yields in Tanzania (Ikerra and Kalumuna, 1992; Mnkeni *et al*., 1994) in highly weathered soils, which constitute about 52% of all the Tanzania soils (De Pauw, 1984).

Use of mineral or organic amendments is a possible option to reverse this trend of declining crop yields. However, use of these amendments is constrained by several socio-economic limitations like high prices of inorganic fertilizer, their timely availability, high transport costs and lack of credit facilities. Although most organic soil amendments are low in P (Palm *et al*., 1997), they can improve soil parameters such as soil pH, exchangeable Al and Ca, which are closely related to P fixation (Warren, 1992). Organic soil amendments also improve P availability through reduction of the P sorption capacities of soils (Easterwood and Sartain, 1990; Nziguheba *et al*., 2000) and supply of the P released during their decomposition (Nziguheba *et al*., 2002). Use of high rates of inorganic P fertilizers has been suggested as one of the strategies for managing high P-fixing soils (Sanchez and Jama, 2002). However, this is limited by the high costs involved in purchasing and applying the fertilizers. Integrated use of organic soil amendments with modest rates of locally available inorganic P sources like phosphate rocks could be a cheaper and more appropriate option for small scale peasant farmers in terms of reduced costs, increased yields and enhanced and sustained soil fertility.

Minjingu phosphate rock is a sedimentary biogenic phosphate deposit found around lake Manyara in Arusha, Tanzania. The estimated reserve of this deposit is 10 million tons (Van Straaten, 2000). The P concentration ranges from 13-15%, with neutral ammonium citrate solubility (NAC) of 4.4% (Szilas 2000). Use of MPR as an alternative P source to TSP has received attention in Tanzania since the 1960's (Anderson, 1965; Ikerra *et al*., 1994; Szilas, 2002). Research findings from eight agro-ecological zones in Tanzania indicate that TSP is superior to MPR in the first year of application but MPR had a better residual effect (Ngatunga and Deckers, 1984; Mnkeni *et al*. 1991; Szilas, 2002). The superior and long lasting residual effect was attributed to a continual release of P from MPR. Organic anions like oxalates and malates, produced during decomposition of organic materials, competed with P for the P fixation sites (Hue, 1991; Iyamuremye *et al*., 1996) through anion exchange processes and blocked the P fixation sites (Reddy *et al*., 1980; Easterwood and Sartain, 1990), making the solubilized P more available. Ikerra *et al*., (1994) observed that the agronomic effectiveness of MPR increased when it was combined with high quality farmyard manure but not with low quality compost. In contrast, Mowo (2000) found that composted farmyard manure and MPR had no effect on MPR dissolution when co-applied on a Rhodic Ferralsol. This was attributed to the high pH of farmyard manure and a lack of proton supply. Farmyard manure, however, is not available to all the farmers, implying that locally available green manures on the farm could be evaluated. Although many studies have concentrated on the use of these materials for nitrogen supply (Ikerra *et al*., 1999; 2001a), little has been reported in Tanzania on their contribution to P availability and transformations in soils and their effects on soil properties related to P availability. Integrated use of these materials with modest rates of soluble P fertilizers like TSP has been documented in the region (Nziguheba *et al*., 2000, 2002). Combining green manures with locally available inorganic P sources like MPR could reduce the cost on P fertilizers, improve nutrient balances and crop yields, and sustain soil fertility. Although information about soil P fractions is useful in predicting the bio-availability of P in soils, and in monitoring the fate of P after fertilization with different inorganic and organic P sources, such information is still lacking in the published work dealing with MPR use in Tanzania.

In view of the foregoing knowledge gaps, this study was carried out to evaluate the effects of combined application of MPR or TSP with *Tithonia diversifolia* green manure on some soil chemical properties associated with P availability, soil P pools, and grain yields of maize grown on a Chromic Acrisol in Morogoro, Tanzania.

Materials and Methods

Study site

A field experiment was conducted in 2001 and 2002 in the Magadu area of the Sokoine University of Agriculture (SUA) farm, located at 6° 51' S and 37 ° 39' E, at an altitude of 568 m asl in Morogoro, Tanzania. The area had been under fallow for the previous five years. The area has a mean annual total rainfall of 750 – 1,000 mm, with two growing seasons. The long rains, from mid February to May (277 - 530 mm), are more reliable and better distributed, while the short rains, from October to December (298 - 410 mm), are light and erratic. The study was undertaken during the long rain seasons. The soil at the experimental site was an isoperthemic ustic, fine clayey kaolinitic, kanhaplic Haplustults (Soil Survey Staff, 1975) or Chromic Acrisol (WRB, 1998).

Soil sampling and analysis

Prior to setting up the trial, 20 surface (0 - 15 cm depth) soil samples were randomly collected in the 0.5 ha experimental site and thoroughly mixed by hand to form one composite sample. The composite sample was air-dried, sieved through a 2-mm sieve and subsequently analysed for site characterization. In all the two years (2001 and 2002) soil samples were also collected at the maize tasselling stage (55 days after planting) and analysed for pH, Ca, exchangeable Al and P sorption capacity.

The composite soil sample was analysed for pH (1:2.5 water) according to McLean (1965). Exchangeable Al was extracted using 1 M KCl and determined titrimetrically using the method of McLean (1965). Organic C was determined by sulphuric acid-dichromate digestion and colorimetric determination of Cr^{3+} (Anderson and Ingram 1993). Total nitrogen (N) was determined using the Kjeldahl method (Bremner and Mulvaney, 1982). Nitrate nitrogen (NO^-_3-N) was extracted using 2 M KCl and determined after reduction with cadmium (Dorich and Nelson, 1984) while inorganic ammonium was determined in the 2 M KCl extract using the salicylate-hypochlorite colorimetric method (Anderson and Ingram, 1993). Total inorganic nitrogen was taken as the sum of nitrate N and ammonium N. The CEC and exchangeable bases were determined following extraction using 1 M NH_4- acetate at pH 7 (Rhodes, 1982). Zinc and Fe were extracted by EDTA or DTPA and measured by Atomic Absorption Spectroscopy according to Lindsay and Norvell (1978). Particle size distribution was determined according to Gee and Bauder (1986). Anion resin extractable P was determined by the method of Sibbesen (1978).

Soil samples were collected at tasselling in the second season, and available P was characterized by sequential extraction following the method of Tiessen and Moir (1993). In the sequential fractionation procedure, the different fractions are interpreted as follows: (i) Resin-Pi (RP), stated as resin-extractable inorganic phosphate represents inorganic P that is in equilibrium with the soil solution. (ii) Sodium bicarbonate P (Bic-P) inorganic and organic P (Bic-Po) represents the weakly adsorbed Pi and easily hydrolysable organic P that is plant available. (iii) Sodium hydroxide extractable inorganic P (NaOH-Pi) and organic P (NaOH-Po) are less available to plants and are thought to be associated with amorphous and crystalline Al and Fe hydroxides and clay minerals. (iv) Dilute hydrochloric acid extractable P (HCl-Pi) is that P associated with apatite or octacalcium P.

The P sorption index was determined using the method of He *et al.* (1996) but with an initial solution P concentration of 50 mg l^{-1} rather than 150 mg l^{-1} to avoid precipitation of calcium phosphate at high P concentration. A 2.5 g soil sample was equilibrated by shaking for 18 h with 50 mL of 0.01 M $CaCl_2$ containing 50 mg P l^{-1} (as KH_2PO_4). Phosphorus in the equilibrium solution was determined by the phosphomolybdate colorimetric method (Murphy and Riley, 1962). The P sorption index was then calculated as follows: P sorption index = sorbed P (mg P kg^{-1})/log_{10} P concentration (mg P l^{-1}) in the equilibrium solution. The P adsorption maximum (Pmax) was determined according to Fox and Kamprath (1970).

Analysis of MPR

Minjingu PR, collected from the Minjingu factory in Babati, Arusha, Tanzania was ground and sieved such that 80% of the material passed a 0.15 mm sieve (100 mesh). It was analysed for pH, total P, calcium carbonate, calcium oxide and neutral ammonium citrate (NAC)-extractable P. The pH was measured in a 1:2.5 MPR-H_2O suspension (McLean 1965). Calcium carbonate was determined by the acidification-titration procedure (Loeppert and Suarez 1996), and its equivalence computed according to Tisdale *et al*. (1993). Calcium oxide content was determined by the wet digestion method using HF-H_2SO4-$HClO_4$ (Hossner 1996). Neutral ammonium citrate soluble P was determined as described by McClellan and Gremillion (1980). Total P was determined according to Okalebo *et al*. (2002).

Analysis of Tithonia green manure

Tithonia green manure (GM) samples were thoroughly washed and rinsed using distilled water, dried, ground and analysed for pH, N, P, K, Ca, Mg, C, lignin and polyphenol. The samples were analysed for pH in water at a manure: water ratio of 1:5, total N (Bremner and Mulvaney 1982), and P, K, soluble and organic C (Anderson and Ingram, 1993). Lignin and polyphenols were determined using the acid detergent method and the revised Folin - Denis method, respectively (Anderson and Ingram, 1993).

Plant sampling and analysis

To determine nutrient uptake at 45 days after planting, six maize plants per plot outside the net plot area were randomly sampled and cut using a knife at about 2 to 2.5 cm above the soil surface. The maize stumps were uprooted using a hoe after prior wetting of the surrounding soil to loosen it, and washed by spraying water to retain most of the small roots. The maize shoots and roots, and Tithonia GM samples were oven dried at 70ºC to constant weight and ground to pass through a 0.5 mm sieve. The dried maize shoots and roots were analysed for total P and Ca using the same methods as for Tithonia GM. The data were used to calculate P and Ca uptake at tasselling, by multiplying the dry matter yields and the nutrient concentrations.

Experimental design

The experiment was established during the long rains of 2001. Twelve treatments, in a randomized complete block design with three replications, were randomly allocated to 4 x 7 m plots. The treatments included a control (no P); MPR and TSP at 80 kg P ha^{-1}; Tithonia alone at 2.5, 5.0, or 7.5 Mg dry matter ha^{-1} and MPR and TSP at 40 kg P ha^{-1} each combined with Tithonia at 2.5, 5.0, or 7.5 Mg dry matter ha^{-1}. The experimental plots were left fallow during the short rain periods (October- December). During the long rains of 2001 and 2002, fresh Tithonia leaves and rachis were surface applied and incorporated into the soil to 15 cm depth using hand hoes one-week before planting. MRP was broadcasted and incorporated into the soil using a hand hoe at planting. Triple superphosphate was banded along the rows and incorporated into the soil along the rows at planting. Ammonium sulphate at 80 kg N ha^{-1} was split applied in the plots without Tithonia, one third at planting and two-thirds at 5 weeks after planting. Following chemical analysis, the Tithonia green manure was found to contain 4% N. This high N content was considered enough for supplying N initially and hence no inorganic N application was done at planting in the plots that received *Tithonia* green manure. Since decomposition of Tithonia is generally fast (Gachengo *et al*., 1999), there was a need of top-dressing the plots with *Tithonia* 5 weeks after planting to avoid N deficiency. Thus, in the plots with *Tithonia*, two thirds of the basal N (i.e. 53.3 kg N ha^{-1}) was top-dressed 5 weeks after planting. In plots without *Tithonia*, potassium, as potassium sulphate, was applied at 50 kg K ha^{-1} at planting. No K application was made in the plots that had received Tithonia GM because Tithonia has a high K content (4%). Zinc, as zinc sulphate at 5 kg Zn ha^{-1}, was applied at planting time because the Chromic Acrisol was deficient in zinc (Table 1).

In both years, after the treatments had been assigned, two maize (*Zea mays* L. var. TMV-1) seeds were sown per hill at a spacing of 75 x 30 cm, and were thinned to one plant per hill 21 days after planting. Weeding was done twice per season using hand hoes. Harvesting was done in June by opening the maize cobs, removing the husks, and hand shelling. Maize grain yields were expressed at 12.5% moisture content. After harvesting, all the maize stover and weeds were removed from the plots to reduce confounding effects from additional organic inputs of different qualities.

Table 1: Some physiochemical properties of the top- soil (0–15 cm) of the experimental site at Morogoro, Tanzania

Parameter	Value	Rating	Reference
pH (H_2O) (1:2.5)	4.8	very acidic	Landon (1991)
pH $_{KCl}$ (1:2.5)	4.4		-
Organic C (g kg^{-1})	9.9	Low	Landon (1991)
Total N (g kg^{-1})	0.9	Low	Landon (1991)
Mineral N (mg kg^{-1})	6.8	-	-
Total P (mg kg^{-1})	0.3	very Low	Landon (1991)
Available P (mg kg^{-1})			
Bray-1	6.4	Low	Singh et al. (1977)
Resin	4.1	Low	Landon (1991)
Exch. Al ($cmol_c$ kg^{-1})	3.2	Moderate	Landon (1991)
Exch. bases ($cmol_c$ kg^{-1})			
Ca	1.80	Low	Landon (1991)
Mg	1.34	Medium	Landon (1991)
K	0.53	Medium	Landon (1991)
Na	0.05	-	-
CEC (pH 7)	8.40	Low	Landon (1991)
DTPA (mg kg^{-1})			
Zn	1.04	Low	Lindsay& Norvell (1978)
Fe	60.69	Very high	Lindsay&Norvell (1978)
Texture (%)			
Sand	32		
Silt	13		
Clay	55		

Statistical analysis and mathematical calculations

Statistical analysis

Analysis of variance was conducted using the general linear models procedure (GLM) of the SAS program (SAS Institute, 1995) to determine the effects of treatments on soil parameters, P sorption index, P availability indices, nutrient uptake and maize grain yields. Statistical significances were determined at the 0.05 level of probability. Means were compared using the Duncan's New Multiple Range Test.

Mathematical calculations

Relative agronomic effectiveness

The relative agronomic effectiveness (RAE) of MPR compared to TSP was calculated as:

$$RAE = (Y_{MPR} - Y_{control}) / (Y_{TSP} - Y_{control}) \times 100$$

where:

Y_{MPR} = maize grain yield from MPR treatment at the rate of 80 kg P ha^{-1}

Y_{TSP} = maize grain yield from TSP treatment at the rate of 80 kg P ha^{-1}

$Y_{control}$ = maize grain yield from the control treatment (-P, +N, +K)

Results

Characteristics of the soil, MPR and Tithonia green manure used

The soil used in this experiment was very acidic, with low extractable P, low exchangeable Ca and moderate aluminium saturation (Table 1). It had low organic matter content and low cation exchange capacity (Table 1). The sample of MPR used had 13% total P, 35.5% Ca and 3.6% NAC-soluble P, indicating a moderate to high reactivity of the material (Table 2a). The P, N, lignin and polyphenol contents of the Tithonia GM used had high contents of Ca and K (Table 2b) that would supplement the low levels of Ca and K in the Chromic Acrisol used.

Table 2a. Chemical characteristics of MPR and TSP used in the study

Parameter	Magnitude	
	MPR	TSP
pH (H_2O)	8.5	2.1
P (%)	13.0	19.4
Ca (%)	35.5	13.5
$CaCO_3$ (%)	6.9	nil
Bray 1-P (%)	0.01	20.1
NAC solubility (%)	3.6	43.7

Effect of Tithonia green manure with MPR or TSP on soil properties determined at tasselling time in 2002.

Soil pH

In the two seasons, soil pH increased significantly (P≤ 0.0001) with increasing rate of *Tithonia* application. In 2002, there was no difference in soil pH between the 2.5 and 5.0 Mg ha^{-1} treatments (Table 3). Combining *Tithonia* at this rate with MPR (40 kg ha^{-1}) increased soil pH compared to that of the control. MPR at 80 kg P ha^{-1} had a similar effect on pH as had Tithonia, but TSP reduced soil pH relative to that of the control. The effect of combining TSP with *Tithonia* on soil pH was generally similar to that of *Tithonia* alone.

Table 3. Some soil characteristics from the field site in Morogoro as affected by different treatments at 45 days after planting in 2001 and 2002

Treatment	pH (water)		Ca (cmol (+) kg^{-1})		Al (cmol (+) kg^{-1})		P-max	PSI
	2001	2002	2001	2002	2001	2002	(mg P kg^{-1})	
Control (-P)	4.80f	4.57d	1.73h	1.78h	0.55b	0.36a	717 a	231
Tithonia 2.5 t ha^{-1}	5.20cde	4.85b	2.47def	2.45ef	0.22de	0.25b	606 c	nd
Tithonia 5 t ha^{-1} (T5)	5.40b	4.80bc	2.53def	2.44ef	0.20e	0.22bc	592 c	157
Tithonia 7.5 t ha^{-1}	5.30bc	5.30a	2.90c	2.57e	0.10fg	0.22bc	538 de	nd
MPR (P 80)	5.22cde	4.83bc	4.45a	3.32b	0.17ef	0.20bc	550 d	133
TSP (P 80)	4.70g	4.34e	3.73b	2.24g	0.73a	0.39a	641 b	144
MPR (P 40) + T2.5	5.14e	4.86b	2.44def	2.34fg	0.40c	0.22bc	518 def	nd
MPR (P 40) + T5	5.14e	4.88b	2.26fg	2.84d	0.28d	0.17c	512 ef	149
MPR (P 40) + T7.5	5.57a	4.87b	2.67cde	3.12c	0.08gh	0.20bc	525 ed	nd
TSP (P 40) + T2.5	5.16de	4.68cd	1.98gh	2.45ef	0.18e	0.21bc	602 c	nd
TSP (P 40) + T5	5.18de	4.82cb	2.32efg	2.55e	0.10fg	0.18c	592 c	107
TSP (P 40) + T7.5	5.30bc	5.36a	2.69cd	3.68a	0.01h	0.02d	525 de	nd
CV (%)	1.33	2.04	8.12	3.35	19.03	16.06	3.46	

Means followed by the same letter in the same column are not significantly different P < 0.05 according to DMRT.
nd = not determined

Exchangeable Ca

The trend of exchangeable Ca was similar to that of soil pH. *Tithonia* increased exchangeable Ca compared to that in the control (Table 3). Combining *Tithonia* with MPR further increased exchangeable Ca relative to that under Tithonia alone. Similararly, TSP increased exchangeable Ca when compared to that in the control and when combined with *Tithonia*.

Exchangeable Al

Tithonia at all rates significantly ($P<0.0001$) reduced exchangeable Al. Combining *Tithonia* with MPR had a similar effect. TSP increased exchangeable Al in 2001 but not in 2002, while combining it with Tithonia gave a similar effect as *Tithonia* or MPR applied alone.

Phosphate – sorption

There was a decrease in P sorption by *Tithonia* as indicated by decrease in the Langmuir adsorption maximum (P max) in all treatments as compared to that in the control (Table 3). Similarly, soil P sorption capacity, as indicated by the PSI determined on selected treatments, was decreased by 32% due to Tithonia applied at 5 Mg ha^{-1} compared to that in the control. Tithonia alone and when combined with MPR had a similar depressing effect on the PSI. A similar depressing effect on PSI was obtained with TSP alone. Though not statistically different from each other, MPR had a slightly higher depressing effect on PSI than that of TSP. Combination of TSP with Tithonia led to the lowest PSI that was 54% lower than that in the control. The decrease in PSI had a significant ($P \leq 0.0001$) negative correlation ($r = -0.81$), $P<0.0001$) with maize grain yields in 2002.

Soil P pools

The treatments (namely *Tithonia* alone, or combined with MPR or TSP) significantly ($P \leq 0.0001$) influenced the different P pools (namely resin P, Bic-Pi, Bic-Po, NaOH-Pi, NaOH-Po, HCl-Pi). Tithonia significantly increased resin P compared to that in the control (Table 4). The resin P fraction increased with increasing Tithonia green manure rates but there were no significant differences between 2.5 and 5.0 Mg *Tithonia* ha^{-1}. The significant increase in Bic-Pi fraction was obtained at a rate of 7.5 Mg Tithonia ha^{-1}. Although there was an increase in moderately labile P pool (NaOH-Pi) with an increase in *Tithonia* application rate compared to control, the increase at the lowest rate was not significant. Combining *Tithonia* with MPR or TSP resulted in a four-fold increase of labile P (Resin P) compared to that in the control but the effect on moderately labile P (NaOH-Pi) was only one and half fold. The effect of *Tithonia* green manure on organic P pools varied from one extractant to the other. Although Tithonia significantly increased Bic-Po at all rates, its influence on NaOH-Po was the same or lower than the control.

With the exception of TSP for the NaOH-Po fraction, both MPR and TSP had a drastic effect on inorganic P pools compared to those in the control but had no effect on organic P pools. Most of the applied inorganic P (from MPR or TSP) was extracted in the NaOH-Pi form, a fraction associated to the P chemi-sorbed by hydrous oxides of Fe and Al, and hence relatively unavailable to plants. The NaOH-Pi fraction from MPR (100 mg kg^{-1}) at 80 kg P ha^{-1} was smaller than that from TSP (118 mg kg^{-1}) at the same P rate. Addition of MPR produced the largest HCl-Pi fraction that is related to P in Ca-P forms. *Tithonia* green manure alone had similar or no effect on HCl-Pi compared to that in the control however, its combination with either MPR or TSP resulted in larger HCl-Pi than that of the control.

Table 4. Sequentially extracted soil P pools at 45 days after planting in 2002 as affected by Tithonia and inorganic P fertilizers

Treatment	RP	Bic-Pi	Bic-Po (mg kg^{-1})	NaOH-Pi	NaOH-Po	HCl-Pi
Control	2.6 k	6.7 e	10.4 e	51 h	139 bc	1.6 gh
Tithonia 2.5 t ha^{-1} (T2.5)	5.1 j	8.4 e	12.3 cd	55 gh	143 abc	1.1 h
Tithonia 5.0 t ha^{-1} (T5)	5.7 j	7.9 e	12.5 cd	59 g	131 c	1.4 h
Tithonia 7.5 t ha^{-1} (T7.5)	8.0 I	12.6 d	11.7d	69 f	136 bc	2.0 fg
MPR 80 kg P ha^{-1}	48.7 b	33.6 b	9.9 e	100 b	145 abc	11.1 a
TSP 80 kg P ha^{-1}	37.8 c	41.3 a	10.6 e	118 a	160 a	5.4 b
MPR 40 + T2.5	21.1 h	20.5 c	13.3 bc	93 c	133 bc	3.3 d
MPR 40 + T5	23.2 g	18.5 c	13.9 b	81 e	145 abc	2.9 de
MPR 40 + T7	31.6 e	14.1 d	15.4 a	87 d	150 ab	2.4 ef
TSP 40 + T2.5	28.9 f	32.9 b	15.3 a	95 c	148 abc	3.1 d
TSP 40 + T5	36.0 d	41.5 a	15.2 a	85 de	140 bc	4.5 c
TSP 40 + T7.5	58.4 a	34.8 b	15.4 a	84 de	149 ab	4.5 c
CV (%)	3.53	6.07	4.56	3.74	6.37	7.85

RP = Resin P; Bic-Pi and NaOH-Pi = inorganic extractable P; Bic-Po and NaOH-Po = organic extractable P.

Maize grain yields

The maize grain yields varied from year to year due to drought and termite attacks. However, the applied treatments significantly ($P \leq 0.0001$) increased maize grain yields compared to that in the control in both seasons (Table 5). Both MPR and TSP significantly ($P \leq 0.0001$) increased maize grain yields in both seasons. The relative agronomic effectiveness of MPR increased from 46% in the first year to 142% in the second. In the first year (2001), maize yields from Tithonia alone were similar to those when Tithonia was combined with MPR but the yields from *Tithonia* alone were significantly ($P \leq 0.0340$) lower in the second year (2002). Combining *Tithonia* with TSP produced significantly higher maize grain yields ($P < 0.0014$) than when Tithonia was applied alone in year two. When the total yield for two years is considered, the yield increase was 70% for Tithonia alone, and 109% when, Tithonia was combined with MPR. Maize grain yields obtained in the year 2002 correlated with shoot P uptake ($r = 0.81$). The resin P and bicarbonate Po fractions (Table 7) accounted for 49.6 and 43.4% of the variation in maize grain yields, respectively.

Table 5. Effect of Tithonia when applied alone or combined with MPR or TSP on maize yields

Treatments	MGY t ha^{-1}	
	2001	2002
Control (-P)	1.34 f	0.87 e
Tithonia 2.5tha^{-1} (T2)	2.10 bcde	1.50 d
Tithonia 5 tha^{-1} (T5)	2.33 abc	1.69 cd
Tithonia 7.5tha^{-1} (T7)	2.29 abcd	2.06 bcd
MPR (P 80)	1.87 e	2.21 abc
TSP (P 80)	2.50 a	1.81 cd
MPR (P 40) + T2	2.36 ab	2.30 abc
MPR (P 40) + T5	2.34 abc	2.31 abc
MPR (P 40) + T7	2.36 ab	2.74 a
TSP (P 40) + T2	2.07 cde	2.50 ab
TSP (P 40) + T5	2.29 abcd	2.72 a
TSP (P 40) + T7	2.48 a	2.84 a
CV (%)	7.62	15.69

Means followed by the same letter in the same column are not significantly different P<0.05 according to DMRT; MGY=Maize grain yield

Phosphorus and Ca uptake by the maize plants at tasselling

Tithonia significantly ($P \leq 0.0001$) increased P uptake in both shoots and roots, as well as concentrations in leaves over those in the control (Table 6). Similarly, combining Tithonia with MPR increased shoot and root P compared to that in the control treatment. The increases in shoot P for the highest level of Tithonia + MPR was higher than that of Tithonia alone. The trend for P uptake was similar when Tithonia was combined with TSP. The Ca uptake in both shoots and roots followed a similar pattern as P uptake.

Table 6. Influence of Tithonia applied alone or co-applied with MPR or TSP on shoot and root Ca and P uptake at tasselling of maize in the field experiment in 2002

Treatment	Shoot P and Ca uptake ($kg\ ha^{-1}$)		Root P and Ca uptake ($kg\ ha^{-1}$)		Leaf P and Ca conc. (%)	
	P	Ca	P	Ca	P	Ca
Control (-P)	1.25 h	1.77 g	0.04 g	0.09 e	0.22 d	0.14 d
Tithonia2.5tha^{-1} (T2)	2.63 fg	2.36 ef	0.07 f	0.14 cd	0.27 abc	0.19 abc
Tithonia5tha^{-1} (T5)	2.45 g	2.62 de	0.08 f	0.13 d	0.28 abc	0.20 ab
Tithonia7.5tha^{-1} (T7)	2.70 fg	2.63 de	0.16 d	0.20 b	0.28 abc	0.21 a
MPR (P 80)	3.02 ef	3.38 bc	0.15 d	0.24 a	0.29 a	0.19 abc
TSP (P 80)	4.14 bc	2.53 ef	0.14 de	0.14 cd	0.25 bc	0.18 bc
MPR (P 40) + T2	3.91 cd	1.92 fg	0.14 de	0.15 c	0.28 abc	0.16 cd
MPR (P 40) + T5	4.39 bc	3.26 bcd	0.15 de	0.16 c	0.29 ab	0.18 bc
MPR (P 40) + T7	4.62 b	4.41 a	0.19 c	0.15 c	0.28 abc	0.18 bc
TSP (P 40) + T2	3.50 de	2.84 cde	0.13 e	0.08 e	0.25 cd	0.18 bc
TSP (P 40) + T5	4.45 b	3.85 ab	0.22 b	0.13 d	0.28 ab	0.17 bc
TSP (P 40) + T7	5.76 a	4.35 a	0.25 a	0.24 a	0.28 ab	0.18 bc
CV (%)	7.97	13.35	7.02	7.52	6.77	9.18

Means followed by the same letter in the same column are not significantly different P<0.05 according to DMRT.

Table 7. Linear regressions of maize yields in 2002 (Y) on different P pools

P Pool	R^2-	Probability	Equation
Resin P	0.4963	***	Y = 0.023 RP + 1.53
Bic-Pi	0.2687	**	Y = 0.025 Bic-Pi + 1.55
Bic-Po	0.4339	***	Y = 0.202 Bic-Po - 0.49
NaOH-Pi	0.2210	**	Y = 0.015 NaOH-Pi + 0.88
NaOH-Po	0.0038	ns	Y = 0.010 NaOH-Po+ 0.59
HCl-P	0.0690	ns	Y = 0.063 HCl-P + 1.90

Discussion

Characteristics of the soil and organic material used

The experimental site had low soil pH, P and Ca, which are conducive for increased MPR dissolution (Mnkeni *et al.,* 1991). Dissolution of any phosphate rock is enhanced by low pH, Ca and P (Rajan *et al.,* 1996; Szilas, 2002) because such a situation provides protons and Ca and P sinks. The high green manure quality of Tithonia (as depicted by high N, P, low lignin and polyphenol contents, narrow C:N ratio) ensures rapid decomposition and net N and P mineralization (Palm *et al*., 2001). The high N, P and K concentrations of Tithonia (Table 2b) make it a good source for plant nutrients on this Chromic Acrisol (Gachengo *et al*., 1999; Nziguheba *et al*., 2000). The high basic cation concentrations of Tithonia green manure (Table 2b) makes it a fairly good acidity ameliorating amendment on this Chromic Acrisol (George *et al*., 2002).

Effects of the treatments on soil properties

The increase in soil pH due to Tithonia and MPR can be attributed to the large Ca concentration of Tithonia (Table 2b) and MPR (Table 2a). These results are consistent with the work of Phan Thi Cong (2000) and George *et al*. (2002) who reported increase in pH on similar soils due to Tithonia application in Vietnam and Kenya, respectively. Displacement of hydroxyls from sesquioxide surfaces by organic anions can also be a cause for increase in pH (Parffit 1978). Ikerra (2004) found that Tithonia contained relatively high concentrations of organic acids like oxalic and tartaric, and these could have participated in such reactions. The same reason explains why there was increase in exchangeable Ca for the same treatments. Since the soil under study was Ca deficient (Table 1), application of Tithonia and MPR improved the supply and availability of Ca to crops as depicted by increased concentrations and uptake by maize (Table 6). However, when Tithonia is combined with MPR, and depending on the Ca gradient created by plant uptake, it can decrease MPR dissolution because of the common ion effect (Rajan *et al.,* 1996; Savini 2000; Ikerra *et al*., 2001b). Reduction of exchangeable Al by Tithonia and MPR was caused by the increase in soil pH and exchangeable Ca (Table 3). Some of the exchangeable Al could have been complexed by Ca or chelated by organic ligands produced during decomposition of Tithonia (Ikerra 2004). Decrease in pH due to TSP application is attributed to the production of phosphoric acid during its hydrolysis and its low pH (Table 2a).

The decrease in exchangeable Al accompanied by increase in pH and Ca, has a positive effect of reducing P sorption (Sanyal and De Datta, 1991). This was revealed by a decrease in the P sorption index due to application of Tithonia either alone or combined with MPR or TSP (Table 3). The Decrease in P sorption capacity, as reflected by the P-adsorption maximum and PSI, could be due to (1) increase in soil pH which results in precipitation of exchangeable Al and Fe, (2) competitive adsorption of organic ligands on P sorption sites (Hue 1991; Ikerra, 2004), (3) chelation of Fe and Al by organic ligands, which releases the fixed P (Ikerra 2004), (4) addition of P from organic material decomposition (Singh and Jones, 1976), and (5) addition of inorganic P from MPR dissolution (Ikerra *et al*., 1994, 2001b). Decrease in P sorption reduces the P buffer capacity and hence decreases MPR dissolution (Wright *et al*., 1992). The positive interactive effects observed by combining MPR with Tithonia should, therefore, be the result of improved P availability rather than enhanced MPR dissolution because Ca, P and proton affinity were all increased following Tithonia application (Ikerra *et al.,* 2001b).

P pools

The significant increase in both labile and moderately labile P obtained through application of MPR alone (Table 4) implies that MPR underwent considerable dissolution. The substantial MPR dissolution could be attributed to the low pH, Ca and P contents of this soil (Ikerra et al. 1994). Most of the P released from inorganic fertilizers was extracted in the NaOH-Pi and NaOH-Po fractions. Since these fractions are associated with Al and Fe, this indicates that there was rapid adsorption of the P in soil solution through chemi-sorption by Al and Fe. Tithonia at all rates increased resin P compared to that in the control due to the high concentrations of P in Tithonia and its depressing effect on P sorption. Tithonia GM at all rates produced significantly more bicarbonate extractable organic P than did inorganic fertilizers, and this may have contributed to a better residual P effect in plots that received the GM (Gachengo *et al.,* 1999). The lack of significant differences between GM treated plots and controls in the NaOH-Po fraction indicates that the soil has a good reserve of chemi-sorbed organic P that can be available through management strategies that reduce P fixation. This P fraction has been reported to be an important P source in unfertilized systems (Beck and Sanchez, 1994). More P was found in the HCl-Pi fraction (Ca-P) in treatments with MPR than in those with TSP, revealing that unlike TSP which dissolves instantaneously, MPR dissolution is a slow process, and in this case part of it was still undissolved and hence more residual effects could be expected in subsequent years from MPR than from TSP. This makes MPR an agronomically better P source on this Chromic Acrisol than TSP.

Maize grain yields

Maize grain yields were increased by Tithonia in both years (Table 5). This reflects the corresponding increase in resin P (Table 4) and improvement in soil chemical properties that enhance P availability. It was further revealed by the remarkable positive correlation between resin P and maize grain yields. Both P and Ca uptake by the shoots and roots were increased following GM application because uptake is a product of yield and concentration. Combining Tithonia with MPR at half the recommended rate (40 kg P ha^{-1}) in 2002 gave higher yields than using Tithonia alone and this was probably due to the increased resin P and improvements in other soil parameters. The lower relative agronomic effectiveness for MPR in the first year of application was due to its slow dissolution (Szilas, 2002).

Conclusions

Application of Tithonia to this soil resulted in improvement in soil chemical properties related to P availability (i.e. pH, Ca, Al) and reduced P sorption as reflected by the P max and PSI. Combining Tithonia GM at 5 Mg ha^{-1} with MPR at half the recommended rate of 40 kg P ha^{-1} further improved these soil chemical properties and consequently maize grain yields. The positive interactive effects on resin P cannot be attributed to enhancement in MPR dissolution by Tithonia but rather to improvement in P availability because Tithonia increased soil pH and exchangeable Ca, and reduced exchangeable Al. Where Tithonia is easily obtained within farmer's fields it could be used in conjunction with MPR at half the recommended rate of P for increasing maize yields. This would be a cheaper option than supplying P from either MPR or TSP alone at the recommended rate of 80 kg P ha^{-1}. Transfer of Tithonia from off-farm might be expensive since large amounts of fresh Tithonia are needed to obtain moderate maize yields of 2 Mg ha^{-1}. Hence, integrating lower rates of Tithonia with MPR could be a viable option for improving soil chemical and physical properties and consequently maize grain yields on this Chromic Acrisol in Morogoro, Tanzania.

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SUB-THEME: FODDER PRODUCTION

9. EFFECT OF CUTTING MANAGEMENT ON FODDER PRODUCTION AND QUALITY OF *LEUCAENA PALLIDA* AND *A. ANGUSTISSIMA* FODDER BANKS

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Abstract

An experiment to determine dry matter yields and nutritive value of *L. pallida* and *A. angustissima* browse fodder was conducted on-farm in three villages, Tumbi, Kazima and Mtakuja in Tabora, Western Tanzania. One plot for each browse species was randomly selected in each of the villages and divided into 4 sub-plots each with 4-6 rows on ridges at 0.75 m within and 1.0 m between rows. Four cutting regimes at 1-month, 2-months, 3-months and a control (coppice regrowths harvested at about 1.0 m height) were applied on each respective sub-plot. At harvesting time, plants were cut at 0.5 m above ground and fodder materials separated into mature leaves, young leaves and tender twigs (< 0.5 mm diameter) and whole edible fractions. These fractions were then used to determine fodder yield and for chemical analysis. There were significant differences ($P<0.05$) in dry matter yield between cutting regimes. The 3-months cutting interval had the highest fodder yield (3.44 and 5.41 t Dmha^{-1} for *L. pallida* and *A. angustissima*, respectively) while 1-month cutting regime had the lowest fodder yield (2.8 and 3.4 t DM/ha for *L. pallida* and *A. angustissima*, respectively). Nitrogen and mineral contents varied between cuttings and edible fractions, which ranged from 27.1 to 47.7 for nitrogen, 2.37 to 8.49 for calcium, 1.40 to 4.90 for phosphorus and 11.6 to 23.1 gkg^{-1} DM for potassium. The Neutral Detergent Fibre (NDF) was higher in *L. pallida* than in *A. angustissima* at each cutting and ranged from 351 – 494 and 427 – 531 gkg^{-1} DM for *A. angustissima* and *L. pallida,* respectively. These results indicate that optimal yield and quality fodder materials of the two browse species could be obtained at 2-months cuttings. *Leucaena pallida* and *A. angustissima* are potentially good sources of supplemental protein and minerals for dairy cattle.

Introduction

One of the major constraints to dairy cattle production in semi-arid areas, including Tanzania, is shortage of dry season feed, particularly shortage of cheap sources of supplementary nitrogen. The main feed sources are natural pasture and crop residues, which are inadequate both in quality and quantity. During the dry months, animals are forced to subsist on mature grass and crop residues which are generally very low in crude protein, and relatively low digestible energy and low concentration of minerals, particularly phosphorus and calcium (Leng, 1997; Norton, 2003) and are high in fibre and lignin (Kimbi, 1997; Kimoro, 2003). Consequently, the animals show poor intake and digestibility, resulting into low milk yield.

Strategic supplementation with energy and protein rich concentrates could alleviate the deficiency and significantly improve milk yields. However, conventional protein supplements such as cottonseed and sunflower seed cakes, from agro-processing industries are rarely fed because they are expensive and not readily available to most of the smallholder farmers. This necessitated the search for alternative protein supplements based on locally available feed resources including browse tree fodder.

Supplementation using tree and shrub fodder could be an alternative option to conventional protein supplements for ruminant animals subsisting on low quality roughage. Browse species have many advantages in animal production, amongst which is high feeding quality based on protein and mineral contents, tolerance to wide range of management practices, longevity and are capable of producing fodder even during the dry season when other species are dormant (Patterson *et al.,* 1998). Browse species also maintain high levels of protein in the dry season.

Leucaena leucocephala was the most productive fodder tree and highly demanded for supplementation of low quality herbage in Tanzania and other tropical areas (Brewbaker, 1987). However, the damaging effect of the Leucaena psyllid has halted its promotion as an important fodder species. Consequently, several leguminous shrubs and tree species have been introduced for screening and evaluation in different ecological zones of Tanzania. A large number of fodder tree species are now available for the replacement of the species. In Western Tanzania, *L. pallida* and *A. angustissima* are some of the promising fodder species when considering biomass production, psyllid resistance and survival (Otysina *et al.,* 1998). Thus, they are likely to replace *L. leucocephala* and be used to provide supplementary fodder for low quality feedstuffs. However, there is limited information on the feeding value and appropriate cutting management of these important fodder materials for dairy cattle production. This experiment was therefore carried out to study the effect of different cutting regimes on fodder production and quality of the two browse species in terms of their chemical composition.

Materials and Methods

Study area

This experiment was conducted in three villages, Tumbi, Kazima and Mtakuja in Tabora Region located in mid-western part of Tanzania on the central plateau between latitude 4 - 7^0 S and Longitude 31 - 34^0 E. The altitude of the area varies between 1000 and 1200 m a.s.l. Soils are sandy, 80 to 90%, mostly ferric Acrisoils (FAO system), low in organic carbon (0.4 to 0.8%), total nitrogen (0.01 to 0.03%), available phosphorus (3 to 12 mgkg^{-1}) and exchangeable bases (Otsyina *et al.,* 1998). The area has a long, (5 - 6 months), hot dry season. Annual rainfall, ranges between 700 – 1000 mm; with an average of 880 mm rainfall falling mainly from November to May. Temperatures range from a mean minimum of 14^O C in June - July to a mean maximum of 33^O C in September - October. The area supports vegetation typical of the deciduous Miombo woodland occurring throughout the Southern interior of Africa. The main feature of the farming system is maize/tobacco rotation with livestock integration.

Planting and management of the fodder banks

The study was carried out using fodder bank plots already existing in farmers' fields as part of an on-going on-farm study aimed at evaluating the potential of psyllid tolerant *Leucaena species* (*L. pallida* and *L. diversifolia*) and a shrub legume, *A. angustissima* in an attempt to boost the quality of available feed resources for dairy cattle production in Tabora Region. The fodder plots were established in the 1997/98 growing season in three villages, Tumbi, Kazima and Mtakuja, all located in Tabora municipality. The trees were planted on ridges at a spacing of 0.75 m within the ridges and 1.0 m between ridges. The farmers did all field operations including land preparation, ridging, planting and weeding of the fodder bank plots.

Cutting regimes

In each of the three villages, two fodder plots, one of *L. pallida* and another of *A. angustissima* were randomly selected for the study. The fodder plots (approximately, 800 m^2) were divided into 4 sub-plots consisting of 4-6 rows each with 20-30 plants. Four cutting regimes at one, two and three monthly intervals and control were applied on the respective sub-plots in the wet season. The control sub-plots were cut when the coppice regrowths reached a height or length of about 1 m, which is the normal farmer practice. Farmers in the area normally cut their fodder trees at one and a half months interval. These cutting intervals were therefore chosen above and below the farmers practice. All browse tree plots were cut at 0.5 m above the ground at the end of the dry season in November of 2000, 2001 and 2002 so as to obtain uniform regrowth at the beginning of the wet season.

Fodder production measurements

Estimates of fodder yield for each browse species was done by harvesting 6 plants marked and tagged in the middle rows of each sub-plot. At each cutting time, plants were cut back to 0.5 m above the ground. The fodder materials were separated into three components including mature leaves, young leaves together with tender twigs (less than 5 mm in stem diameter) and whole edible factions (representing the fodder material as fed to the animals). Two most upper leaves starting from the branch tip were considered as young leaves and the rest as mature leaves. Total fresh and a sub-sample fresh weight for each of the three components were taken in the field for yield determination using spring balance. Subsequent to yield determination, representative samples for each of the three components of *L. pallida* and *A. angustissima* were taken for dry matter (DM) and nutritive value determination. The samples were immediately taken to Agricultural Research Instittue (ARI) Tumbi, Tabora laboratory and dried to constant weight in a forced air oven at 60^0 C for dry matter determination. The dry samples were then grounded in a Wiley mill and sieved through a 2 mm sieve and mixed thoroughly. A minimum sample of 200 g of each of the milled sample for each fraction was packed in labelled polythene bags before they were shipped to the Department of Animal Science and Production (DASP), Sokoine University of Agriculture (SUA), Morogoro for chemical analysis.

Sampling for chemical analysis

Fodder yield measurements were carried out for three subsequent years starting from January 2000 to November 2002. For each year, samples were collected during both the dry and wet seasons. The dry season samples were collected in November at the end of the dry season, while wet season samples were collected from December to May when the coppice regrowths length or heights were at least 30 cm long. The wet and dry season samples were bulked separately for each of the cutting regimes to form a single bulk sample for each of the three fractions for each browse species from which representative samples were taken for chemical analysis.

Chemical analysis

The samples were dried in a forced air oven at 60 ^{0}C to a constant weight for dry matter determination. Ash was obtained by incinerating the samples in a muffle furnace at 550 ^{0}C for 3 hours. Total nitrogen in the samples was determined by the Kjeldahl technique, using a semi-automated N-analyser (2200 Kjeltec Auto Distillation). Neutral Detergent Fibre (NDF), Acid Detergent Fibre (ADF) and Acid Detergent Lignin (ADL) were analysed according to the procedure of Van Soest *et al.* (1991). Hemicellulose was calculated as the difference between NDF and ADF, while cellulose was presented as the difference between ADF and ADL. Phosphorus was determined calorimetrically using spectrophotometer set at 420 ηm as recommended by AOAC (1990) and described by Helrich (1990). Sodium and potassium contents were determined using flame photometry. Calcium was determined as recommended by AOAC (1990) and as described by Milner and Whiteside (1984) using atomic absorption spectrophotometer.

Experimental design

The experimental design used was 2 (browse species) $\times$ 3 (fractions) $\times$ 4 (cutting regimes) factorial arrangements of treatments in a randomized block design using village as blocks and individual plots as replicates.

Data analysis

General Linear Model (GLM) procedure of Statistical Analysis System (SAS, 2000) was used in data analysis. Fodder yields and nutrient contents data were subjected to analysis of variance using different models. The Least Significant Differences (LSD) test was used to compare the treatment means. Differences between parameters analysed were considered to be significant at P < 0.05. When there was no significant interaction between given parameters the data were analysed by considering the main effect only in a reduced model.

Results and Discussion

Fodder yield

Total wet and dry season fodder DM yields data are presented in Table 1. In the wet season, the lowest young leaves DM yield of *L. pallida* was obtained from 3-month cuttings (0.30 t/ha) and the highest yield from 1-month cuttings (0.67 tha^{-1}). The 3-months cuttings of *L. pallida* produced the highest (P < 0.05) old leaves DM yields than other cutting regimes. However, the whole edible fraction DM yields did not differ significantly (P > 0.05) between cutting regimes. *Acacia angustissima* young leaves DM yields were lowest at 3-months cuttings and did not differ significantly (P > 0.05) between the 1-month and 2-months cuttings. The 3-months cuttings produced highest (P < 0.05) old leaves and whole edible fraction DM yields than the other cuttings, which did not differ significantly. *Acacia angustissima* consistently produced relatively more leaf biomass yield than *L. pallida* at all cuttings in the wet season. Fodder DM yields was relatively invariant (P > 0.05) between cutting regimes in the dry season. Both species produced relatively higher quantities of fodder during the wet season than they did in the dry season. Fodder yields were 3 to 8 times higher in the wet season than in the dry season.

The increase in the foliage and stem DM yield from the trees at intervals of 1-month to 3-months is as reported elsewhere in literature. Guevara *et al*. (1978), for example observed total biomass DM yields (foliage and stem) of 11.9, 16.9 and 20.8 t ha^{-1} for the *Leucaena* hedgerows harvested at 2, 3, and 4 months, respectively. Assefa (1998) reported annual increased biomass production of tagasaste (*Chamaecytisus palmensis*), when the harvesting interval was prolonged from two to six months. Similar observation was made by Krishnamurthy *et al*.,(1986) working with *L. leucocephala.*

The possible explanation is that under extended harvesting, trees accumulate adequate carbohydrate reserves to support more foliage regrowth, whereas frequent cutting depletes reserved carbohydrate and reduces residual leaf area required for regrowth, thus leading to low fodder yields. Thus, replenishment of carbohydrate reserves must be considered in determining intensity and time of cutting. Strategic cutting frequencies of browse plants should therefore be applied for improved biomass production.

The increased biomass yield by trees with extended interval between harvests can also be attributed largely to the increase in the proportion of stem as reported by Guevarra *et al*. (1978). In general, longer intervals between cuttings increases total DM yields, but the proportion of wood materials also increases, leading to decline in forage quality (Shelton and Brewbaker, 1994). In the present study, it was observed that additional yields beyond 2-months cutting interval consisted more of wood materials than frequent cuttings (Figure 1), which resulted into decline in foliage quality. Fodder harvested at 3-months had relatively higher fibre (NDF) contents and low in DM digestibility compared to those cut at 1-month and 2-months intervals. The ideal cutting stage to optimise fodder yields and quality is therefore at 2-months. At this period the edible forage DM yields were 64% and 76% out of the total biomass produced for *L. pallida* and *A. angustissima,* respectively.

Differences observed between species in fodder yields was due to differences in growth forms and physiological characteristics associated with acquisitions of light, moisture and nutrients for biomass production (Larbi *et al.,* 1996). The rate of coppice regrowth after defoliation depends on the available regrowth buds, carbohydrate reserves and residual leaf area. All these factors are quite variable between species and depend more on plant growth forms and defoliation intensity or cutting height.

Table 1. Total wet and dry seasons fodder DM yields (tha^{-1}) of *L. pallida* and *A. angustissima* fodder banks at different cutting regimes

Season	Plant Fraction	Cutting Regime (month) 1	2	3	Control	SEM	Pr > F
Wet	**Young leaves**						
	A. angustissima	0.66^{a}	0.67^{a}	0.39^{b}	0.54^{ab}	0.07	0.0492
	L. pallida	0.67^{a}	0.37^{ab}	0.30^{b}	0.38^{ab}	0.09	0.0478
Dry	*A. angustissima*	0.11	0.15	0.15	0.22	0.05	0.4847
	L. pallida	0.19	0.11	0.20	0.21	0.05	0.5108
	Old leaves						
Wet	*A. angustissima*	2.73^{a}	3.28^{a}	5.02^{b}	3.03^{a}	0.42	0.0311
	L. pallida	2.10^{a}	2.85^{ab}	3.15^{b}	1.99^{a}	0.28	0.0488
Dry	*A. angustissima*	0.45	0.38	0.84	0.56	0.16	0.3019
	L. pallida	0.56	0.39	0.70	0.62	0.22	0.7789
	Whole edible						
Wet	*A. angustissima*	3.40^{a}	3.95^{a}	5.41^{b}	3.57^{a}	0.41	0.0484
	L. pallida	2.77	3.22	3.44	2.37	0.36	0.2603
Dry	*A. angustissima*	0.64	0.49	1.03	0.77	0.19	0.3042
	L. pallida	0.68	0.53	0.85	0.84	0.23	0.7560

Figures with the same letter in the same row have no significant difference at 5% level

Edible fodder production appeared to be relatively higher in the wet than in the dry season. This was partly due to reduction in or lack of moisture and the accompanying reduction in uptake of nutrients from the soil during the dry season, resulting in slower growth rates. Cobbina *et al*. (1990) reported 82% and 35% reduction in coppice productivity rates for *L. leucocephala* and *G. sepium* respectively during the dry season in South-eastern Nigeria. It was also due to physical loss of fodder due to leaf senescence and shedding. Extensive leaf shedding in Leucaena trees under extended cutting intervals has been reported by Guevara *et al*. (1978). The amount of leaf litter produced was not measured in the present study. The difference observed between the species in fodder yield in the dry season could be due to response to drought stress.

Annual total DM fodder yields varied from 3.21 to 4.29 tha^{-1} and 4.03 to 6.44 tha^{-1} for *L. pallida* and *A. angustissima* respectively (Table 2). In all the three years, the coppice regrowths under 3-months cuttings produced highest ($P < 0.05$) fodder while those under 1-month cuttings produced the lowest fodder. Annual fodder DM yields from 2-months and from the control cuttings did not differ ($P > 0.05$). Both species produced relatively higher quantities of edible fodder during the second year of cutting than they did in the first and third years of cuttings, however no significant variations were observed between years in fodder DM yields.

Fodder: inedible wood ratios were generally higher in the wet season than in the dry season (Figure 1 and 2). There were no significant differences ($P > 0.05$) recorded between species and cutting regimes in inedible wood yields in both seasons. The highest biomass production in favour of fodder was achieved when the coppice regrowths were harvested at 1-month intervals, only 12% of the total DM consisted of inedible wood while 88% was edible fodder. The 2-months cutting regime resulted into 76% and 24% edible fodder and inedible wood yields, respectively. The 3-months cutting regime produced 64% of the total DM yields as edible fodder and 36% as inedible wood in the wet season (Figure 1). In the dry season, increase in wood yields relative to fodder yields (Figure 2) contributed to the low fodder to inedible wood ratios.

Table 2. Cumulative annual total DM fodder yield (t ha^{-1}) of *L. pallida* and *A. angustissima* fodder banks at different cutting regimes

Cutting regime	Browse spp	Fodder yield (t ha^{-1}) Year 1	Year 2	Year 3	Mean
1-Month	*L. pallida*	2.85^{b} (5)	3.82 (7)	3.34^{b} (5)	3.34^{c}
	A. angustissima	3.88^{b} (5)	4.93 (7)	3.29^{b} (5)	4.03^{c}
2-Months	*L. pallida*	2.99^{b}(3)	4.81 (4)	3.46^{a} (3)	3.75^{bc}
	A. angustissima	4.33^{b}(3)	4.99 (4)	4.07^{a} (3)	4.44^{b}
3-Months	*L. pallida*	3.68^{b} (3)	5.51 (3)	3.69^{a} (2)	4.29^{b}
	A. angustissima	7.23^{a} (3)	6.71(2)	5.38^{a} (2)	6.44^{a}
Control	*L. pallida*	3.03^{b} (4)	3.90(4)	2.69^{b} (3)	3.21^{c}
	A. angustissima	4.44^{b}(4)	4.89 (4)	3.69^{a} (3)	4.34^{b}
SEM		0.67	0.01	0.70	0.27

Figures followed by the same letter in the same column have no significant difference at 5%
Parentheses are number of cuttings for each respective year.

Total annual fodder yield data reported in the present study compare fairly well with the results from studies done elsewhere. Fodder yield values reported for *Acacia angustissima* are in agreement with the findings of Dzowella *et al*., (1997) who reported fodder yield values of 3.5 to 5.2 tha^{-1} from Makoholi and Domoshawa in Zimbabwe. Evaluation of *A. angustissima,* under fodder banks technology in Shinyanga, Tanzania gave fodder yield of up to 5.41tons/ha per year (Otsyina *et al*., 1998), which is consistent with the reported value in the present study. However, fodder yield values for *A. angustissima* in the present study were much lower compared to those reported by Brook *et al.,* (1992). Fodder yields for *L. pallida* fall within the range of 2.25 to 4.23 t DMha^{-1} reported by Mawenya (1995) from Arusha and Kusekwa *et al*., (1997) from Mpwapwa, Tanzania.

The relatively low fodder yields recorded in 2001 and 2002 might be due to low rainfall received and poor distribution in those two years, which subjected trees to prolonged moisture stress and hence resulted into low fodder yields. Rainfall received in 2000/01 rain season amounted to 1204.4 mm, which was 93% and 29% higher and better distributed than that of 1999/00 (624.3 mm) and 2001/02 (933.2 mm) rain seasons, respectively.

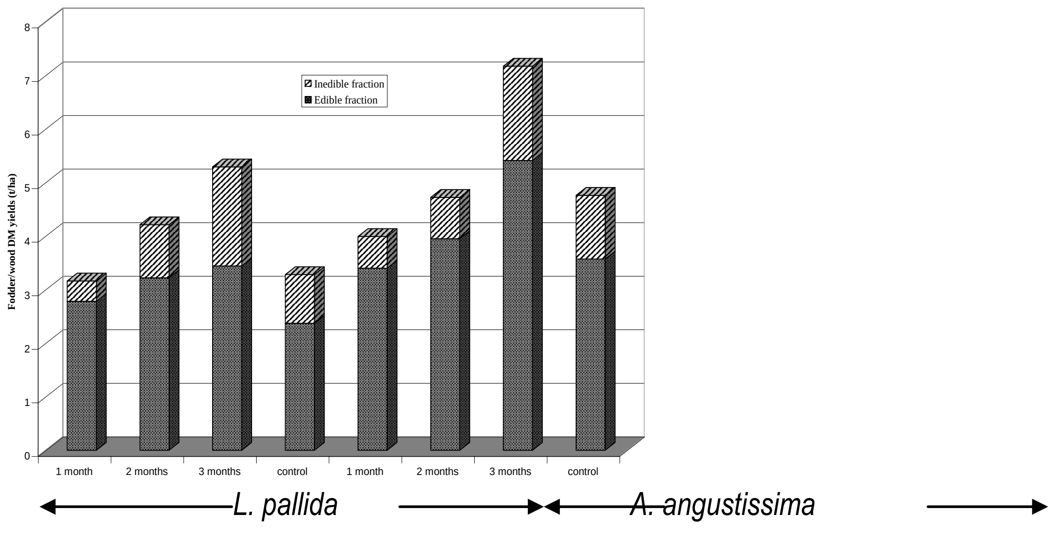

Figure 1. Effect of cutting regimes on fodder and inedible wood DM yields (tha^{-1}) of *L. pallida* and *A. angustissima* fodder banks in wet season

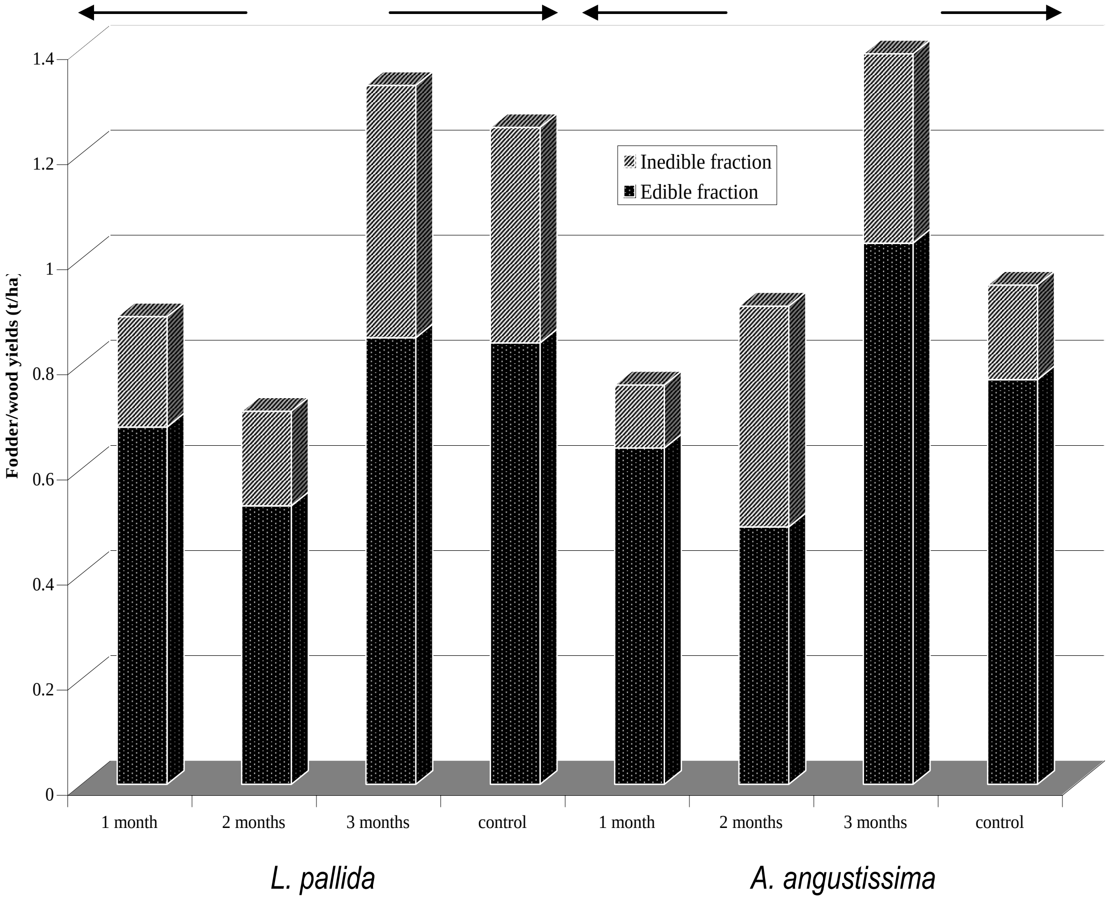

Figure 2. Effect of cutting regimes on fodder and inedible wood yields of *L. pallida* and *A. angustissima* fodder banks in dry season

Management implications

Tree foliage makes great contribution to livestock feed and crude protein production in the dry season than in the wet season. However, both species showed poor performance in terms of fodder yields in the dry season when fodder is most needed. Results from the present study clearly indicate that these new fodder materials cannot be used effectively for dry season feeding without proper management and utilization strategies such as harvesting and drying extra leaf biomass produced in the wet season for dry season feeding as leaf meals, application of mulch to conserve soil moisture and harvesting tree fodder one or two months before the onset of the dry season so as to enhance tree survival and recovery at the end of the dry season, which may also improve the overall performance of the browses.

Based on fodder yield data reported in the present study, a farmer with one hectare of *L. pallida* could produce enough fodder (as leaf meal) to supplement 7 to 10 dairy cows per day in 5 - 6 months in the wet season and only 1 to 2 dairy cows in 6 - 7 months in the dry season, assuming an average daily intake of 2.5 kgcow^{-1}day^{-1} of the leaf meal. Similarly, a farmer with one hectare of *A. angustissima* could produce enough fodder to supplement 9 to 18 dairy cows per day in the wet season and 1 to 3 cows in the dry season. As most of the farmers in the study area keep 1 to 2 dairy cows, the extra leaf biomass produced during the wet season could be harvested, dried and used as leaf meals in the dry season to compliment the little fodder produced in the dry season.

Nitrogen content

There was no significant (variation $P > 0.05$) between cutting regimes in nitrogen content in the dry season nor were they between seasons. Concentration of nitrogen in the edible fraction of *A. angustissima* and *L. pallida* in the wet season is shown in Table 3. The young leaves of *A. angustissima* from 1-month and the control plots cuttings had higher nitrogen content ($P < 0.05$) than those for the 2 and 3-months cuttings. There was no significant variation ($P > 0.05$) between cutting regimes in nitrogen content in old leaves and whole edible fraction. For *L. pallida*, the young leaves from 1-month, 2-months and the control plots cuttings did not differ significantly ($P > 0.05$) in nitrogen content, but had higher nitrogen content than that from the 3-months cuttings. The old leaves from 1, 2, and 3-months cuttings did not differ significantly ($P > 0.05$) in nitrogen content, but had lower nitrogen content than that from the control plots cuttings. The whole edible fraction from 3-months cuttings had the lowest nitrogen content while the control plot cuttings had the highest.

The values of nitrogen content reported in the present study are higher when compared to that of young tropical grasses, which seldom exceed 15% CP and far above that of mature tropical grasses, which is usually less than 5% CP (Leng, 1991). The nitrogen contents in the edible fractions of *A. angustissima* compares fairly well with the values of 33.2 – 40.8 g kg^{-1} DM reported by Dzowela *et al*. (1997) and Odenyo *et al*., (2003) for the same plant species. However, Sandoval *et al*., (2000) reported lower value (29.1 g N kg^{-1} DM) for *A. angustissima* foliage. At a range of 34 – 38 g N kg^{-1} DM, *A. angustissima* compares fairly well with the values of 38.9- 43.5 g N kg^{-1} DM reported by Simons and Sterwart (1994) for *Gliricidia sepium*, respectively. The values of nitrogen in the edible fractions of *L. pallida* reported in the current study are comparable to the 27.2 - 36.5 g N kg^{-1} DM reported by Austin *et al.* (1992). When compared to other Leucaena species, these values are lower than that of 37.6 - 50.4 g N kg^{-1} DM for *L. leucocephala* reported by various workers (Kimbi, 1997; Ndemanisho *et al.,* 1998; El Hassan *et al.,* 2000).

Considering the minimum protein requirement of 10 to 12 % proposed by NRC (2001) for the lactating dairy cow, the CP level in the edible fractions in both species are satisfactory for the cows and are far above the threshold of 7- 8 % required for the optimum microbial activity in the rumen (Van Soest, 1994; Norton, 2003). However, high concentrations of condensed tannins found in the fodder, particularly in *L. pallida* may decrease protein availability and utilization by the ruminant animals (Mupungwa *et al.,* 2000; Ammar *et al.,* 2003). It is known that animals require a continuous supply of protein if they are to maintain a constant level of production throughout the year. Given that *A. angustissima* and *L. pallida* are able to maintain their crude protein contents at higher levels (17 - 27%) than in grasses (3 - 5%) in the dry season, makes them particularly useful as protein supplements to the poor quality pastures and crop residues during the dry season.

Table 3. Nitrogen contents (g kg^{-1} DM) in edible fractions of *A. angustissima* and *L. pallida* at different cutting regimes in the wet season

	Cutting regime (month)				
	1	2	3	Control	SEM
Young leaves					
A. angustissima	46.7^{a}	38.7^{b}	41.1^{b}	47.3^{a}	0.82
L. pallida	43.0^{a}	43.3^{a}	37.2^{b}	47.8^{a}	1.47
Old leaves					
A. angustissima	36.3^{a}	37.4^{a}	35.1^{a}	37.0^{a}	1.35
L. pallida	31.8^{b}	28.4^{b}	28.4^{b}	36.9^{a}	1.47
Whole ediblle					
A. angustissima	37.4^{a}	34.3^{a}	37.2^{a}	38.0^{a}	1.36
L. pallida	33.9^{ab}	29.9^{bc}	28.7^{c}	34.9^{a}	1.35

Figures with the same subscripts in the same row have no significant difference at 5% level.

Mineral concentrations

The contents of ash and minerals in the edible fractions of *A. angustissima* and *L. pallida* are given in Table 4. There were no significant (P > 0.05) variations between cutting regimes in ash, calcium and sodium contents. However, significant differences (P < 0.05) between cutting regimes were recorded for phosphorus and potassium contents. The P content was higher (P < 0.05) in the edible fractions from 1-month and the control plots cuttings than from 2 and 3-months cuttings. The edible fractions harvested from the control plots cuttings had higher (P < 0.05) K content than that harvested from 2 and 3-months cuttings. No significant (P > 0.05) variation was found between 2 and 3 months cuttings in K content.

Information on mineral contents in browse species is limited. However, the values obtained in the present study are comparable to those reported by Norton (1994) for some tropical forage tree legumes. Low values of phosphorus in the edible fractions of *A. angustissima* are similar to that of *A.* aunera (1.3 gkg^{-1} DM) reported by Ahn *et al.,* (1990) and consistent to the values of 0.9 - 1.6 gkg^{-1} DM reported by Abdulzarak *et al*.,(2000) for six species of Acacia from Kenya. Topps (1992) also reported low values of phosphorus for most of the tree legume fodder studied. The concentration of calcium in *A. angustissima* was lower compared to the values of 6.4 -11.3 gkg^{-1} DM reported in other works with *Acacia species* (Abdulrazak *et al.,* 2000; Sandoval *et al.,* 2001). Calcium content in *L. pallida* was comparable to the values of 6 – 16 gkg^{-1} DM reported by Karachi and Shirima (1996) for *L. leucocephala.* In the present study, young leaves were lower in calcium than old leaves at each cutting. Karachi (1998) also observed that leaves and immature fractions of Leucaena lines were high in phosphorus and potassium, but low in calcium.

Basing on the NRC (2001) mineral requirements for a lactating dairy cow and other research data (McDowell *et al.,* 1992; Norton, 1994), the calcium and potassium contents in both species were adequate for maintenance and moderate production requirements of dairy animals. However, phosphorus and sodium were below the levels recommended for lactating dairy cows, which suggest that animals would require additional sources of P and Na to avoid deficiencies in these elements.

Table 4. Mineral concentration (gkg^{-1} DM) in whole edible fractions of *A. angustissima* and *L. pallida* at different cutting regimes

Mineral	Cutting Regime (Month)				SEM
	1	2	3	Control	
Ash					
A. angustissima	50.9	46.5	52.1	53.0	2.12
L. pallida	60.7	57.2	55.5	60.8	2.34
Calcium (Ca)					
A. angustissima	4.97	3.30	5.13	5.57	0.91
L. pallida	5.60	4.93	7.17	5.47	0.61
Phosphorus (P)					
A. angustissima	2.77^{a}	1.60^{b}	1.70^{b}	2.50^{a}	0.11
L. pallida	1.90	1.40	1.87	2.57	0.23
Sodium (Na)					
A. angustissima	9.76	8.37	10.2	10.4	1.23
L. pallida	11.7	12.2	14.1	11.7	1.26
Potassium (K)					
A. angustissima	14.3^{ab}	11.6^{b}	12.6^{b}	16.4^{a}	0.84
L. pallida	17.5	16.7	17.2	22.4	1.36

Figures followed by the same letter in the same row have no significant difference at 5% level

Fibre contents

There were no significant (P > 0.05) variations between browse species and cutting regimes in fibre contents in the wet season. The whole edible fractions of both species harvested from the control plots and 1-month cuttings had higher NDF content than that from 2 and 3-months cuttings in the dry season

(Table 5). The NDF content of *L. pallida* from 2 and 3-months cuttings did not differ (P > 0.05). However, *A. angustissima* from 3-months cuttings had lower NDF content than that from the 2-months cuttings. The 3-months cuttings of *A. angustissima* had the lowest ADF content while the control plot cuttings had the highest content of ADF. The 2-months cuttings of *L. pallida* had the lowest ADF content and the control plot cuttings had the highest content of ADF than the other cuttings. The ADL content was highest from 2-months and the control plot cuttings for *A. angustissima* and *L. pallida,* respectively. The hemicellulose content in the edible fractions of both species was lowest from 3-months cuttings and highest from 1-month cuttings. *Leucaena pallida* consistently had higher NDF, ADF and ADL contents than *A. angustissima* at each cutting. The fibre contents did not differ significantly (P > 0.05) between wet and dry season cuttings.

Table 5. Fibre contents (g kg^{-1} DM) of whole edible fractions of *A. angustissima* and *L. pallida* at different cutting regimes in the dry season

Cutting Regime	Browse species	Fibre contents (g/kg DM)				
		NDF	ADF	ADL	Hemi-cellulose	Cellulose
1-Month	*A. angustissima*	494^{b}	277^{c}	174^{d}	228^{a}	104^{c}
	L. pallida	505^{ab}	325^{b}	209^{b}	169^{b}	116^{bc}
2-Months	*A. angustissima*	413^{d}	270^{cd}	183^{c}	194^{b}	87.1^{cd}
	L. pallida	464^{c}	275^{c}	212^{b}	138^{c}	67.7^{d}
3-Months	*A. angustissima*	351^{e}	249^{d}	159^{f}	102^{d}	89^{cd}
	L. pallida	469^{c}	346^{ab}	166^{e}	123^{cd}	180^{a}
Control	*A. angustissima*	483^{bc}	312^{b}	178^{cd}	171^{b}	133^{b}
	L. pallida	523^{a}	353^{a}	221^{a}	170^{b}	132^{b}
SEM		0.82	0.81	0.18	0.93	0.73

Figures followed by the same letter in the same column have no significant difference at 5% level

Fibre contents (NDF and ADF) of *A. angustissima* edible fractions compare fairly well with data reported by Balogun *et al*., (1998) and Sandoval *et al.,* (2000) and to those reported by Dzowella *et al*., (1997) and Hove *et al*. (2001) from Zimbabwe. These authors reported values ranging from 259 - 532 and 191 – 394 g kg^{-1} DM for the NDF and ADF, respectively. With respect to *L. pallida*, the NDF and ADF contents were consistent with the values of 368 – 565 g kg^{-1} DM and 204 – 232 g kg^{-1} DM, respectively reported by Austin *et al.* (1992) for other psyllid tolerant Leucaena species. However, they were much higher when compared to that of *L. leucocephala* (312 – 336 g kg^{-1}and 175 - 191 g kg^{-1} DM for NDF and ADF, respectively reported by Kimbi, (1997), Ndemanisho *et al*. (1998) and El-Hassan *et al*. (2000). The ADF fraction was a large proportion of the NDF in both species, which indicate high contents of cellulose and lignin and low levels of hemicellulose.

Conclusion and future research needs

Cutting regimes showed that optimum productivity of high quality fodder for ruminant feeding is obtained by harvesting the coppice regrowths at 2-months intervals. Both species however showed poor performance in fodder yields in the dry season when fodder was most needed. This clearly indicated that these new fodder materials cannot be used effectively for dry season feeding without proper cutting management regimes. Farmers should therefore be encouraged to harvest the extra leaf biomass produced during the wet season, dry and use them as dried leaf meals during the dry season to compliment the little fodder produced in the dry season. The edible fractions of both species were sufficiently high in CP and mineral contents for them to be used as supplements for low quality feedstuffs. Agronomic strategies such as application of mulch and cow dung manure to maximize fodder production during the dry season should be given attention. These will ensure availability of high quality fodder during the dry season when it is most needed.

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10. THE PERFORMANCE OF LACTATING DAIRY COWS FED LOW QUALITY GRASS HAY SUPPLEMENTED WITH *LEUCAENA PALLIDA* AND *ACACIA ANGUSTISSIMA* DRIED LEAF MEALS

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Abstract

Two experiments were conducted to evaluate the feeding value of *Leucaena pallida* and *Acacia angustissima* dried leaf meals as supplement to a basal diet of low quality hay. Experiment 1 was a milk production study and experiment two was an *in-vivo* digestibility and nitrogen balance study. In both experiments, four lactating dairy cows were fed on four diets in a 4 × 4 Latin Square Design (LSD) experiment. The diets were: LP = basal feed and *L. pallida* leaf meal (2.28 kg day^{-1}), AA = basal feed and *A. angustissima* leaf meal (2.07 kg day^{-1}), LPAA = basal feed, 50% *L. pallida* leaf meal and 50% *A. angustissima* leaf meal and CSC = basal feed and cotton seed cake. In all treatment diets, cows were fed 90 g cow^{-1} day^{-1} of mineral mixture and hominy meal was used as an energy source. Dry matter intake and milk yield was highest for cows fed on CSC (11.1 kg DMI^{-1} day^{-1} and 9.94 kg milk day^{-1}) and lowest for cows fed on LP (10.4 kg DMI day^{-1} and 7.78 kg milk day^{-1}). Treatment diets had no effect on milk components. Apparent DM and N digestibility were higher for cows fed on CSC (588g kg^{-1} and 931g kg^{-1} for DM and N, respectively) and lowest for cows fed on LP (466 g kg^{-1} and 603 g kg^{-1} DM for DM and N, respectively). The N absorbed was more efficiently retained ($P < 0.05$) with cows fed CSC (21.8 g day^{-1}) and poorly retained with cows fed LP (4.24 g day^{-1}). The cows fed LP, AA and CSC lost weight at an average of 70, 130, and 60 g day^{-1}, respectively, while cows fed LPAA gained weight at an average of 70 g day^{-1}. Both browse leaf meals proved to be potential protein supplements for milk production.

Introduction

Dairy cattle nutrition in arid and semi-arid regions of sub-Sahara Africa including Tanzania is based to a large extent on natural pasture and crop residues. Utilization of these feed resources is often constrained by their low nitrogen content, which limits microbial activity in the rumen (Van Soest, 1994; Norton, 2003). The consequence of this situation is manifested by slow ruminal digestion, low passage rate and DM intake and ultimately low animal productivity (Romney and Gill, 2000).

Feeding leguminous fodder to dairy cows have been reported to improve rumen fermentation parameters, leading to increased intake and digestibility of low quality roughages and hence improve milk production (Kakengi *et al.,* 2001; Shem *et al.,* 2003). However, most tropical browse species contain anti-nutritive factors such as tannins that may limit nutrient availability and utilization by the host animals below what the concentration imply from the chemical analysis (Leng, 1997; Aregheore, 1999). Screening of browse fodder for nutritive values by chemical analysis only may therefore lead to some erroneous conclusion if not supported by feeding trials. The feeding trials have an added advantage of providing information on animal health and productivity such as live weight gain and milk production upon feeding such diets.

Information on nitrogen balance by the host animal is necessary for the efficient use of browse fodder materials as protein supplements to the low quality forages. A more accurate evaluation of a protein could be obtained by using the results of nitrogen balance experiments. The difference between N-intake and N-output (e.g. in urine and faeces) is a good index of protein status of ruminant animals. Nitrogen retention serves as an estimate of productive plus non-productive protein deposition (McDonald *et al.,* 1998).

Most studies however have put emphasis on utilization of *Grilicidia sepium* and *L. leucocephala* and little work has been done with other browse species, particularly with the lesser known Leucaena species such as *L. pallida*. On the other hand, *A. angustissima* is a relatively unknown browse plant whose potential as a ruminant feed has not been thoroughly investigated. This study was therefore carried out to investigate the effects of supplementing *L. pallida* and *A. angustissima* leaf meals to dairy cows fed low quality grass hay on milk yields and quality, and nitrogen balance.

Materials and Methods

Two experiments were conducted at Magadu dairy farm of the Sokoine University of Agriculture (SUA), Morogoro, Tanzania between March and September 2003. Morogoro is located between Latitudes 6 and 7^0 S and 37 and 38^0 E Longitudes. Magadu farm is situated at the foot of the Uluguru Mountains on the North-western slope at an elevation of approximately 600 m a s l. The rainfall pattern of the area is bimodal with an average annual rainfall of between 600 to 800 mm. Short rains fall during November to January and long rains during March to May. Peak rainfall is normally received in April. The daily temperature ranges between 20 - 27 ^{0}C in the coolest months in April to August and 30 - 35 ^{0}C during the hottest months in October to January. Experiment 1 was milk production study conducted to mimic small-scale dairy cattle production in the semi arid areas during the dry season and experiment 2 was an *in-vivo* digestibility and nitrogen balance study.

Experiment 1

Preparation of the feeds

The grass hay used for the feeding trial was a mixture of grasses comprising of *Chloris gayana, Bothriochloa insculpta* and *Brachiaria brizantha* from the Sokoine University Of Agriculture (SUA) farm. The grass were cut in late July 2002, the second month of the dry season and at the late stage of maturity, sun dried in the field for 3 days and stored in an open shed. *Leucaena pallida* and *A. angustissima* leaf meals were obtained from on-station fodder bank plots at the Agricultural Research Institute, Tumbi, Tabora. Leaves and tender twigs were harvested from 2-months coppice regrowths, dried in the sun on a concrete floor to minimize leaf loss, contamination, spoilage and reduce the effect of secondary compounds before they were fed to cattle. After drying, the fodder materials were separated from the stems by threshing. The dry leaf materials were further sorted to remove pieces of stem and leaf raches, and then packed in polythene bags before they were shipped to SUA, Morogoro for the feeding experiments.

Animals and their management

Four dairy cows (2 Friesian and 2 Ayrshire crosses) in their second months of lactation and in their second to third lactation weighing 315 ± 30kg live weight were used in the experiment. There were no animals of the same breed and on the same lactation and thus two different breeds were used. The assumption made is that the animals will be in the same nutrient requirements as they were not different in body mass and milk production.

The animals were housed in individual pens in a well-ventilated shed and allowed free access to water. Deworming of the animals was done using Milsan, a broad-spectrum anti-helminthic according to the manufactures instructions. External parasites, mainly ticks were controlled using Ectopor, a pour-on acaricide once every four weeks.

Treatment diets and feeding

Four diets comprising of grass hay as basal feed, cotton seed cake or browse leaf meals as sources of protein and hominy meal as energy source were formulated based on the nutrient requirement of the experimental animals. The treatment diets were as follows; T_1 = basal feed and *L. pallida* leaf meal (2.28 kg DM day^{-1}), T_2 = Basal feed and *A. angustissima* leaf meal (2.07 kg DM day^{-1}), T_3 = basal feed, 50% *L. pallida* leaf meal and 50% *A, angustissima* leaf meal and T_4 = basal feed and cotton seed cake (1.21 kg DM day^{-1}) as standard dairy supplement and positive control. The four dietary treatments were formulated to have similar protein and energy levels based on prior analysis of the feeds for crude protein (CP) and *in-sacco* dry matter digestibility. The calculations of energy and protein requirements of the animals were based on the NRC (2001) feed tables for cows weighing between 350 and 400 kg of live weight and producing 8 litres of milk per day.

The experiment was done in two phases: the adaptation and actual experimental periods. A preliminary period of 14 days was allowed for the animals to acclimatize to the diets and to avoid carry over effects from the previous period followed by 10 days of data collection during which feed on offer, refusal and milk yield were recorded. The basal feed was offered to the animals at *ad libitum* in two equal portions at 0800 and 1500 hours by allowing about 15 to 20% excess above appetite. The supplements were offered twice daily at milking time, in the morning at 0700 hours and evening at 1800 hours. All the cows were fed 90 g $cow^{-1}day^{-1}$ of mineral mixture (Maclicksuper) manufactured by Welcome Tanzania Limited and with the following chemical composition percentage, Ca 19.95, P 11.76, Na 10.26, Cl 15.83, Mg 1.1, Cu 0.16, Co 0.02, Fe 0.05, K 0.006, I 0.02, Zn 0.5, Mn 0.4, S 0.33 and Se 0.001. During the 14 days adaptation period, the animals were offered the test diets in exactly the same way as was done in the actual experimental period.

Experimental design

The experiment was carried out in 4 × 4 balanced Latin Square Design, using individual cow as a replicate and period as blocks. Treatment diets were assigned to each milking cow in each period at random (Table 1). In that way, each treatment diet was tested 4 times.

Table 1: Arrangement of treatment diets in 4 x 4 Latin Square Design

	Animal			
Period	1	2	3	4
1	LP	AA	LPAA	CSM
2	AA	LPAA	CSM	LP
3	LPAA	CSN	LP	AA
4	CSM	LP	AA	LPAA

Treatment consisted of basal feed + LP = *L.eucaena pallida* dried leaf meal or AA = *A. angustissima* dried leaf meal or LPAA = 50% *L. pallida* and 50% *A. angustissima* dried leaf meal or CSM = cotton seed cake.

Measurements

Dry matter (DM) intake

The amounts of feed offered and refusals were recorded daily and representative sample of each feed was taken at weekly interval for DM determination and chemical analysis, upon which amount of basal feed offered was adjusted accordingly. Before each meal, refusals from previous meals were removed from the feeding troughs and weighed. The difference between amount offered and amount refused was regarded as the quantity consumed. Refusals for each animal were taken daily and added to the previous day sample for each period, after which all refusals were mixed and sub-sampled to obtain a representative sample for each treatment feed. The samples were then stored at room temperature in well-labelled plastic bags for chemical analysis.

Milk yield and quality

The cows were hand milked every morning and evening and daily milk yield recorded. The same person was used in the whole experimental period to ensure that style of milking was not a factor in determining milk yield. Aliquot milk sample (200 ml) from each cow was taken daily and frozen at -27^0 C. At the end of the experiment, the samples were thawed, bulked for each cow and period, shaken thoroughly and representative samples (500 ml) taken for subsequent analysis for butter fat content, protein, total solids and solids not fat.

Chemical analysis

Feed samples were dried in a forced air oven at 60 ^{0}C to a constant weight for dry matter determination. The content of ash was determined by incinerating the samples in a muffle furnace at 550 ^{0}C for 3 hours. Total nitrogen was determined by the Kjeldahl technique, using a semi-automated N-analyser (2200 Kjeltec Auto Distillation). Neutral detergent fibre (NDF) and Acid detergent fibre (ADF) were analysed according to the procedure of Van Soest *et al*. (1991). Phosphorus was determined calorimetrically using spectrophotometer set at 420 ηm as recommended by AOAC (1990). Calcium was determined as recommended by AOAC (1990) using atomic absorption spectrophotometer. Extractable condensed tannins were measured using butanol-HCl (95:5 v/v) assay as reported and modified by Makkar (2000).

Milk butterfat content was determined using the standard Gerber method according to Marth (1978) and milk protein by Kjeldahl method using a semi automated N analyser (AOAC, 1990). Total solid was calculated using the Richmond formula as shown below:

$$TS = 0.25LR + (1.22\%\ BF) + 0.72$$ (O'Mahony, 1988).

Whereby TS = Total solids, LR = Lactometer reading and BF = Percent butter fat in the milk. Solids not fats (SNF) were calculated as the difference between the total solids (TS) and butterfat content of the milk.

Experiment 2

In this particular experiment, the nitrogen consumed in the feed (basal diet and the supplements) was weighed parallel to that voided in the faeces, urine and milk. Finally, differences in nitrogen intake and output were calculated to obtain the nitrogen balance. Treatment diets, feeding and management of the animals and experimental design were similar to those of the previous experiment.

Dry matter (DM) and Organic matter (OM) digestibility

Faeces from each cow were collected in separate 20 litres plastic buckets. Faeces were collected from the floor using a shovel after defecation, for each cow once daily every morning at 0900 hours using spring balance. The collected faeces were then mixed thoroughly and 10% aliquot samples taken and frozen at –50^0 C for chemical analysis. At the end of the experiment, the frozen samples were thawed, bulked by cow for each period, mixed thoroughly and representative samples taken for faecal DM and nitrogen determination.

Apparent digestibility of the diets was estimated, as the proportion of the feed consumed not excreted in the faeces, thus assumed to be absorbed by the animal. Algebraically represented as:

$$D = (Q_i - Q_r)/Q_i$$

Where Q_i is the average daily dry matter intake and Q_r is the average quantity of undigested dry matter voided daily and D is the feed's apparent digestibility. The organic matter digestibility (OMD) was determined by the use of the following equation:

$$OMD = \frac{(DMI - Ash) - (Faecal\ (DM) - Faecal\ Ash)}{DMI - Ash}$$

The digestible organic matter in the dry matter (DOMD) was computed according to McDonald *et al.* (1998) by multiplying the organic matter in the diet with the digestibility coefficient.

Calculation of the energy

The metabolizable energy (ME MJ/kg DM) was calculated using the following equation adopted fro MAFF (1975).

ME MJ/kg DM = 0.15 or 0.16 DOMD%

Where DOMD (Dry Organic Matter Digestibility) = 0.98 DMD% - 4.8. The DMD% (g kg^{-1} DM) is the dry matter degradability at 48-hour degradability. The coefficients were varied according to the class of feed, 0.15 was used for hay and 0.16 for the supplements.

Collection of urine for nitrogen determination

Urine was collected using special funnel-like device fitted with a tube harnessed to the animal to avoid urine being contaminated with faeces. A 14 days adaptation period was used to get the animals accustomed to the devices before the actual collection period. Urine from each cow was collected directly into plastic bags containing 500 ml of 10% sulphuric acid to lower pH to 3 in order to prevent ammonia volatilisation. Daily total urine volume excreted by each cow was measured every morning at 0900 hours. A representative sample (200 ml) from each day's collection per cow was taken and stored at -20^0 C for later analysis for nitrogen contents. At the end of the experiment, the urine samples were thawed, bulked by cow for each period, mixed thoroughly and sub-sampled. A representative sample (50 ml) was then taken for subsequent analysis for nitrogen content.

Animal body weight measurements

The animals were weighed at the beginning of the experiment and subsequently at the end of each experimental period using a weighbridge. Weighing was carried out between 0700 and 0800 h before morning feeding. The weight recorded at the end of each period was taken as the initial weight for the next period.

Chemical analysis

Milk, faecal and urine samples were analyzed for nitrogen content as described in experiment one.

Statistical analysis

Analysis of variance (ANOVA) was carried out to test the effect of dietary treatments on feed DM and OM digestibility, body weight changes and nitrogen utilization using the General Linear Models (GLM) procedure of Statistical Analysis System (SAS 2000) for a balanced 4 × 4 Latin square design. Data for milk yield was analysed using the statistical model:

$$\mathbf{Y_{ik} = \mu + T_i + \beta j + b\,(x_{ik} - x) + \Sigma_{ik}}$$

Where $\mathbf{Y_{ij}}$ is milk yield of *k*th cow assigned to i_{th} ration, $\boldsymbol{\mu}$ the overall mean effect, $\mathbf{T_i}$ the dietary effect, $\boldsymbol{\beta}\mathbf{j}$ breed effect, **b** the coefficient of regression, x_{ik} the initial milk yield of *k*th cow assigned to i_{th} ration, x the overall mean of milk yield during the initial period, $\mathbf{b(x_{ij} - x)}$ the covariance or correlation factor for initial milk yield of the cow and $\mathbf{\Sigma_{ik}}$ is the residual effect. The data for DM and OM digestibility was analysed using the statistical model:

$$\mathbf{Yijk = \mu + \rho_i + \alpha_j + \lambda_k + (\alpha\lambda)_{jk} + \Sigma_{ijk}}$$

Where $\mathbf{Y_{ijk}}$ is the k-th observation of the j-th animal assigned to the i-th treatment, μ is overall mean effect, ρ_i is animal effect (as random effect), α_j is period effect, λ_k is treatment effect, $(\alpha\lambda)_{jk}$ is interaction effect between $j\text{-}^{th}$ treatment and $k\text{-}^{th}$ period and Σ_{ijk} is the error term. The differences between treatment (ration) means were compared using probability of difference based on Least Significant Differences (LSD) at $P < 0.05$.

Results and Discussion

The chemical composition of the ration components is shown in Table 2. Both *Acacia angustissima* and *L. pallida* leaf meals had lower CP content (233 and 221 g kg^{-1} DM, respectively) than Cotton Seed Cake (CSC) (315 g kg^{-1} DM). However, CSC had relatively higher fibre contents than the browse leaf meals. The crude protein content (4.2%) of the hay used in the present study as the basal feed was below the critical threshold of 7 - 8% (Van Soest, 1994; Norton, 2003). Its NDF was high and comparable to the values reported elsewhere (Shem *et al.,* 1995). Calcium and phosphorus contents were also low and not adequate for maintenance and production requirements of lactating dairy cows (NRC, 2001).

The level of CP in the browse leaf meals and cotton seed cake were high and well above the level of 13-16% required for normal growth and moderate lactation (NRC, 2001). *Leucaena pallida* leaf meal had CP content (22%), which was within the range of 17 to 29% reported for most *Leucaena species* (Austin *et al.,* 1992; Kimbi, 1997; Ndemanisho *et al.,* 1998).

The NDF and ADF contents of the two browse leaf meals were within the range reported elsewhere (Austin *et al.,* 1992; Sandoval Castro *et al.,* 2001). The mineral contents (Ca and P) were adequate for normal metabolic body function and comparable to most findings reported in the literature (Karachi, 1998). The CP content of the cotton seed cake fell within the range of 300 - 330g kg^{-1} DM reported by Kimoro (2003), but slightly lower when compared to those of 340 – 370 g kg^{-1} DM reported by Shem *et al*., (2003). These variations in CP contents of cotton seed cakes may be due to differences in processing prior to and after oil extraction and seed variety. The high CP content (22 - 23%) in browse leaf meals in the present study underline their potentials as protein supplements in ruminant nutrition, especially in systems where nitrogen is considered a constraint to production. On the other hand, the low CP content (4.2%) and high fibre contents of grass hay is an indication of its low quality and limitation as a dairy feed.

Table 2. Chemical composition of grass hay (GH), cotton seed cake (CSC), dried leaf meals of *L. pallida* (LP) and *A. angustissima* (AA), and hominy meal (HM) used in the experiment

	Chemical Composition (g kg^{-1} DM)				
Constituent	GH	CSC	LP	AA	HM
Dry matter	925.3	928.9	934	932.5	898.2
Organic matter	842	874.8	874.4	873	856.7
NDF	800.3	485.2	391.4	412.2	*
ADF	513.7	283.0	219.3	227.4	*
Crude protein	41.9	315	221.1	233	118.5
Phosphorus	4.0	14.1	8.3	6.4	7.6
Calcium	2.8	1.9	6.6	6.4	4.0
Energy (MJkg^{-1} DM)	6.99	10.22	7.74	8.39	12.56
Condensed tannins	*	*	14.56	9.62	*

* Not determined, NDF = Neutral detergent fiber, ADF = Acid detergent fiber

Dry matter intake (DMI) and organic matter intake (OMI) differed significantly (P > 0.05) between the rations fed (Table 3). However, DMI and OMI for ration 1, 2, and 3 did not differ significantly (P > 0.05). Protein intake was similar (P > 0.05) among the rations fed, but calcium and phosphorus intakes were highest for cows fed ration 1, lowest for cows fed ration 4 and intermediate for cows fed ration 2 and 3. However there were no differences (P > 0.05) in Ca and P intakes between ration 2 and 3. Estimated energy intake was highest (P < 0.05) for the animals fed ration 4 and lowest for animals fed rations 1 and 2.

Milk yields differed significantly (P < 0.05) between rations and was highest for cows fed ration 4 (9.94 kg day^{-1}), lowest for cows fed ration 1 (7.78 kg day^{-1}) and intermediate for cows fed ration 2 and 3 with average milk yield of 8.17 and 8.25 kg day^{-1}, respectively (Table 3). There was no statistically significant difference between the rations in milk composition. Milk fat, which is the most variable component of milk, was also fairly stable between the rations. A similar finding was reported by Kakengi *et al.* (2001) when Leucaena leaf meal was fed as a supplement to grazing dairy cows. Shem *et al.,* (2003) made similar observation when using *Gliricidia sepium* to supplement lactating dairy cows as an alternative protein supplement to cotton seed cake.

Table 3. Voluntary DM, OM, nitrogen, Calcium (Ca), phosphorus (P), and estimated energy (MJ) intake and milk yield by dairy cow fed grass hay supplemented with cotton seed cake and dried leaf meals from *L. pallida* and *A. angustissima*

Ration	DM (kg day^{-1})	OM (kg day^{-1})	N (g day^{-1})	Ca (g day^{-1})	P (g day^{-1})	Energy (MJ day^{-1})	Milk yield (kg day^{-1})
1	10.4^{b}	9.06^{b}	167^{a}	41.8^{a}	81.6^{a}	88.2^{bc}	7.78^{c}
2	10.1^{b}	8.85^{b}	163^{a}	40.1^{b}	76.4^{b}	89.3^{b}	8.17^{b}
3	10.3^{b}	9.09^{b}	164^{a}	39.8^{b}	76.9^{b}	85.9^{c}	8.25^{b}
4	11.1^{a}	9.79^{a}	165^{a}	32.2^{c}	71.4^{c}	95.5^{a}	9.94^{a}
SEM	0.16	0.14	1.07	0.450	0.64	1.11	0.09

Means in the same column with the same letters (a-c) do not differ (i.e. P > 0.05).

Ration: 1 = basal feed + *L. pallida* leaf meal, 2 = basal feed + *A. angustissima* leaf meal, 3 = basal feed + 50% *L. pallida* and 50% *A. angustissima* and 4 = basal feed + cotton seed cake.

The notable feature about the responses to supplementation was higher DM and organic matter intake and higher milk yield in cows supplemented with cotton seed cake (ration 4) than in those receiving rations 1, 2 and 3. A possible reason for higher DM intake observed in ration 4 when compared to the other rations could be that it supplied more nitrogen to rumen microbes thus facilitating the breakdown of the digesta, as a result of increased crude protein digestibility (Table 4). Digestibility of the forage is closely related to dry matter intake and foods that are digested rapidly promote high intakes. The faster the rate of digestion and outflow rates the higher the intake (McDonald *et al.,* 1998; Mgheni, 2000). On the other hand, low DMI of ration 1 and 2 was possibly due to high content of condensed tannins and mimosine in browse leaf meals. The presence of DHP [3-hydroxy-4 (1h)-pyridone] a by-product of mimosine breakdown is known to depress cellulolytic activity and cause rumen stasis when the animal is fed with Leucaena. It may be possible that tannin which are present in large amount in these browse materials could have reacted with leaf protein and formed protein: tannins complexes, which reduced protein availability to the rumen microbes (Patterson *et al.,* 1998). This would result in depressed microbial metabolism and consequently reduced dry matter intake and digestibility (Reed, 1995; Mupungwa *et al.,* 2000). Minson *et al.* (1993) found a decrease in DM intake from 50 to 40% due to condensed tannins. Differences observed in Ca, P and energy intake by the animals relate to chemical composition and proportion of different components used in the rations.

The higher milk yield observed in the present study when the cows were offered ration 4 compared to the other rations could be attributed to the higher potential of cotton seed cake to supply microbial nitrogen in the rumen and its ability to provide more amounts of total amino acids digested and absorbed in the small intestine (Mgheni *et al.,* 1996). Relatively low milk yield by cows on ration 1 could have been caused by binding of protein by insoluble proanthocyanidins (condensed tannins) resulting in reduced protein availability and utilization by the dairy cows. The amount of milk produced in the current study are about 60% higher than 4 to 5 litres of milk produced under traditional management system during the dry season (Otysina *et al.,* 1998). These values relate closely to that of Kakengi *et al*. (2001) who reported a net increase in milk yields of 46%, 77% and 83.4% in grazing dairy cows supplemented with 1.2, 2.0 and 2.6kg DM of Leucaena leaf meal in semi-arid Western Tanzania.

Table 4 shows apparent dry matter, organic matter and nitrogen digestibility by dairy cows of the 4 rations used in the feeding trial. The DM, OM and nitrogen digestibility were highest (P < 0.05) for cows fed ration 4 and lowest for cows fed ration 1. The animal fed ration 3 had (P < 0.05) higher DM, OM and nitrogen digestibility than those fed rations 1 (*L. pallida*) and ration 2 (*A. angustissima*). The *in vivo* digestibility coefficients from the present study compare closely with results of studies conducted elsewhere with other browse species within the tropic (Abdulrazak *et al.,* 1997; Smith *et al.,* 1995). The high DM and OM digestibility coefficients of ration 4 compared to the other rations was possibly attributed to the superiority of cotton seed cake over browse leaf meals with regards to the supply of additional essential nutrients to the rumen microbes.

Table 4. Apparent digestibility of DM, OM and crude protein, and nitrogen utilization and body weight changes by dairy cow fed cotton seed cake and dried leaf meals from *L. pallida* and *A. angustissima* as supplements to grass hay

	Ration				
Parameter	1	2	3	4	SEM
Digestibility (g kg^{-1})					
DM	466^{d}	505^{c}	534^{b}	585^{a}	7.85
OM	494^{d}	532^{c}	566^{b}	615^{a}	7.63
N (g kg^{-1} DM)	60.3^{d}	66.4^{c}	70.4^{b}	93.1^{a}	1.54
Nitrogen utilization:					
Nitrogen intake (g day^{-1})	168^{a}	166^{ab}	164^{b}	162^{b}	1.07
g kg^{-1} $BW^{0.75/day}$	3.60^{a}	3.59^{a}	3.58^{b}	3.57^{b}	0.01
N-excretion (g/day)					
Milk	35.3^{c}	40.6^{b}	36.3^{c}	46.5^{a}	0.51
Faecal	105^{a}	97.2^{b}	92.2^{b}	67.7^{c}	1.85
Urine	21.8^{c}	24.0^{b}	18.4^{d}	25.9^{a}	0.66
Total	162^{a}	162^{a}	147^{b}	140^{c}	1.94
gkg^{-1}N intake (faecal)	623^{a}	585^{b}	560^{c}	418^{d}	9.49
g kg^{-1}N intake (urine)	130^{c}	144^{b}	113^{d}	161^{a}	4.05
g kg^{-1}N intake (milk)	210^{d}	245^{b}	223^{c}	289^{a}	3.58
Nitrogen retained					
gday^{-1}	6.15^{b}	4.24^{b}	17.3^{ab}	21.8^{a}	1.62
gkg^{-1}N intake	37.4^{c}	26.1^{c}	104^{b}	132^{a}	9.86
Live weight changes (kg day^{-1})	-0.70^{a}	-0.13^{a}	0.07^{a}	-0.06^{a}	0.25

Means in the same row with the same letters (a-d) do not differ (i.e. P > 0.05).

* = Significant at P < 0.05.

Ration: 1 = Basal feed + *L. pallida* leaf meal, 2 = Basal feed + *A. angustissima* leaf meal, 3 = Basal feed + 50% *L. pallida* and 50% *A. angustissima* and 4 = Basal feed + cotton seed meal

Cows on ration 3 had significantly higher nitrogen digestibility coefficient than those on ration 1 and 2, possibly due to dilution of inhibitors associated with *L. pallida* and *A. angustissima* below the threshold levels. Feeding mixtures of browse fodder have been reported to improve dry matter intake and digestibility of browse fodder than feeding single species alone (Phiri *et al.,* 1992; Bosman *et al.,* 1995; Rosale, 1996). The low nitrogen digestibility of ration 1 was possibly due to the presence of high level of condensed tannins which lowed protein digestibility (Paterson *et al.,* 1998; Makkar and Becker, 1998). This also explains the large variation in nitrogen digestibility observed between ration 4 and other rations. The high levels of nitrogen in the faeces of the cows fed ration 1 (*L. pallida*) compared to those on other rations further confirms the binding effects of tannin on the protein digestibility and availability.

The results for nitrogen intake, excretion and retention are presented in Table 4. The cows fed ration 1 (*L. pallida* supplemented ration) had relatively higher N intake and the highest faecal-N losses. The cotton seed cake supplemented diet (ration 4) had relatively lower (P < 0.05) N intake and the least (P < 0.05) faecal-N losses. Urinary nitrogen levels were generally low in all diets, with ration 3, resulting in the lowest (P < 0.05) urinary N excretion. The amount of nitrogen excreted in the milk differed (P < 0.05) between the rations. The cows fed ration 4 excreted more (P < 0.05) nitrogen in the milk than those on the other rations. Feeding the cows with ration 1 resulted in less milk nitrogen excretion. The cows receiving ration 4 had the highest N retention value while those on ration 1 and 2 retained similar (P > 0.05) amount of nitrogen. There was no statistically significant difference between the rations in live weight changes.

Animals in all treatment diets manifested positive nitrogen balance (4.2 - 21.8 g day^{-1}) an indication that the amount of nitrogen supplied by the rations was adequate and met their maintenance needs and extra for milk production. The positive N retention reported in the current study are in agreement with the findings of Reed *et al*., (1990), Wiegand *et al*., (1995) and Ayers *et al*., (1996) using tropical browse supplementation in ruminant diets. The amount of nitrogen excreted in the milk was positively correlated to the amount of milk produced. The relatively lower N excretion in the urine is an indication that the correct nutrient balance (protein: energy ratio) was achieved. The animals fed ration 3 utilised nitrogen more efficiently compared to those on ration 1 and 2. This was possibly due to their relatively high efficiency in protein digestibility, which also explains their relatively lower urinary N loss. The higher faecal N loss compared to urinary nitrogen was due to the fact that a larger portion of faecal N is of a non-dietary origin. According to McDonald *et al*., (1998) about 70 - 80% of nitrogen arises from endogenous sources such as microbial protein, enzymes and cell wall sloughing. However, judging from the proportion of N excreted in the faeces, it seems possible that browse leaf meals provide more escape protein than cotton seed cake as animals fed browse leaf meals had significantly more faecal N than those consuming cotton seed cake. Tannins found in browse species form complexes with plant proteins which decrease their rate of degradability in the rumen, thereby increasing the amount of plant protein by passing the rumen (Norton, 1994).

Comparing the two browse leaf meals, animals fed ration 1 had significantly higher faecal nitrogen than those fed ration 2. It may be possible that *L. pallida* tannins are stronger or more efficient in binding protein than those of *A. angustissima*, probably due to the differences in tannin molecular structure (weight) and the reactivity of phenolic hydroxyl groups, which influence protein precipitation capacity of the tannins (Hagerman *et al.,* 1992). In another related study, Norton and Ahn (1997) observed consistent increases in faecal N content in sheep when *C. calothyrsus* was included in barley straw based diet.

Conclusion and Recommendation

In this particular study, browse leaf meals proved to be a potential protein supplements for milk production, however, tannins and other related polyphenolic compounds may interfere with protein use. Optimal utilization of browse fodder could be achieved through feeding mixtures of browse species to dilute toxic effects of anti-nutritive compounds. Studies to determine the effect of tannins and other inhibitors on protein availability and utilization by ruminant animals should be carried out in order to improve the prediction of the nutritive value of potential browse species such as *A. angustissima.*

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11. THE POTENTIAL OF *MORINGA OLEIFERA* TREE LEAF MEAL AS A PROTEIN SOURCE IN COMMERCIAL EGG STRAIN CHICKENS IN TANZANIA

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Abstract

In Tanzania poultry feeding particularly protein sources has been one of the most critical constraints causing low productivity in both commercial and traditional sub- sector. Nevertheless, the major sources of protein in commercial poultry production has been fish meal and oil seed meals such as sunflower and cotton seed meals which are usually scarce, expensive and used extensively by other livestock species and humans. This situation has created a need to look for cheap, locally available and less competitive protein source ingredients for commercial chicken feeding. Therefore the study was conducted to assess the effect of substituting *Moringa oleifera* leaf meal (MOLM) for sunflower seed meal (SSM) on the egg production performance of layers. It aimed to increase an alternative use of cheap and locally available protein sources ingredients in commercial chickens feeding. In the experiment, four dietary treatments based on MOLM and SSC as plant protein sources were formulated such that MOLM replaced SSC giving the treatments containing 0 (control), 5, 10 and 20% MOLM levels for TI, T2, T3 and T4, respectively. All dietary treatments were iso-nitrogenous (17%CP) and iso-calorific (11MJ ME kg^{-1} DM). A total of 96, at 20 weeks of age egg- strain commercial pullets were randomly allocated to the treatments. In both experiments data obtained were analyzed by General Linear Model (GLM) Inc, (1998). In this experiment, dietary treatments had a significant effect laying percentage (LP), egg mass (EM), Feed Conversion Ratio (FCR), Daily Feed Intake (DFI) and Daily Dry Matter Intake (DDMI). LP had a slight decreasing trend as MOLM levels increased and ranged between 75.43 and 80.36% for T4 and TI, respectively. Further, EM was significantly low (40.46 g $bird^{-1}$) in T4. DFI and DMI significantly had a progressive increase in T3 and T4 and had a range of 108.93 to 114.55 g $bird^{-1}$ and 100.16 to 105.28 g $bird^{-1}$ for T1 and T4, respectively. FCR (g feed intake g^{-1} egg mass) were significantly higher (3.29) in T4. But, egg weight (EWT) was significantly lowest in T4. Therefore, it can be concluded that substitution of MOLM for SSM to 10% in laying chickens is optimal for better feed efficiency, egg production and weight. However, where quality of eggs can fetch high premium and MOLM is obtained free complete (20%) substitution of SSM with MOLM is highly encouraged. Therefore, MOLM could be utilized as an alternative source of protein for laying chickens. Promotion of integrating Moringa trees in Agro-forestry production system as a source of protein in livestock feeding is highly recommended.

Introduction

In most areas of the world, there are fewer religious or social taboos associated with poultry than they are with pigs and cattle. Thus, poultry products provide an acceptable form of animal protein for most people, with exception of strict vegetarians. It is estimated that the number of poultry worldwide exceeds combined total of sheep, goats, pigs and cattle and more than 90% are chickens (Smith, 1990). However, their contribution as protein suppliers in the developing countries have been very low. Poultry productivity in developing countries (Tanzania inclusive) is adversely affected by management and environmental factors such as feeding, diseases and climate.

In Tanzania poultry feeding particularly protein sources has been one of the most critical constraints causing low productivity in both commercial and traditional sector. Commercial feeds are found in few urban areas in the country and are usually very expensive. Taking in consideration that nutrition accounts for 60-70% of the total production cost poultry production systems (Smith, 1990), expensive feeds rise cost of production will undermine poultry enterprises. On the other hand, the major sources of protein in commercial poultry production in Tanzania are mainly fish meal and oil seed cakes such as sunflower and cotton seed cakes which are usually scarce, expensive and used extensively by other livestock species and humans. This situation has created a need to look for cheap, locally available and less competitive protein source ingredients. In the recent years, the use of leguminous multipurpose trees (MPTs) and shrubs has been suggested to be a potential alternative source of proteins, vitamins and minerals for poultry feeding and other monogastric animals (Church, 1991).

Plant leaves are commonly processed into leaf meals (LMs) for use as poultry feed. A review of available literature shows that *Leucaena leucocephala, Gliricidia sepium, Sesbania sesban* and *Manihot esculenta* have been widely used in feeding non-ruminants and especially poultry resulting in improvement of their productivity. Though, the uses of LMs are limited by their high fibre contents and in some cases, presence of toxic factors or metabolic inhibitors. Consequently, in most cases levels higher than about 5-10% have shown detrimental results on survival and production. *Moringa oleifera* is a Multi-purpose tree (MPT) of significant economic importance with industrial and medicinal uses (Baumer, 1983). *Moringa oleifera* leaves have very low anti-nutritional factors which have negative effect in animal feeding (Makkar and Becker, 1997). Also, Moringa leaves have high nutritive value in terms of protein, mineral, vitamins and well balanced Amino acid (Becker, 1996: Makkar and Becker 1997). Cultivation of Moringa oleifera trees is currently promoted in Tanzania for production of oil seeds. Its utilization in chicken feeding, will boost up the marketing of eggs. However, little information is available which specifies the utilization of MOLM in chicken feeding. Therefore, the study was conducted aiming to increase alternative use of cheap and locally available protein sources ingredients in poultry feeding and increase of commercial chicken productivity so as to increase the contribution in poverty alleviation and food insecurity in the country. The main objective therefore was to increase cheap and locally available feed resource base for chickens through utilization of MOLM in laying chickens so as to improve their productivity.

Material and Methods

Experimental birds and their management

Ninety-six (96) egg -strain commercial brown pullets 20 months of age were used. Before commencement of the experiment all birds were dewormed, vaccinated against Newcastle and weighed individually. Thereafter, birds were randomly distributed in four groups of 24 birds per treatment. 24 birds in each treatment were further subdivided into 3 groups of 8 birds each as replicates. In each treatment, replicate birds were assigned identification numbers and wing banded with tags. A group of 8 birds was placed in separate pen of approximately 4 x 4 x 1.5 m. Sunlight was used as a source of light during the day and fluorescent tubes were used to illuminate the pens at night. The birds were kept under deep litter management system and rice husks were used as litter materials to cover the floor. At the beginning of the study period, there was a preliminary period of 14 days before data collection to allow acclamatization of birds with experimental diets. Birds in each replicate were group fed and water was provided daily on ad-libitum basis. The feeding regime comprised of providing the ration once daily in the morning at 9.00 am. The amount provided in each pen daily was weighed and was approximately 20 - 25% above the expected daily requirements. The left over was weighed the next day, just before provision of another ration.

Treatments and experimental diets

The study had four dietary treatments containing varying combination of MOLM and SSM. MOLM reciprocally substituted with sunflower seed cake (SSM) in the diets. MOLM replaced SSM at levels of 20, 15, 10, and 0% dietary treatment containing 0, 5, 10, 20% MOLM levels. Maize meal (MM), hominy meal (HM) and rice polish (RP) were used as a source of energy in the experimental diets. Other ingredients used were fish meal (FM) mineral, cotton seed cake (CSM), vitamin premixes, limestone and salt. The compound dietary treatments were iso-calorific and iso-nitrogenous. *Moringa oleifera* leaves (MOL) were harvested from an orchard located within DASP compound as shown on plate 1a, b,

c. Branches were cut from the Moringa trees, spread out and dried under the shade for a period of 3 to 4 days. Thereafter, branches were threshed carefully to separate leaves from twigs before milling. The dried leaves were ground with hammer mill to make a leaf meal. The leaf meals were stored in the nylon bags during entire period of the study.

Analysis of ingredients and diets

Proximate analysis procedure was used in determining the percent dry matter (DM), crude protein (CP), ether extract (EE), crude fibre (CF), and ash contents of the ingredients and experimental diets. Likewise, calcium and phosphorus were determined in the ingredients and diets. The chemical analysis was carried out according to the AOAC (1990) procedure. Metabolizable energy (k cal kg^{-1} DM) content of each sampled feed ingredients carried out as cited by NRC (1994) and Energy Value of experimental diets and MOLM were calculated using prediction equations.

Experimental design and block layout

Complete Randomized Design (CRBD) was used. Ninety six birds were randomly allocated to four dietary treatments. Each treatment had 3 replicates. In each replicate, there were 8 experimental birds.

Data collection procedure

During the entire study period, feeds provided and left over were recorded daily in each treatment replicate using electronic sensitive weighing balance. The differences between feed given and left over were used to calculate intake (grams). Then, calculated daily intakes in each treatment replicate were used to calculate daily and weekly intake per bird in each dietary treatment. Feed Conversion Ratio (FCR) of laying chickens in each dietary treatment was calculated by dividing total feed intake (gm) by total egg mass (gm). Eggs were collected daily three times a day at 9 h, 13 h and 16 h. All the eggs and their weights in each treatment replicate were recorded daily. Daily egg productions in each treatment replicate were used to calculate weekly and daily laying percentages in each dietary treatment Moreover, daily egg weights records in each treatment replicate were used to calculate weekly and daily egg weight per bird in each dietary treatment. Egg mass was calculated as a factor of egg weight and egg production (g hen^{-1} day^{-1}).

Data analysis

The data for body Dry Matter Intake (DMI) and Feed Conversion Ratio (FCR), Egg Mass Production (EMP) were subjected to Analysis of Variance (ANOVA) according to Snedecor and Cochran (1992) using General Linear Model (GLM) procedures of Statistical Analysis System (SAS) (SAS Inc, 1998). Values were considered significant at P<0.05. The data for EMP and FCR were analysed using Model 1, whereas for DMI was analysed using Model 2

Model 1

$Y_{ijk} = U + A_i + T_j + (AT)_{ij} + E_{ijk}$

Where:

U = overall mean

Y_{ij} = Observations of k^{ith} bird assigned to i_{th} level of MOLM taken at j^{th} weeks of age

A_I = Effect associated with the i_{th} level of MOLM

T_j = Effect associated with j^{th} weeks of age

$(AT)_{ij}$ = Interaction between MOLM levels and age (weeks)

E_{ij} = Random error

Model 2

$Y_{ijk} = U + A_i + T_j + (AT)_{ij} + b\,(x_{ijk}-x) + E_{ijk}$

Where:

U = Overall mean

Y_{ijk} = Observations of k^{th} bird assigned to i_{th} level of MOLM taken at j^{th} weeks of age

A_I = Effect associated with the i_{th} level of MOLM

T_j = Effect associated with j[th] weeks of age
$(AT)_{ij}$ = Effect associated with interaction between MOLM levels and age (weeks)
Xijk = Initial body weight of an individual
X = Overall mean for initial body weight
b = Regression coefficient of Y_{ijk} on x_{ijk}
E_{ij} = Random error

Results and Discusion

The experimental birds were generally in good health condition throughout the experimental period. Nevertheless, yellowing around the shanks, feet and beaks was the most prominent feature in birds fed with MOLM. The yellow colour intensity increased progressively in body parts of the birds as the proportions of MOLM increased in the diet. However, colour intensity became lighter as the laying period progressed.

Table 1: Chemical composition (% DM) of ingredients used for diet formulation

	% DM								
Ingredients	DM	CP	CF	Ash	EE	Ca	P	NFE	ME (MJ kg^{-1} DM)
SSM	89.99	24.92	42.06	5.17	14.71	0.74	0.41	12.11	4.9
MOLM	85.99	29.74	22.49	14.77	4.38	2.79	0.26	10.63	7.86
FM	87.94	56.62	1.4	30.3	9.95	1.08	3.56	1.92	6.09
HM	84.9	11.11	8.95	4.62	11.59	0.12	0.54	61.73	7.57
MM	85.12	11.72	1.75	1.79	3.22	0.06	0.21	81.52	9.5
RP	86.21	11.99	16.74	13.69	13	0.14	0.94	44.62	3.54
BM	98.28	-	-	-	0.1	70.97	20.81	-	-
LS	98.19	-	-	-	-	44.23	-	-	-
CSM	94.49	33.87	27.58	7.98	9.78	0.62	0.62	20.83	6.12

The chemical composition of ingredients used in the experimental diets is shown in Table 1. The DM ranged between 84.9 and 98.25% for hominy and bone meal, respectively. The CP content was highest in the fishmeal (56.62% DM) and lowest in maize meal (11.72% DM). The CF was highest in sunflower (42.06% DM) and lowest in the fishmeal (1.4% DM). The ash content was lowest in maize meal (1.79% DM) and highest in fishmeal 30.3% DM). Furthermore, the sunflower showed the highest EE content (14.71% DM) whereas bone meal had the lowest (0.1% DM). However, bone meal had the highest calcium content (70.77% DM) and P (20.21% DM). The lowest values of Ca and Phosphorous were observed in maize meal at 0.06% and 0.21% DM, respectively. The highest energy values (9.5MJ kg^{-1} DM) were observed in maize meal whereas rice polish had the lowest (3.54 MJ kg^{-1} DM). The NFE values were highest in maize meal.

Table 2: Lsmean ± (SE) for overall performances of laying chickens fed different MOLM levels

Parameters	Percentage (%) MOLM levels				(±SE)
	0	5	10	20	
Daily laying percentage (%)	80.36^{a}	79.26^{ab}	77.34^{ac}	75.43^{bc}	1.43
Daily egg mass (g bird^{-1})	43.17^{a}	43.48^{a}	42.06^{ab}	40.46^{b}	0.71
Daily feed intake (g bird^{-1})	108..93^{a}	108.24^{a}	111.55^{b}	114.55^{c}	0.89
Daily DM intake (g bird^{-1})	100.16^{a}	99.52^{a}	102.57^{b}	105.28^{c}	0.82
Egg weight	53.21b	54.24^{a}	53.47^{bc}	52.46^{c}	0.3
Feed conversion ratio (FCR)	2.71^{a}	2.64^{a}	2.90^{a}	3.29^{b}	0.09

^{a,b,c}, Means within each row bearing same letter are not significantly different at (P<0.05)

Table 2 shows the overall mean of Dry matter (DM) intake and feed intake of birds fed different levels of MOLM. The dietary treatments had significant ($P<0.05$) effects on overall mean feed intake of laying birds, although birds in the control treatment (0%MOLM) and that fed 5 % MOLM level did not differ significantly ($P>0.05$). However, significant and progressive increases in feed intake were observed for birds' fed 10 and 20 % MOLM levels in the diet. Interaction between dietary treatments and age in weeks was also significant. Moreover, feed intake in all dietary treatments increased progressively with age as shown in Figure 1.

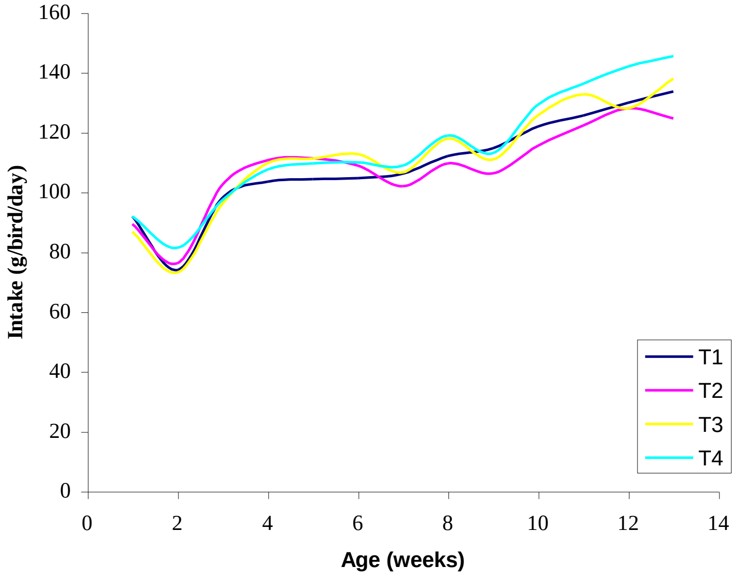

Figure 1. Weekly feed intake of laying chickens fed different dietary treatments

The summary of dietary treatment effects on overall eggs mass and laying percentages are shown in Table 2. The dietary treatments had significant effect ($P<0.05$) on egg mass. The lowest overall mean egg mass (40.46 ± 0.76) was observed in birds fed diet containing 20% MOLM levels. However, birds in the control treatment and those fed 5 percent MOLM level did not differ significantly for overall mean egg mass. The overall mean egg mass decreased significantly in birds fed 10 and 20% MOLM levels respectively. On the other hand, the mean weekly egg mass showed a tendency of increasing with weeks of age as demonstrated in Figure 2. Treatment effects were significant for the laying percentages. The lowest overall mean laying percent (75.43 ± 1.53) was observed in-birds fed 20% MOLM diet whereas the highest (80.36 ± 1.43) was in birds fed the control treatment. An increase in laying percentages with weeks of age was noted in all dietary treatments.

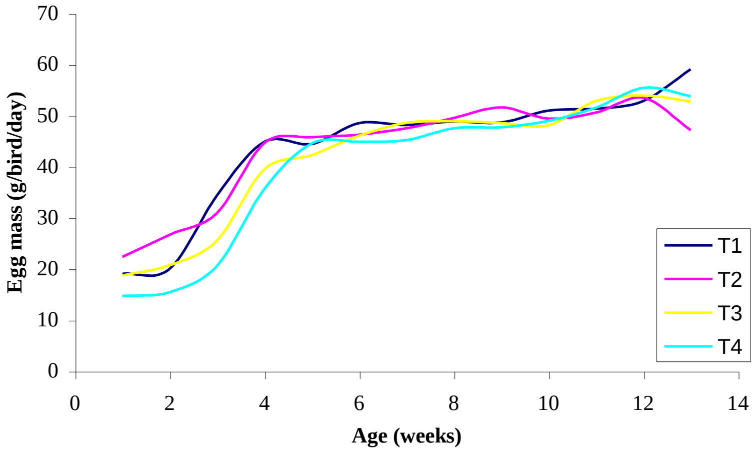

Figure 2: Weekly egg mass of laying chickens fed different dietary treatments (g bird^{-1} day^{-1})

The summary of FCR of laying birds is shown in Table 2. The dietary treatments had a significant (P<0.05) effect on feed conversion ratio. The growing pullets in the control and those fed 5% and 10% MOLM levels showed significant differences in the overall mean of FCR. The highest FCR (3.29±0.1) was observed in birds fed the 20% MOLM levels in the diet. The FCR decreased with age of birds in all dietary treatments. Figure 3 show a linear relationship between FCR and MOLM inclusion levels in the diet.

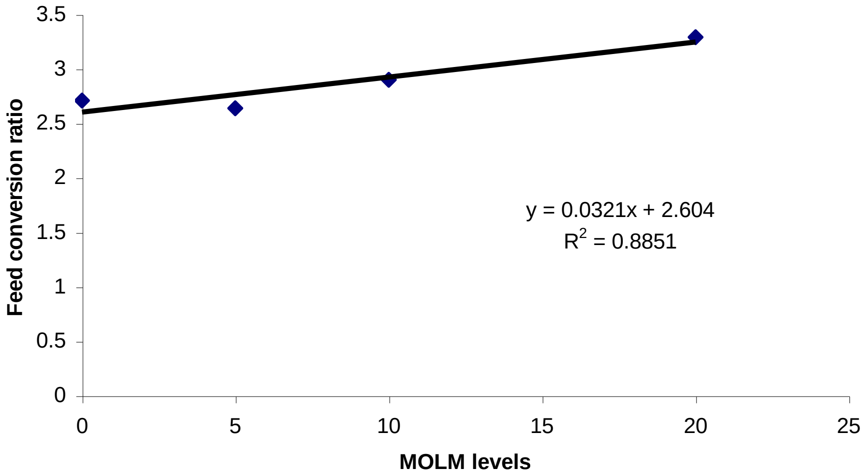

Figure 3: Linear correlation between feed conversion ratio and MOLM levels in the diet

The overall means of egg weights of different dietary treatments are shown in Table 2. The dietary treatments had a significant effect on mean egg weights. Egg weight was highest (54.24±0.1g) in birds fed diets containing 5% MOLM and lowest (52.46±0.1g) in birds fed diets containing 20% MOLM diet. The interaction between dietary treatments and age on mean egg weight was significant (P<0.05). Mean egg weights were not significantly different (P>0.05) between birds in the control and those fed 20% MOLM levels diets during the 27th to 33rd weeks of age. The mean egg weights increased with an increase of weeks of age in all dietary treatments.

Good healthy status of experimental birds observed during entire period of the present study, suggest that MOLM have negligible amount of toxic materials in comparison with other leaf meals fed in poultry. Various leave meals were reported to have serious compounds which have deleterious effect in mono-gastrics particularly when fed above 5|% inclusion level in the diet. Yellowing of the body parts which was observed in-groups of birds fed MOLM based diets demonstrate that MOLM have substantial amount of Xanthophylls and carotenoid which are commonly found in most of tree and shrub leaves (Austic and Neishem, 1990; NRC, 1994). Similar observations were reported elsewhere by Okot (1998) and Mellau (1999) in egg strain pullets fed *Leucaena* leaf meal based diets. However, in this study, there was a decreasing trend of yellow colour intensity on body parts with time which might be partly due to the gradual losses of xanthophylls and carotenoids in MOLM or partly by transfer of pigmenting agents for production of egg yolk pigment(North, 1990). On the other hand, body stores of xanthophylls in muscle and skin are usually transferred to the ovary at onset of sexual maturity and when egg laying is rapid, most xanthophylls from the feed are used for production of yolk pigment. Consequently, after long periods of egg production body parts become bleached to the natural blue - white colour (North, 1990).

The chemical composition of MOLM observed in this study compare well with the value reported by Makkar and Becker (1997). The similarities of chemical composition of MOLM with other studies indicate that probably environmental factors such as season, geographical locality and stage of maturity of the Moringa plant parts at the time of harvest for leaf meal play a minor role in determining nutritive value of MOLM. Further, values for chemical composition of MOLM were close to those reported in other leaf meals such as *Leucaena leucocephala*, *Sesbania sesban* and *Gliricidia sepium*. This suggest that potential of MOLM as animal feed agree with other leaf meals from nutritional point of view. On the other hand, SSM chemical composition values were smilar to those reported by Okot, (1998), But, CF and EE values were higher than those reported by NRC, 1994. Differences in the nutritive value of sunflower seed meal observed in the present study with those reported by other authorities suggest high variability of nutritive values in sunflower seed cake. This is probably due to the differences in the methods used in oil extraction from sunflower, the variety used, soil fertility and analytical procedures used. However, the chemical composition of the other feed ingredients used i.e. maize meal, hominy meal, cotton seed cake, fish meal in the present study were within the ranges reported elsewhere (NRC, 1994; McDonald *et. al*., 1995; Okot, 1998; Mellau, 1999). The CP content of dietary treatments of laying birds showed a well-defined increasing trend with an increase of MOLM levels in the diet. The similar phenomenon was observed in ash content. The observed trend was expected since relatively higher CP and ash contents were found in MOLM than in SSM in the present study. However, the decreasing trend of EE and CF with an increase of MOLM levels in the dietary treatments was also expected. This could be due to relatively lower EE and CF than SSM observed in the present study. Hence, the substitution of SSM with MOLM was likely to increase CP and ash content in the diet. Also, the decreasing tendency of CF,EE and P with addition of MOLM levels in the diet share similar explanation.

Results obtained in this study associated with feed intake demonstrate that MOLM is highly palatable and preferred by chickens in contrast with what has been observed in other leaf meals.These findings were inconsistent differ those reported in other leaf meals by Vohra, 1972, Ravindran *et al*. (1986), Osei *et al.,* (1990) and Bhatnagar *et al.,* (1996) who observed a depression in intake when laying chickens were fed diets containing various levels of Leucaena Leaf Meal (LLM). This still demonstrate the lower anti-nutritional factors in MOLM in comparison with other leaf meals (Marker and Backer, 1997). The increase of feed intake with increasing levels of MOLM probably was due to lower energy associated with lower digestibility of energy in CF component of MOLM (Tangendjaja *et. al*., 1990). The increase in feed intake was associated with compensatory mechanism to energy demand (Smith, 1990). This suggests substitution of sunflower with MOLM at higher proportions in the diet should be accompanied with high energy in the diet for better utilization.

From the results obtained in this study, it was evident that substitution of SSM with MOLM slighly depressed EMP and LP. However; their values remained at optimum recommended values (Austic and Neisheim, 1990), even at high MOLM inclusion levels in the diet. This suggests that MOLM has higher potential feed for laying chickens in comparison with other conventional leaf meals. The severe negative patterns have been reported in other conventional leaf meals whereby egg production in laying hens was adversely affected by dietary inclusion of Leucaena leaf meal (Mateo *et al.,* 1970; Vohra, 1972; Mellau, 1999). The slight decrease of egg mass production and laying percent at high levels of MOLM in the diet observed in this study might be attributed to the lower energy and CP fraction when MOLM constituted higher proportion of the diet. Based on the cheapness of MOLM in farmer's condition, the complete substitution of SSM with MOLM have a negligible adverse effect on egg production.

The present findings revealed SSM substitution with MOLM maintained better FCR up to 10% MOLM levels. This implies for better utilization the optimal inclusion level of MOLM in the diet, should not exceed 10%. An increase in FCR at higher levels than 10% of MOLM in the diet was due to increase in feed intake and decrease in egg mass value as MOLM proportion increased in the diet which probably attributed by slightly lower metabolizable energy. In the present study, the egg weights with a range of 52.46 ± 0.1 to 54.24 ± 0.1 g were recorded. These values were within the values reported by Shenstone (1968) from artificially selected chickens. Also agree with a range egg weight values observed by Mellau (1999) when LLM was fed to laying chickens. However, mean egg weight values were slightly lower compared with standard egg weight (58 g) reported by Shenstone (1968) and Katule (1989). Also were lower than egg weight value of 57 g reported by McDonald *et al.* (1995). The reason for the lower egg weight values may have been contributed by the fact that laying chickens used in the present study were within the first phase of egg production. Eggs in first phase are usually smaller than those in 2nd and 3rd phase (North, 1990).

Moringa inclusion levels influenced egg weight at different magnitude in the present study. The substitution of sunflower with MOLM at 5 % levels in the diet showed a positive effect on egg weight but the reason for this could not be explained although probably might be associated with high sulphur containing amino acids reported in Moringa leaves. North (1990) reported a positive influence of sulphur containing amino acids on egg weight. However, the substitution of sunflower seed meal with MOLM at 10 and 20% levels in the diet showed a moderate progressive depression of egg weight. The results were in contrast with the results from other leaf meals. Mellau (1999) observed an increase in egg weight values with an increase of LLM in the diet up to 15% inclusion levels. The decrease in weight at higher levels of MOLM was also not clear but probably was due lower energy and CP availability, associated with lower digestibility of CF component reported in various other leaf meals. The mean egg weight increased with weeks of age in all treatment groups. This phenomenon was expected because among other factors egg weight is also affected by the age of the bird. Usually egg weight increases with an increase of age (North, 1990).

Conclusion and Recommendation

The realized responses due to substitution of SSM with MOLM in this study suggest that *M. Oleifera* trees have high potential to be used in poultry feeding. This is exhibited through its protein content, relatively low fiber and higher mineral contents. It was demonstrated that MOLM is highly palatable and accepted even at high inclusion levels in the diet. Moreover, LP, EMP and EWT remained within the recommended level even when MOLM given as a sole plant protein source in the diet. FCR remained relatively low at 10% MOLM levels in the diet. Therefore, for optimum utilization of MOLM, substitution should go up 10%. However, where MOLM can be obtained for free, quality of eggs fetch high premium and high energy ingredients are used, complete substitution of SSM to MOLM (20%) is encouraged. Promotion of integrating Moringa trees in Agro-forestry production systems as a source of protein in poultry feeding is highly recommended.

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12. CONTENT OF MINERALS AND POLYPHENOLICS AND EFFECT OF TANNIN ON IN *VITRO* DIGESTIBILITY OF *ACACIAS* AND SELECTED BROWSE TREE SPECIES LEAVES

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Abstract

Browse tree and shrub foliages could form cheap protein and mineral supplements for ruminants. However, optimal utilisation of browse feed could be limited by scanty information on type, nature and levels of feed anti-nutritive factors (ANFs) such as phenolics and tannins. Leaves of six species of *Acacia* (*A. angustissima*, *A. drepanolobium*, *A. nilotica*, *A. polyacantha*, *A. tortilis* and *A. senegal*); *Dichrostachys cinerea*, *Flagea villosa*, *Harrisonia abyssinica* and *Piliostigma thorningii* were screened to quantify levels of conventional chemical composition including minerals; extractable total phenolics (TEP), extractable tannin (TET) and condensed tannin (CT), protein-bound and fibre-bound CT using chemical assays. Proanthocyanidins (PAs) flavonoid composition was assayed using high performance liquid chromatography (HPLC) technique. Effect of tannins on *in vitro* organic matter digestibility (OMD) was assessed by polyethylene glycol (PEG, MW 6000) tannin bioassay. Crude protein (CP) varied ($P<0.05$) among the species from 109 (*P thorningii*) to 229 g kg^{-1} DM (*A. angustissima*). The species had variable ($P<0.05$) and low levels of fibres. Calcium (Ca), phosphorus (P), magnesium (Mg) and sulphur (S) varied among the species from 6.6-31.5, 3.5-5.2, 1.4-3.8 and 1.7-2.8 g kg^{-1} DM, respectively. Copper (Cu), molybdenum (Mo), iron (Fe), manganese (Mn), zinc (Zn) and cobalt (Co) ranged from 4.5-23.8, 54.1-173.6, 146-432, 41.0-177.9, 10.9-22.2 and 0.05-0.65 mg kg^{-1} DM, respectively. The species had variable ($P<0.05$) levels of TEP and TET that ranged from 99-281 and 84-256 g kg^{-1} DM in *A. drepanolobium* and *A. nilotica*, respectively. Total CT ranged from 52.8 (*A. nilotica*) to 98.3 g/kg DM (*A. polyacantha* and *P. thorningii*). Most of CT was bound to protein (22.2-50.5 g kg^{-1} DM). Characterisation of PAs of selected species' leaves revealed presence of flavan-3-ol and flavan-3,4-diols flavonoids. These species represent good sources of CP and mineral supplements to ruminants. The feeds would satisfy requirements of Ca, P, Mg and S for different functions and classes of ruminants. Assayed Cu, Mn, Zn and Co would satisfy the lower range of recommended dietary levels in ruminants. Supplementation of PEG *in vitro* increased gas production, OMD and metabolisable energy (ME) content with the highest response ($P<0.05$) in *A. angustissima* compared to other species. Increased gas production due to PEG supplementation represent recovered feed nutrient by PEG binding tannins. High levels of phenolics and tannins of these species' leaves could limit their nutritive potential as CP and mineral supplements in ruminants. There is a need to identify natural PEG analogies that could be fed as a mixture with tanniniferous browse supplements to neutralise tannin anti-nutritive activity.

Introduction

Productivity of grazing ruminants livestock in the tropics including Tanzania is limited due to inadequate feed nitrogen (N) or CP (Leng, 1990) and mineral supply (McDowell, 1996) from low quality basal feeds such as hays, straw and stovers (Leng, 1990). Most low quality roughages often contain as low as 20 to 50 g kg^{-1} CP in the dry matter (DM) and so do not meet the minimum CP requirement of 80 g kg^{-1} DM for optimal rumen microbial function (Annisson and Bryden, 1998). Browse tree legumes and shrub foliages (*i.e.*, leaves, twigs, pods and fruits and barks) with their high CP contents of 100-250 g kg^{-1} DM (Le Houérou, 1980) have potential as CP supplements in ruminants where they form important components in the diets of cattle, sheep, goats and wild ungulates. However, their utilisation could be limited by their high content of polyphenolic compounds (*e.g.*, phenolics and tannins), especially when fed at high levels, due to their adverse effects on feed digestibility and nutrient availability. Tannins are high molecular weight (*i.e.*, >3000 daltons) phenolic compounds that bind to, and form chemical complexes which precipitate dietary feed nutrients such as carbohydrates, proteins and minerals (Mangan, 1988).

Despite the key role of browse tree foliages in agriculture in the tropics, the use of browse tree foliage supplements in livestock feeding has not been optimised in part to less available information on their nutritive values, e.g., presence of polyphenolics and other feed toxic compounds. Screening of browse fodder for phenolic and tannin contents is limited by inconsistent analytical techniques used for quantification of tannins (Schofield *et al.,* 2001). Little is known about the chemistry, tannin activity and tannin structure-biological activity relationship of different species of tropical browses. There is also a lack of knowledge on the nutritive potential of browse legume fodder from the different species for example, the *A. angustissima* toxicity that has been reported on rumen microbes (Osuji and Odenyo, 1997) and in sheep (Odenyo *et al.,* 1997), and there is little information on the performance of animals fed browse tree foliages, *e.g., Acacia* spp. As a result, there is little utilisation of browse trees and shrub foliages (Makkar, 2003). A study was therefore conducted to screen nutritive potential of leaves of six species of *Acacia* (*A. angustissima*, *A. drepanolobium*, *A. nilotica*, *A. polyacantha*, *A. senegal* and *A. tortilis*), and other four key fodder species: *Dichrostachys cinerea*, *Flagea villosa*, *Harrisonia abyssinica* and *Piliostigma thorningii,* indigenous to north-western Tanzania rangelands, to determine (1) potential chemical composition and contents of macro- and micro minerals; (2) quantify levels of phenolics and tannins, (3) determine soluble or extractable CT, protein-bound and fibre-bound CT fractions and, (4) assess effect of tannin activity on feed digestibility and nutrient availability *in vitro* using a polyethylene glycol (PEG MW 6000) tannin bio-assay.

Materials and Methods

Study Site

This study was conducted in five districts (Bariadi, Kahama, Meatu, Shinyanga Rural and Shinyanga Urban) of Shinyanga Region (1000 - 1300 m a. s. l) in north-western Tanzania (2- 3^{o} S; 31 to 31.5^{o} E). The region receives low unimodal annual rainfall of 600 - 800 mm between November and mid May. Minimum and maximum temperatures vary from 16.7 to 28.9^{o} C, respectively. Common vegetation includes short grasses and scattered shrubs and trees, mainly dominated by *Acacia* spp.

Forage sample collection and processing

Samples of leaves and soft twigs of each of the ten species were hand plucked from 8-10 trees that were selected at random from four sub-plots of 70 m x 70 m in four grazing lands in the five districts. Leaf samples were harvested in the late rainy season of May (2002) and pooled for each individual species. The samples were dried at 50^{o}C in a forced air oven for 48 h to constant weight and ground to pass a 2.0 mm sieve. The samples were then sub-sampled to obtain two sets of 30 samples (*i.e.*, three samples of each species) for chemical analyses including phenolics, tannins and *in vitro* digestibility. Samples for phenolics, tannins and *in vitro* digestibility studies were further ground to pass a 1.0 mm sieve.

Chemical analyses

Chemical analyses were conducted in duplicate. Ash was determined by ignition of dried samples in a muffle furnace at 550^{o}C for 3 h (AOAC, 1990). The CP was determined by a Kjeldahl method (AOAC, 1990). Ash-free neutral detergent fibre (NDF), ash-free acid detergent fibre (ADF) and acid detergent lignin (ADL) were determined using methods described by Van Soest *et al.* (1991).

Minerals composition

Forage mineral concentrations were determined by wet ashing using a microwave oven according to Mullis *et al*. (2003). Forage samples, (0.5 g), were weighed into teflon-lined digestion vessels to which 5 ml of HNO_3 was added, and were allowed to digest for 25 min. in a microwave oven (CEM Corporation, Mathews NC., USA) as detailed by Rubanza *et al*. (2006). The samples were analysed for macro minerals, *viz*: Ca, P, Mg, and S; and micro minerals, Fe, Zn, Mn, Mo, Co and Cu.

Extraction and determination of polyphenolics

Extractable phenolics and tannins

Approximately 200 mg (DM) sample was extracted in 10 ml of aqueous acetone (7:3 *v/v*) in a water bath, maintained at 40° C, and rotating at 130 cycles for 90 min (Makkar, 2000). The supernatants were carefully transferred into 10 ml centrifuge tubes and centrifuged at 1,670 x *g* (4°C) for 20 min. The aqueous aliquots were assayed for total extractable phenolics (TEP) and extractable tannins (TET) and the residue discarded. Contents of TEP was assayed using the Folin-Ciocalteu's reagent as described by Jolkumen–Tiito (1985) and Makkar (2000). Content of TET were estimated gravimetrically as the difference of phenolics remaining from total phenolics after binding tannins with polyvinyl polypyrrolidone (PVPP) according to Makkar *et al*. (1993). The concentrations of TEP and TET were expressed as the tannic acid equivalent.

Soluble/ free-bound condensed tannins

An approximate 0.1 g sample was extracted thrice with a mixture of 4 ml of acetone/water (7:3 v/v), containing 1 g l^{-1} ascorbic acid, and 2 ml of dichloromethane according to Stewart *et al*., (2000) as detailed by Rubanza *et al*., (2005a). The soluble CT fraction was determined using the butanol/HCl assay (Porter *et al.,* 1986).

Protein-bound condensed tannins

The solid residues obtained following extraction of free-bound CT were dried for a few minutes in a stream of N_2 gas at room temperature to eliminate residual volatile solvents (Terrill *et al.,* 1992). The residues were then heated at 95°C on a metal block for 45 minutes with 3 ml of 10 g l^{-1} aqueous SDS containing 50 g l^{-1} 2-β-mercaptoethanol (SDS solution). The protein-bound CT fraction was estimated by the butanol/HCl/Fe^{3+} assay of Porter *et al*. (1986).

Fibre-bound condensed tannins

Fibre-bound CT were estimated similar to protein-bound CT with 6 ml of butanol/HCl/ Fe^{3+} plus 0.5 ml of SDS solution, added directly to the solid residue according to Jackson *et al*. (1996). Absorbance values for soluble, protein-bound and fibre-bound CT were converted to condensed tannin concentrations by including the internal (*i.e*., authentic) tannin standard purified from *A. nilotica* at known concentrations in each of the three runs (Waterman and Mole, 1994; Jackson *et al.,* 1996). The CT concentrations were converted to mg *A. nilotica* CT equivalent g^{-1} DM from *A. nilotica* tannin using the regression equation: $Y = 0.0636 + 112.83X$ ($R^2 = 0.99$) where Y is absorbance at 550 nm, and X is CT concentration expressed as *A. nilotica* tannin. Purification of tannin from *A. nilotica* leaves for the standard was achieved by back extraction with diethyl ether to remove lower molecular weight phenolics and pigments as detailed by Terrill *et al.* (1992). Use of purified tannin from *A. nilotica* was preferred to commercial standards due to the similarity in the nature of tannins among *Acacia* spp. samples as compared to commercial standards (Makkar and Becker, 1993).

Characterisation of condensed tannin flavonoids

The condensed tannins of six selected species' leaves were assayed into proanthocyaninds or leucoanthocyanidin flavonoid composition by high performance liquid chromatography (HPLC) based on techniques described by Stewart *et al*., (2000) with slight modifications as detailed by Rubanza *et al*., (2005b).

***In vitro* gas production and polyethylene glycol (PEG) tannin bioassay**

Animals and management

Rumen fluid for the *in vitro* digestibility tannin bioassay was obtained from three healthy mature cannulated Japanese corriedale female sheep fed a daily ration of 800 g timothy hay and 200 g concentrates divided into two equal meals at 8:00 and 16:00 h daily. The sheep were supplied with minerals and water throughout the experiment.

Rumen fluid sampling and handling

Rumen fluid was obtained from the three sheep in the morning before feeding, flushed with CO_2, filtered through three layers of cheese-cloth and mixed (1:2 *v/v*) with an anaerobic mineral buffer solution as described by Makkar *et al*., (1995) and revised by Makkar (2000). Preparation of an *in vitro* mineral buffer media for gas test was carried out as described by Menke and Steingass (1988). Composition of the rumen mineral buffer medium for PEG tannin bioassay was prepared according to Tilley and Terry (1963).

Polyethylene glycol (PEG) tannin bioassay

Adverse effects of tannins on *in vitro* OM digestibility (OMD) were assessed by incubating approximately 500 mg (DM) of triplicate test feed samples with or without 1.0 g PEG (MW, 6000). Feed samples were incubated in 100 ml glass syringes based on Menke and Steingass (1988) procedures. The PEG tannin bioassay was conducted according to Makkar *et al., (*1995) as revised by Makkar (2000). Gas production readings (ml) were recorded after 2, 4, 6, 8, 12, 16 and 24 h for both PEG treated samples and blank samples. Feed OMD (g kg^{-1} OM) and metabolisable energy (ME) in MJ kg^{-1} DM were estimated from equations of Menke and Steingass (1988) and Makkar and Becker (1996) based on 24 h gas production, (GAS, ml) and CP content (g kg^{-1} DM): OMD (g kg^{-1} OM) = 148.8 + 8.89 GAS + 4.5CP; and ME (MJ kg^{-1} DM) = 2.20 + 0.136 GAS + 0.0057 CP.

Statistical analysis

Data on chemical composition including minerals and polyphenolics were subjected to analysis of variance (ANOVA) using the General Linear Model (GLM) procedure of SAS Statview (1999), and were analysed based on the statistical model: $Y_{ij} = \mu_{ij} + S_i + e_i$.Where, Y_{ij} is the general observation on chemical composition and tannin estimates. μ_{ij} is the general mean common for each parameter under investigation. S_i is the i[th] effect of browse species on the observed parameters; and e_i is the standard error term. Data on *in vitro* gas production and digestibility estimates were subjected to the ANOVA using GLM (SAS Statview, 1999), and were analysed based on the statistical model: $Y_{ij} = \mu_{ij} + S_i + P_j + (SxP)_{ij} + e_i$..Where, Y_{ij} is the general observation on gas production and *in vitro* digestibility estimates, S_i are the i[th] effect of browse species on the observed parameters. The $(SxP)_{ij}$ term represents i[th] and j[th] interaction effects of species and PEG on gas production and in vitro digestibility, e_i is the standard error term common for all observations.

Results

Chemical composition

Ash varied among the species from 48 to 101 g kg^{-1} DM in *P. thorningii* and *A. polyacantha*, respectively, (Table 1). The CP varied among the species from 109 g kg^{-1} DM (*P. thorningii*) to 229 g kg^{-1} DM in *A. angustissima*. There was no difference ($P>0.05$) in CP among *A. Drepanolobium*, *A. nilotica* and *A. tortilis*. There was also no difference in CP between *A. senegal* and *H. abyssinica*. *A. nilotica* and *A. senegal* had lower NDF, ADF and ADL than *A. polyacantha* and *P. thorningii*.

Minerals

The contents of minerals are shown in Table 2. With exception of *A. angustissima*, *A. tortilis* and *P. thorningii*, the species contained high levels of Ca (>17.1 g kg^{-1} DM). The content of Ca varied (*P<0.05*) from 6.6 (*P. thorningii*) to 31.5 g kg^{-1} DM in *A. polyacantha.* The content of P varied (*P<0.05*) among the species from 3.5 *(A. senegal* and *A. polyacantha*) to 5.2 g kg^{-1} DM (*D. cinerea*). The rest of the species had intermediate levels of P (4.0-4.9 g kg^{-1} DM). The species showed both variable and wide ratios of Ca:P (1.4:1-9.1:1). *A. nilotica* and *P. thorningii* had lower Mg than both *D. cinerea* and *F. villosa*. *A. polyacantha* and *H. abyssinica* had higher contents of Mg than *A. nilotica* and *P. thorningii*. The content of S ranged from 1.7 (*A. angustissima*) to 2.8 g kg^{-1} DM (*A. drepanolobium*). *A. angustissima*, *A. polyacantha*, *A. senegal*, *H. abyssinica* and *P. thorningii* had lower contents of S than *A. nilotica*, *A. tortilis*, *D. cinerea* and *F. villosa*. Similarly, *A. polyacantha* and *A. angustissima* contained higher ratios of N:S of 16.3:1 and 22:1, respectively, than the rest of the species.

Table 1. Chemical composition (g kg^{-1} DM) of selected browse tree fodder species leaves native to north- western Tanzania rangelands

Species	Ash	†CP	╫NDF	‡ADF	§ADL
A. angustissima	58^{a}	229^{a}	354^{a}	171^{a}	79^{a}
A. drepanolobium	93^{b}	178^{b}	435^{b}	230^{b}	101^{b}
A. nilotica	55^{a}	176^{b}	222^{c}	134^{c}	56^{c}
A. polyacantha	101^{c}	193^{c}	505^{d}	286^{d}	145^{d}
A. senegal	97^{bc}	145^{d}	250^{c}	148^{c}	64^{c}
A. tortilis	60^{a}	189^{bc}	376^{a}	215^{b}	82^{a}
D. cinerea	94^{b}	160^{b}	468^{bd}	278^{d}	128^{d}
F. villosa	77^{d}	154^{bd}	317^{e}	214^{b}	73^{a}
H. abyssinica	90^{b}	147^{bd}	306^{e}	221^{b}	94^{b}
P. thorningii	48^{e}	109^{e}	559^{f}	417^{e}	183^{e}
Mean	77.2	168.0	379.2	231.4	100.5
SEM	2.01	3.28	11.07	8.19	4.01
Effect of species	***	***	***	***	***

†CP, crude protein; ╫NDF, neutral detergent fibre; ‡ADF, acid detergent fibre; §ADL, acid detergent lignin

Table 2. Contents of macro and micro minerals of selected browse tree species leaves native to north western Tanzania rangelands

Species	Macro minerals (g kg^{-1} DM)				Micro minerals (mg kg^{-1} DM)					
	Ca	P	Mg	S	Cu	Mo	Fe	Mn	Zn	Co
A. angustissima	17.1^{a}	3.6^{a}	2.7^{ac}	1.7^{ad}	4.5^{a}	111^{ac}	296^{a}	66.1^{a}	16.2^{a}	0.31^{a}
A. drepanolobium	19.0^{a}	4.6^{ab}	2.0^{ab}	2.8^{b}	6.9^{bd}	125^{ac}	322^{a}	61.6^{a}	21.7^{b}	0.05^{b}
A. nilotica	20.7^{ae}	4.3^{ab}	1.4^{b}	2.4^{c}	15.6^{c}	126^{ac}	147^{b}	51.6^{ac}	22.2^{b}	0.36^{a}
A. polyacantha	31.5^{b}	3.5^{a}	3.0^{c}	1.9^{a}	8.1^{d}	174^{b}	235^{ab}	90.1^{b}	10.9^{c}	0.06^{b}
A. senegal	31.3^{b}	3.5^{a}	2.2^{ac}	1.9^{a}	23.8^{e}	172^{b}	182^{be}	59.5^{a}	13.1^{c}	0.65^{c}
A. tortilis	14.6^{c}	4.9^{b}	2.7^{ac}	2.5^{c}	10.5^{f}	99^{c}	146^{b}	41.0^{c}	20.1^{b}	0.35^{b}
D. cinerea	26.7^{d}	5.2^{b}	3.8^{d}	2.4^{c}	9.7^{f}	157^{b}	432^{c}	85.6^{a}	17.9^{a}	0.50^{c}
F. villosa	18.9^{a}	4.7^{ab}	3.8^{d}	2.4^{c}	9.4^{f}	126^{ac}	231^{ab}	94.9^{a}	17.7^{a}	0.52^{c}
H. abyssinica	24.4^{de}	4.0^{ab}	3.0^{c}	2.0^{a}	9.2^{d}	158^{b}	220^{ab}	177.9^{d}	15.4^{a}	n.a
P. thorningii	6.6^{f}	4.7^{ab}	1.5^{b}	1.9^{a}	15.0^{c}	54^{d}	180^{b}	42.5^{c}	21.8^{b}	0.27^{b}
Mean	21.1	4.3	2.6	2.2	11.3	130.2	239.1	77.1	17.7	0.34
SEM	3.69	0.62	0.72	0.23	0.54	43.4	89.2	9.52	3.86	0.09
Effect of species	***	*	***	***	***	***	***	***	***	***

n.a= not detected

Content of micro minerals is also shown in Table 2. *A. angustissima* and *A. drepanolobium* had lower (*P<0.05*) levels of Cu than *A. senegal*. Concentration of Mo varied from 54.1 (*P. thorningii*) to 173.6 mg kg^{-1} DM (*A. polyacantha*). *A. tortilis* and *A. nilotica* had the lowest Fe-content (146.2 and 147.2 mg kg^{-1}

DM, respectively), compared to *D. cinerea* (432.4 mg kg^{-1} DM). *A. tortilis* and *P. thorningii* had the lowest level of Mn, compared to *H. abyssinica*. Concentration of Zn ranged from 10.9 (*A. polyacantha*) to 22.2 mg kg^{-1} DM (*A. nilotica*). Other species had intermediate to high levels of Zn. *A. drepanolobium* and *A. polyacantha* had lower Co-level than *A. senegal*, which had (*P<0.05*) the highest Co concentration.

Total extractable phenolics and tannins

All species had tannin contents higher than 50 mg g^{-1} DM (Table 3). All *Acacia* spp. had high TET contents (84 to 256 mg g^{-1} DM) and TEP (99 to 281 mg g^{-1} DM) for *A. drepanolobium* and *A. nilotica*, respectively. *A. nilotica* had the highest (*P<0.05*) content of TET, although its values did not differ from those of *A. senegal* and *A. tortilis*. The different species had variable total extractable condensed tannins (CT) or proanthocyanidins (PAs) levels. Extractable TCT varied among the species from 52.8 (*A. nilotica*) to 98.3 mg kg^{-1} DM (*A. polyacantha* and *P. thorningii*). There was no (P>0.05) difference in the content of CT among *A. senegal*, *F. villosa* and *H. abyssinica*. the highest (P<0.05) concentration of CT compared to *A. nilotica*, that had the lowest. The content of CT in the other Acacia species ranged from 54 *in A. senegal* to 84 mg g^{-1} DM in *A. drepanolobium*.

Soluble and bound condensed tannins

The CT fractions are also shown in Table 3. Fractionation of condensed tannins in leaves revealed different (*P<0.05*) CT fractions among the species. Soluble or free CT fraction varied from 14.5 (*A. senegal* and *H. abyssinica*) to 22.9 mg g^{-1} DM in *A. angustissima*. Protein-bound CT varied from 22.2 (*A. nilotica* and *F. villosa*) to 50.5 mg g^{-1} DM in *A. polyacantha* and *P. thorningii*. *A. nilotica* and *F. villosa* had lower (*P*<0.05) fibre-bound CT (13.0 and 13.4 mg kg^{-1} DM, respectively), compared to both *A. polyacantha* and *P. thorningii* (28.6 mg kg^{-1} DM). A large proportion of CT was bound to protein (40.0-51.4 %CT) compared to fibre-bound (23.0 - 29.1 %CT) and free-bound CT fractions (19.5 - 33.3 %CT).

Table 3. Content of total extractable phenolics (TEP), total extractable tannins (TET) and total condensed tannins (TCT) (mg g^{-1} DM); soluble and bound condensed tannins (mg/g DM) in selected *Acacia spp.* leaves harvested from north-western Tanzania rangelands

Species	*TEP†*	*TET†*	*TCT‡*	*Soluble CT‡*	*% total CT*	*Protein-bound CT‡*	*% total CT*	*Fibre-bound CT‡*	*% total CT*
A. angustissima	202 ^{ad}	185 ^{a}	74.4 ^{a}	22.9 ^{a}	30.8	35.4 ^{a}	47.6	17.1 ^{a}	23.0
A. drepanolobium	99 ^{b}	84 ^{b}	84.2 ^{ab}	17.8 ^{bc}	21.1	43.4 ^{b}	51.5	23.0 ^{b}	27.3
A. nilotica	281 ^{c}	256 ^{c}	52.8 ^{c}	17.6 ^{b}	33.3	22.2 ^{c}	42.1	13.0 ^{c}	24.6
A. polyacantha	104 ^{b}	93 ^{b}	98.3 ^{b}	19.2 ^{c}	19.5	50.5 ^{d}	51.4	28.6 ^{d}	29.1
A. senegal	236 ^{cd}	217 ^{ac}	54.2 ^{c}	14.5 ^{d}	26.8	24.9 ^{c}	45.9	14.8 ^{c}	27.3
A. tortilis	241 ^{ac}	226 ^{ac}	77.8 ^{a}	18.9 ^{bc}	24.3	37.5 ^{a}	48.2	21.5 ^{b}	27.6
D. cinerea	114 ^{b}	96 ^{b}	75.4 ^{a}	22.9 ^{a}	30.4	35.4 ^{a}	46.9	17.1 ^{a}	22.7
F. villosa	234 ^{cd}	220 ^{ac}	53.2 ^{c}	17.6 ^{b}	33.1	22.2 ^{c}	41.7	13.4 ^{c}	25.1
H. abyssinica	156 ^{e}	139 ^{d}	54.3 ^{c}	14.5 ^{d}	26.7	25.0 ^{c}	40.0	14.8 ^{c}	27.3
P. thorningii	112 ^{b}	95 ^{b}	98.3 ^{b}	19.2 ^{c}	19.5	50.5 ^{d}	51.4	28.6 ^{d}	29.1
›effect of species	***	***	***	***		**		**	

^{a,b,c,d,e} Means with different superscripts in the same column differ (*P<0.05*); *** P0.001.; † Total extractable phenolics (TEP) and total extractable tannins (TET) were expressed as mg/g tannic acid equivalent; ‡ Total condensed tannins (TCT), protein-bound CT and fibre-bound CT were expressed as mg/g *Acacia nilotica* tannin equivalent; n.a = The respective fractions of CT were not assayed

Characterisation of condensed tannins

Flavonoid composition of selected species is presented in Table 4**.** The species' leaves had detectable and (*P<0.01*) variable proanthocyanidins (PAs) or leucoanthocyanidin composition. Delphinidins varied

($P<0.05$) among the species from 0.062 (*A. nilotica)* to 5.288 mg kg^{-1} DM (*A. tortilis*). *A. tortilis* had the lowest concentration of cyanidins compared to *A. polyacantha* (0.188 vs. 4.179 mg/kg DM). Pelargonidins varied ($P<0.05$) among the species from 0.004 (*F. villosa*) to 4.392 mg kg^{-1} DM (*D. cinerea*). The species had wide and variable delphinidins/ cyanidins ratios ranging from 0.11 (*A. polyacantha*) to 28.1 (*A. tortilis*).

Effect of polyethylene glycol (PEG) treatment on *in vitro* gas production and digestibility

Effect of incubation of browse leaf samples with PEG on *in vitro* gas production (GP) of selected species (Acacias) is shown in Figure 1. Addition of PEG resulted in ($P<0.05$) increased GP at all incubations in all the species. The species showed variable responses on increase in GP and OM fermentation characteristics. *A. angustissima* had the highest ($P<0.05$) response on fermentation due to PEG treatment at all incubations. *A. drepanolobium* and *A. nilotica* had higher GP potential at all incubations than other species. Among other species, *A. polyacantha* and *D. cinerea* (not shown) had relatively high responses on gas production due to *in vitro* PEG supplementation.

Table 4. Flavonoid composition (mg g^{-1} DM) of selected browse species leaves indigenous to north-western Tanzania rangelands

Species	*Delphinidins*	*Cyanidins*	*Pelargonidins*	*Delph/Cyanid ratio*
A. nilotica	0.062^{a}	0.243^{a}	0.009^{a}	0.26
A. tortilis	5.288^{b}	0.188^{b}	0.017^{a}	28.1
A. polyacantha	0.454^{c}	4.179^{c}	0.098^{b}	0.11
D. cinerea	1.630^{d}	1.424^{d}	4.392^{c}	1.14
F. villosa	0.461^{c}	0.537^{e}	0.004^{a}	0.86
H. abyssinica	0.384^{a}	0.619^{e}	0.017^{a}	0.62
P. thorningii	0.191^{e}	0.311^{a}	0.009^{a}	0.61
ffect of species	***	***	***	

$^{a,\ b,\ c,d,e}$ different letters in the same column indicate significant differences (P<0.05); ****p<0.001.*

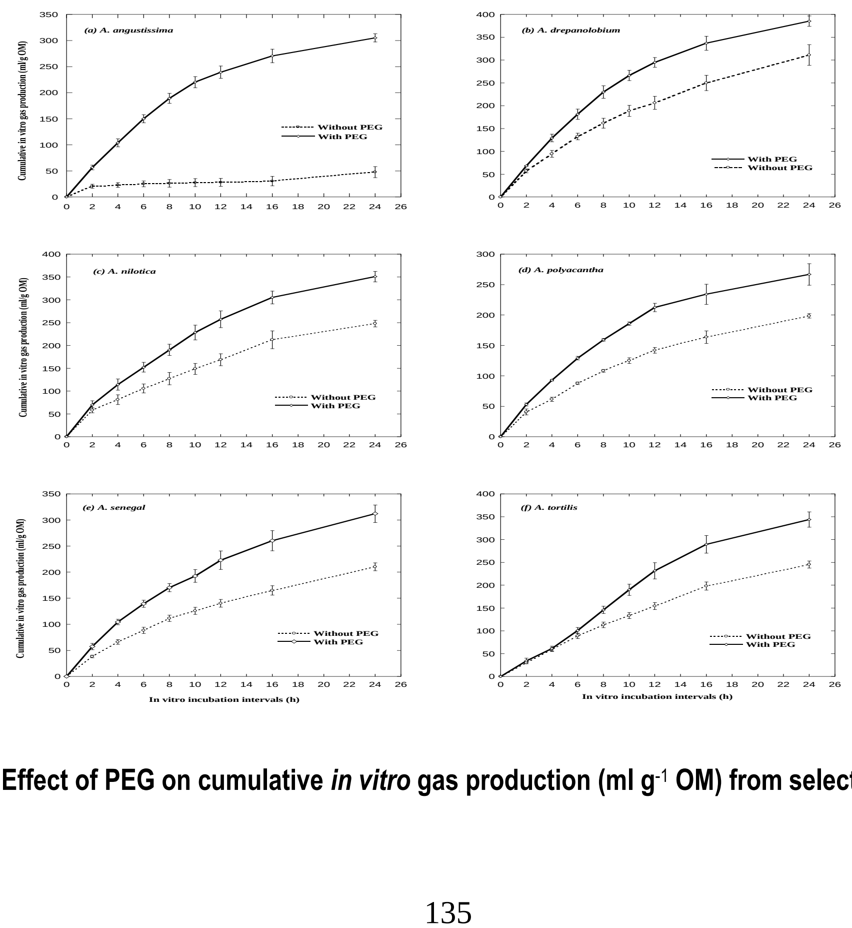

Figure 1. Effect of PEG on cumulative *in vitro* gas production (ml g^{-1} OM) from selected *Acacia* spp.

Effect of PEG on organic matter digestibility

Addition of PEG resulted in higher (*P*<0.05) OMD and ME content, with variable responses among the species (Table 5). Responses in OMD and ME due to addition of PEG *in vitro* were influenced by species (*P<0.001*), PEG treatment (*P<0.001*), and interaction of species and PEG treatment (*P<0.001*). Among the species, *A. angustissima* had (*P<0.05*) the lowest OMD (344 g kg^{-1} DM) and ME content (4.4 MJ kg^{-1} DM) in the absence of PEG compared to *H. abyssinica*, which had the highest OMD (838 g kg^{-1} DM) and ME (11.6 MJ kg^{-1} DM). *A. angustissima* had the highest ME increment of 7.1 MJ kg^{-1} DM (*i.e.*, 161.4 %) due to addition of PEG compared to *H. abyssinica* (1.2 MJ kg^{-1} DM; *i.e.*, 10.3%). The rest of the species had intermediate responses in both OMD and ME.

Table 5. Effect of polyethylene glycol (PEG) treatment on *in vitro* organic matter digestibility (g kg^{-1} DM) and feed metabolisable energy (MJ kg^{-1} DM) at 24 h incubations from selected *Acacia* spp. leaves harvested from north-western Tanzania rangelands

Species	Effect of PEG treatment on							
	OMD response				ME response			
	- PEG	+ PEG	Increment	%	- PEG	+ PEG	Increment	%
A. angustissima	344 ^{a}	836 ^{b}	492	143.0	4.4 ^{a}	11.5 ^{b}	7.1	161.4
A. drepanolobium	810 ^{a}	911 ^{b}	101	12.5	10.4 ^{a}	12.4 ^{b}	2.0	19.2
A. nilotica	706 ^{a}	911 ^{b}	205	29.0	9.5 ^{a}	12.3 ^{b}	2.8	29.5
A. polyacantha	602 ^{a}	726 ^{b}	124	20.6	7.9 ^{a}	9.9 ^{b}	2.0	25.3
A. senegal	607 ^{a}	795 ^{b}	188	31.0	7.7 ^{a}	10.4 ^{b}	2.7	35.1
A. tortilis	702 ^{a}	889 ^{b}	187	26.6	9.1 ^{a}	11.7 ^{b}	2.6	28.6
D. cinerea	639 ^{a}	896 ^{b}	257	40.2	8.3 ^{a}	12.4 ^{b}	4.1	49.4
F. villosa	669 ^{a}	894 ^{b}	225	33.6	10.0 ^{a}	11.9 ^{b}	1.9	16.0
H. abyssinica	838 ^{a}	900 ^{b}	62	7.4	11.6 ^{a}	12.8 ^{b}	1.2	10.3
P.thorningii	607 ^{a}	838 ^{b}	231	38.1	8.4 ^{a}	11.4 ^{b}	3.0	35.7
Significance of effects								
Treatment	***	***			***	***		
s x PEG	***	***			***	***		

^{a,b}Means with different superscripts along the same rows between non-PEG (- PEG) and PEG treated (+ PEG) for OMD and ME, respectively, for similar species differ significantly (*P<0.05*); **P<0.05*; ***P<0.01*; ****P<0.001*.

Discussion

Chemical composition

High contents of CP of the species' leaves in the current study were consistent to high CP values of browse (100-220 g kg^{-1} DM) reported elsewhere (Le Houérou, 1980; Abdulrazak *et al.,* 2000). The species' leaves could be utilised as CP supplements to ruminants fed on low quality roughages in the tropics which usually have lower CP concentrations (30-50 g kg^{-1} DM) (Leng, 1990) than the minimum CP requirement of 80 g kg^{-1} DM needed for optimal rumen microbial function (Annison and Bryden, 1998). Low contents of fibre of these feeds could be associated with high digestibility of browse fodders. Variations in chemical composition among these species' foliages could be partly explained by genotypic factors that control accumulation of forage nutrients. Accumulation of nutrients in plants is a property of species (Minson, 1990) and varies among species and genera. Differences in CP and fibres among the species could be due to stage of growth and proportion of leaf samples harvested for analysis.

Minerals

Most species had higher levels of Ca, P, Mg and S than most established tropical legumes (9.4, 2.7 and 2.8 g kg^{-1} DM, respectively). All the species except *A. angustissima*, had high levels of S comparable to most plant feeds (1.4-4.0 g kg^{-1} DM) and other protein supplements (Underwood and Suttle, 1999). The feeds had higher concentrations of Ca than tabulated requirements (g Ca kg^{-1} DM) of growing (2.4 - 10.8), pregnant (1.4 - 3.5) and lactating ruminants (2.8 - 5.3) (ARC, 1980; Meschy, 2000). Similarly, the species had higher levels of P than the minimum dietary requirements of ruminants needed for growth (1.1 - 4.8), pregnancy (0.9-2.6) and lactation (2.0 - 3.0 g P kg^{-1} DM), (ARC, 1980; INRA, 1989; NRC, 2001). With exception of *A. nilotica* and *P. thorningii*, all species had higher concentrations of Mg than the normal dietary requirements (g Mg kg^{-1} DM) of growing (0.85 - 1.6), pregnant (0.45 - 2.0) and lactating ruminants (0.65 - 2.2) (Minson, 1990; Underwood and Suttle, 1999). High levels of S of these feeds could be associated with lowered Cu, Mn and selenium (Se) utilisation efficiency due to its antagonistic interactions with micro minerals. For example, S x Cu, and S x Mo and S x Cu x Mo interactions could lead to induced copper-deficiency in ruminants due to reduced Cu utilisation efficiency (Spears, 2003a,b).

High contents of Cu of *A. nilotica*, *A. senegal* and *P. thorningii* were comparable to high concentrations (15-35 mg Cu kg^{-1} DM) of most tropical legumes (Minson, 1990). The rest of species had lower contents of Cu than tropical legumes. Detected high levels of Mo were comparable to the higher range of most forages (0.5-1000 mg Mo kg^{-1} DM) (McDowell, 1992). These feeds had higher levels of Mo than recommended dietary requirements of < 2.0 mg Mo kg^{-1} DM in the diets of ruminants (Meschy, 2000). High levels of Mo of these species could be associated with induced copper-deficiency in ruminants due to the antagonistic interactions between Cu and S (Meschy, 2000; Spears, 2003a,b). The species had higher levels of Cu than lower range of dietary requirements (mg Cu kg^{-1} DM) of growing lambs (4.3 - 17), pregnant ewes (7.0 - 21), lactating ewes (5.8 - 28.4), (ARC, 1980), and goats (8 - 10) (INRA, 1989; Meschy, 2000). The species' foliage supplements would thus provide the minimum dietary requirement of Cu for calves (3.6 - 16.8), pregnant cows (7.5 - 18.0) and lactating cows (4.4-20.8 mg Cu kg^{-1} DM) (Underwood and Suttle, 1999) depending on its availability. All the species contained excessive Fe than requirements of ruminants.

Detected slightly high levels of Mn of *A. polycantha*, *D. cinerea* and *F. villosa* leaves were comparable to the normal range of 85.6 - 94.9 mg Mn kg^{-1} DM of both grass and legume forages (Minson, 1990). The species had higher concentrations of Mn than normal dietary requirements of 20 - 25 mg Mn kg^{-1} DM recommended by the ARC (1980), and were even higher than the recommended dietary requirement of 30 mg Mn kg^{-1} DM of dairy cattle (NRC, 2001). With exception of *A. tortilis* and *P. thorningii*, the rest of species had higher levels of Mn than high estimates of 40 - 50 mg Mn kg^{-1} DM in the diets of ruminants (NRC, 2001; Meschy, 2000).

The contents of Zn of these browse species in the current study were lower than the mean concentration of Zn (36-47 mg kg^{-1} DM) of most forages (Minson, 1990). Except *A. Drepanolobium*, *A. polyacantha* and *H. abyssinica*, rest of the species had higher levels of Co than the recommended dietary requirement of ruminants (0.10-0.11 mg Co kg^{-1} DM), (ARC, 1980; NRC, 2001). However, high concentrations of Co assayed in some feeds, for example, *D. cinerea*, *F. villosa* and *A. senegal* leaves, would be detrimental if fed in large amounts due to cobalt toxicity in ruminants (Meschy, 2000). In addition to Fe, Cu and Mo-toxicity, utilisation of browse foliage supplements in this work would depend on their level of feed ANFs such as phenolics and tannins.

Content of polyphenolics and characterisation of condensed tannins flavonoids

High levels of phenolics and tannins could impair utilisation of CP and mineral supplements from browse supplements by ruminants (Aerts *et al.,* 1999) due to tannin activity through formation of chemical complexes with dietary nutrients, depressed feed intake and digestibility and overall nutrient availability to the animal (Mangan, 1988). Abdulrazak *et al*. (2000) and Rubanza *et al*. (2003) also reported high contents of phenolics and tannins in Acacia and other species' leaves. Differences in levels of TEP and TET among the species could partly be accounted for by differences in genotypic factors that control biosynthesis and accumulation of polyphenolic compounds in plants (Wong, 1973; Haslam, 1998).

High levels of soluble CT in forages have been associated with reduced feed palatability and intake (Muhammed *et al.,* 1994) probably due to precipitation of saliva. High soluble CT fraction of *A. angustissima, A. polyacantha*, *D. cinerea* and *P. thorningii* could thus result in depressed palatability, and intake, of these feeds. Adverse effects due to high proportions of CT bound to protein would be through reduced CP digestibility, mainly by formation of protein-tannin complexes (Aerts *et al.,* 1999). Negative effects of the fibre-bound CT fraction on feed digestibility would be mainly through formation of complexes with dietary carbohydrates (Muhammed *et al.,* 1994). Variable CT fractions among the species could be associated with variable tannin activity among the species, due to the close relationship between proanthocyanidins composition and distribution of CT fractions; tannin stereochemistry (Waterman, 2000), as well as the influence of tannin structure on tannin biological activity (Haslam, 1998). Previous findings (Rubanza *et al.,* 2003) revealed a mixture of flavan-3-ols and flavan-3,4-diols flavonoids in *A. nilotica*, *A. tortilis* and *A. polyacantha* leaves and pods that support this possibility.

Variation in flavonoid classes among browse species in this study could be due to differences in genetic and biochemical processes that control synthesis and accumulation of flavonoids in plant tissues, environmental factors (light intensity, mineral deficiency and moisture stress) and interactions between the environment and genetic factors (Wong, 1973; Haslam, 1998; Aerts *et al.,* 1999). Some important genetically controlled biochemical processes include overall flavonoid production, specific flavonoid synthesis and distribution of flavonoids in different plant tissues (Wong, 1973). Variable levels of pelargonidin, delphinidin and cyanidin flavonoids composition among species' foliages could be associated with tannin reactivity and thus biological activity due to the chemical structure or stereochemistry of the polymerised proanthocyanidins. The detected proanthocyanidins in these species could have different tannin anti-nutritive activity and thus variable biological activity due to their variable flavonoid structure (Haslam, 1998).

Effect of polyethylene glycol treatment on in vitro gas production and OM digestibility

Increase in gas production due to *in vitro* supplementation with PEG in browse leaves in this study shows the negative role of tannin on lowered fermentation and digestibility of the feed organic matter (OM). Therefore, condensed tannins in these species leaves could limit digestibility of browse fodder and thus lower their nutritive potential. Variable responses on the increase in *in vitro* gas production shown by tannin-PEG bioassay among the species could be associated with depressed feed OM digestibility potential probably due to content of tannin and variable tannin anti-nutritive activity among the species' leaves (Aerts *et al.,* 1999)**.** Tannins bind and complex feed proteins and carbohydrates (Mangan, 1988), which result to lowered feed digestibility (Makkar *et al.,* 1995).

Improved gas production and probably OM digestibility of tannin-rich browse could be due to high affinity of PEG to tannins (Makkar and Becker, 1996), and due to its ability to bind and inactivate tannins by forming tannin-PEG complexes (Makkar *et al.,* 1995) and the release of feed nutrients, for example, protein, from tannin-protein complexes (Getachew *et al.,* 2000). Improved *in vitro* gas production in the current study concur to findings reported elsewhere (Makkar and Becker, 1996; Rubanza *et al.,* 2003) in different browse fodder species.

Higher responses on the increase in gas production due fermentation of some species, for example, *A. angustissima*, *A. polyacantha* and *D. cinerea* with PEG than other species suggests different tannin anti-nutritive activity among browse species' leaves (Aerts *et al.,* 1999). Results on variable improved gas production between browse species' leaves due to addition of PEG were consistent to previous findings reported earlier (Rubanza *et al.,* 2003) in *A. nilotica*, *A. polyacantha*, *A. tortilis* and *D. cinerea* leaves and pods. Low digestibility of *A. angustissima*, *A. polyacantha*, *D. cinerea* and even *P. thorningii* could also be attributed to their high proportions of free CT, protein-bound CT and fibre-bound CT fractions due to their effects on depressed protein and fibre digestibility (Muhammed *et al.,* 1994); and probably due to their toxic effects reported on rumen microbes fed on *A. angustissima* (Odenyo *et al.,* 1997). Variable *in vitro* gas production potential and thus their digestibility among the species could also be partly explained by type of fibre and extent of fibre lignifications. Low gas production and probably low digestibility of *A. angustissima*, *A. polyacantha*, D. *cinerea* and *P. thorningii* compared to the rest of the species could also be partly accounted for by their relatively high lignin contents.

Conclusion

Browse species in this study could form good sources of protein and mineral supplements to ruminants due to their high contents of CP and minerals. These feeds contained higher levels of Ca, P, Mg and S than their recommended dietary requirements in ruminants. The feeds had moderate to high levels of Cu, Mn and Co which could suffice the minimum requirements of the respective elements in the diets of ruminants. However, the species had high levels of Mo and Fe in excess of requirements that could be non-beneficial. Utilisation of the species' foliages supplements in ruminant feeding would depend on their rate of inclusion in the diets due to their high contents of phenolics and tannins. The species' leaves had higher contents of phenolic and tannin ANFs than the lower beneficial level of tannin (50 mg g^{-1} DM) in ruminant diets. High proportion of total CT was bound to protein compared to soluble CT and fibre-bound CT fractions. The species' leaves contained detectable proanthocyanidins that constituted flavan-3-ols and flavan-3,4-diols that elucidate variable flavonoids' stereochemistry among species. Improved *in vitro* gas production due to fermentation of the species' leaves with PEG were mainly due to the deactivation and reversed tannin anti-nutritive activity by PEG binding tannins; and the release of feed nutrients bound by tannins. Further studies are needed to investigate effect of PEG and PEG analogies supplementation on effects of tannins *in vivo* in ruminants fed on tannin-rich browse foliages, and effect of browse foliages supplementation on animal productivity.

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13. EFFECTS OF *ACACIA NILOTICA*, *A. POLYACANTHA* AND *LEUCAENA LEUCOCEPHALA* LEAF MEAL SUPPLEMENTATION ON GROWTH PERFORMANCE OF SMALL EAST AFRICAN GOATS FED ON NATIVE PASTURE HAY BASAL FORAGES IN WESTERN TANZANIA

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Abstract

Browse tree foliages represent cheap nitrogen (N) or crude protein (CP) supplements for ruminant livestock in the tropics although their optimal utilisation is limited by scanty available information on their feed nutritive potential. Two studies were conducted to 1.) determine rate and extent of ruminal dry matter (DM) degradability (DMD), and 2.) investigate effect of sun-dried *Acacia nilotica* (NLM), *A. polyacantha* (PLM) and *Leucaena leucocephala* leaf meal (LLM) supplementation on growth performance of 20 growing Small East African male goats (randomised into four treatment groups) fed on native pasture hay (NPH) basal diet for 84 d in Meatu district. Three supplement diets: 115.3 g NLM (T_2), 125.9 g PLM (T_3), and 124.1 g LLM (T_4), which was used as a positive control, were supplemented to the three animal groups fed on NPH (basal diet) compared to the animals in a control group that were fed on NPH without browse supplementation (T_1). NLM, PLM and LLM had ($P<0.05$) higher CP (159, 195 and 187 g kg^{-1} DM, respectively) than NPH (45.5 g kg^{-1} DM). NPH had lower ruminal DM degradability characteristics and ME ($P<0.05$) than NLM, PLM and LLM. Supplementation of the animals with browse resulted to ($P<0.05$) higher average daily weight gains (ADG) of 157.1 g d^{-1} in T_4 than the animals fed on T_2 (114.3 g d^{-1}) and T_3 (42.9 g d^{-1}), and even to those fed on T_1 (control), which lost weight (-71.4 g d^{-1}). Improved weight gains were mainly due to corrected feed N or CP due to supplementation of the animals with browse fodder. Higher ADG due to LLM (T_4) and NLM (T_2) supplementation suggest optimised weight gains due to browse supplementation; while lower weight gains of the animals on PLM (T_3) indicate the possible utilisation of *A. polyacantha* leaves to overcome weight losses especially during dry seasons.

Introduction

Browse tree foliages (*i.e.*, leaves, twigs, pods and pod fruits), soft tender stems, and barks represent cheap and affordable crude protein (CP) supplements for ruminants fed on low quality basal roughages such as hays, stover and straws in the traditional livestock sector in the tropics including Tanzania. Livestock production during dry seasons in semi-arid areas of central and north-western Tanzania is limited by both low biomass productivity (1.5 - 2.5 tonnes dry matter (DM) ha^{-1}) and crude protein (CP), (30-50 g kg^{-1} DM) of deferred feed (Rubanza *et al.,* 2005a). Less has been reported on utilisation of indigenous browse fodder supplements such as Acacias compared to exotic species, *e.g.*, *Gliricidia* spp., *Sesbania* spp. and *Leucaena leucocephala*, which have been used as CP supplements extensively in the tropics (Gutteridge and Shelton, 1994). Previous studies on utilisation of dried *L. leucocephala* leaves supplements in Tanzania showed increased milk yield in dairy cattle (Kakengi *et al.,* 2001), and improved growth rates of beef steers (Rubanza *et al.,* 2005a). However, sustainable utilisation of browse supplements from the promising *L. leucocephala* is limited by psyllid insect (*Heteropsylla cubana*) threat on the foliages, which suggests a search for an alternative indigenous browse feed resources. However, information from the literature on utilisation of indigenous browse fodder species such as *Acacia* spp. as fodder supplements in ruminant feeding in many areas of sub-Saharan Africa is scanty.

Optimal utilisation of browse fodder supplements to ruminants as resource feed in agroforestry based systems could be limited by presence of high levels of feed anti-nutritional factors (ANFs) such as phenolics and tannins reported in some *Acacia* spp. and other browse species leaves grown in semi-arid areas of Tanzania (Rubanza *et al.,* 2003; Rubanza *et al.,* 2005b); in other parts of East Africa (Abdulrazak *et al.,* 2000) and south African region (Mlambo *et al.,* 2004). Phenolics and tannins lower feed digestibility (Mangan, 1988) and nutrient utilisation in ruminants (Aerts *et al.,* 1999). Utilisation of browse foliage supplements could also be limited by presence of other toxic compounds such as cyanogenic glycosides (Kumar and Vaithyanathan, 1990), or even non-protein amino acids such as 2,4-diaminobutanoic acid (DABA) and 4-N-acetyl-2,4-diaminobutyric acid (ADABA) reported in *A. angustissima* (McKie *et al.,* 2004), which together act as feed ANFs. There are also evidences that suggest presence of toxic compounds in browse foliages, for example the *A. angustissima* toxicity reported on rumen microbes *in vitro* (Osuji and Odenyo, 1997), or even death of sheep fed on the dried foliages without prior exposure (Odenyo *et al.,* 1997). There is also a lack of knowledge on the nutritive potential of other browse foliage species and even within the genus *Acacia*.

A study was therefore conducted to assess nutritive potential of sun-dried *Acacia nilotica* and *A. polyacantha* leaf meals (LM) through chemical composition, contents of phenolics and tannins, *in sacco* ruminal dry matter degradability (DMD) compared to *L. leucocephala*; and (2) to investigate effect of *A. nilotica* (NLM) and *A. polyacantha* (PLM) and *L. leucocephala* leaf meal (LLM) supplementation on growth performance of growing Small East African goats fed on native pasture hay (NPH) basal diet in the dry season in Tanzania.

Materials and Methods

Study site

This study was conducted at Meatu district ICRAF research sub-station (3 - 4^o S; 34 - 35^o E), a semi-arid area located at 1000 - 1500 m above sea level in north-western Tanzania. Meatu district receives 600 - 800 mm rainfall per annum. Minimum and maximum temperatures vary from 16.1 to 33.5^o C, respectively. Vegetation includes short grasses and scattered trees and shrubs.

Feeds and treatment diets

Treatment diets consisted of native pasture hay (NPH), 100 g maize bran and 30 g minerals as a basal ration fed alone (T_1), and NPH fed with three browses: *A. nilotica* (NLM), (T_2); *A. polyacantha* (PLM), (T_3) and *L. leucocephala* leaf meals (LLM), (T_4), as supplements. Browses were provided to each animal in individual (separate from NPH) feed troughs. The quantities of browse supplements offered were estimated based on 20% of the expected DM intake (DMI), *i.e*., 3% liveweight. These levels were adopted based on optimised weight gains in ruminants with 20% DMI supplementation with dried *L. leucocephala* leaves (Rubanza *et al.,* 2005a), and assumed sufficient to optimise weight gains under traditional livestock management system. All browse supplements were computed in excess (15 %) of expected intake**.** Minerals and MB were mixed thoroughly and fed in separate feed troughs from basal and browse supplements.

Preparation of basal feed and browse supplements

Standing hay (NPH) was harvested during the start of dry season in June 2003 by cutting the herbage at about 5 cm above the ground using hand cycles, and baled manually in wooden boxes. Browse leaves and soft twigs (< 5 mm diameter) used for supplementation in the growth performance study were harvested by cutting selectively small tree branches from *A. nilotica* and *A. polyacantha* (Acacias) grown in preserved grazing lands in Mwanhuzi ward in Meatu District of Tanzania towards the end of rainy season in May 2003. *L. leucocephala* leaves were harvested by hand plucking from fodder agronomic performance trial plots in Meatu HASHI/ICRAF research sub-station and processed into leaf meal (LLM) by simple manual defoliation and clashing while removing small branches, stalks and hard twigs.

Experimental design and treatment diets

Treatment diets were arranged in a Complete Randomised Design (CRD) experiment in four groups with five goats in each group. The four treatments were then randomly allocated to the four groups. The treatments were NPH fed without browse supplementation, which was used as a negative control (T_1); and 115.3 g NLM (T_2), 125.9 g PLM (T_3) and 124.1 g LLM (T_4) supplemented to goats fed on NPH (*i.e*., basal diet) in the rest of the three treatment groups. Representative basal and browse supplement samples were collected daily for estimation of the respective treatment DMI, degradability study and for latter chemical composition analyses.

Feeds and sampling

A representative sample, (50 g in duplicate), of daily feed offers and refusals were collected separately once daily for basal diet, and twice a day for NLM, PLM and LLM from similar batches of feeds that were offered to the animals in T_2, T_3 and T_4, respectively. The representative quantities (DM) of each treatment's daily offer and refusal samples were weighed for fresh weight and oven-dried at 60°C for 48 h to constant weight, and later bulked on weekly basis. The respective NPH, NLM, PLM and LLM samples were then later thoroughly mixed between offers and refusals by treatment groups, and further sub-sampled into two-200 g representative bulk samples, which were analysed in duplicates for DM and chemical composition. Therefore, presented results on chemical composition represent means of the two samples analysed in duplicates to make a total of four replicates each. Chemical composition of the feeds that were used in the growth performance trial is shown in Table 1.

Chemical analyses

Chemical analyses were conducted in duplicate. Ash content was determined by ignition of the feeds in a muffle furnace at 550°C for 3 h (AOAC, 1990; method ID 942.05). The CP was determined by the Kjeldahl method (AOAC, 1990; ID 954.01). Ash-free neutral detergent fibre (NDF), ash-free acid detergent fibre (ADF) and acid detergent lignin (ADL) were determined using methods described by Van Soest *et al.* (1991) without addition of sodium sulphite and α-amylase.

Phenolic and tannin assays

Approximately 200 mg (DM) of finely ground (1.0 mm sieve) sample was extracted in 10 ml of aqueous acetone (7:3, v/v) in a water bath, maintained at 40°C, and rotating at 130 cycles for 90 min. (Makkar, 2000). The supernatants were carefully transferred into 10 ml centrifuge tubes and centrifuged at 1670 *x g* (4°C) for 20 min. The aqueous aliquots were assayed for total extractable phenolics (TEP), total extractable tannins (TET) using Folin-Ciocalteau's reagent based on tannic acid standard as described by Jolkumen-Tiito (1985) and Makkar (2000). Content of TET was estimated gravimetrically as the difference of phenolics remaining from total phenolics after binding tannins with polyvinyl polypyrrolidone (PVP) according to Makkar *et al*. (1993). The concentrations of TEP and TET were expressed as tannic acid equivalent. The total condensed tannin (TCT) or total proanthocyanidins were assayed according to Porter *et al*. (1986) using *n*-butanol/HCl (95:5 v/v) and ferric (Fe^{3+}) reagents. The concentrations of TCT were expressed as leucocyanidin equivalent.

In sacco ruminal dry matter degradability (DMD)

Animals and management

Degradability of the treatment diets used in the supplementation study were determined by *in situ* incubation of an approximately 2.5 g DM samples in triplicates with each sample incubated in each of the three healthy mature fistulated Japanese Colliedale female sheep using the nylon bag (*in sacco)* technique (Ørskov and McDonald, 1979). The animals were fed daily a ration of 800 g timothy hay and 200 g concentrates divided into two equal meals at 8:00 and 16:00 h daily. The sheep were supplemented with minerals and had free access to water throughout the experiment.

The DM disappearances from rumen incubated nylon bags were determined according to Ørskov and McDonald (1979). DM degradability curves were fitted based on McDonald's (1981) mathematical model: $P = A + B (1 - e^{-ct})$. Where P is the potential disappearance of DM at time, t; A is the rapidly soluble feed fraction; B is the slowly degradable feed fraction; A+B is potential degradability, and c is the rate of DM degradation. Degradability constants A; B and c, were computed using the NAWAY computer program (The Rowett Research Institute, Aberdeen, Scotland). Metabolisable energy (ME) contents of the treatment diets were estimated according to the formulae (MAFF, 1975):

$$\text{ME (MJ kg}^{-1}\text{)} = 0.15 \text{ or } 0.16 \text{ DOMD \%; and DOMD \%} = 0.98\text{DMD \%} - 4.8 ,$$

Where DOMD % is digestible organic matter in DM; and DMD (g kg^{-1} DM) is the 48 h DM degradability (adopted following its high correlation to *in vivo* digestibility coefficient (Chenost *et al.,* 1970). Coefficients 0.15 and 0.16 were used to correct ME for the basal diet (*i.e.*, NPH), and browse supplements (NLM, PLM and LLM), respectively.

Growth performance trial

Effects of NLM, PLM and LLM supplementation on growth performance was assessed in Small East African goats stall fed on NPH basal diet at Meatu HASHI/ICRAF sub-station in north-western Tanzania. A total of 20 male Small East African growing goats (9-12 months old), weighing 14.4-14.8 kg (mean 14.6±0.68 kg SE), were used in a 84 d growth performance trial in July-October (dry season) 2003. The goats were ear-tagged for identification purposes. The experiment was preceded by a two-week preliminary period to acustom the animals to the premises, treatment diets and experimental procedures. The animals were kept indoors in slatted floor in individual pens throughout the experimental duration. The animals were fed in individual feed troughs. The animals were dewormed by Milsan® broad-spectrum anthelmintic three months prior the experiment to control internal parasites. The animals were also sprayed twice weekly with Steladone® acaricide to control ticks and other external parasites. The goats were stall fed on NPH (basal diet) and NLM, PLM and LLM browse supplements.

Effect of browse supplementation on growth performance

The goats were weighed on weekly intervals early in the morning at 07:00 h before had any access to feeds or water. To achieve for restricted feeding, all the feed and water troughs were withdrawn from the animal pens a midnight preceding weighing day. The animals were weighed using a sensitive balance (± 0.01 kg) three days consecutively both at the beginning of the experiment and at the termination of the experiment; and were weighed weekly throughout the 84 d experimental period. Initial and final liveweight changes were computed as the average of liveweights during the three days at the start and termination of the experiment, respectively. The body weights for each animal were recorded against each animal in the four treatment groups.

Animal feeding

The NPH (basal diet) was offered *ad libitum* (*i.e.*, 20% refusals), and was recorded for daily offers and refusals. NLM, PLM and LLM supplements were offered at half rations twice daily at 08:00 and 16:00 h for morning and evening meals, respectively, and were recorded separately from the basal diet. The amounts of supplements were adjusted weekly based on animals' weekly liveweight changes. Goats in T_1 were fed on NPH without browse supplementation (*i.e.*, control). The daily DMI for basal diet and browse supplements were estimated from the difference of daily quantity of feed refusals from the quantity of feed offered, and were all expressed as DM.

Statistical analysis

Data on chemical composition and DMD characteristics were subjected to the General Linear Model (GLM) procedure of SAS/Statview (1999) statistical package based on the statistical model; $Y_{ij} = \mu_i + T_i + e_i$, where Y_{ij} is the general response of the specific parameter under investigation, μ_i is the general

mean peculiar to each observation, T_i is the i^{th} effect of the dietary treatment on the observed parameters, and e_i is the random error term for each estimate.
Analysis of variance (ANOVA) on liveweight gains were conducted by subjecting weekly weight changes to the GLM procedure of SAS/Statview (1999) based on statistical model:

$$\text{Liveweight gain, kg d}^{-1}, (Y_j) = \mu_i + T_i + b(x_i\text{-}x)_{ij} + e_i,$$

where μ_i is general mean, T_i is the effect of i^{th} treatment diet on growth performance parameters. The $b(x_i\text{-}x)_{ij}$ term represents a covariate factor for adjustment of liveweight changes from initial body weight of the goats, and e_i is the random error term. All treatment means were compared by least square difference (LSD).

Results

Chemical composition

Chemical composition of treatment diets are presented in Table 1. Crude ash varied among the treatment diets from 63.3 to 120.3 g kg^{-1} DM in NLMM and LLM respectively. As was expected, browse supplements had higher *(P<0.05)* levels of CP of 159, 195 and 187 g kg^{-1} DM for NLM, PLM and LLM, respectively, than NPH. NPH had higher (*P<0.05*) NDF, ADF and ADL than browses. Contents of polyphenolics of browses are also shown in Table 1. NLM had the higher (*P<0.05*) levels of TEP and TET, and relatively lower TCT than *A. polyacantha*. LLM had the lowest contents of polyphenolics.

Feed degradability characteristics

DM degradability characteristics of the feeds are shown in Figure 1 and Table 2. The feeds had variable DM degradability pattern (Figure 1). NLM was degraded faster than the rest of treatment diets.

Table 1. Chemical composition (g kg^{-1} DM) of feeds used in growth performance experiment

	MB	NPH	NLM	PLM	LLM
Ash	54.1^{a}	70.8^{b}	63.3^{ab}	111^{c}	120.3^{c}
CP	12.2^{a}	45.5^{b}	159^{c}	195^{d}	187^{d}
NDF		702^{a}	189^{b}	448^{c}	264^{d}
ADF		528^{a}	95^{b}	225^{c}	158^{d}
ADL		111.7^{a}	52.2^{b}	121.5^{c}	80.7^{d}
TEP†	n.a	n.a	281^{a}	104^{b}	6.7^{c}
TET‡	n.a	n.a	256^{a}	93^{b}	5.1^{c}
TCT§	n.a	n.a	52.8^{a}	98.3^{b}	2.3^{c}

^{a,b,c,d} Means with different superscripts along the same rows differ significantly (*P<0.05*); †TEP, total extractable phenolics; ‡ TET, total extractable tannins; § TCT, total condensed tannins; n.a TEP, TET and TCT not assayed; MB, maize bran; NPH, native pasture hay; NLM, *A. nilotica* leaf meal; PLM, *A. polyacantha* leaf meal; LLM, *Leucaena leucocephapla* leaf meal.

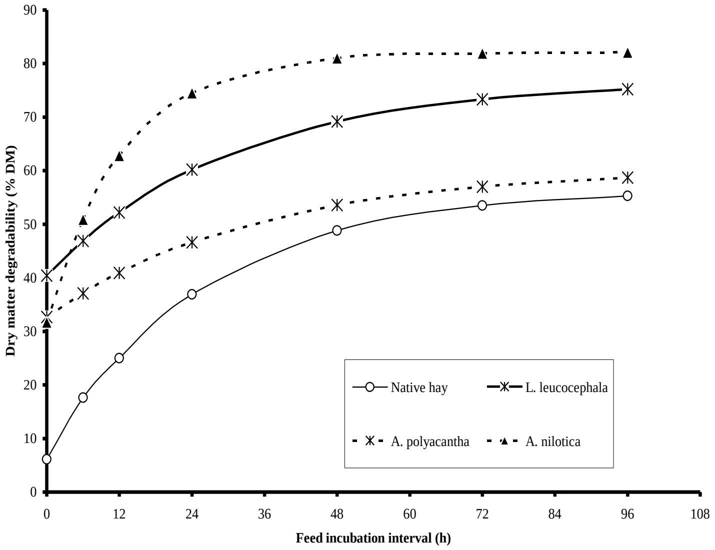

Figure 1. DM degradability characteristics of feeds used in the growth performance trial

Table 2. Dry matter degradability (DMD) characteristics of feeds used in the growth performance study

Degradability characteristics	Native hay (Basal, T_1)	NLM (T_2)	PLM (T_3)	LLM (T_4)	Effect of treatment
A (g kg^{-1} DM)	6.1^{a}	317^{b}	327^{b}	404^{c}	***
B (g kg^{-1} DM)	504^{a}	502^{a}	277^{b}	363^{c}	***
(A+B), (g kg^{-1} DM)	565^{a}	821^{b}	604^{c}	767^{d}	***
48 DMD (g kg^{-1} DM)	488^{a}	810^{b}	536^{c}	692^{d}	**
c (DM Fractions h^{-1})	0.039^{a}	0.080^{b}	0.029^{c}	0.033^{c}	***
ED (g kg^{-1} DM)	289^{a}	548^{b}	429^{c}	636^{d}	***
ME (MJ kg^{-1} DM)	6.3^{a}	11.9^{b}	7.6^{c}	10.1^{d}	**

^{a,b,c,d} Means with different superscripts along the same row differ significantly (*P<0.05*); A is the immediately soluble feed fraction; B is the slowly degradable feed time; (A+B) is potential feed degradability; C is the feed DM degradation constant; ED is effective degradability; ** *P<0.01*; *** *P<0.001*; MB, maize bran; NPH, native pasture hay; NLM, *A. nilotica* leaf meal; PLM, *A. polyacantha* leaf meal; LLM, *Leucaena leucocephapla* leaf meal.

M and PLM. The slowly degradable feed fraction B varied among the treatment diets (*P<0.05*) from 277 (PLM) to 504 g kg^{-1} DM in NPH, which was also not different (*P>0.05*) from NLM. Potential degradability (A+B) varied among the feeds (*P<0.05*) from 565 (NPH) to 821g kg^{-1} DM (NLM). LLM had higher (A+B) value than those of NPH and PLM. PLM showed the lowest (*P<0.05*) degradation rate constant (C) compared to NLM, which had the highest rate constant. There was no difference (*P>0.05*) in C between PLM and LLM. NLM had the highest effective degradability (ED), compared NPH, PLM and LLM. ME content of feeds used in the growth performance study varied among the treatment diets (*P<0.05*) from 6.3 (NPH) to 11.9 MJ kg^{-1} DM in NLM.

Effect of browse supplementation on dry matter intake and growth performance

Supplementation of the animals with sun-dried browse leaves in T_2, T_3 and T_4 resulted to higher (*P<0.05*) total DMI than the control animals on T_1 (Table 3). Animals supplemented with browse (T_2, T_3 and T_4) had higher total DMI per metabolic weight (DMI/$W^{0.75}$) than those on T_1. PLM (T_3) and LLM (T_4) supplements were consumed in slightly higher quantities than PLM (T_2). Animals on T_4 consumed slightly more NPH (basal diet) than those on T_1, T_2 or T_3. Supplementation of the goats with browse foliages resulted to (*P<0.05*) higher weight gains in T_2, T_3 and T_4 than the control group T_1 fed on NPH without supplementation (Table 3). Animals supplemented with LLM (T_4) had higher (*P<0.05*) average daily weight gains (ADG) of 157.1 g d^{-1} than those on T_2 and T_3, which showed (P<0.05) lowest ADG. Animals in the control group (T_1) lost weight (-71.4 g d^{-1}).

Table 3. Effect of browse leaves supplementation on DMI and growth performance in goats

Parameter	Control (T_1)	NLM (T_2)	PLM (T_3)	LLM (T_4)
Animals	5	5	5	5
Basal DMI (g)	284.7 [a]	276.5 [a]	276.5 [a]	299.8 [b]
Browse supplement DMI (g)	0 [a]	115.3 [b]	125.9 [c]	124.1[c]
Maize bran DMI (g)	75.2[a]	75.3[a]	75.3[a]	75.3[a]
Total DMI (g)	359.9	467.1	477.7	499.2
Average initial body weight (kg)	14.4 [a]	14.4 [a]	14.7 [a]	14.8[a]
Average final body weight (kg)	13.9 [a]	15.2 [b]	15.0 [b]	15.9 [c]
Average weekly liveweight change (kg)	- 0.50 [a]	0.80 [b]	0.30 [c]	1.10 [d]
Average daily weight gain (ADG, g d^{-1})	- 71.4 [a]	114.3 [b]	42.9 [c]	157.1[d]

[a,b,c,d] Means with different superscripts along same rows differ significantly *($P<0.05$)*.

Discussion

Chemical composition

Higher levels of CP in browse supplements compared to NPH were consistent with reported higher CP levels CP of *A. nilotica* (140 - 150 g kg^{-1} DM) and *A. polyacantha* (180 - 190 g kg^{-1} DM) (Abdulrazak *et al.,* 2000; Rubanza *et al.,* 2003). Also, Kakengi *et al*. (2001) and Rubanza *et al*. (2005a) similarly reported high levels of CP of *L. leucocephala* leaf meal in these semi-arid areas of Tanzania. The relatively low values of fibre (NDF, ADF and ADL) of NLM were consistent to the reported low contents of NDF, ADF and ADL of *A. nilotica* leaves (Rubanza *et al.,* 2003). Higher contents of NDF, ADF and ADL of *A. polyacantha* could be associated with its low *in vitro* digestibility reported elsewhere (Rubanza *et al.,* 2003; Rubanza *et al.,* 2005b).

NLM and PLM contained higher levels of polyphenolics than the levels that are considered beneficial (50 gkg^{-1}) in ruminants (Mangan, 1988), which could be associated with lowered feed digestion and utilisation of feed nutrients in the animal through formation of chemical complexes with dietary carbohydrates, proteins and vitamins. High levels of phenolics and tannins of *A. nilotica* and *A. polyacantha* noted in the current work were comparable to those reported by Abdulrazak *et al.* (2000) and Rubanza *et al*. (2005b) of similar species leaves. The noted high levels of phenolic and tannin ANFs in these *Acacia* spp. foliages could offset their high CP potential due to the adverse effects of tannins on lowered feed digestibility (Mangan, 1988). Tannins bind and form complexes with feed protein and carbohydrates, reduce feed digestibility and supply of nutrients to the animal. However, the adverse effects of tannin on impaired feed digestibility and utilisation of nutrients in animals in vivo in addition to levels of tannin in the diet would depend on tannin structure and chemical nature and the nature of tannin anti-nutritive activity. Low levels of tannin in *L. leucocephala* foliages could be beneficial by promoting by-pass protein and flow of nutrients to the lower intestines (Aerts *et al.,* 1999), and probably due to its post-ruminal ability to release protein from prior formed protein-tannin complexes (McNeill *et al.,* 1998).

Degradability characteristics

The A value denotes the rapidly degradable feed fraction. The B fraction denotes slowly degradable feed fraction but fermentable with time. The (A+B) constants indicate feed degradability potential, while c denotes feed degradation rate constant. High degradability of NLM and LLM were consistent to higher *in vitro* digestibility of *A. nilotica* and *L. leucocephala* reported by Rubanza *et al*. (2003) and high *in sacco* degradability of *L. leucocephala* compared to hay (Rubanza *et al.,* 2005b) in the same study area. Findings on relatively low DMD of PLM concur to the reported low *in vitro* OM degradability of *A. polyacantha* (Rubanza *et al.,* 2003), probably due to either its high lignin content or its level and nature of tannin. High rate of DMD of NLM especially during early incubations (Figure 1) could represent ruminal N loss as ammonia compared to the proportion absorbed in the lower intestines and thus available to the animal. The reported findings of high DM degradability of *A. nilotica* leaves is comparable to its previously reported both high extent and rate of *in vitro* OM degradability (Rubanza *et al.,* 2003; Rubanza *et al.,* 2005b). The noted low DMD of NPH supports the low nutritive potential of most low quality roughages such as hays.

Effect of supplementation on and DM intake (DMI) and growth performance

Observed higher total DMI in animals on T_2, T_3 and T_4 were mainly due to browse fodder supplements. Relatively higher DMI of the basal diet of the animals on T_4 than those in the rest of the treatment groups could be associated with high digestibility of protein in *L. leucocephala* leaf meal. Feeding NPH (basal diet) without supplementation with protein sources could be reflected through reduced feed digestibility due to their lower CP content (45 g kg^{-1} DM) than the normal CP requirements of 80 gkg^{-1} DM for optimal rumen microbial function (Annison and Bryden, 1998).

Higher weight gains of goats due to LLM supplementation in T_4 could be partly explained by high content of CP (180-220 g kg^{-1} DM) of *L. leucocephala* and its good protein quality; high digestibility potential and high utilisation efficiency in ruminants (Jones, 1994). High weight gains due to NLM supplementation in T_2 could be explained in part by reported high CP content (130 - 150 g kg^{-1} DM), and the previously reported high *in vitro* digestibility of *A. nilotica* (Rubanza *et al.,* 2003). Lower weight gains of animals supplemented with PLM in T_3 (vs. T_2 and T_4), could be associated with low ruminal degradability, and low *in vitro* digestibility characteristics of *A. polyacantha* noted elsewhere (Rubanza *et al.,* 2003; Rubanza *et al.,* 2005b), probably due to its high lignin and polyphenolics. Loss in weight of animals fed on NPH without browse supplementation in T_1 could be probably due to low digestibility of the basal diet following their low CP contents and high fibre fractions (Table 1). Limitation of low dietary CP on animal performance would first be reflected through reduced microbial activity in the rumen, and thus reduced feed digestibility (Annison and Bryden, 1998), that could be associated with low nutrient supply to the animals.

Higher weight gains of animals supplemented with NLM (T_2) and LLM (T_4) were consistent to previous report on improved weight gains of steers supplemented with LLM (Rubanza *et al.,* 2005a) in the same study area. Higher weight gains of goats supplemented with NLM than those supplemented with PLM could be due to less adverse effects of tannin in *A. nilotica* compared to *A. polyacantha*, probably due to their variable nature of tannin and anti-nutritive activity on feed digestibility (Aerts *et al.,* 1999) and nutrients' utilisation efficiency *in vivo*.

Loss in weight of the animals in the control group (T_1) could be mostly explained by low CP and high contents of fibres (NDF, ADF and ADL) of NPH due to their influence on reduced feed digestibility and nutrients supply to the animals. Low content of CP of NPH probably could not meet the normal CP requirement of 80 g kg^{-1} DM for optimal rumen microbial function (Annison and Bryden, 1998), which could be associated with the observed loss in weight of the animals in T_1. The current findings on loss in weight of non-supplemented animal group represent poor animal performances in the traditional livestock sector during dry seasons due to fodder scarcity in these semi-arid areas of Tanzania.

Conclusions

Supplementation of the animals with browse tree leaves resulted to improved weight gains with higher ($P<0.05$) weight gains of animals fed on *L. leucocephala* (T_4) than those supplemented with *A. nilotica* (T_2) and *A. polyacantha* (T_3), compared to the control group (T_1), which lost weight. Improved weight gains were mainly due the corrected dietary CP in the basal diet from browse supplements and probably due to improved feed digestibility and nutrients supply to the animals. Supplementation of animals with *A. nilotica* and *L. leucocephala* leaves at 20% of the expected DMI optimised weight gains. Supplementation of goats with *A. polyacantha* sustained minimal weight gains and was able to overcome weight losses during the critical fodder scarcity in the dry season. Further studies need be conducted to determine supplementation levels that would optimise animal productivity (growth, meat, and milk and draft power) in ruminants using indigenous browse fodder species such as *Acacia* spp. foliages.

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14. EFFECT OF COCONUT CANOPY RADIUS ON DRY MATTER YIELD AND QUALITY OF PASTURE SPECIES

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Abstract

Four pasture species were established in Chambezi coconut plantation in Bagamoyo District between March 2002 and July 2003 to assess dry matter yield, chemical composition and dry matter degradation. The pastures were established at 0 – 50, 50 – 100% coconut canopy radius (CR) and in open area and harvested at flowering stage using 0.25 m quadrat. The harvested pastures were oven dried at 65^o C for 48 hours. Dry matter yield (DMY), chemical composition and dry matter degradability (DMD) were determined using standard methods. *Brachiaria ruziziensis* and *Macroptilium atropurpureum* were found to produce more DMY (7.29 – 8.28 and 6.5 - 8.14 t ha^{-1}, respectively) followed by *Digitaria mombasana* (3.05 – 7.68 t ha^{-1}) and *Panicum trichocladum* (1.03 – 1.49 t ha^{-1}). Except for *D. mombasana*, the DMY of other pastures were not reduced (P>0.05) by the CR. The crude protein (% DM) ranged from 5.36 – 6.61 for *D. mombasana* to 12.5 – 13.6 for *M. atropurpureum.* With exception of *M. atropurpureum,* the crude protein in other pasture species was higher (P<0.05) under coconut canopy than in open area. The DMD was highest in *M. atropurpureum* (66.35%) and lowest in *P. trichocladum* (42.0%). Among the grasses, *Brachiaria ruziziensis* had highest DMD and higher (P<0.05) DMD under the coconut canopy than in open area. The overall mineral contents of the pastures were 0.452 Ca, 0.176 P and 0.791 K and they were higher (P<0.05) under the coconut canopy than in open area. Basing on the findings from this study, *M. atropurpureum* and *B. ruziziensis* are recommended for integration in the coconut plantations.

Introduction

The plantation crop system with the greatest potential for further development is the integration of livestock (cattle, goats and sheep) with coconut (*Cocos nucifera* family Arecaceae). The benefits of integrating livestock in coconut plantations include increased and diversified income and higher plantation crop yield through better weed control and nutrient recycling. However, the successful integration of livestock in coconut plantations depends on the quality of pastures found. Light intensity available under the coconut canopies vary from 10 – 80% of full sunlight (Nelliat *et al.,* 1974). Low light intensity depresses dry matter yield of most tropical forages (Wong, 1991; Congdon and Addison, 2003). However, shade tolerant grasses show little yield depression or even increase in yield under moderate shade (Wong, 1991). Shade decreases plant soluble carbohydrate level with an accompanying increase in cell wall contents and decrease in cell dry matter digestibility (Samarakoon, 1987). However, in studies by Wong (1989) and Norton *et al*. (1991), shade had no effect on dry matter digestibility of some pastures (*Macroptilium atropurpureum* and *Panicum maximum)* and therefore led to the conclusion that shade may have variable effects on cell wall content and composition, lignin and *in-vitro* dry matter digestibility of pastures. The effect of shade on crude protein content of pastures is much clearer. In most studies shade increased the crude protein content of grasses where nitrogen is a limiting factor and decreased the crude protein content of legumes (Reynolds, 1995). Mineral content of forages tend to be higher under shade than in full sunlight (Belsky, 1992) but in tropical grasses (Norton *et al.,* 1991) and legumes (Congdon and Addison, 2003) there has been a small and inconsistent effect of shade on P content in the forage species. Livestock feeding on low quality pastures will mostly end up with low productivity. This study aim at finding out the best pasture species for introduction in coconut plantations.

Materials and Methods

This experiment was conducted at Chambezi Experimental Station in Bagamoyo District (Latitude $6^0$40` S, Longitude $38^0$40` E) in the costal belt of Tanzania. Coconut trees at the experimental site were 22 years old with pure stands of 'East African Tall' variety planted at 9 x 9 m spacing. Three representative coconut trees (as replications) with 64.44% light intensity along 50 - 100% coconut canopy radius (CR) and 57.55% light intensity along the coconut tree to 50% CR (0 – 50%) were selected for pasture establishment. Coconut canopy radius was measured by a tape measure from the coconut stem to the end of coconut canopy (determined by radial extension of the mature coconut leaf). A control area in open area (30 m outside the plantation) was also selected for pasture establishment making a total of 3 main plots. In the main plots, four sub plots of 1 x 2 m were developed using hand hoe. Farmyard manure at a rate of 13 tons DM ha^{-1} and phosphorus in the form of Triple Super Phosphate fertilizer (20% P) at a rate of 30 kg ha^{-1} P were applied to each sub plot. In the developed sub plots, *Brachiaria ruziziensis, Digitaria mombasana, Panicum trichocladum* and *Macroptilium atropurpureum* were planted on March 6, 2002. Grasses were established using young actively growing tillers and *Macroptilium atropurpureum* legume was established by seeds. The planting space was 10 x 10 cm. Five weeks after planting the grasses were cut at 5 cm and *M. atropurpureum* at 10 cm height from the ground to allow even re-growths.

Dry matter yield (DMY) estimation was done on 5th July 2002 (end of rain season), on 22nd December 2002 (during the short rains), on 16 March 2003 (the beginning of long rain season) and on 5th July (the end of rain season). A quadrat of 0.25 m^2 was placed randomly in the sub plots and forages within the quadrat were cut using a sickle and weighed. The representative samples were kept separately in labelled paper bags, oven dried at 65^0C for 48h and weighed. The samples for determination of in-*sacco* dry matter degradation were ground using a Christy Norris hammer mill with 3 mm sieve and those for chemical analysis were ground and sieved through 1 mm sieve. The ground samples of respective pasture species for year 2002 and 2003 were bulked and sub sampled and analyzed for dry matter content at 105^oC, ash, crude protein (CP), calcium, phosphorus and potassium according to the AOAC (1990) methods. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were analyzed according to Van Soest *et al,* (1991) method. The DMD of the pastures was determined using nylon bag technique (Ørskov *et al.,* 1988) where three fistulated steers of 'Mpwapwa' breed were used. The incubation times used were 0, 6, 12, 24, 48, 72 and 96 hours. For each forage sample, a sample weighing 3 g was placed into six separately labelled and weighed nylon bags measuring 8 x 10 cm with pore size of 41 μm. For each incubation period, two bags were suspended into the rumen of the three steers. The data collected was subjected to General Linear Model procedure of Statistical Analytical System using split plot models (Oliver, 1996). Least significance difference test was used to compare the means.

Results and discussion

Dry matter yield of the pastures

The extent of decline in dry matter yield of pastures due to coconut canopy varied (Table 1), The yield of *Brachiaria ruziziensis* was reduced by coconut canopy by 13%, *P. trichocladum* by 28%, *M. atropurpureum* by 20% and *D. mombasana* by 50%. This indicates that *B. ruziziensis*, *P. trichocaldum* and *M. atropurpureum* are more shade tolerant than *D. mombasana*. The possible reason for decline in DMY of the pastures under the coconut canopy is the low light intensity received under the coconut canopy that reduce photosynthetic capacity of the plants (Congdon and Addison, 2003). Under the coconut canopy *B. ruziziensis* and *M. atropurpureum* had higher dry matter yield than other pastures. This suggests that these pastures have both high dry matter yield and shade tolerance potential. Wong (1991) and Reynolds (1995) reported similar results.

Chemical composition of the pastures

The average CP content of the grasses was 6.64% and for *M. atropurpureum* legumes was 12.96% (Table 1). As expected, *M. atropurpureum* had higher ($P<0.05$) CP content than the grasses. Among the grasses, *B. ruziziensis* had the highest CP followed by *P. trichocladum* and lastly *D. mombasana*. The CP content of the grasses increased (P<0.05) from the open area to the coconut canopy. In *M. atropurpureum* the trend was opposite, it's CP content decreased significantly (P<0.05) from the open area to the coconut canopy. The high CP contents in *M. atropurpureum* (as a leguminous pasture) than in grasses and high level of CP content in *B. ruziziensis* than *D. mombasana* and *P. trichocladum*s gives an indication that if these pastures are intergrated in coconut plantations can improve the CP content of the pastures. The increase in crude protein content under coconut canopy relative to that in the open area was 0.23 – 0.68, 0.7 – 1.25 and 0.71 – 1.07% for *B. ruziziensis*, *D. mombasana* and *P. trichocladum,* respectively. Norton *et al.* (1991) also reported an increase in CP of grasses under shade, which occurs when soil N is limiting. The effect was a result of a more favourable environment for microbial activity in the soil due to reduced soil moisture decline in dry periods and lower soil temperatures at the litter interface. On the other hand, the CP content of *Macroptilium atropurpureum* was lower by 0.86 - 1.16% under coconut canopy compared to the open area. This is in support of most studies that shade decreases CP contents of some legumes (Wong, 1991) and is associated with adverse effect of shade on symbiotic nitrogen fixation since the number of nodules decreased under shade (Congdon and Addison, 2003). The CP content of *Macroptilium atropurpureum* and *B. ruziziensis* was above the minimum level (7%) required for proper functioning of microbes in the rumen (McDowell *et al.,* 1983). The native grasses (*D. mombasana* and *P. trichocladum*) had CP content below the critical levels. Protein supplementation will be important if these two grasses are the only feed available for ruminants. The high CP contents in *M. atropurpureum* (as a leguminous pasture) than in grasses and high level of CP content in *B. ruziziensis* than *D. mombasana* and *P. trichocladum*s gives an indication that if these pastures are integrated in coconut plantations can improve the CP content of the pastures.

The NDF content of the pastures in this study varied from 60.79 – 79.20% (Table 1). The NDF in *M. atropurpureum* was lower (P<0.05) than in grasses. In grasses, *P. trichocladum* had highest NDF varying from 78.1 – 79.2% and *B. ruziziensis* had the lowest NDF varying from 71.2 – 75.1%. *Brachiaria ruziziensis* grown under coconut canopy (0 – 100 % CR) had lower (P<0.05) NDF than that in open area. In other pastures the NDF was higher (P<0.05) under coconut canopy than in open area. The ADF content of the pastures studied varied from 43.6 – 51.0% (Table 1). *Macroptilium atropurpureum* had higher (P<0.05) ADF than the grasses. Among the grasses *B. ruziziensis* had the lowest ADF varying from 43.6 – 46.0% while *P. trichocladum* had the highest ADF varying from 48.5 – 48.4%. Coconut CR (P<0.05) decreased the ADF content of *B. ruziziensis* from 46.03% in open area to 43.7% at 0 – 50% canopy radius. In *D. mombasana* and *P. trichocladum*, the ADF was not affected (P>0.05) by coconut canopy. The ADF of *M. atropurpureum* in 50 – 100% canopy radius was lower (P<0.05) than in 0 – 50% CR and in open area. The effect of coconut canopy on cell wall contents in the forages studied was variable as in study by Senanayake (1995). In his study, 64% light intensity decreased the cell wall contents of *Imperata cyllindrica* and *Cynodon dactylon* and increased the cell wall contents of *Axonopus compressus* and *Imperata cyllindrica.* The decline in cell wall content as a response to coconut canopy in *B. ruziziensis* is an indication of increase in nutritive value. There was an increase in NDF content of *M. atropurpureum* from 60.79% in the open area to 63.09%. However, its NDF under the coconut shade was below the critical value of 75% in the grass based diet reported by Buxton (1996). With such low NDF, *M. atropurpureum* can also be one of the important legumes to integrate into coconut plantations. In most studies, the soluble carbohydrates of plants decrease under shading, and this decrease in cell contents lead to apparent increase in cell wall fraction of the dry matter (Norton *et al.,* 1991). This could explain the increase in cell wall content of the forages sampled under coconut shade.

Dry matter degradability of the pastures

The 48h DMD was highest in *M. atropurpureum* and lowest in *P. trichocladum* (Table 1). Among the three grasses, *B. ruziziensis* had the highest 48h DMD. The 48h DMD of *B. ruziziensis* was higher (P<0.05) under the coconut canopy than in the open area. In *D. mombasana,* the 48h DMD at 50 – 100% CR was lower (P<0.05) than in the open area. Coconut canopy did not affect (P>0.05) the 48h DMD of *P. trichocladum.* The high 48h DMD (56.3%) of *B. ruziziensis* over the other local grasses indicates that this grass if fed to ruminants, most of its nutrients will be available to the animal.

Brachiaria ruziziensis can support moderate producing cattle that require feed with 48h DMD of 50 - 65% (Schneider and Flat, 1975). Mixing the grass with *M. atropurpureum* that had relatively higher 48h DMD (63.92 to 66.35%) could improve its degradability. *Panicum trichocladum* and *D. mombasana* had the lowest 48h DMD that can not have potential to support animal growth and milk production. High cell wall contents (Table 1) contributed to the low 48h DMD of *P. trichocladum*. The increase in 48h DMD of *B. ruziziensis* under shade could be associated with low cell wall contents under coconut canopy. The results from the present study agree with the conclusion made by Norton *et al.,* 1991) that the effect of decreasing light intensity on digestibility varies with grass species tested.

Degradation characteristics of the pastures

Degradation characteristics (**a, b,** and **c**) of pastures as affected by coconut canopy are presented in Table 1 where a = rapidly soluble fraction (%), b = percentage potential degradable fraction and c = rate of degradation of the b fraction. Generally the soluble fraction **(a)** of the legume (*M. atropurpureum)* was higher (P<0.05) than in grasses. Among the grasses, *B. ruziziensis* had the highest **a,** with 8.78 – 11.8%. The **a** of *B. ruziziensis* and *D. mombasana* was lower (P<0.05) under the coconut canopy than in open area by 2.7%. Conversely, in *M. atropurpureum,* **a** was higher (P<0.05) under coconut canopy than in open area by 1.96%. In *P. trichocladum* the **a** was not (P>0.05) affected by coconut canopy. *Brachiaria ruziziensis* had the highest potential degradability (**b**) followed by *D.mombasana, M.atropurpureum* and the least was *P. trichocladum.* The **b** of the pastures except in *D. mombasana* were not affected (P>0.05) by CR. In *D. mombasana,* **b** increased from 50.43% in the open area to 54.90% at 0 – 50% CR. The rate of DM degradation (**c**) in *M. atropurpureum* was highest and varied from 0.048 - 0.05% per hour. Among the grasses, *B. ruziziensis* had highest **c** (0.036 - 0.042% per hour) while *P. trichoclodum* had the lowest (0.031 - 0.033% per hour). The **c** of *B. ruziziensis* was higher (P<0.05) under the coconut canopy than in the open area. In other pastures **c** was not affected (P>0.05) by CR. High soluble fraction (**a)** in *M. atropurpureum* indicates that most of its nutrients would be degraded before reaching the rumen while low value of (**a)** in grasses indicates that most of their nutrients are degraded in the rumen by microbes. Higher (**a**) in legumes than grasses were also reported by Shem *et al*. (1995) and are due to genetic difference between legumes and grasses. Ludlow and Wilson (1971) reported that shaded leaves are thinner than unshaded leaves, and contain fewer, smaller and densely packed cells. Chlorophyll concentration also decreases with shade. All these could be the reasons for low (**a**) observed in *B. ruziziensis* and *D. mombasana* under coconut canopy. *Brachiaria ruziziensis* had higher potential degradability (**b**) than *D. mombasana* and *P. trichocladum* possibly due to low cell wall contents in *B. ruziziensis. Macroptilium atropurpureum* had higher **b** and **c** than the grasses. This can be explained by difference in genetical makeup (Ludlow and Wilson 1971) and high CP content (Shem *et al.,* 1995). The increase in rate of degradation (**c**) of *B. ruziziensis* under the coconut canopy could be related to decline in cell wall content and increase in CP content of the grass (Table 1). *Panicum trichocladum* grass had lowest **c** and this can be associated with high cell wall contents.

Table 1: Effect of coconut canopy on DMY (t/ha), chemical composition, 48h DMD and digestibility characteristics of pastures (%DM)

CR (%)	Pasture specie	DMY	CP	NDF	ADF	48h DMD	a	b	C (% h^{-1})
Open	*B. ruziziensis*	8.28^{a}	7.20^{f}	75.05^{e}	46.03^{g}	53.97^{d}	11.82^{d}	49.90^{b}	0.036^{de}
	D. mombasana	7.68^{ab}	5.36^{k}	76.70^{d}	46.81^{f}	50.23^{e}	5.46^{g}	50.43^{b}	0.039^{c}
	P. trichocladum	1.49^{d}	5.79^{j}	78.15^{b}	48.50^{d}	41.98^{g}	5.37^{g}	46.64^{c}	0.031^{e}
	M. atropurpureum	8.14^{ab}	13.63^{a}	60.79^{j}	50.49^{b}	63.92^{b}	18.12^{c}	50.39^{b}	0.049^{a}
50 – 100	*B. ruziziensis*	7.09^{ab}	7.48^{e}	73.05^{f}	43.62^{l}	58.85^{c}	9.46^{e}	54.90^{a}	0.042^{b}
	D. mombasana	4.58^{c}	6.06^{l}	77.61^{c}	47.45^{e}	47.97^{f}	3.85^{h}	51.46^{b}	0.039^{c}
	P. trichocladum	1.12^{d}	6.50^{h}	78.93^{a}	48.36^{d}	42.40^{g}	4.93^{g}	45.67^{c}	0.032^{e}
	M. atropurpureum	6.50^{ab}	12.77^{b}	63.47^{h}	49.60^{c}	66.35^{a}	20.47^{a}	50.54^{b}	0.05^{a}
0 – 50	*B. ruziziensis*	7.29^{ab}	7.87^{d}	71.25^{g}	43.70^{h}	56.13^{d}	8.78^{f}	53.53^{ab}	0.041^{bc}
	D.mombasana	3.05^{cd}	6.61^{h}	77.41^{c}	47.00^{f}	50.71^{e}	4.21^{h}	54.90^{a}	0.035^{de}
	P.trichocladum	1.03^{d}	6.86^{g}	79.20^{a}	48.51^{d}	42.56^{g}	5.41^{g}	45.79^{c}	0.033^{e}
	M. atropurpureum	6.50^{b}	12.47^{c}	63.09^{l}	51.01^{a}	63.92^{b}	19.20^{b}	49.82^{b}	0.048^{a}
SEM		0.574	0.047	0.091	0.081	0.769	0.20	1.02	0.001

^{abcdefghi} Means with different superscripts in a column differ significantly (P<0.05) ; SEM = Standard error of the mean; a = rapidly soluble fraction (%); b = % potential degradable fraction; c = rate of degradation of the b fraction

Mineral content of the pastures

The overall mineral contents of the pastures (% DM basis) were 0.452 Ca, 0.176 P, 0.791 K and Ca : P ratio of 2.3 : 1 (Table 2). *Macroptilium atropurpureum* had highest (P<0.05) Ca and Ca : P ratio. *Digitaria mombasana* in open area had lowest Ca : P ratio. The concentrations of P in *B. ruziziensis* and *M. atropurpureum* did not differ (P>0.05) but were higher (P<0.05) than that of the other two grasses. *Brachiaria ruziziensis* in 0 – 50% CR had higher (P<0.05) K content than other pastures. In all pastures the concentration of Ca, P and K increased (P<0.05) from the open area to 0 – 50% CR. The Ca : P ratio of *B. ruziziensis* and *M. atropurpureum* was not affected (P>0.05) by CR. Calcium content in the pastures under the coconut plantation observed in this study was within the normal range for tropical pastures (Kayongo – Male, 1975; Andrew and Robbins, 1969ab). The calcium content in *M. atropurpureum* was above the level required for maintenance, growth, pregnancy and lactating in dairy cattle (0.7 – 0.9%) but the calcium content in the grasses was below the requirement for dairy cattle (NRC, 2001). Therefore, integration of *M. atropurpureum* in the coconut plantation of Chambezi could increase the calcium content of the pastures. Phosphorus content in all pasture species was below the recommended range (0.4 – 0.9%) for dairy cattle (NRC, 2001). This indicates the need of increasing soil P levels in Chambezi coconut plantation since soil P is the main source of P in pastures. The K content of the pastures in open area was below the recommended range (0.8 – 1.4%) for lactating dairy cattle (NRC, 2001). In 0 – 50% CR, *M. atropurpureum, B. ruziziensis* and *P. trichocladum* had K content that was within the recommended range. The concentration of Ca, P and K in all pastures studied was higher under the coconut shade than in open area. This is in agreement with Belsky (1992) who reported higher concentration of minerals in pastures under tree shade and is associated with higher Ca, P and K concentration in the soil solution since soil moisture tends to be higher under tree canopies. The Ca : P ratio in *B. ruziziensis* was within the recommended range (1 : 1 to 2 : 1) for livestock production (McDonald *et al.,* 1995) but in *M. atropurpureum*, *D. mombasana* and *P. trichocladum* was below the recommended range.

Table 2: Effect of coconut canopy on mineral content (%DM) in pastures

CR (%)	Pasture specie	Ca	P	K	Ca : P ratio
Open area	*B. ruziziensis*	0.31[f]	0.18[c]	0.63[e]	1.68 : 1[cd]
	D. mombasana	0.18[g]	0.13[e]	0.61[e]	1.39 : 1[d]
	P. trichocladum	0.21g	0.12[e]	0.72[d]	1.76 : 1[c]
	M. atropurpureum	0.75[c]	0.18[bc]	0.77[cd]	4.10 : 1[a]
50 – 100	*B. ruziziensis*	0.35[e]	0.19[bc]	0.79[c]	1.83 : 1[c]
	D. mombasana	0.33[ef]	0.15[d]	0.73[d]	2.23 : 1[bc]
	P. trichocladum	0.29[f]	0.13[e]	0.84[bc]	2.24 : 1[b]
	M. atropurpureum	0.83[b]	0.20[b]	0.83[bc]	4.17 : 1[a]
0 – 50	*B. ruziziensis*	0.41[d]	0.22[ab]	1.02[a]	1.91 : 1[c]
	D. mombasana	0.42[d]	0.19[bc]	0.76[cd]	2.23 : 1[bc]
	P. trichocladum	0.43[d]	0.19[bc]	0.89[b]	2.29 : 1[bc]
	M. atropurpureum	0.91[a]	0.23[a]	0.90[b]	3.96 : 1[a]
SEM		0.011	0.006	0.024	0.11

[abde] Means with different superscripts in a column differ significantly (P<0.05):
DM = dry matter; SEM = standard error of the mean; NS = Non significant; * = Significant at P<0.05.

Conclusions and recommendations

The quantity and quality of pastures in coconut plantations can be improved by encouraging the introduction of *B. ruziziensis* and *M. atropurpureum*. These two pasture species have higher dry matter yield and nutritive value than the common natural pastures (*D. mombasana* and *P. trichocladum*) under coconut plantations of the coastal belt of Tanzania. In addition, the coconut shade does not have adverse affect on the dry matter yield of the two pastures. In addition, it improves the crude protein and mineral content the grasses making them more nutritive to livestock. Livestock (ruminants) can therefore be integrated in coconut plantation with introduction of pasture species that are shade tolerant.

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SUB-THEME: DOMESTICATION OF INDIGENOUS FRUITS AND MEDICINAL PLANTS

15. GENDER AND SOCIO-ECONOMIC FACTORS AFFECTING DOMESTICATION OF MEDICINAL PLANTS AS AN INDIGENOUS AGROFORESTRY PRACTICE IN WEST USAMBARA MOUNTAINS, TANZANIA

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Abstract

A study to investigate the impact of gender and socio-economic factors on indigenous agroforestry practices with the main focus on domestication of medicinal plants was conducted in the West Usambara Mountains, Tanzania. Participatory Rural Appraisal (RPA), questionnaire surveys, Semi-Structured Interviews (SSI), botanical surveys and participant observations were the main methods employed in data collection. It was revealed that, being an important practice in agroforestry, domestication has played fundamental role in conservation of medicinal plants in the study area. Twenty-three (66%) out of 35, and 6 (55%) out of 11 forest plant species domesticated on farms and around homesteads respectively, were medicinal plants. Furthermore, although 89% of the respondents had domesticated medicinal plants on their farms and around homesteads, gender and socio-economic factors had influence on the number of domesticated medicinal plants. Male-headed households had significantly domesticated more medicinal plants than female-headed households. Age, education, wealth, farm size, household size and ethnicity had also influence on the number of domesticated medicinal plants. It is concluded that, being a strategy for conservation of threatened medicinal plants in farmlands and around homesteads, domestication has been influenced by gender and socio-economic factors. Therefore, agroforestry research in area of domestication should focus on devising new strategies for better integration of forest resources into farmlands and their related socio-cultural, socio-economic and institutional aspects.

Introduction

Domestication of medicinal plants needs more attention due to the important role they play in the improvement of people's health. Medicinal plants are essential component of primary health care especially for the rural communities who sorely rely on forest plants for food, shelter, energy and medicines. It was estimated that about 80% of the rural populations in Tanzania depend on herbalists to handle their medical problems (FAO, 1986; Rulangaranga, 1989). The reliance of medicinal plants for primary health care in Tanzania will not decrease due to the smaller number of conventional medical doctors as compared to traditional healers and the high cost of modern medicine, consultation and hospital fees (Otieno, 2000; Ishengoma and Gillah, 2002). Further, in this decade, the world is experiencing an increasing rate of resistance by pathogens to some of the synthetic drugs, as well as the struggle against Cancer and AIDS which have not found treatments from modern medicine. Consequently, this has challenged the scientific community to seek solutions from plant species as reflected by a number of research programmes aimed at testing plant species for their pharmacological value (Msuya, 1998).

In spite of its long historical background, the traditional medicine as a discipline faces a lot of problems that threaten its existence. This includes the high rates of habitat destruction caused by human disturbances. Activities such as land clearance for agricultural production, fire burning (either accidentally or deliberately) as well as improper extraction of some forest products like timber, fuelwood, building poles and withes have significant impact on the survival of plant species medicinal plants inclusive. In some instances, extraction (harvesting) of medicinal plants involves ring debarking and root cutting that causes death of the respective plants.

Regardless of the factors that have increased scarcity and loss of medicinal plants, domestication has saved many medicinal plants, which are been threatened in their natural habitats. For instance, *Prunus africana* has been planted in areas bordering natural forests in Cameroon and Madagascar in order to reduce pressure on its harvesting and protect this species from getting extinct due to excessive harvesting of its bark for export for medicinal use (Cunningham and Mbenkum, 1993; Dawson, 1997). Being an indigenous agroforestry practice, domestication involves both leaving some species of forest origin in the farms during the process of opening up land for cultivation and also bringing forest plants to the farms or homesteads with an intention of tending such valuable species (Michon and de Foresta, 1996; Kessy, 1998). Domestication of medicinal plants has been practiced in the West Usambara Mountains since the pre-historic times (Wiersum *et al.,* 1985; Kajembe, 1994; Kaoneka and Solberg, 1997; Moshi, 1997, Msuya, 1998). Although it is unlikely that the situation will change in the near future, there are a number of factors affecting domestication of medicinal plants in the West Usambara Mountains, which need to be documented for sustainable use and management of these plants. Gender and socio-economic factors have affected domestication of medicinal plants. Women's capacities to domesticate medicinal plants differ from those of men and there is a tendency of overlooking their contribution towards conservation of biodiversity and natural resources (Talhouk *et al.,* 2001). Also socio-economic factors influencing domestication of medicinal plants such as age, education, wealth, ethnicity, farm and household size need to be analyzed.

This paper presents results on how gender and socio-economic factors have impacted on the indigenous agroforestry practices with the main focus on domestication of medicinal plants.

Materials and Methods

Study area

The study was conducted in the West Usambara Mountains located in Lushoto district, Tanga region, in the northeastern Tanzania (Latitudes 4° 24' – 5° 00' S and Longitudes 38° 10' – 38° 36' E). The mountains cover an area of 4,500 km^2, which is 90% of the total area of Lushoto district (Kerkholf, 1990). The altitude varies from 400 – 2400 m a.s.l. Climatically the area is characterized by two rainy seasons with short rains (October – December) and long rains (March – May). Mean annual rainfall ranges between 600 mm and 1200 mm. Temperatures are not uniform over the West Usambara Mountains as they vary with altitude. At 500 m, the mean monthly temperature ranges between 25 – 27° C while on the plateau, at 1500 - 1880 m, the range is 17 - 18° C (Wiersum *et al.,* 1985). The mean minimum and maximum temperatures are 13° C and 26.5° C, respectively. However, in cold months such as July and August minimum temperatures can be as low as 7° C while frost occurs above 1900 m (Msuya, 1998). Soils are of two types: humic ferralitic and humic ferrisols, characterized by high leaching, low cation exchange capacity and low basic nutrient elements such as calcium potassium and magnesium (Graaff, 1996).

Three types of natural forests are found in the West Usambara Mountains – lowland, intermediate (submontane) evergreen and highland (montane) evergreen forests.

According to 2002 National Census, the population in the study area was 419,970, with an annual growth rate of 1.8% (URT, 2003). Ethnically the area has Shambaa as the predominant tribe (78%) followed by the Pare (16%) and the Mbugu (5%), while other small tribes form 1% of the population (Msuya, 1998; Moshi, 1997). The Pare, Mbugu and other tribes beside Shambaa are the immigrants to the study area. People's livelihood depends on subsistence farming. The crops grown include maize, beans, wheat, irish potatoes, yams, banana and cassava. Cash crops include coffee, tea, cardamom, sugarcane, fruits (plums, pears and apples) and vegetables.

Data collection

Data was collected from six villages of Irente, Kwemakame, Viti, Mwangoi, Lwandai-Mlola and Kiluwai. Systematic random sampling was employed in selecting the study villages in which the strata was the distance from the Forest Reserves. While Irente, Kwemakame and Viti villages were randomly selected from the villages bordering the Forest Reserves (Mkussu and Shume-Magamba), Mwangoi, Lwandai-Mlola and Kiluwai are located far from the Forest Reserves. It was assumed that the distance from the Forest Reserves had some influence on the domestication of medicinal plants.

Primary data were collected in three phases. Phase one involved Participatory Rural Appraisal (PRA), in which 30 people of different age groups and gender from each village participated. PRA tools included participatory wealth ranking, pair wise and preference ranking. The second phase involved structured and semi-structured questionnaires administration. A total of 173 households were interviewed using structured questionnaire. The sample consisted of 25 households from Irente, 38 from Kwemakame, 15 from Viti, 35 from Mwangoi and 30 households each from Lwandai-Mlola and Kiluwai at a sampling intensity of 5%. Systematic sampling was adopted so as to include people of different gender, age and wealth categories, as reflected from PRA results. The key informants who were interviewed using semi-structured questionnaire included district government officials, village leaders, village elders, ritual leaders and traditional healers. The third phase involved botanical survey, which aimed at identifying medicinal plants domesticated on farms and around homesteads. As most of farms in the surveyed villages were located near houses, it was possible to survey all farms of 173 interviewed households and identify medicinal plants. The exercise was done concurrently with the household interviews. Also medicinal plants domesticated around homesteads were identified during the course of household interviews. Participant observation was done to observe domestication of medicinal plants in farms and around homesteads.

Data analysis

Data collected using PRA was analyzed with the help of the communities, and results were communicated back to them. Data collected in the second and third phases were analyzed using both qualitative and quantitative methods. The qualitative data were analyzed using content analysis technique (Kajembe, 1994), whereas quantitative data were analyzed using MINITAB Statistical Package. Correlation analysis was used to establish the influence of different socio-economic parameters on domestication of medicinal plants.

Results and Discussion

Being an important practice in agroforestry, domestication has played fundamental role in conservation of medicinal plants in the study area. Twenty-three (66%) out of 35, and 6 (55%) out of 11 forest plant species domesticated on farms and around homesteads respectively, were medicinal plants (Table 1). Names of medicinal plant species domesticated on farms and around homesteads are shown in Table 2.

Table 1: Total number and percentages of medicinal plants domesticated on farms and around homesteads in West Usambara Mountains

Place of domestication	Number of medicinal plants	Percentage	Total number of domesticated forest plants
On farm	23	66	35
Around homesteads	6	55	11
Total	29	63	46

On average each household has domesticated 5 ± 3 (SE) medicinal plants in the study area. However, the villages located far from the Forest Reserves have domesticated more medicinal plants (an average of 6 ± 4 (SE) per household) with significant difference ($P = 0.09$, $t = 2.62$) than villages bordering the reserves. Village wise response also reflect similar situation as indicated in Figure 1. Kiluwai, Lwandai-Mlola and Mwangoi (the villages located far from the Forest Reserves) had high percentages of respondents reported to have domesticated medicinal plants as compared to villages located close to Forest Reserves (Irente, Kwemakame and Viti) (Figure 1). This could be attributed to the fact that people living closer to Forest Reserves can fulfill their need of forest resources by obtaining them from the reserves than those living far from the reserves and hence the need for domestication becomes low.

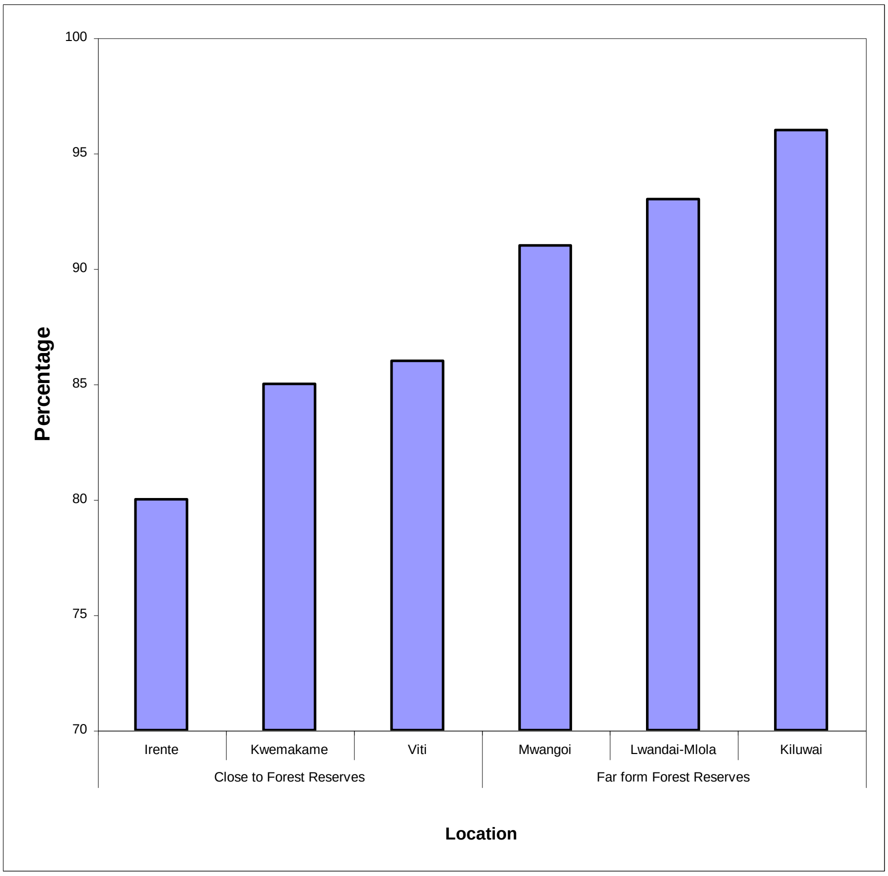

Figure 1: Response on domestication (in percentage) per village and location in the West Usambara Mountains

Furthermore, domestication is common practice in the West Usambara Mountains and is believed to have existed in this area for many years. This was revealed by this study as most respondents (89%) reported to have practiced this type of agroforestry for long period. Hamilton (1989) reported that domestication as part of the traditional agroforestry system; domestication has started in the West Usambara Mountains as early as about 2000 years ago.

Similarly, this agroforestry system has been reported by various studies conducted in the West Usambara Mountains by Kaoneka (1993), Kajembe (1994), Moshi (1997) and Msuya (1998). Certain medicinal plant species such as *Albizia* spp., *Erythrina abyssinica*, *Catha edulis,* and *Tamarindus indica* were domesticated for the purpose of conserving them due to the excessive harvesting of these species in their natural habitant (the forests). Similar practice was reported in Cameroon and Madagascar where domestication of *Prunus africana* has served the species from extinction due to excessive bark harvesting for export for medicinal use (Cunningham and Mbenkum, 1993; Dawson, 1997). Nevertheless domestication as an indigenous agroforestry practice is not only been practiced in the West Usambara Mountains (Hamilton, 1989; Kaoneka, 1993; Kajembe, 1994; Moshi, 1997; Msuya, 1998), but also in other parts of the world (Daniels *et al*., 1993; Zemede and Ayele, 1995; Dawson, 1997; Kessy, 1998; Cunningham *et al*., 2002).

Table 2: Medicinal plant species domesticated on farms and around homesteads reported and identified from the West Usambara Mountains

Species Name	Family	Domesticated on farm	Domestication around homesteads
Adenia cissampeloides	Passifloraceae		×
Albizia gummifera	Mimosaceae	×	
Artemisia afra	Compositae		×
Basella alba	Basellaceae		×
Catha edulis	Celastraceae	×	
Combretum molle	Combretaceae	×	
Commiphora eminii	Burseraceae	×	
Cordia africana	Boraginaceae	×	
Cussonia arborea	Araliaceae	×	
Dombeya rotundifolia	Sterculiaceae	×	
Ehretia cymosa	Boraginaceae	×	
Erythrina abyssinica	Mimosaceae	×	
Euclea divinorum	Ebenaceae	×	
Grewia similis	Tiliaceae	×	
Hibiscus fuscus	Malvaceae	×	
Jasticia engleriana	Acanthaceae		×
Juniperus procera	Cupressaceae	×	
Lonchocarpus capassa	Papilionaceae	×	
Markamia lutea	Bignoniaceae	×	
Microglossa densiflora	Compositae	×	
Microglossa oblongifolia	Compositae	×	
Plectranthus barbatus	Labiatae	×	×
Ptaeroxylon obliquum	*Ptaeroxylaceae*	×	
Senna singueana	Caesalpiniaceae	×	
Stereospermum kunthiamum	Bignoniaceae	×	
Tefairia pedata	Cucurbitaceae	×	×
Turraea robusta	Meliaceae	×	
Total		23	6

Gender influence on domestication of medicinal plants

Gender had significant influence on forest conservation, as depicted by the domestication of medicinal plants. Female-headed households have domesticated more medicinal plants around homesteads than on farms while male-headed households have domesticated more medicinal plants on farms (Figure 2). Elsewhere in the world especially in Thailand, women have domesticated a total 230 indigenous forest plant species around homesteads for food, medicines and decorative value (Geraldine *et al.,* 1994). On the other hand, male-headed households have domesticated 6 ± 4 (SE) medicinal plants significantly more than female-headed households (3 ± 4 (SE), $t = 3.77$, $p = 0.002$). This could be explained by land tenure insecurity for women. In these mountains and elsewhere in Tanzania, land ownership is patrilineal and only few widowed women could inherit land (Kaoneka, 1993; Msuya, 1998; Luoga *et al*., 2004).

Socio-economic factors affecting domestication of medicinal plants

Age of the respondents had a significant effect on the number of domesticated medicinal plants in the study area ($P = 0.002$) with a correlation coefficient of 65%. This could be attributed to the fact that most elders are the ones who own land and knowledge on medicinal plants, consequently they have more medicinal plants retained or planted on their farms and around homesteads. Quiroz (1994) reported that in Kenya young people of 20 years old did not know anything concerning medicinal plants as compared to the elders of about 70 years old.

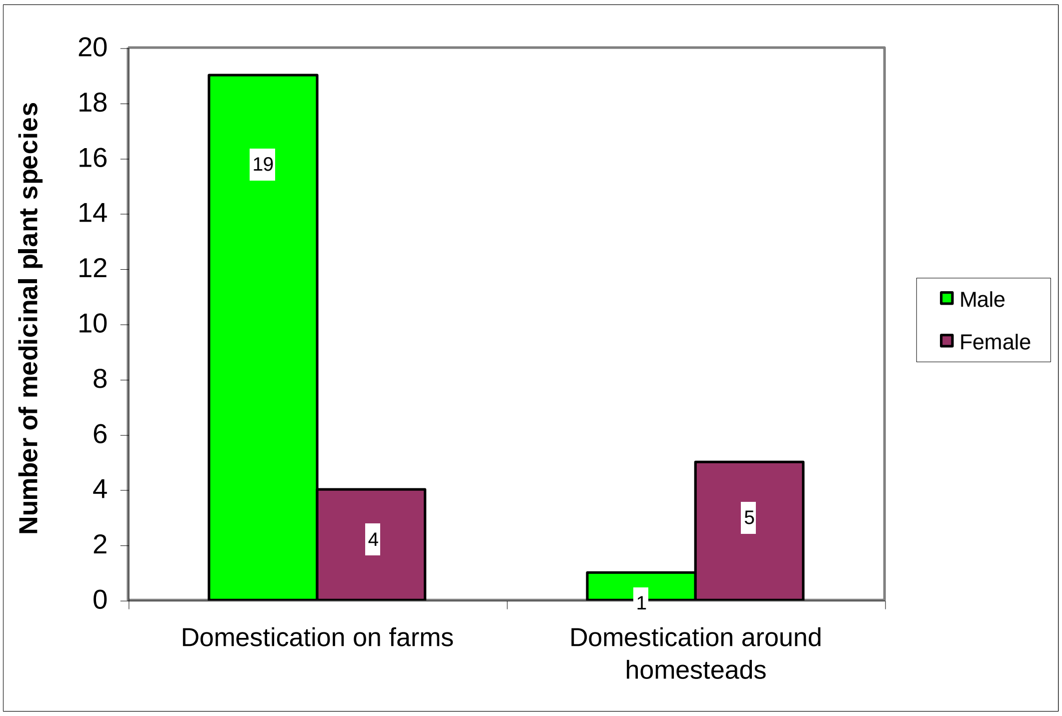

Figure 2: Gender effect on domestication of medicinal plants on farms and around homesteads in the West Usambara Mountains

Wealth of the respondents had also significant impact on the number of domesticated medicinal plants in this area (P = 0.001) with correlation coefficient of 81%. Although poor households constitute the majority of households in the study area (Figure 3), they have domesticated fewer medicinal plants than few rich households. This might be explained by the relationship between poverty and the use of forest resources and the fact that even rich people respect their traditional practices such as domestication. Also probably due to the cost of maintaining or managing their farms as poor farmers may spend more time looking for food than caring for medicinal plants which they can collect from the forests. Other socio-economic factors reported in the study area include education, which had no significant effect on the number of domesticated medicinal plants (P = 0.21, and correlation coefficient of 26%), farm size and household size in which both have significant effect on medicinal plants domestication (P = 0.023 with correlation coefficient= 45% and P = 0.012, with correlation coefficient of 52%) for farm size and household size, respectively.

The reason to why education has no significant impact on domestication of medicinal plants might be due to large number of household heads having formal education. Historicaly of formal education in these mountains started during the colonial period (Kaoneka, 1993; Kajembe, 1994; Msuya, 1998).

Households with big farms and big families have domesticated more medicinal plants than those with small farms and families. This is so because household size has an implication on the household labour force, and thus big families have more labour, which could contribute positively to the domestication of forest plants including medicinal plants compared to small ones. A similar trend was reported by the study conducted at Ruvu Fuelwood Pilot Project in Kibaha and HASHI/ICRAF where households with big families have planted more trees compared to those with small families (Luoga *et al.,* 2004). The positive correlation between farm size and domestication has also been reported by others who conducted studies in the study area and elsewhere in the country and in the world (Kajembe and Luoga, 1996; Michon and de Foresta, 1996; Moshi, 1997; Ndomba, 2004).

Ethnicity has also influenced domestication of medicinal plants in this area. The Shambaa tribe has domesticated more plants (8 ± 4 (SE) significantly different than other tribes (4± 6 (SE), P = 0.001 and t = 5.84. This could be attributed to the fact that the Shambaa is the native tribe in the study area and other tribes are immigrants to the West Usambara Mountains, and that domestication has been one of the indigenous wild plants conservation method in these mountains over 2000 years ago (Hamilton, 1989; Kajembe, 1994; Msuya, 1998; Msuya and Mndolwa, 2004). Also most of the Shambaa are traditional healers and hence domestication of medicinal plants could make healing activity easier as they can get plants for healing purposes from their farms or around their homes.

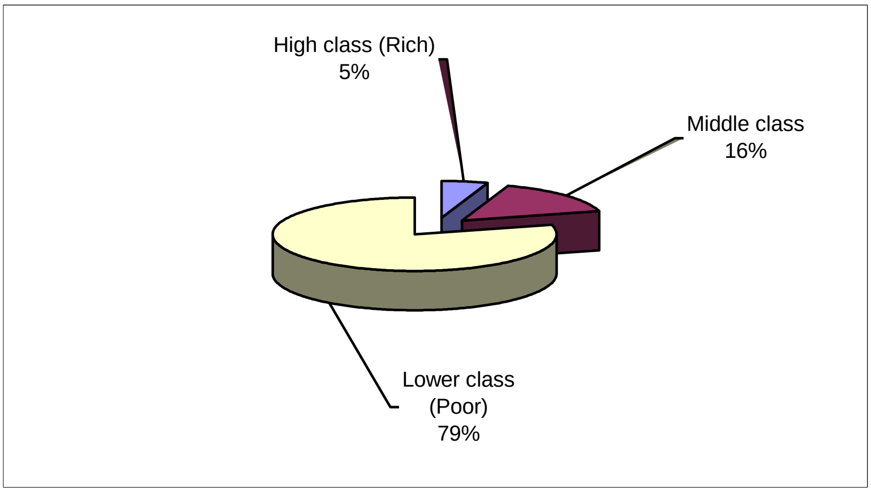

Figure 3: Wealth status/class of the households in the surveyed villages in the West Usambara Mountains

Conclusion and recommendations

Domestication of medicinal plants is been influenced by gender, socio-economic and cultural factors such as wealth (income), age, education, farm and household size, and ethnicity. Being part of indigenous agroforestry practice, domestication has played big role in conservation of medicinal plants especially threatened species due to over harvesting and human activities in the West Usambara Mountains. It is recommended that more research should be done on medicinal plants to identify other threatened species available in the forests and elsewhere in the study area and come up with appropriate procedures for domesticated them either on farms or around homesteads for sustaining their availability. In the process of domestication; gender, socio-economic and cultural factors that have both positive and negative influence should be taken into consideration.

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SUB-THEME: WOOD PRODUCTION

16. SOME WOOD PROPERTIES OF FIVE TREE SPECIES GROWN UNDER AGROFORESTRY SYSTEM IN SHINYANGA AND COAST REGIONS

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Abstract

Some physical and strength properties of five tree species grown under agroforestry system at the Natural Forestry Resources Management and Agroforestry Centre (NAFRAC) Shinyanga Region and Ruvu Fuelwood Pilot Project (RFPP) in Coast Region were determined. Trees studied from NAFRAC included*, A. polyacantha, Eucalyptus camaldulensis* and *Melia azedarach* while from RFPP were *Acacia mangium* and *Eucalyptus tereticornis.* A total of 3 trees per species were randomly sampled with elimination basing on free from defects and tree form and then felled. For each tree felled, three logs were extracted (at 1.3 m (DBH), 50% and 75% of the tree height), test samples were prepared and tested for basic density and some strength properties. For each sampled trees, a total of 60 test samples were used for each property test. The data were analysed using Microsoft Excel computer software and SAS statistical programme. Strength properties determined included modulus of elasticity, modulus of rupture, work to maximum load, total work, compression parallel to grain, shear parallel to grain and cleavage strength. The physical property assessed was basic density. At the age of 15 years *E. camaldulensis* had both high basic density (621.09 kg m^{-3}) and strength values. At the age of 4 and 5 years *M. azedarach* and *A. mangium* had low basic density (381.95 kg m^{-3} and 455.18 kg m^{-3} respectively) as well as strength values. However *A. polyacantha* (9 years) and *E. tereticornis* (4 years) had medium basic density (503.95 kg m^{-3} and 528.23 kg m^{-3} respectively) and strength values. Utilization of *E. camaldulensis* for poles, furniture and construction purposes will depend on proper air drying in order to produce timber with minimum splits. *A. polyacantha* and *E. tereticornis* had slightly high strength properties at 9 and 4 years respectively thus timber use from these trees at that young age is limited to areas which demand medium strength properties. Despite low basic density and strength values of *M. azedarach* and *A. mangium,* they can be used for fuelwood production and simple furniture at young age of 4 and 5 years. The properties tested have tendency to improve with age and equations should be developed for each species to predict strength and physical properties at older ages.

Introduction

Agroforestry is a land use system in which wood perennials (trees, shrubs, palms and bamboo's) are deliberately used on the same land management unit as agricultural crops (wood or not), animals or both, either in some form of spatial arrangement or temporal sequence. In agroforestry systems there are both ecological and economical interactions between the different components (Rocheleau *et al.,* 1988). Agroforestry is defined as "Dynamic, ecologically based, natural resources management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels" Leaky (1996). By providing a supply of fuel wood from farm, agroforestry can help to reduce pressure on forests and communal woodlands (Ramadhani, *et al.,* 2002).

Agroforestry research and development in Tanzania started in mid 1980's. The main goal of the agroforestry research is to improve the economic and nutritional well being of resource poor farmers through the development and dissemination of appropriate technologies to reduce deforestation, improve food security and contribute to poverty alleviation. The extraction of woodfuel (fuelwood and charcoal) is a major driver of dryland forestry degradation both in Shinyanga, Ruvu and many other parts of Tanzania in general. These products are largely the main source of domestic energy in Tanzania and, many other developing countries and at the same time an important source of income for many people in drylands. Most of the trees currently used for woodfuel are indigenous hardwoods of the

Miombo and Acacia woodlands (Jama *et al.,* 2003). Many forests in drylands are getting ecologically degraded as a result of these activities. However to mitigate these problems, agroforestry systems are applied. Some of the agroforestry practices adopted are: rotational woodlots, improved fallow, fodder banks, boundary planting, and windbreak. Apart from providing woodfuel, trees under agroforestry systems provide also timber for furniture and for building purposes. These trees grow fast abd are thus reliable in meeting the increased demand not only for woodfuel but also for timber (Nyadzi, 2004). Their suitability for these uses however depends on the mechanical and physical properties, which have not been determined for the trees grown at Shinyanga and Ruvu, Tanzania.

The objective of this study was to determine the physical and mechanical properties of *Acacia mangium, A. polyacantha, Eucalyptus camaldulensis E. tereticornis* and *Melia azedarach* tree species grown under agroforestry systems at Natural Forestry Resources Management and Agroforestry Centre (NAFRAC) and Ruvu Fuelwood Pilot Project (RFPP) in Shinyanga Region and Coast Region respectively.

Materials and Methods

Study areas

Ruvu

Ruvu Fuelwood Pilot Project (RFPP) is part of Ruvu North Forest Reserve, located in Kibaha District in Coast Region. The reserve is located between 6° 33' and 6° 43' S and 38° 48' and 39° 03' E, at 80 m above sea level, covering an area of 32,000 ha. By the year 2002, the Coast Region had a population of 889,154 people of which 440,161 were male and 448,993 females (URT, 2002). The area has bimodal rainfall pattern falling in two seasons. The long rains fall between March and May and short rains fall between November and December. Occasional rains can be obtained in January and September. The mean annual rainfall is about 900 mm falling in average of 81 days per year. Average temperature ranges between 23° C and 27° C tending to be the highest in January and having occasional minima as low as 18° C and maxima of 33° C. Soils are free draining, primarily sandy, sandy loam and gravel, varying substantially over short distances. Clay is occasionally found along valleys. The top soil up to 50 cm is dominated by pH 5.0 – 6.5 and decreases with increasing soil depth up to pH 9.4 at 72 cm below surface (Maghembe, 1979). The vegetation is semi deciduous open to partly closed woodlands dominated by coastal forests and miombo woodlands.

Shinyanga

Natural Forestry Resources and Agroforestry Centre (NAFRAC) is found in Shinyanga Region. The region is located in the north-western part of Tanzania and lies between 2° and 5° S; and 31° and 35° E. By year 2002, the population is 2,805,580 people of which 1,369,581 are males and 1,435,999 females (URT, 2002). The altitude within the region varies between 1000 and 1500 m above sea level and it is characterized by small hills with rock outcrops separated by mbuga plains. The region falls under the semi arid zone of the country with mean annual rainfall ranging from 600 mm in the East and 1200 mm in the West falling in average of 700 mm. There is only one rainy season falling between November and ending in April/May. Rainfall is erratic and poorly distributed. Temperatures are relatively high with maximum temperatures of 27° C to 30.2° C and sometimes as low as 15° C to 18° C. The high temperatures and low rainfall create serious moisture deficits throughout the year as the rate of evapo-transpiration exceeds the monthly rainfall almost every year (Otsyina *et al.,* 1999). Soils are mainly clayish but vary tremendously from hilltops where soils are well drained, brownish and sandy to valley bottoms where the soils are poorly grained black clays. Vertic soils are quite intensive, which are relatively fertile but susceptible to inundation for at least two months during the rainy season. The vegetation in most parts of the region is dominated by *Acacia* species: such as *A. tortilis, A. polyacantha, A. nilotica* and *A. drepanolobium* (Bakengesa, 2001).

Methods

Tree sampling and sample preparation

Tree sampling was random with elimination from different plantations and only trees with good form and free from defects were selected (Lavers, 1969). For each species, a total of 3 to 5 trees were sampled and marked for felling. For each felled sample tree, diameter at breast height and total tree height were measured and dimensions recorded. From each felled tree, three disks of about 5 cm each were cut at breast height (1.3 m), 50% and 75% of the sampled total tree height for the determination of basic density. Three sample billets of 1 m long were also cut from the butt above 1.3 m, at 50%t and 75 percent of the total tree height; each billet was then resawn into 45 – 65 mm thick centre cants and labeled to indicate tree number and position in the tree. The centre cants were transported to the laboratory of wood utilization SUA. In the laboratory, the centre cants were stacked to air dry for 10 weeks where air circulation was ensured using ceiling fans. After the centre cants were sufficiently air dried, they were sawn into planks of 30 x 45 – 60 x 1000 mm from the pith outwards east and west, labeled sequentially to indicate position of extraction from the pith. The planks were further air dried and then accurately machined to 20 x 20 x 1000 mm scantlings (Lavers, 1969). Each scantling was further converted into five different sizes depending on the type of test to be carried out (Table 1).

Table 1: Dimension of test samples and number of samples per test

Type of test	Dimension (mm)	No. of samples
Basic density	20 x 20 x 20	60
Static bending	20 x 20 x 300	60
Compression parallel to the grain	20 x 20 x 60	60
Shear parallel to the grain	20 x 20 x 20	60
Cleavage (splitting)	20 x 20 x 45	60

Laboratory procedure

Basic density determination

Basic density was determined according to BS 373 (1957), Lavers (1969) and ISO 3131 (1975). Basic density determination involved getting green volume and oven dry weight of test samples. Basing on Archimedes Principle, green volume was determined using the following formula:

V = M / D

Where: V = Volume of displaced liquid (distilled water)

M = Weight of water recorded

D = Density of displaced liquid (distilled water = 1)

After measuring green volume, all test samples were oven dried in order to determine oven dry weights. The samples were oven dried 102 ± 3^{o} C to constant weight and cooled in a desiccator containing an absorbent for drying air. The test samples were weighed and their oven dry weight recorded. Basic density was calculated from the following formula by Panshin de Zeew (1970) and ISO 3131 (1975).

$$Bd = \frac{od\ (g)}{gv\ (cc)} = g/cc$$

Where: Bd = Basic density (g/cm^3)

od = Oven dry weight (g)

gv = Green volume (cm^3)

Basic density values calculated in g/cm^3 were later converted to kg/m^3 for consistency and easy understanding.

Strength properties determination

Strength tests were determined according to BS 373 (1957), Lavers (1969), ISO 3133 (1975) and Ishengoma and Nagoda (1991). All tests were conducted using a Monsanto Tensiometer Wood Testing Machine and deflection curves were plotted manually. The moisture content for each test sample at time of test was calculated according to ISO 3130 (1975). The following strength tests and strength properties were determined using above standards:

- Static bending
  - Modulus of Elasticity (MOE)
  - Modulus of Rupture (MOR)
  - Work to maximum load (W/Max)
  - Work total (W/Total)

- Compression (COMP)
- Shear parallel to grain (SHEAR)
- Cleavage perpendicular to grain (CLEAV)

The strength properties values for test samples tested at a moisture content lower or more than 12% were corrected to 12% according to formula by Desch (1981).

Data analysis

Means, standard deviation, and standard error values were determined. Simple regression analysis was also conducted to determine the relationships between basic density and strength properties. Excel computer software and SAS statistical programme were used to analyse the data.

Results and Discussion

The physical and strength properties of the five tree species tested at different ages are as shown in Table 2. Basic density ranged from as low as 381.95 kg m^{-3} for *Acacia mangium* to as higher as 621.09 kg m^{-3} for *Eucalyptus camaldulensis*. Basic density is usually positively correlated to strength properties (Desch, 1981) and this trend is clearly seen with low basic density tree species having low strength values and high basic density tree species having high strength values. The results showed that, strength values (except in compression) for *Melia azedarach* (4 years) were higher than that of *A. polyacantha* (9 years) despite the later being twice as much older than the former. However *A. polyacantha* (503.95 Kg m^{-3}) has higher basic density than *M. azedarach* (455.18 Kg/m^3). The phenomenon indicates possibility of *M. azedarach* at 9 years old to have high physical and strength properties. The same prediction is true for *E. tereticornis.* Therefore these tree species at that age can be utilized for woodfuel, building poles, timber for light furniture and pulp for fiberboard production.

Results in Table 2 shows that the mean cleavage strength for the 4 year tree species *Eucalyptus tereticornis* and *Acacia mangium* is 24.08 and 13.88 N mm^{-1} respectively. It is clear that these two timber species have low cleavage strength, which means, they split easily, and therefore are excellent for fuelwood use. However cleavage strength property alone is not enough indicator for a tree species to be recommended for fuelwood. Other properties like calorific value need be high. *E. camaldulensis* at an age of 15 years had higher strength values. With high strength value this tree species at that age can be used for production of fencing and building poles, timber for furniture and pulp for fiberboard production.

Table 2: Mean physical and strength properties of the five tree species tested at different ages (years)

Species	Age (Yrs)	Variable							
		B/density	MOE	MOR	W/Max	W/Total	COMP	SHEAR	CLEAV.
		Kg m^{-3}	N mm^{-2}	N mm^{-2}	mmN mm^{-3}	mmN mm^{-3}	N mm^{-2}	N mm^{-2}	N mm^{-1}
Acacia mangium	4	381.95 (13.94)	2550.3 (28.16)	23.89 (19.50)	0.054 (49.36)	0.054 (80.72)	22.10 (21.31)	8.26 (16.51)	13.88 (26.06)
A. polyacantha	9	503.95 (12.58)	5212.4 (18.23)	52.5 (20.9)	0.076 (56.42)	0.122 (68.43)	33.11 (18.32)	10.68 (16.51)	21.41 (23.47)
Eucalyptus camaldulensis	15	621.09 (8.24)	8141.5 (21.76)	95.23 (11.55)	0.14 (51.89)	0.22 (41.16)	50.24 (7.85)	13.76 (102.91)	26.01 (19.33)
E. tereticornis	4	528.23 (10.83)	7192.0 (27.52)	70.26 (22.73)	0.089 (34.41)	0.159 (47.03)	38.66 (10.75)	12.06 (12.36)	24.08 (13.06)
Melia azedarach	5	455.18 (8.02)	5912.1 (24.49)	66.83 (15.74)	0.10 (52.28)	0.134 (55.49)	31.92 (8.18)	11.14 (8.57)	23.05 (15.00)

Values in parentheses are Standard Errors

Relationship between basic density and strength properties

Regression equation was used to establish the relationship between basic density and strength properties of the five tree species tested (Table 3a-e).

Table 3(a): Basic density – strength properties regressions for *Acacia mangium*

Property	Equation	R^2 (%)
Modulus of Elasticity	y = 30.706x - 13540	86
Modulus of Rupture	y = 0.5409x - 258.74	66
Work to Maximum Load	y = 0.0018x - 0.8719	74
Work total	y = 0.0043x - 2.1689	51
Compression	y = 0.1676x - 65.472	82
Shear	y = 0.1436x - 66.784	87
Cleavage	y = 0.3272x - 157.1	94

Table 3(b): Basic density – strength properties regressions for *Acacia polyacantha*

Property	Equation	R^2 (%)
Modulus of Elasticity	y = 25.847x - 7813.6	92
Modulus of Rupture	y = 0.2255x - 61.105	60
Work to Maximum Load	y = 0.0008x - 0.339	75
Work total	y = 0.0021x - 0.9314	80
Compression	y = 0.0281x + 18.948	74
Shear	y = 0.0356x - 7.2457	61
Cleavage	y = 0.0755x - 16.656	98

Table 3(c): Basic density – strength properties regressions for *Eucalyptus camaldulensis*

Property	Equation	R^2 (%)
Modulus of Elasticity	y = 70.609x - 35680	98
Modulus of Rupture	y = 0.6383x - 301.13	99
Work to Maximum Load	y = 0.0004x - 0.1211	67
Work total	y = 0.0016x - 0.7457	88
Compression	y = 0.1528x - 44.666	89
Shear	y = -0.0342x + 35.965	75
Cleavage	y = 0.1254x - 48.354	94

Table 3 (d): Basic density – strength properties regressions for *Melia azedarach*

Property	Equation	R^2 (%)
Modulus of Elasticity	y = 72.091x - 26901	48
Modulus of Rupture	y = 1.0088x - 392.35	47
Work to Maximum Load	y = 0.0036x - 1.5355	35
Work total	y = 0.01x - 4.4674	73
Compression	y = 0.1235x - 23.963	82
Shear	y = 0.1304x - 50.287	98
Cleavage	y = 0.2173x - 75.862	55

Table 3(e): Basic density – strength properties regressions for *Eucalyptus tereticornis*

Property	Equation	R^2 (%)
Modulus of Elasticity	y = 2.3862x + 5931.6	60
Modulus of Rupture	y = 0.0377x + 50.356	98
Work to Maximum Load	y = 0.0002x - 0.0189	99
Work total	y = 3E-05x + 0.1437	99
Compression	y = 0.0104x + 33.162	48
Shear	y = 0.0005x + 11.813	58
Cleavage	y = 0.0069x + 20.431	98

Where: x = Basic density
y = Strength property

The pattern of the strength properties variation followed a similar pattern for basic density variation, probably because basic density influences very much the strength properties of wood. This means that an increase in basic density subsequently increases strength properties. The observed results are similar to those reported by Desch and Dinwoodie, (1996). However age seems to have influence on the strength properties. At age of 5 years *M. azedarach* had lower regression values in static bending and higher to other strength values (Table 3e). Whereas *E. camaldulensis* had higher regression values in all strength properties tested (Table 3c).

Generally all mechanical and physical properties of wood are more or less influenced by density. A linear relationship exits between density and mechanical properties of wood, like toughness, shear, modulus of elasticity and modulus of rupture (Desch, 1981). Low density wood is easily compressed and frequently tears out. Wood with high density value is usually recommended for higher tension works like bridge construction, housing, boat building and simple furniture (Desch and Dinwoodie, 1996). Therefore wood with higher density will eventually have high strength properties.

Conclusion and Recommendation

Trees grown under agroforestry systems at young ages can be utilized for different purposes rather than being used only for fuelwood production. It also allows investment returns from plantations to be realized at a very young age. This may have tree impact to farmers as they will be encouraged to plant those tree species and get returns in a very short period. Provided the properties of these trees are suitable for different uses at that young age. Timber from these trees can be used for making simple furniture as well as production of fencing and building poles. Utilization of these trees will reduce pressure of exploitation of indigenous tree species from natural forests in the country particularly in semi arid areas. However to have sound utilisation of these timbers, they should be at least ten years old. More utilization of such trees will generate income to poor rural communities thus improving living standards. It is recommended for the properties to be tested again at a later age that is 10 – 15 years in order to note the trends. There is also a need of testing natural durability of the species at that age in order to know their life span.

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17. WOOD BIOMASS, NUTRIENT ACCUMULATION AND CARBON SEQUESTRATION IN ROTATIONAL WOODLOTS AGROFORESTRY SYSTEM IN WESTERN TANZANIA

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Abstract

Deforestation contributes significant quantities of gases and particulate matter to the atmosphere. An effort to surmount deforestation involves the promotion of village and community forestry, including planting trees using several agroforestry systems. Agroforestry systems can have a beneficial influence on the global climate. Here we indicate how planting trees in the form of woodlots can slow or reverse the release of carbon (C) into the atmosphere. We compared woodlots of *Acacia crassicarpa*, *A. julifera*, *A. leptocarpa*, *Leucaena pallida* and *Senna siamea*. The aim of the study was to analyze the effectiveness of woodlots in sequestering carbon. After 5 years, trees were harvested, biomass allocation for wood, leaves and twigs were measured and analyzed for C content. Wood constituted 32 to 85% of the total aboveground biomass. Large amounts of nutrients are withdrawn with the harvested wood biomass, making application of nutrients from external sources (e.g. fertilizers) essential for sustainable woodlots. Results also indicated that different trees planted in woodlots after five years affected C sequestration differently due to their biomass allocation patterns and C mass fractions. Acacia species were superior in C sequestration, and among the *Acacia* species, *A. leptocarpa* and *A. crassicarpa* sequestered almost twice as much as *A. julifera*, especially in the wood fraction. *Senna siamea* and *L. pallida* had the lowest C sequestration potential among the tested trees. Wood production at the end of the five-year growing period ranged from 30 to 90 Mg ha^{-1}. The total storage of C in foliage plus wood ranged from 13.3 to 30.3 Mg ha^{-1} at 5 years, indicating that all species do have the potential for C sequestration and thereby to mitigate CO_2 emissions into the atmosphere. Agroforestry plantations, such as woodlots, are clearly a carbon reservoir and do contribute to saving natural miombo forest ecosystems, to nearby provision of wood fuel and to a net C sequestration. Wise stewardship practices can mean more carbon is sequestered in an agroforestry system than is lost to the atmosphere.

Introduction

The objectives of tree plantings in the tropics vary from perpetually ‘natural looking forests’, development of high yielding and sustainable industrial plantations for wood production, control of land degradation and development of agroforestry systems (Nambiar, 1995). High biomass production is an important consideration in all-tropical tree planting programmes aimed at meeting the increasing demand for fuel-wood (firewood and charcoal) and timber. Fast growing plantation trees and secondary forests are also considered as highly efficient carbon sinks (Dyson, 1977). The planting of trees and shrubs can mitigate emissions of the greenhouse gas carbon dioxide (CO_2) to the atmosphere (e.g. IPCC, 1995).

In western Tanzania, there is an increasingly indiscriminate use of natural miombo forest resources due to the domestic and industrial energy crises (fuel-wood shortages). An alternative to clearing natural miombo forests in the region is to plant multipurpose trees on farmers’ fields. However, the trees must be managed such that competition with crops in the cropping phase is minimised (Ong *et al.,* 1996; Lott *et al*., 2000) and care must be taken that labour requirement for managing the trees suits farmer’s labour endowment. Planting of trees in the form of rotational woodlots (a sequential agroforestry system) in farmers’ fields has been shown to offer an alternative to clearing natural miombo vegetation (Nyadzi *et al*., 2003a). To minimize competition between crop and trees it is crucial to select appropriate tree species and tree spacing design (Ong *et al*., 2002).

Nutrient accumulation and export from the site have become an important consideration in short-rotation, high-yield plantation systems. Nutrients removed through frequent harvests may exceed the natural rates of nutrient inputs via soil mineral weathering, atmospheric deposition and biological fixation (Hopman *et a*l., 1993). Heavy nutrient drain may have an adverse impact on the long-term site quality as well as on the sustainability of the production. Information on wood biomass, wood quality and nutrient accumulation is required to forecast productivity and C sequestration, and to design schemes for optimum nutrient management and proper felling cycles of rotational woodlots.

The most appropriate measure of biomass is considered to be 'basic density'. In general, tree species with high density, low ash and moisture fractions are favoured as fuel woods, as they show better combustion characteristics (Shanavas and Kumar, 2003). According to Fearnside (1997) the 'basic density' of wood or 'basic specific density', calculated as oven-dry weight divided by wet volume, reflects the apportioning of C within the tree and is an important factor in converting forest volume data to biomass. Wood basic density is said to be a strong indicator of successional state in tropical trees, with pioneer species being lighter than mature forest species (Fearnside, 1997). Basic density is also a measure that equates to wood quality (strength in compression, tension, fuel-wood quality) (Niklas, 1997).

In western Tanzania *Acacia*, *Senna* and *Leucaena* species, established in rotational woodlots system, have been shown to grow fast and use water and N differently under semi-arid tropics (Nyadzi *et al*., 2003a and b). Some of these species have been tested for biomass production in short-term rotational fallows elsewhere (Szott and Palm 1996; Bray *et al*., 1997; Salako and Tian 2001). Evidently, the selection of proper tree species is a key to the success of rotational woodlots; all possible pros and cons need to be assessed before a proper evaluation can be made.

The overall objective of this study was to evaluate the biomass production potential of five fast growing tree species in a rotational woodlot system in semi-arid western Tanzania. Specific objectives were (1) to determine wood density for selecting trees with best qualities for fuel (2) to determine the contribution of various components to biomass production to be able to partition C and nutrients between harvested wood and residues left in the field, (3) to assess nutrient accumulation of different tree species, and (4) to assess the impact of nutrient removal in the harvested biomass on long-term site quality, C sequestration and production sustainability.

Materials and Methods

Study site

A trial was established in 1996 at Tumbi Agricultural Research Institute in Tabora western Tanzania. The site has a warm climate with mean temperature of 23^{o} C and receives an average annual rainfall of 928 mm mostly in one season between November and April (Nyadzi *et al*., 2003a). Soils are Oxic Haplustalfs with 82% sand and 12% clay, slightly acidic (pH in water 5.7 to 6.1), low in organic carbon (4 to 8 g kg^{-1}), total nitrogen (0.1 to 0.3 g kg^{-1}), low to medium in Olsen extractable P (3 to 12 mg kg^{-1}) and low in exchangeable bases (Nyadzi *et al.,* 2003b).

Experimental treatments and design

The trial involved seven fallow treatments, five of which included woodlots, one natural fallow and one continuous cropping. Treatments were arranged in a randomised complete block design with three replications. Woodlots included the following trees species: *Acacia crassicarpa*, *A. julifera*, *A. leptocarpa*, *Senna siamea* and *Leucaena pallida.*. The woodlots were established using 8-week-old seedlings planted at 4 x 4 m spacing (625 trees ha^{-1}) in 16 m by 20 m plots. The young trees were intercropped with maize during the first three years of establishment. In the subsequent two years trees were left to grow as woodlots. Details of location, climate, soil characteristics, experimental design and planting arrangement of trees within the rotational woodlot set-up were described in Nyadzi *et al*., (2003a and b). Procedures for biomass harvest, basic wood density, C and nutrient accumulation analysis are outlined below.

Tree biomass sampling

The aboveground biomass of the trees was sampled during the first week of November 2001 (end of dry season) when trees were approximately 5 years old. Three trees were selected from the net plot of six trees from each treatment for destructive sampling to determine tree biomass production. Trees were categorised into small, medium and large, and per net plot one tree of each category was selected. Only trees that had survived from the initiation of the trial were sampled, implying that if a tree was small because of gap filling (beating up), it was not used. Trees were cut at 15 cm aboveground, separated into foliage (leaves + twigs), branches, and stem, and components fresh weights were assessed. For dry matter determination and nutrient analysis, 200, 500, and 1000 g fresh matter of foliage, branches, and stems, respectively, were retained. The remaining trees of the plots were harvested to allow land preparation and re-cropping of maize. Stem and branches were removed from the plots, while leaves, twigs and grasses were incorporated into the ridges and covered with soil before planting maize, to assess the nutrient availability of the residues.

Determination of wood basic density

Variation in density along the length of trunks is a potential source of bias in biomass estimates, as most density samples come from only one point along the length of the trunk (normally at breast height level i.e. 1.3 m) (Fearnside, 1997). In this study, wood basic density was determined following the procedures described by Aldred and Alemdag (1988). Briefly the procedure involved sampling of three disks (wood cores) of about 4 cm thickness from straight boles of the three categorized trees, one at breast height mark (1.3 m from the base), the second at 1/3 and the third at 2/3 of the merchantable stem height. Each disk was wrapped in a paper bag labelled to indicate sample details and immediately air dried to prevent fungal growth. In the laboratory, the disks were soaked in distilled water for at least 72 h in order to regain green condition, after which their volumes were determined by the water displacement technique. After this, samples were kept in an oven at 103 ± 2 °C until a constant weight was reached. Wood basic density (kg m^{-3}) for each disk was calculated as the ratio of oven dry weight to green volume.

Plant analysis and calculation of dry mass, C and nutrient accumulation

The foliage sub-samples were immediately transferred to the laboratory in double-sealed polythene bags. After recording the fresh weights, the samples were oven-dried at 70 °C to constant weight. The dried samples were ground to pass through a 2 mm sieve. Ratios of dry weight to fresh weight of the sub-samples were used to calculate the dry mass of the components and of the total tree biomass on per tree category basis. The average biomass of tree parts was then summed to obtain the total wood component and the total aboveground biomass per tree. It was then multiplied by the number of trees per plot and extrapolated to a hectare.

Foliage samples were digested according to Anderson and Ingram (1993) and the digest was analysed for N, P, and cations (K, Ca and Mg). N and P were determined colorimetrically (Parkinson and Allen, 1975), K by flame photometry, and Ca and Mg by atomic absorption spectrophotometer (Anderson and Ingram, 1993). In another foliage sub-sample, organic C was determined by colorimetric method after wet oxidation with a H_2SO_4-$K_2Cr_2O_7$ mixture (Anderson and Ingram, 1993). The ratios of the mass fractions of nutrients in the leaves were calculated and compared with the ratios found in the leaves of primary forests and secondary vegetation reported elsewhere (Van Reuler and Janssen, 1989). By multiplying mass fractions of C and nutrients with the dry mass of the foliage, the storage was calculated. Data on nutrient accumulations in wood were estimated based on the ratios of mass fractions in leaves to mass fractions in wood in Table 6.

Statistical analysis

Analysis of variance (ANOVA) was carried out using GenStat Programme (Payne *et al.*, 2002) to determine the variations among species in biomass production, wood basic density, C, and nutrient mass fractions and accumulations in tree foliage per tree category and per hectare basis. Fisher's protected LSD test at $P < 0.05$ was applied to distinguish groups (classes) of different values.

Results

Wood basic density and biomass production

Acacia leptocarpa had significantly higher wood basic density than the other species (Table 1). Differences among tree categories in wood basic densities were not significant, neither were the interactions of species and category. Total biomass accumulation ranged from 26 to 58 Mg ha^{-1} (Table 2). The biomass of foliage (leaves/twigs) ranged from 6.3 to 20.2 Mg ha^{-1} whereas the total wood biomass ranged from 9.6 to 40.9 Mg ha^{-1}. Stem wood differed significantly among species, while branch wood biomass did not differ. *Acacia leptocarpa* and *A. crassicarpa* had significantly higher wood and total aboveground biomass per tree as well as per ha than the other species. Overall, dry mass of wood was larger than that of foliage biomass. The percentage wood biomass of total aboveground biomass decreased in the following order: *S. siamea* (85%) >*A. leptocarpa* (71%) >*A. crassicarpa* (66%) >*A. julifera* (65%) >*L. pallida* (32%). *Senna siamea* was low in foliage biomass because most of the leaves had fallen as litter during the dry season (Nyadzi, 2004).

Table 1. Wood basic density (kg m^{-3}) of 5-year-old woodlots of five different tree species grown at Tabora, Tanzania.

Species	Tree category			Weighted mean
	Large	Medium	Small	
Acacia crassicarpa	519	448	660	542 b
A. julifera	580	583	538	567 b
A. leptocarpa	722	635	618	658 a
Leucaena pallida	526	517	519	521 b
Senna siamea	510	498	459	489 b
Mean	571	536	559	555 b
LSD (species)		78.9 (0.002)		
LSD (tree category)		61.1 (0.50)		
LSD (species x tree category)		136.6 (0.16)		

LSD = Least significant difference in means. Values in parentheses are probabilities of F significance. Treatment means within a column followed by the same letter are not significantly different based on LSD at $P < 0.05$.

Carbon and nutrients mass fractions and stocks

Carbon mass fractions did not differ significantly among species and ranged from 402 to 469 g kg^{-1} (Table 3). Nutrient mass fractions varied markedly among species. *Leucaena* leaves had higher N and P than other species, while among the acacias, *A. julifera* had the highest N and P mass fractions. The mass fractions of K and Mg were similar ($P > 0.05$), but Ca mass fraction was different between tree species. The ratios of the nutrient contents in the leaves were significantly different among species with high C:N, C:P, N:P and K:P quotients in *A. leptocarpa*. Leucaena had a low C:N ratio. The non-fixing senna had a low N:P ratio.

Carbon stock in the foliage and wood at the time of tree cutting ranged from 1.8 to 7.9 and 5.4 to 23.0 Mg C ha^{-1} yr^{-1}, respectively (Table 4). The amounts of nutrients tied up in foliage differed significantly among species, except for Ca, with Senna having the lowest amount.

Amounts of C and nutrients tied up in acacia wood were significantly higher than that in Senna and Leucaena wood, except for P. Owing to the wide variations in nutrient mass fractions among species, nutrient stocks did not follow a one-to-one correspondence with the biomass.

Table 2. Mean biomass accumulation in 5-year old woodlots of different tree species at Tabora, Tanzania

Species	*A.crassicarpa*	*A.julifera*	*A.leptocarpa*	*L. pallida*	*S. siamea*	$LSD_{0.05}$ (F probability)
			($Kg\ tree^{-1}$)			
Stem	49.4 a	29.5 b	46.7 a	10.4 c	29.5 b	14.1(<0.001)
Branches	6.5	3.2	18.8	4.9	5.8	18.3 (0.439)
Total wood	55.9 ab	32.8 bc	65.5 a	15.3 c	35.3 bc	20.3 (<0.001)
Foliage	28.6 a	18.0 ab	26.7 a	32.4 a	6.3 b	17.6 (0.037)
Total	84.5 a	50.8 b	92.2 a	47.7 b	41.6 b	30.8 (0.005)
			($Mg\ ha^{-1}$)			
Stem	30.9 a	18.5 b	29.2 a	6.5 c	18.4 b	8.8 (<0.001)
Branches	4.1	2.0	11.7	3.1	3.6	11.5 (0.439)
Total wood	35.0 ab	20.5 bc	40.9 a	9.6 c	22.1 bc	12.7(<0.001)
Foliage	17.9 a	11.2 ab	16.7 a	20.2 a	3.9 b	11.0 (0.037)
Total	52.8 a	31.7 b	57.6 a	29.8 b	26.0 b	19.2 (0.005)

LSD = Least significant difference in means. Treatment means within a column followed by the same letter are not significantly different based on LSD at $P < 0.05$. Reported here are the mean for three tree categories. This was then multiplied by the number of trees per plot and extrapolated to a hectare.

Table 3. Mass fractions of carbon, nitrogen, phosphorus, potassium, calcium and magnesium (g kg^{-1} in dry mass) and the ratios of these mass fractions in tree foliage

Species	*A. crassicarpa*	*A.julifera*	*A.leptocarpa*	*L. pallida*	*S. siamea*	$LSD_{0.05}$ (F probability)
C	406	469	446	402	445	59.2 0.123
N	19.4 c	22.7 b	16.4 c	27.8 a	17.7 c	3.17 (<0.001)
P	0.8 c	0.9 bc	0.6 d	1.1 a	1.0 b	0.15 (0.006)
K	10.2	7.2	6.9	7.9	6.7	3.09 (0.40)
Ca	5.7 bc	4.6 c	5.4 bc	6.0 b	9.8 a	1.25 (<0.001)
Mg	4.9	4.2	4.5	6.1	4.1	3.34 (0.68)
C:N	21.1 b	20.7 b	27.1 a	14.5 c	25.4 a	4.2 (0.001)
C:P	495 b	527 b	736 a	378 b	431 b	18.6 (0.017)
N:P	23.6 a	25.4 a	27.0 a	26.1 a	17.1 b	5.7 (0.025)
K:P	12.3 a	7.9 b	11.1 a	7.5 b	6.4 b	2.7 (0.004)
N:K	1.9 c	3.2 ab	2.5 bc	3.6 a	2.7 bc	0.9 (0.02)

LSD = Least significant difference in means. Treatment means within a column followed by the same letter are not significantly different based on LSD at $P < 0.05$.

Amounts of C and nutrients tied up in acacia wood were significantly higher than that in Senna and Leucaena wood, except for P. Owing to the wide variations in nutrient mass fractions among species, nutrient stocks did not follow a one-to-one correspondence with the biomass.

Table 4. Total C (Mg ha^{-1}) and nutrient stocks (kg ha^{-1}) in tree foliage and wood of 5 – years old woodlot of different trees at Tabora, Tanzania

Species	*A.crassicarpa*	*A.julifera*	*A.leptocarpa*	*L. pallida*	*S. siamea*	$LSD_{0.05}$ (F probability)
			Foliage			
C	7.3	5.3	7.3	7.9	1.8	6.3 (0.25)
N	344 ab	256 ab	272 ab	539 a	69 b	387 (0.018)
P	14.7 ab	10.0 ab	10.7 ab	21.5 a	4.1 b	15.9 (0.023)
K	182 a	79 ab	123 ab	138 ab	26 b	117 (0.01)
Ca	102	52	91	112	39	87(0.30)
Mg	88 ab	46 ab	83 ab	145 a	16 b	124 (0.023)
			Wood[a]			
C	20.0 ab	11.5 c	23.0 a	5.4 c	12.4 bc	7.99 (0.006)
N	180 ab	111 bc	215 a	65 c	44 c	74.7 (0.004)
P	7.3	5.2	6.7	6.4	3.7	4.4 (0.44)
K	86 a	34 bc	28 c	34 bc	54 b	21.1 (0.001)
Ca	88 b	27 cd	115 a	11 d	52 bc	37.1 (0.001)
Mg	32 ab	19 bc	48 a	11 bc	10 c	21.8 (0.018)
			Foliage+ Wood			
C	27.3 ab	16.8 bc	30.3 a	13.3 c	14.2 c	12.4 (0.039)

LSD = Least significant difference in means. Treatment means within a column followed by the same letter are not significantly different based on LSD at $P < 0.05$. [a] Estimates based on the ratios of nutrient mass fraction of foliage to nutrient mass fraction of wood (Table 5.6), wood was assumed to contain 560 g C kg^{-1}.

Discussion

In *L. pallida,* foliage contributed much to the total biomass. The contribution of wood of more than 65% of the total biomass and the high basic density make a very substantial part of the acacias and senna biomass useful as fuel-wood or as construction material. Wood basic densities for acacias were comparable to the ones found in studies conducted elsewhere (Khasa *et al*., 1995).

All species in the present study at an age of 5 years were denser than 14-years old plantation pines (soft wood) grown in southern highlands of Tanzania (Mugasha *et al*., 1996). Other wood quality parameters such as heat of combustion (calorific values), rapidity of burning, ash content and sapwood to heartwood ratios are also important, but still need to be quantified.

Results presented in Table 5 indicate that there is a considerable variation between tree species from different climatic zones in amounts of biomass and nutrient mass fractions in different parts of the vegetation. Nutrient contents of tissue types generally decrease in the order: foliage > branches = roots > stem (Kumar *et al*., 1998) and the mean ratio of nutrient contents in foliage to wood is between 3.3 and 5.1 (Table 6). Linear relationships between nutrient mass fractions in leaves to those in wood were also observed in tropical forests, and in most situations the ratio of mass fractions in leaves to mass fractions in wood was around 4 (Noij *et al*., 1993). These relationships (Table 6) were used to estimate the amount of nutrients tied up in wood during tree harvesting.

A comparison of Table 5 with Table 2 makes clear that above-ground wood biomass in our experiment was much lower than that reported for the sub-humid and bimodal humid tropics for 5-year old woodlots. The observed variations in foliar nutrient contents were generally within the range found elsewhere for these and other but similar species (Table 3 and Table 5). A part of the difference with other studies may be ascribed to differences in the length of growing season with different climatic conditions and soil characteristics.

Table 5. Dry biomass yield (Mg ha^{-1}), nutrient mass fractions (g kg^{-1}) and nutrient stocks in the biomass (kg ha^{-1}) in 2.5 to 5-years-old short-rotation trees*

Biomass type	Site	Species*						
		AA	AC	AJ	AL	LL	LP	SS
Leaf/twigs	SA	-	-	-	-	-	-	-
	SH	16	-	-	17	3.5	-	15
	H	129	-	-	-	4.1	-	-
Wood	SA	-	-	-	-	-	-	-
	SH	77	-	-	78	76	-	143
	H	129	-	-	-	62	-	-
Roots	H	16.3	-	-	-	12.0	-	-
Nutrient mass fractions (leaf/twigs)								
N	SA	28.9	24.4	17.8	13.4	34.9	28.0	
	SH	20.4	-	-	18.2	24.6	Nd	20.6
	H	23.19	-	-	-	40.51	-	-
P	SA	0.8	0.8	0.7	1.0	1.6	1.8	-
	SH	0.4	-	-	0.5	0.7	-	0.6
	H	0.81	-	-	-	1.71	-	-
K	SA	6.5	4.5	11.0	6.0	29.4	4.0	-
	SH	14.0	-	-	9.2	15.7	-	11.4
	H	10.82	-	-	-	13.92	-	-
Ca	SA	10.5	7.5	12.4	10.5	11.1	10.0	-
	SH	14.1	-	-	12.8	25.9	-	19.1
	H	-	-	-	-	-	-	-
Mg	SA	2.5	3.3	3.2	3.8	2.7	6.0	
	SH	4.0	-	-	3.3	3.5	-	3.8
	H	-	-	-	-	-	-	-
Nutrient mass fractions (Wood)								
N	SA	-	6.1	4.2	-	-	7.0	-
	SH	7.1	-	-	5.1	4.3	-	2.4
	H	5.18	-	-	-	5.94	-	-
P	SA	-	0.2	0.2	-	-	1.1	-
	SH	0.1	-	-	0.2	0.2	-	0.1
	H	0.31	-	-	-	0.57	-	-
K	SA	-	1.5	1.1	-	-	2.0	-
	SH	1.6	0.6		4.2	2.6	-	4.2
	H	2.62	-	-	-	1.34	-	-
Ca	SH	5.3	-	-	6.0	4.0	2.0	4.5
Mg	SH	0.6	-	-	1.0	1.2	1.0	0.4

*at semi-arid (SA) (Karachi *et al*., 1997; Karachi, 1998b), sub-humid (SH) (Salako and Tian, 2001), and humid (H) (Kumar *et al*., 1998) sites.
* AA = *Acacia auriculiformis*; AC = *A. crassicarpa*; AJ = *A. julifera*; AL = *A. leptocarpa*; LL = *Leucaena leucocephala*; LP = *L. pallida*; SS = *Senna siamea*; - = not determined.
SA = semi-arid; SH = sub-humid; H = humid

In all species the N:P ratio was well over 15, and the K:P ratio was over 10 in acacias except in *A. julifera*. Compared to leaves of secondary vegetation, primary forest trees, and perennial crops at optimum nutrition (as cited by Van Reuler and Janssen, 1989; Palm *et al*., 2001), the ratios point to shortage of P. This confirms also our results presented by Nyadzi (2004), where relative shortage of P followed from measured nutrient mass fractions in leaves of standing biomass and in decomposing leaves in the soil. Relative shortage of P also follows from the high C:P ratios. The ability of N_2-fixing acacias and leucaena to secure their N supply in nutrient-poor environments (Noij et al. 1993), is indicated by the relatively high ratios of N:P compared to those in senna.

Table 6. Calculated ratios of nutrient mass fractions in foliage to nutrient mass fractions in wood

Species	N	P	K	Ca	Mg
Acacia auriculiformis	3.9	3.3	4.2	2.3	5.4
A. crassicarpa	4.0	4.0	4.3	-	-
A. julifera	4.2	3.5	10.0	-	-
A. leptocarpa	3.1	3.8	1.8	1.9	3.6
Leucaena leucocephala	6.5	3.5	8.4	4.6	2.6
L. pallida	4.0	1.6	2.0	5.0	6.0
Senna siamea	8.6	6.0	2.7	4.2	9.5
Mean	4.3	3.3	5.1	3.5	4.4

Source: Karachi *et al*., 1997; Kumar *et al*., 1998 and Salako and Tian, 2001.

Nutrient removal from the site at harvest depends on both nutrient mass fractions and the biomass yield of the different components (Kumar *et al*., 1998). With wood harvesting, acacias and senna withdrew substantial amounts of nutrients. Fast growing trees such as *Acacia* species gave a marked export of nutrients via whole tree harvesting. However, if the branches and stem wood alone are removed (wood exportation), leaving the foliage and roots at the site (recycling nutrients through slash and mulch techniques), nutrient export from the site can be reduced substantially. Noij *et al*., (1993) observed a high total productivity at low soil fertility sites, which was entirely ascribed to high root productivity and a fast turnover of fine roots. A similar situation may exist at our study site with its low fertility (Nyadzi *et al*., 2003b). Unfortunately, there is limited data on amounts of nutrients accumulated by roots, which makes it impossible to draw firm conclusions about the total nutrient recycling. This indicates that for firm conclusions it is necessary to quantify the accumulation of nutrients in roots too.

Our results presented in Tables 3 and 4 have highlighted that the trees affected C sequestration differently due to their biomass allocation patterns and C mass fractions. *Acacia* species were superior in C sequestration, and among the *Acacia* species, *A. leptocarpa* and *A. crassicarpa* sequestered almost twice as much as *A. julifera*, especially in the wood fraction. The total storage of C in foliage plus wood ranged from 13.3 to 30.3 Mg ha^{-1} at 5 years, indicating that all species do have the potential for C sequestration and thereby to mitigate CO_2 emissions into the atmosphere (Fearnside, 2000; Sanchez, 2000). Agroforestry plantations, such as rotational woodlots, are clearly a carbon reservoir. However, the duration of the carbon offset that a rotational woodlot represents depends on its life span and fate (Kort and Turnock, 1999). If the woodlot coppices after biomass harvesting, the fixation of C in the woodlots could be considered to be an on-going process but if the woodlot is simply destroyed or removed at the end of its lifespan, the C removed from the atmosphere would return to the atmosphere due to organic C decomposition and vegetation burning (Fearnside, 2000). Usually farmers in the study area slash and burn the major part of the natural fallow vegetation and crop residues. By means of ash, nutrients (P, K, Ca and Mg) are added to the soil while considerable amounts of N and C are lost (Van Reuler and Janssen, 1996). Woodlot plantations on farms reduce the dependence on natural forest for wood fuel. Hence, woodlot plantations on farms do contribute to saving natural miombo forest ecosystems, to nearby provision of wood fuel and to a net C sequestration.

Conclusions

The study aimed to assess wood biomass, and nutrient accumulation and removal during harvest of five multipurpose tree species in semi-arid environment. There was a rapid accumulation of C and nutrients in aboveground woody components and in foliage. Wood constituted 32 to 85% of the total aboveground biomass. *Leucaena pallida* had the smallest wood proportion but retained the largest part of foliar materials in the field during clear cutting. Trees also played a role in weed control.

Clearly, planted woody fallows can contribute to C sequestration, and *Acacia* species are promising in this regard. When the goal is a high production of wood biomass with high wood density that can be used in fuel-wood and charcoal industries, *Acacia* species are preferred species. When the goal is dual, i.e. production of wood biomass and soil fertility restoration, *L. pallida* seems to be the preferred species.

Large amounts of nutrients are withdrawn with the harvested wood biomass, making application of nutrients from external sources (e.g. fertilizers) essential. An imbalance in N and P in tree components can be expected when grown on soils having relatively poor fertility characteristics such as those of this study. Evidently, supplementation of nutrients from external sources is needed during cropping after clear cutting of trees in order to have a productive and sustainable rotational woodlot system.

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SUB-THEME: ADOPTION, IMPACT OF AGROFORESTRY/INFORMATION AND DISSEMINATION

18. EXPLORING MARKET OPTIONS FOR SCALING UP AGRO-FORESTRY IN TANZANIA

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Abstract

Agro-forestry has a big potential for improving the livelihoods of the majority of Tanzanians, particularly in rural areas through sustainable use and management of natural resources. Benefits are many as evidenced for instance in Shinyanga region through Hifadhi Ardhi Shinyanga (HASHI), which is a development-oriented conservation project that has yielded very encouraging results. However, many of the agro-forestry programmes in the country including the aforementioned do not address the role of market. Many of the agro-forestry practices do not yield products for sale but mainly provide substitutes for purchased inputs, such as fodder for dairy feeds or improved fallows for mineral fertilizers. Yet other agro-forestry products such as fruit and timber may be sold and the potential benefits for marketing them are huge. Moreover most agro-forestry research does not focus in developing market options. Hence, this is an area that requires research in order to explore the potential of market in scaling up agro-forestry and ultimately contribute to increased social, economic and environmental benefits in Tanzania, consistent with the national policy guiding documents e.g. NSGRP (or MKUKUTA). Hence, this paper attempts to first assess the role of market in scaling up agro-forestry and second recommend strategies for scaling up agro-forestry through research in agro-forestry product development and marketing. The paper does so by subjecting for analysis secondary data from a study on the social, economic and environmental impacts of forest landscape restoration on Shinyanga region. The results indicate that the Non-Timber Forest Products are highly undervalued due to inadequate marketing system. This is a big disincentive factor for sustainability of agro-forestry in the region once the project duration ends. Therefore, exploring market options for scaling up agro-forestry in Tanzania is vital.

Introduction

The livelihoods of many Tanzanians, particularly those living in rural areas can be greatly improved through agro-forestry. In the arid and semi-arid lands (ASALs) that include Dodoma, Tabora and Shinyanga, trees are vital economic assets to the people in those areas. Apart from providing wood they are also a source of other non-wood products such as gums and resins, which are of high economic value. In addition, various types of indigenous fruits, vegetables and medicinal plants are obtained in the ASALs of Tanzania. In view of this fact and in spite of implementation of a number of natural resource management projects including agro-forestry projects, the communities living in these areas are amongst the poorest in the country. Nonetheless, several agro-forestry projects being implemented in the country have yielded very encouraging results in terms of economic, social and environmental benefits. A few of the projects include Hifadhi Ardhi Dodoma (HADO), Hifadhi Ardhi Shinyanga (HASHI) and Soil Conservation and Agro-forestry Project Arusha (SCAPA). Apart from these projects some agro-forestry technologies being practiced in the ASALs include trees on farm, boundary planting, rotational woodlots, improved fallows, fodder banks and Ngitili (traditional fodder banks).

In Shinyanga region, which is one of the dry regions of the country, HASHI, which is a development oriented conservation project has had broad success in reversing land degradation through rebirth of traditional forms of enclosure-based resource management; traditionally known as Ngitili system of land management. Ngitili has enabled farmers to have better access to fuel wood, timber and fodder species that they are planting in their farms, leading to healthier and more prosperous lives. However, this improvement of livelihood is still very little to effectively contribute to alleviation or reduction of poverty to the people in the project area. One of the major reasons is that the project like many others of their kind does not address the role of market in improving the natural resource management system for enhanced environmental and economic benefits. Much as the Ngitili has enhanced the availability of abundant fodder, wood products such as fuel wood, poles, timber and non-timber forest products like fruits, gum, grass, medicine, honey and condiments; the economic returns and or income from these products to the people is small. For instance, the annual average household income from different Ngitili products in Shinyanga region is estimated at Tshs. 589,000.00 or USD 589.0 only. Also the total monthly value of benefits from Ngitili per person in Shinyanga region is estimated at Tshs. 14,046 or USD 14.046 only (MNRT and IUCN, 2005). The reason for this is largely to do with an inadequate market for the Ngitili products. Conversely, if there were an efficient and effective marketing system in the project area, the same Ngitili products would have generated much higher incomes through better prices per unit of the products. Furthermore, marketing is done best by private firms and Tomich (2005) established that farm gate prices in developing countries are higher under competitive private marketing then when marketing is done by state enterprises. Hence, according to MNRT and IUCN (2005), the low level of expenditure per capita in Shinyanga region could be an indication of limited market potential in the region especially in rural areas where Ngitili are a critical land use of high value to households both socially and economically. This assertion is supported in a study at Lushoto District by Mbwambo et al. (2005) when discussing the extent of use and marketing of gum olibanum, a product of *Boswellia neglecta* tree species, where they say that there is non-existence of a formal market for the crop in spite of its high use value. Furthermore, Mbwambo (2004) when discussing the processing of indigenous and exotic fruits in the Miombo and Acacia woodlands in semi-arid areas of Tanzania asserts that income generated from these fruits is very low because of poor markets and processing technologies leading to huge fruit wastage. There is also extensive literature on the aspect of market failures on Non-Timber Forest Products (NTFP). There is little if any research studies on the role of market in scaling up agro forestry in Tanzania. But there is extensive literature on the influence of market on price, quantity and quality of agricultural products. Generally, in developing countries, missing markets, lack of property rights, externalities and diverse production sources have been identified as major obstacles in development and trade in NTFP (Witcover and Vosti, 1995). However, externalities and diverse production sources can be ruled out as major obstacles to development of the Ngitili products for trade and export. This is because the Ngitili products have high use value and have not yet saturated the local and foreign markets like other traditional export crops, which are very sensitive to world price trends. In fact, they are of high demand only if they could find their way to an efficient formal marketing system.

It is thus clear from the aforementioned insights that markets have a crucial role to play in development and trade in agro-forestry products. Therefore, this paper explores how markets would scale up agro-forestry and contribute to increased social, economic and environmental benefits through focusing on HASHI project.

Methodology

Some very basic economic principles have been used to come up with a number of assumptions to show the role of market in scaling up agro-forestry. Secondary data has been used from a study on the social, economic and environmental impacts of forest landscape restoration on Shinyanga region. The data on direct values by broad groups of species from Ngitili to the household and village economies in Shinyanga region was subjected to a computational method based on a set of assumptions to come up with a presumed market value of Ngitili products. Analysis followed from the computed market value to come up with conclusion and recommendations. The following are the assumptions made:

- The economic value of Ngitili products to households and individuals is equal to income
  i.e. Economic Value (EV) = Income (I)
  and
  Income (I) = Price (P) x Quantity (Q)

Where P is also assumed to be equal to farm gate price.

- The price (P) of Ngitili products would be much higher if there were access to competitive markets i.e. $P_m = P_oX$ Where P_m = Price under competitive market
  P_o = Calculated farm gate price
  X = A factor

NB: The factor X is derived from FAO's Worksheet 1 on calculation of farm gate prices from market prices (FAO, 2005). The derived value of X is 1.23 (Table 1).

- Access to a competitive market would necessitate improvement in the quality, yield and quantity of Ngitili products
- Improvement in quality, yield and quantity of the Ngitili products would demand for more investment in agro-forestry product development and marketing research
- Execution of the preceding assumptions would result in contributing to scaling up of agro-forestry in the country.

Table 1: Example to illustrate the calculation of farmgate prices from whole sale market prices

Secondary wholesale market price *Less*	Percentage of secondary wholesale market price	Unit Price 100
i. Cost of bag and stitching charges paid at primary wholesale market	2.50	
ii. Transport to railway station at primary wholesale market	1.00	
iii. Weighing and trading charges	3.50	
iv. Railway freight from primary to secondary wholesale market	0.75	
v. Unloading charges	1.00	
vi. Transport from railway station to secondary wholesale market	0.75	
vii. Other incidental expenses	3.00	
Secondary wholesaler's margin of profit	2.50	
Sub total (1)	15.00	15
Secondary wholesale market price less Sub total (1) = Secondary wholesaler's purchase price at primary wholesale market		85
Less		
i. Market charges payable to municipality or market committee or owner for use of premises	0.50	
ii. commission agent's fee	1.25	
iii. Handling and weighing charges	0.50	
iv. Charity or festival contribution	0.25	
v. Other incidental expenses	1.00	
Primary wholesaler's margin of profit	1.50	
Sub total (2)	5.00	6
Secondary wholesaler's purchase price at primary wholesale market less sub total (2) = prices received by farmer-seller in primary wholesale market		80
Less		
i. Transport from farm to primary wholesale market	1.00	
ii. Market entry fee	0.75	
Other incidental expenses	1.25	
Sub total (3)	3.00	3
Prices received by farmer-seller in primary wholesale market less Sub total (3) = Prices received by farmer at the farm gate		77

Source: FAO (2005)

* This example is for illustration only and should not be taken as a standard, as the expenses incurred by the farmer vary from country to country.

Results and Discussion

The results on the value of Ngitili products as indicated in Table 2 show that the products are highly undervalued relative to the high use value of the products. Even the computed market value using the factor derived from FAO has no significant impact. For all the products except timber, wood and medicinal, the computed average market price per unit of measure (i.e. kilogram, head load and bundle) is less than Tshs. 100.00. Nonetheless, the average price of a kilogram of medicinal products is slightly over Tshs. 2,000.00, which in reality is too minimal equal to may be the price of a small bundle of medicinal leaves.

Table 3 and Figure 2 respectively show the districts average household values and individual district average household values. There is a great deviation by the individual district values from the average districts value as shown by the zigzagging stacked lines. This trend has been compared to results in Table 4 and Figure 3 respectively, which show quantities and prices at Kariakoo Market in Dar es Salaam of 4 commodities by variety from 4 categorical locations. Here the stacked lines are almost straight.

Table 2: Computed average market value of Ngitili products from 7 districts of Shinyanga Region

Economic use	No. of species	Quantity annually consumed	Unit of measure	Average household annual value (Tshs.)	Farm gate price per unit of measure (Tshs.)	Market price (farm gate price x 1.23)	Market value * (Tshs.)
Medicinal	28	42	Kg	72,257.00	1,720.40	2,116.10	88,876.11
Nutritional (fruits and vegetables)	8	105.71	Kg	5,153.43	48.75	59.96	6,338.72
Fuel wood	16	2521.86	Head loads	48,911.14	19.39	23.86	60,160.71
Timber and wood	12	1	Various	30,780.33	30,780.33	37,859.81	37,859.81
Fodder	3	822.43	Bundles	19,400.86	23.59	29.02	23,863.05
Fencing	4						
Bush meat	14	35.33	Kg	2,156.50	61.03	75.07	2,652.50
Thatch grass	2	104	Bundles	2,526.57	24.29	29.88	3,107.68
Shade, shelter	6						

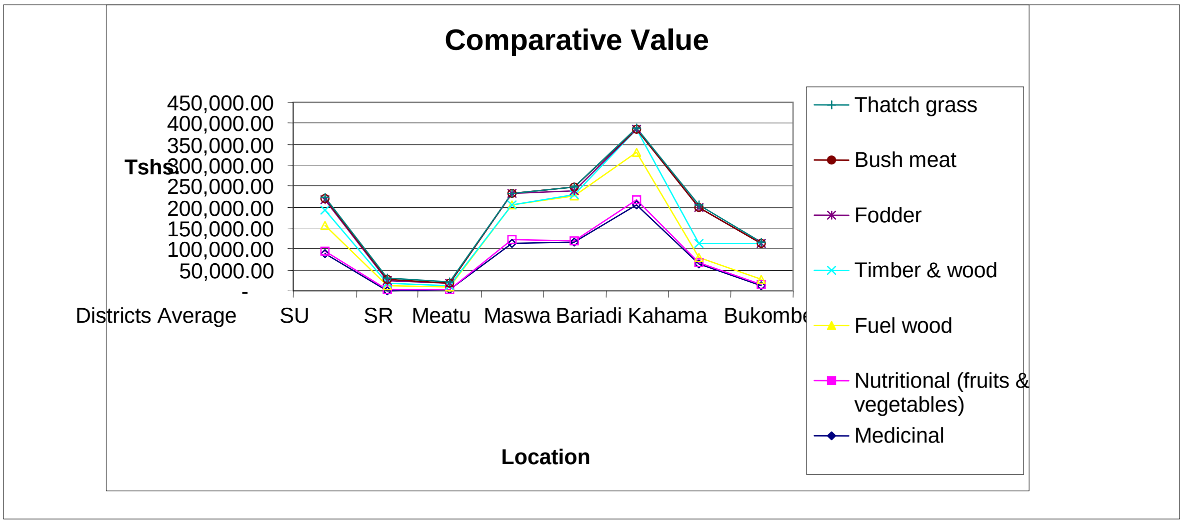
Source: MNRT and IUCN (2005)

Note: * Can be computed either by the product of market price and quantity consumed or average household annual value and the factor 1.23

Table 3: Districts average household annual value and individual district average (TShs) household annual value

Economic use	Districts' average	Shinyanga urban	Shinyanga rural	Meatu	Maswa	Bariadi	Kahama	Bukombe
Medicinal	88,876.11	1,089.00	1,946.00	112,243.00	117,792.00	204,312.00	63,656.00	10,761.00
Nutritional (fruits and vegetables)	6,338.72	3,269.00	76.00	8,978.00	1,490.00	12,798.00	4,442.00	5,021.00
Fuel wood	60,160.71	7,846.00	7348.00		105,830.00	114,269.00	10,185.00	13,092.00
Timber and wood	37,859.81	6,367.00	1,479.00	83,808.00	4,619.00	52,901.00	35,739.00	83,577.00
Fodder	23,863.05	6,130.00	6,966.00	26,190.00	10,061.00	437.00	84,875.00	1,147.00
Bush meat	2,652.50	3,269.00	1,633.00	93.00	7,154.00	73.00		717.00
Thatch grass	3,107.68	3,065.00	469.00	1,558.00	1,490.00	3,648.00	5,304.00	2,152.00

Source**: MNRT and IUCN (2005)**



SU=Shinyanga Urban; SR=Shinyanga Rural

Figure 1: Comparative Value between Districts Average and Individual Districts

Table 4: Quantities and prices at Kariakoo Market of 4 commodities by variety from 4 categorical locations recorded for the week 3 – 9 December 2005

Commodity	Kariakoo market average (Tshs.)	Location 1 (Tshs.)	Location 2 (Tshs.)	Location 3 (Tshs.)	Location 4 (Tshs.)
Irish potatoes	357.50	400.00	350.00	300.00	380.00
Green bananas	295.00	330.00	250.00	300.00	300.00
Ripe bananas	330.00	350.00	320.00	350.00	300.00
Oranges	335.00	300.00	380.00	340.00	320.00

Source: Financial Times, Business & Economic Weekly Newspaper (2005)

Note: Location 1 comprises Hai (West Kilimanjaro), Mkuranga and Njombe
Location 2 comprises Hai (West Kilimanjaro), Ifakara and Mkuranga
Location 3 comprises Mkuranga, Mvomero and Lushoto
Location 4 comprises Muheza, Ifakara and Rungwe

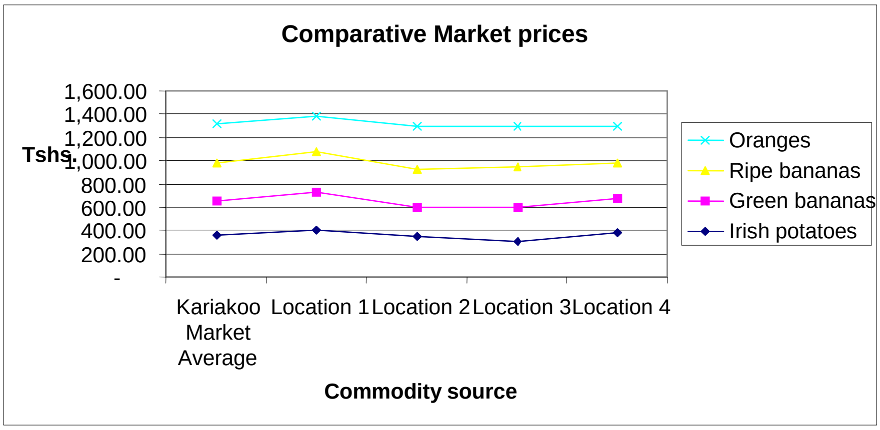


Figure 2: Comparative Market Prices of 4 commodities between Kariakoo Market Average and from 4 Locations

Basing on assumptions one and two of the methodology of the study, the economic value of Ngitili products has been used for the discussion instead of the computed market prices per unit of measure as they are very small for subjecting to any meaningful analysis. So the contrast we see between Figure 1 and 2 indicate that the Ngitili products in Shinyanga region are faced with considerable marketing constraint resulting in being highly undervalued relative to their high use value. A good market environment is illustrated in Figure 2 where there is very little price fluctuations and or price differences of the same commodities. Hence, better and stable prices provide a good incentive for sustaining production, processing and trading activities and the market is the centre stage for this aspect. In view of this fact we can say that in the absence of government and donor support in the Ngitili production system, it would eventually collapse as the economic returns would be insufficient to maintain the traditional system. Therefore, for sustainability of the HASHI project and other similar ones, market options need to be explored, a move that would call for the remaining assumptions in the methodology to be applied.

Exploring market options for scaling up of agro-forestry is crucial as this is an area that has not been fully tapped not only in Tanzania but also elsewhere in the world. In assessing case studies on projects/programmes for scaling up agro-forestry, Franzel *et al.* (2001) asserted that among the ten elements of scaling up agro-forestry, the case studies were weakest in developing market options and most did not even mention the role of market. The agro-forestry practices cited in the case studies did not yield products for sale; rather they provided substitutes for purchased inputs, such as fodder shrubs for dairy feeds or improved fallows for mineral fertilizer. Hence, they assert that issues concerning product markets are not directly related to their promotion and development. And this finding could apply to HASHI and many other agro-forestry projects in the country. Furthermore, Ndabikunze *et al.* (2000) observed that the Miombo and Acacia woodlands in the semi-arid areas of Tanzania are endowed with a rich diversity of indigenous fruit and medicinal trees. The fruits are rich in essential vitamins, minerals, sugar, proteins, oils and fibre. However, they assert that the fruits are under exploited. Nevertheless, some headway has emerged in the last three years in processing of indigenous and exotic fruits via a joint initiative between ICRAF and Tumbi Agriculture Research Institute in central Tanzania. While waiting to see the impact of this initiative, it is imperative that efforts be directed towards identifying market opportunities for agro-forestry products. The National Strategy for Growth and Reduction of Poverty (NSGRP) (VPO, 2005) provides the best framework for pursuance of the market options for scaling up agro-forestry because one of its operational targets under goal number 4 concerned with reducing income poverty of both men and women in rural areas, is increased contributions from wildlife, forestry and fisheries to incomes of rural communities. Amongst the cluster strategies under the target is to scale up participatory forest management in all districts, as a mechanism for increasing income of rural communities from natural resource management.

Conversely, one impediment though identified by Franzel *et al.* (2001) is that most agro-forestry research and development teams lack skills in marketing and product development. Could this be the case for Tanzania? Thus, gaining access to such expertise needs to be a high priority in scaling up.

Conclusion

The broad success of agro-forestry projects and programmes in improving the livelihoods of many Tanzanians cannot be sustained unless market options are included in the promotion and development of the agro-forestry products. HASHI that has had broad success in reversing land degradation through practice of traditional forms of enclosure-based resource management; traditionally known as Ngitili system of land management, has not contributed much to reduction of income poverty to the communities in the project area. The Ngitili products are highly undervalued due to lack of an effective marketing system; a big disincentive factor for sustainability of agro-forestry in the region. However, if there were an effective marketing system, the Ngitili products would have fetched much higher prices and income as they are products of high economic use value. This would ultimately help to maintain and sustain the production system even in the absence of government and donor support. Therefore, exploring market options for scaling up agro-forestry in Tanzania is vital and the NSGRP provides the best framework for achieving this objective.

Recommendation

Researchers should begin to assess market demand and consumer preferences for the non-timber agro-forestry products found in the different agro-ecological zones in the country. While doing so, our research institutions in collaboration with development partners must endeavour to increase programmes for domestication of indigenous fruit and medicinal trees as well as processing of indigenous and exotic fruits. This is important so as to enable establishment of links between producers and markets. Lastly, our researchers should take advantage of the opportunity in the NSGRP, which recognizes the importance of agricultural, forestry and natural resources management programmes in reducing income poverty of the rural communities.

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19. ON-FARM TREE RESOURCES AND FARMER MOTIVES FOR ON FARM TREE RETENTION AND MANAGEMENT IN BUMBULI WARD, LUSHOTO DISTRICT NORTH WESTERN TANZANIA.

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Abstract

On farm tree retention has formed the basis for the present day agroforestry systems in many traditions. We assessed species richness and diversity of on farm trees, farmer motives for tree management and contribution of on farm trees to household tree based needs in Lushoto District. About 46 tree species belonging to 25 families were identified. The most dominant species included *Albizia gummifera, Parinari excelsa, Newtonia buchananii, Cinchona* sp. *Syzygium guineense, Ficus capensis,* and *Caesaria engleri*. The Simpson's and Shannon-Wiener indexes of diversity were 0.07 and 2.8 respectively. This shows a high diversity of on-farm tree species comparable to natural forests. The motives for tree retention on farm ranged from supply of timber to edible fruits, medicine and soil erosion control. About 30% of household tree based needs are obtained from on farm sources. There is apparently high species richness and diversity in on farm trees in Lushoto. Most of on farm trees were retained on farm during farm clearing. A relatively high proportion of household wood based needs is still met by on farm sources. Sustainable management of on farm tree resources hinges much on more information and enhancement of indigenous tree management systems with supplements from afforestation efforts using appropriate fast growing tree species.

Introduction

For thousands of years farmers have been adapting crops to diverse environments and experimenting with and developing new varieties. The interaction between people, the environment and their food crops has provided farmers with a wide range of crops and a remarkable diversity of varieties within single crops. The inclusion of trees within farmlands has been a tradition over years (Kessy, 1998) The trees were typically retained from the natural forests and woodlands that were cleared for agricultural crops. To merit retention, these trees served some useful function such as the provision of fruits, medicines, fodder and other products (Nair, 1993; Leakey, 1999).

On farm tree retention formed the basis for the present day agroforestry systems in many traditions. Agroforestry is not a new concept in Tanzania as it has been practiced successfully for many decades in the highlands. The practice of growing coffee and banana crops mixed with fodder and shade trees which are also used for fuelwood, poles and timber is an excellent example of an agroforestry system. Generally people benefit from agroforestry by obtaining timber, hand tools, food (fruits) and medicinal products (Njenga *et al*, 1994). There is no doubt that in many African countries Tanzania inclusive, farmers have been growing and intensifying tree planting on their farms (Albaek, 1999).

While forests in their traditional sense may be adequate in supplying forest products in some areas, future availability of tree products may need consideration of off-forest tree resources to ensure adequate supply. On farm trees are usually in home gardens and nearby fields. Fernandez and Nair (1985) noted that all tropical homegardens consist of herbaceous layer near the ground and intermediate layer and a tree layer at the upper levels. In addition it was noted that the layered structure is not static such that the pool of replacement of species makes the structure to change. Trees, which grow outside the established forest areas also, perform a critical function. These trees are a composition of the rural landscape around houses, along field boundaries and roadsides and in communal grazing areas. For the majority of the rural population, they are probably of even greater significance than the forests themselves. The higher diversity of plants in the fields and gardens also provides habitat for wild animals including small mammals, birds, reptiles and insects. These have both the merits and demerits to crops and tree resources available.

The importance of trees in supplying domestic woodfuel is obvious, as in most developing countries virtually every rural family uses wood for all or part of its cooking and heating needs. In the majority of third world cities, wood and charcoal remain the predominant cooking fuels. Industries such as tobacco curing, tea and coffee drying and brick making often rely entirely on locally obtained wood fuel. In towns some restaurants, teashops, bakeries and other commercial enterprises add to these demands. In most areas, trees are planted in front of the houses to create an atmosphere appropriate for the pleasure and relaxation of the household members thus playing an aesthetic function. In farmlands and grazing areas, trees provide shade for people and animals; they also act as windbreaks, shielding crops and preventing soil erosion (Roucheleau *et al.,* 1988; SECAP, 1997). They slow down rainfall run-off, protecting the soil and increasing the infiltration of water so that ground water stores are replenished. They also act as nutrient pumps, drawing essential minerals from the subsoil and depositing them, through their leaf fall in surface layers where they are accessible to other plants (Foley and Bernard, 1984; Nair, 1990; Young, 1990).

Despite the fact that off-forest tree resources contribute towards resource conservation and household welfare, their distribution and composition is not clear in West Usambara. Our knowledge of the extent to which farmers efforts are able to contribute towards forest conservation and meeting some of the needs of the communities such as food security, fodder and fibre is inadequate. Different traditions and different agroecological conditions will dictate the type of tree species that are likely to be accommodated on farm. These have not been covered adequately in the west Usambaras. The reasons for tree retention and/planting on farm also differ from one area/culture to another. The difference is so big that one system of on farm tree resources in one area may not adequately be taken as a model for another region. Due to such differences each agroecological and/tradition need be assessed independently to determine the nature of off-forest tree resources and motives behind such systems.

This study is aimed at assessing the on farm tree resources in the west Usambara agroecological zones to determine how such system complements forest resources and biodiversity conservation in the region. Specifically we assessed species richness and diversity of on farm trees, farmer motives for tree management and contribution of on farm trees to household tree based needs in Lushoto District. Such information is important in policy making process, development and extension services and farmers with regard to sound agroforestry and farm tree systems for enhanced local livelihoods as well as global benefits.

Materials and Methods

Study site

The Usambara Mountains are divided into two blocks i.e. the West and the East Usambara mountain blocks, which are separated by the Lwengera valley. West Usambara mountains, located in the north east corner of Tanzania support high tropical rain forests which form part of the Eastern Arc Mountains which include south Pare, west Usambara, east Usambara, Nguu, Nguru, Ukaguru, Uluguru, Rubeho, Malundwe, Uzungava and Mahenge. The West Usambara ranges is in the northern part of the mountains (40^0 25' S – 5^0 07' S and 38^0 10' E - 38^0 35' E). The geology is composed of the late Pre-Cambrian rock of the Usagara system, metamorphic rocks of genesis type with two main highland soil types; the Humic Ferrisols in the drier areas and Humic Ferralitic soils in the more humid and wet areas (Hall, 1980; Tosi *et al.,* 1982; Munishi, 2001). Roughly three different Agro ecological zones can be distinguished in the western Usambara. The “humid-warm zone” which occupies the south, southeast and western central part of the WUS between 800 - 1500 m a.s.l and is characterized by annual rainfall of 800 - 1700 mm, average daily temperature around 18^0 C, three continuos relatively dry months (January-March) and intermediate rains (*Mluati*), which might occur during June/July. The “dry-warm zone” in the northwest area between 800-1800 m is climatologically characterized by 500-800 mm annual rainfall. The average daily temperatures are above 20^{0}C and a dry period of four months (June – September). In the north and northwestern fringes the NE-trade winds cause maximum rainfall in November/December (*Vuli*) whereas the long rains in April/May (*Mwaka*) are often unreliable. The "dry-cold zone" occupies the northwest area between 1700 - 2100 m a.s.l and is climatologically characterized by 500 - 800 mm annual rainfall, average daily temperatures around 16^{0}C, a four month dry period (May-August) and slight frosts, which accur during the dry periods in the valley bottoms especially during the dry season frequent mist improves the water balance of the area (Pfeiffer, 1990).

Data collection

Primary data composed of both socio-economic and ecological data regarding on farm tree crop/resources. Socio-economic data was collected through questionnaires (both open and closed ended), administered to randomly selected households in each of the villages and adopting a sampling intensity of 5%. The head of each household was interviewed independently, but any other household members present at the time of interview were deliberately encouraged to participate and supplement the information given. Pre-testing of the questionnaire was done to 3 households prior to the actual survey. Informal discussions were also held with members of the community where chances arise to supplement information obtained from interviews. The socio economic survey was used to avail information on motives behind tree retention/planting or domestication by respective farmers or other individuals, mode of tree establishment, tree species preferences for on-farm planting/retention, perceived benefits of tree retention on farm, preference for exotic or indigenous species and management approaches by farmers for managing off-forest trees. Ecological data were collected through inventory of on-farm trees. For each sample household, assessment of tree species composition on farm was done using 0.07 ha-sample plot (15 m radius) established in the farm. The following information was collected from each plot; identification of all tree species in both vernacular and scientific names, measurements of diameter at breast height (dbh) for all trees with dbh >5 cm using callipers and/or diameter tape, uses if any of the measured trees.

Secondary data were obtained through reviews of both published and unpublished documentation on farm tree resources and on-farm tree planting practices. Also additional information related to the study area was obtained from available records and documents in the Mazumbai Forest Reserve Library and staff from Sokoine University of Agriculture (SUA) who had made studies in the area.

Data analysis

Data from questionnaires were coded into a format that can give meaningful information and analyzed by using the Statistical Package for Social Sciences (SPSS) and Excel programs. ANOVA and/or T-test were used to determine any differences in response between different villages. Results were presented in the form of descriptive statistics, tables and histograms.

The ecological data were analyzed for species composition, richness and diversity, and Species Importance Value Index (IVI). Species importance values were computed as the average of the relative basal area, relative density and frequency. Family importance values were also computed as the average of the relative basal area and relative frequency for each family. Species diversity was computed using Shannon's diversity index ($H' = -\sum P_i * \ln P_i$) where H' is the index of diversity, P_i is the importance value of a species as a proportion of all species. Simpson's diversity index was computed as $C = \sum Pi^2$ where C is the index number and Pi as defined above (Munishi, 2001).

Results and Discussion

Respondent characteristics

Table 1 shows the main respondent characteristics for the study population. Males represented 76% of the respondents while females represented 24. Most of the interviewees were 30-45 years old and are the ones who mainly plant trees. The younger age group (<30 years) was narrowly represented. Single respondents represented 18% while married couples were 60% and divorced/separated were 22%. The family size average is 8 people (range 6 – 10) and majority of households own less than 3 ha of land. The mode of land acquisition is mainly through village government allocation. It is apparent that forest products though supplemental to agricultural production is among major household income earner in KwaBosa and Mgwashi but less in Mayo. Land size and family size may have big implications on tree planting.

Table 1 Characteristics of respondents in the study population - West Usambaras NE Tanzania.

	% Respondents			
Attribute	Kwabosa	Mayo	Mgwashi	Overall
Age distribution				
<30	14	20	15	16
31-45	29	60	54	47
>45	57	20	31	37
Gender				
Male	86	80	62	76
Female	14	20	39	24
Marital status				
Single	14	10	31	18
Married	72	70	39	60
Divorced/separated	14	20	30	22
Size of the household				
<5 people	28	20	40	29
6-10 people	43	60	40	48
>10 people	29	20	20	23
Mode of land acquisition				
Inherited from parents	14	30	15	20
Purchased	14	10	16	13
Given by the village government	72	30	54	52
Clearing of forest/bushland		30	15	23
Sources of Income				
Forest products/resources	43	25	46	38
Petty trade	38	30	15	28
Others	19	45	39	34

All the respondents raised a concern as to the inadequacy of the sizes of land they own pointing out that the inadequacy is caused by large household size, land being very expensive nowadays and sometimes the land wasn't available even if someone wanted to acquire some due to population pressure. Attempts to distribute land equally to household members results into land fragmentation economically less useful parcels. Such a situation has exacerbated land degradation resulting into low land productivity per unit area thus increasing the need for larger land parcels to ensure adequate food production. Farm inputs and good land husbandry techniques which would improve the situation are not available/adequate intensifying the adverse impacts (Kaoneka, 1993; SECAP, 1997). This is likely to have a negative impact on tree planting/tree retention on farmlands and off-forest tree resources in the area.

On farm tree species composition, richness and diversity

Table 2 shows the general characteristics of on farm tree resources in the West Usambaras NE Tanzania and Table 3 lists the species observed in the area. A total of 46 tree species belonging to 25 families were identified. This richness compares well with a natural forest occurring in the area. Munishi (2001) observed 69 tree species with DBH $\geq$ 6 cm in the natural forest at Mazumbai and Kisimagonja and 90 trees in the Uluguru Mountains. Probably the situation in the farmlands would compare with a relatively degraded natural forest. On the other hand, given the nature and intensity of use of farmlands in this area the observed richness is apparently high.

The tree basal area is also comparable to that of most natural forest ecosystems such as miombo woodlands and some dry montane forests. It is however almost half of that of montane forests in the area which is significant under farmland conditions. The basal area for Usambara and Uluguru forests has been observed to be 52 m^2 ha^{-1} and 42 m^2 ha^{-1} respectivel
The tree density is 147 stems per hectare comparable to a managed plantation forest at rotation age. Generally these parameters are adequate for on farm trees given the fact trees are not the major crop form a farmland rather agricultural crops.

Table 2 Characteristics of on-farm tree resources in the West Usambaras NE Tanzania

Parameter	Values
Richness	46
Basal area(m^2 ha^{-1})	21
Density	147
Shannon's Index	2.7
Simpson's index value	0.07

Species diversity

The index of dominance was 0.07. This low value (Table 2) shows that each species contributes to the community relatively evenly. The Shannon's and Simpson's Diversity Indexes were 2.7 and 0.93 respectively. These values are high which shows high species diversity of on farm tree resources in the west Usambaras. The index of dominance reflects species dominance in a plant community. The lower the index value the lower the dominance of a single or few species. The Simpson's Diversity Index (SIDI) represents the probability that any species encountered at random would be different species, and its range is $0 \geq SIDI < 1$. The Shannon's diversity index represents the amount of "information" per individual (or species in this case) and its range is > 0, without limit. The higher the values the greater the diversity. Values > 2 for Shannon's Index have been assigned medium to high diversity. The diversity of on farm trees compares well with the diversity of natural forests in the area. Munishi (2001) obtained a value of 0.1 and 0.06 for dominance index in the Usambara and Uluguru respectively. For the Simpson diversity index the values were 0.90 for the Usambara and 0.93 for the Uluguru forests while the Shannon's diversity index was 2.93 and 3.31 for the Usmbara and Uluguru natural forests respectively.

Table 3. Different tree species found in the study area

S/N	Species		Family
	Vernacular name	Botanical name	
1	Mbokoboko	*Entandrophragma excelsum*	Meliaceae
2	Kogho	*Croton sylvaticus*	Euphorbiaceae
3	Mchungwa	*Citrus sinensis*	Rosaceae
4	Mfalume	*Sterculia appendiculata*	Euphorbiaceae
5	Mfyokisi	*Prunus persica*	Rosaceae
6	Mhombehombe	*Morinda asteroscepa*	Rubiaceae
7	Mhondoghogho	*Neoboutonia spp*	Euphorbiaceae
8	Mjambega	*Celtis durandii*	Ulmaceae
9	Mkabela	*Grevillea robusta*	Proteaceae
10	Mkaratusi	*Eucalyptus spp.*	Myrtaceae
11	Mkokoko	*Casearia engleri*	Samydaeceae
12	Mkonde	*Myrianthus arboreus*	Moraceae
13	Mkulo	*Ocotea usambarensis*	Lauraceae
14	Mkumba	*Macaranga kilimandscharica*	Euphorbiaceae
15	Mkunguma	*Sorindeia usambarensis*	Sapindaceae
16	Mkunguni	*Fagaropsis angolensis*	Rutaceae
17	Mkuyu	*Ficus capensis*	Moraceae
18	Mkwinini	*Cinchona spp.*	Rubiaceae
19	Mlimao	*Citrus limon*	Rutaceae
20	Mmandai	*Agauria salicifolia*	Ericaceae
21	Mndemzize	*Garcinia volkensii*	Guttiferae
22	Mnyasa	*Newtonia buchananii*	Mimosaceae
23	Mparachichi	*Persea americana*	Lauraceae
24	Mpumu	*Anthocleista zambesiaca*	Loganiaceae
25	Msambu	*Allanblackia stuhlmanii*	Clusiaceae
26	Msambya	*Pachystela brevipes*	Sapotaceae
27	Mshai	*Albizia gummifera*	Mimosaceae
28	Mshegheshi	*Myrica salicifolia*	Myricaceae
29	Mshihwi	*Syzigium guineense*	Myrtaceae
30	Mshinga	*Trema orientalis*	Ulmaceae
31	Msisi	*Faurea saligna*	Proteaceae
32	Msongoma	*Flacourtia indica*	Flacourtiaceae
33	Mtindii	*Cussonia arborea / kirkii*	Araliaceae
34	Mtondoo	*Khaya nyasica*	Meliaceae
35	Mrunguu	*Erythrina abyssinica*	Anacardiaceae
36	Muula	*Parinari excelsa*	Rosaceae
37	Mvilu	*Vangueria tomentosa*	Rubiaceae
38	Mvumo	*Ficus thonningii*	Moraceae
39	Nkwaati	*Teclea nobilis*	Rutaceae
40	Muembe	*Mangifera indica*	Anacardiaceae
41	Mwiza	*Bridelia micrantha*	Euphorbiaceae
42	Mziraghembe	*Olea africana*	Oleaceae
43	Ng'weti	*Rauvolfia caffra*	Apocynaceae
44	Ntendee	*Cussonia spicata*	Araliaceae
45	Toamaghasa	*Isoberlinia schefffleri*	Caesalpiniaceae

Species Dominance

On farm tree species dominance was assessed using individual species importance values. The importance value index (IVI) for a species is a composite of three ecological parameters - density, frequency and basal area (sometimes referred to as dominance), which measure different features and characteristics of a species in its habitat. Ecologically density and frequency of a species measure the distribution of a species within the population while basal area measures the area occupied by the stem of trees. Based on the area quite different feature in the farmlands. The IVI rank species in a way as to give an indication as to which species come out as important elements of the on farm trees. Based on the IVI *Albizia gummifera* was the most dominant species followed by *Parinari excelsa, Newtonia buchananii, Cinchona spp and Ficus capensis, Casearia engleri, Syzygium guineense, Ficus thoningii*, and *Sorindeia usambarensis* (Figure 2). Others are *Eucalyptus* sp, *Croton sylvaticus*, *Flacourtia indica*, *Myrianthus arborea* and *Allanblackia stuhlmanii*. Except for *Cinchona sp* and *Eucalyptus* sp which are exotic, all the other dominant species are indigenous and are likely to have been left on farm during forest clearing for farmlands. Both species have no negative impacts on agricultural crops and are good candidates for on farm management. *Albizia gumifera* and *Croton sylvaticus* seem also to be good for farm fertilization through leaf fall (and probably N-fixation) as it shades its leaves during planting season adding on leaf organic matter and reducing shade to agricultural crops (Munishi – personal observations)

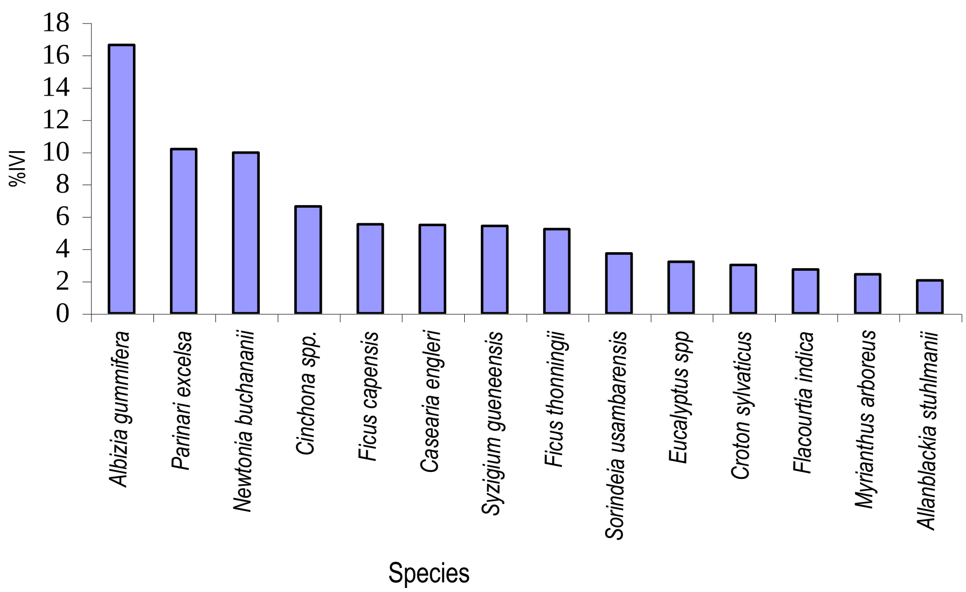

Figure 1: On farm tree species and their dominance in the west Usambaras NE Tanzania

Farmers' motives for tree retention/planting on farmlands

Retaining trees in farms is a tradition, which was found to be common especially in the three villages' Kwa Bosa, Mgwashi and Mayo. These trees are retained for various purposes including supply of construction material, environmental services such as windbreak, catchment, shade, soil fertility improvement (nutrient cycling) and food such as edible fruits and nuts. Table 4 lists tree species with highest frequency of being retained on farm and around houses and the reasons for their management on farm.

Table4: Different reasons for tree retention/planting

Species Name			
Local	Botanical	Family name	Reasons for retention/planning
Mtondoo	*Khaya nyasica*	Meliaceae	Timber, firewood, building, poles, charcoal, conservation
Ng'weti	*Rauvolfia caffra*	Apocynaceae	Firewood, catchment, timber, medicine.
Ntendee	*Cussonia spicata*	Araliacea	Catchment, fodder
Muula	*Parinaria excelsa*	Rosaceae	Edible fruits and nuts, catchment
Mkulo	*Ocotea usambarensis*	Lauraceae	Firewood, catchment, conservation, building poles, timber
Mbokoboko	*Entandrophragma excelsum*	Meliaceae	Timber, catchment, soil conservation
Mshai	*Albizia gummifera*	Mimosaceae	Firewood, medicine, conservation, fodder, ritual.
Mrungu	*Erythrina abyssinica*	Mimosaceae	Building poles, timber, firewood, medicine, catchment, conservation, fodder, ritual
Mvumo	*Ficus thonningii*	Moraceae	Medicine, ritual, fodders, religious.
Mkuyu	*Ficus capensis*	Moraceae	Catchment, ritual
Mshihwi	*Syzigium guineense*	Myrtaceae	Edible fruits and nuts, firewood, medicine, catchment conservation, dyes.
Mziragembe	*Olea africana*	Oleaceae	Building poles, firewood, conservation, insecticides, medicine, rodents & snake repellents.
Mvilu	*Vangueria tomentosa*	Rubiaceae	Medicine and conservation
Mshinga	*Trema orientalis*	Ulmaceae	Firewood, dyes, fodder, ritual, conservation, medicine
Msambu	*Allanblackia stuhlmanii*	Guttiferae	Dyes, edible fruits and nuts
Msisi	*Faurea saligna*	Proteceae	Dyes
Mshegheshi	*Myrica salicifolia*	Myricaceae	Firewood, medicine
Kogho	*Croton sylvaticus*	Euphorbiaceae	Fodder, medicine
Mtindii	*Cussonia arborea*	Araliaceae	Firewood, medicine, fodder, timber
Mwiza	*Bridelia micrantha*	Euphorbiaceae	Fodder, charcoal, timber, building poles, medicine
Mkunguni	*Fagaropsis angolensis*	Rutaceae	Timber, firewood
Mnyasa	*Newtonia buchananii*	Mimosaceae	Timber, firewood, fodder, mulch
Msongoma	*Flacourtia indica*	Flacourtiaceae	Timber, firewood, fodder, edible fruits and nuts,medicine
Mndemzize	*Garcinia volkensii*	Guttiferae	Timber, building poles, firewood.
Mparachichi	*Eucalyptus spp.*	Lauraceae	Timber, building poles, firewood.
Nkwaati	*Teclea nobilis*	Rutaceae	Timber, firewood, building poles, medicine, charcoal
Mkwinini	*Cinchona spp.*	Rubiaceae	Medicine, building poles
Mpumu	*Anthocleista grandiflora*	Loganiaceae	Medicine
Muembe	*Mangifera indica*	Anacardiaceae	Fruits, timber
Toamaghasa	*Isoberlinia scheiffleri*	Caesalpiniaceae	Timber, firewood, building poles, charcoal
Mchungwa	*Citrus sinensis*	Rutaceae	Fruits
Mfyokisi	*Prunus africana*	Rosaceae	Edible fruits and nuts
Mjambega	*Celtis durandii*	Ulmaceae	Timber, firewood, building poles, charcoal,
Mhombehombe	Hallea rubrostipulata	Rubiaceae	Firewood, conservation
Mkonde	*Myrianthus engleri*	Moraceae	Timber, firewood, building, poles, charcoal, conservation
Mkumba	*Macaranga capense*	Euphorbiacea	Timber, firewood, building poles, charcoal,consrvation
Mlimao	*Citrus limon*	Rutaceae	Edible fruits
Mmandai	*Agauria salicifolia*	Ericaceae	Medicine, firewood
Msambya	*Pachystela brevipes*	Rosaceae	Timber, firewood, building poles, charcoal, conservation, medicine, edible, fruits, bee forage, shade
Mkunguma	*Sorindeia usambarensis*	Sapondinaceae	Timber, firewood, building, poles, charcoal, conservation
Mkaratusi	*Eucalyptus spp.*	Myrtaceae	Timber, firewood, building poles, charcoal
Mkokoko	*Casearia englerii*	Flacourtiaceae	Building poles, firewood
Mkabela	*Grevillea robusta*	Proteaceae	Timber, firewood, building poles, charcoal,consrvation

The contribution of off-forest tree resources to household forest based needs.

It was observed that farmers have high dependence on on-farm tree resources for different uses leading to increased demand for forest products and pressure on already meager land resources. Other studies have observed the same.(Munishi et al 2004; Kaoneka, 1993; Kaoneka and Solberg, 1996; Bjondalen, 1992; Pocs, 1988).

Timber production is among the major use of trees on farm lands. Trees are harvested for timber mainly for sale to earn cash income though some is used to satisfy domestic demand. Such earnings are believed to greatly boost household incomes in the west Usambaras though the stock on-farm seems to dwindle at an alarming rate.

The major timber species reported in the present study include *Newtonia buchananii, Ocotea usamabrensis, Fagaropsis angolensis Beilschmedia kweo, Khaya nyasika, Cephalosphaera usambarensis* and *Odyndea zimmermanni.* These species have also been reported as valuable timber species by other studies conducted in these mountains (Kaoneka, 1993; Moshi, 1997).

Like in other developing countries, rural communities in this area depend on trees for supply of building poles and other round wood for construction and firewood for cooking and heating. In harvesting for building poles it seems that the local people are very selective in species choices. The important qualities preferred for poles are durability and straightness of the tree and its fibres (trees with interlocked fibres are not preferred, as these cannot be easily chopped. The most durable species accepted by many people in the area is *Albizia gummifera* which is now in short supply, and *Allanblackia stuhlmanii* which is endemic to the West Usambara. Preferences for these species is based on their resistance to wood borers and durability. TFAP, (1989) Ruffo and Maliondo, (1990), Kessy, (1998) observed that trees species preferred for construction material in the Usambaras are those with high durability. This would be reasonable since the local people would need construction materials that will ensure durable houses which will take long time before replacement. Observations have shown that miombo species preferred for building poles in Malawi have the similar characteristics (Hamilton,1989).

Fuel wood was the other largest (probably the first) consumer of on farm trees. More than 90% of the population rely on farm tree resources for production of firewood. Majority of the respondents (63.3%) face fuel wood shortage due to dwindling on farm tree resources given the fact that the surrounding natural forests are reserved and under strict regulations with respect to their use. Among the on-farm trees used for firewood are *Rauvolfia caffra, Albizia gummifera, Erythrina abyssinca, Syzigium guineense, Eucaluptus* spp and *Newtonia buchananii*.

About 15 tree species with medicinal properties were recorded as obtainable from on farm sources. Traditional medicine is important in primary health care for many rural communities in the West Usambara Mountains and other developing countries. About 90% of the rural population in Tanzania and 60% of the Masai of Kenya for instance, meet their primary health care needs through traditional medicine (Bannerman, 1982; Singida, 1994; Mahunnah and Mshigeni, 1996). Several plants mentioned as medicinal plants in this area have also been reported to be used for the same or other purposes. For example, *Rauvolfia caffra, Rhus natalensis, Albizia gummifera, Ficus thorningii, Vangueria volkensii, Trema orientalis, Myrica salicifolia and Cussonia arborea, Erythrina abyssinica, Ficus thorningii Ficus thorningii* were mentioned as among the plants used for medicinal purposes.

Conclusions and Recommendations.

There is a wealth of on farm tree resources of significant importance to the local people in the West Usambaras. There is a wealth of on farm tree resources of significant importance to the local people in the

West Usambaras. Most of the trees on farm were retained during land clearing for agriculture from the natural forest that existed. The motives for tree retention on farm ranged from supply of timber to edible fruits, medicine and soil erosion control. On farm tree diversity is and richness is high and comparable to the natural forests that exist in the area. Further tree management on farm is constrained by land availability and possibly adequate markets for forest products. Despite signs of decline in on farm tree resources due to different reasons a relatively high proportion of household wood based needs are still met by on farm sources. Sustainable management of on farm tree resources hinges much on more information and enhancement of indigenous tree management systems with supplements from afforestation efforts using appropriate fast growing tree species. Research into the socio-ecology of on farm tree resources is still needed for input into enhancing on farm tree management

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20. FACTORS AFFECTING ADOPTION AND DISSEMINATION OF AGROFORESTRY TECHNOLOGIES IN TANZANIA: A CASE OF HASHI/ICRAF AND RUVU FUELWOOD PILOT PROJECT

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Abstract

A study to investigate factors that contribute to the limited adoption of agroforestry (AF) technologies and delivery of AF information to the end users was conducted in 2004 at HASHI/ICRAF (now NAFRAC) and Ruvu Fuelwood Pilot Project (RFPP) (now Ruvu Fuelwood Development Project). Data were collected using Participatory Rural Appraisal (PRA), semi-structured interviews (SSI), participant observations, questionnaire surveys and use of secondary data. Six AF technologies namely rotational woodlots, boundary planting, improved fallow, fodder bank, scattered trees on farms and traditional and improved *ngitili* have been introduced and practiced at HASHI/ICRAF and only rotational woodlots were introduced at RFPP. Three major AF dissemination methods namely: individual, group and mass methods were revealed at both projects. At RFPP, individual and group extension methods were the most common methods and were reported by 67% and 87% respondents, respectively. At HASHI/ICRAF, mass media method was most popular (100% of respondents) though individual and group methods were also used. Factors that hindered adoption and dissemination of AF technologies included inadequate provision of extension services due to insufficient number of extension staff, inappropriate dissemination methods and language of the extension materials, lack of transparency at project level, land tenure system that hindered investment in tree planting, poor institutional linkage, lack of frontline actors to link the projects extension officers and farmers. It is recommended that factors affecting dissemination and adoption of AF technologies have to be analyzed prior to the initiation of AF programme for proper adoption and dissemination of AF technologies. In addition, a combination of individual, group and mass media depending on circumstances and objectives of AF programme is highly recommended for effectiveness in disseminating agroforestry technologies.

Introduction

Agroforestry is a land use system that integrates trees, crops and animals in a way that is scientifically sound, ecologically desirable, practically feasible and socially acceptable by farmers (Nair, 1979). Sustainable production and optimum environmental conservation are the objectives emphasized in agroforestry systems (Kessy, 1998).

Ruvu Forest Reserve was gazetted in 1957 with the original objective of establishing plantation for supplying industrial fibre for the production of pulp and paper. However, following management failures, partly due to poor species performances, which resulted from severe drought and strong weed competition, the initial objective was abandoned and the scheme was transferred to Sao Hill in 1980 (MNRT, 2002a). The management objective for the Ruvu Forest Reserve was then changed to production of fuelwood to meet the growing wood fuel demand for the city of Dar es Salaam and surrounding populations. To fulfill this objective the Ruvu Fuelwood Pilot Project (RFPP) was started in fiscal year 1999/2000. The project is a result of several management options and strategic decisions attempted by the government of Tanzania through the Forestry and Beekeeping Division (FBD) towards improved management of the Ruvu Forest Reserve. To achieve its objectives RFPP practices Joint Forest Management (JFM) by capitalizing on agroforestry in the forest management plots (Rocheleau *et al,* 1988). The main agroforestry technology advocated at RFPP is rotational woodlots, which consist of clearing and establishing annually, small woodlots until the whole allocated plots are planted with trees. The woodlots may later be sequentially harvested depending upon farmers' production objectives.

The Hifadhi Ardhi Shinyanga (HASHI) project was launched in 1986/87 with funding from the government of Tanzania. In 1990 the Norwegian government, through NORAD, signed an agreement for Shinyanga Soil Conservation and Afforestation Programme (SHISCAP), which commenced in March 1991 as an umbrella programme with three components including support to HASHI, Shinyanga Mazingira Fund (SMF) as well as research component handled by the International Center for Research in Agroforestry (ICRAF) now called World Agroforestry Centre (WAC). The HASHI/ICRAF major objective was to develop appropriate agroforestry technologies that would alleviate the problems of natural resources degradation in the Sukuma agro-pastoral system. Specifically the project aimed at alleviating the shortage of fuelwood and fodder, and declining soil fertility.

SHISCAP as an umbrella programme was phased out in 1993 whereas SMF and ICRAF were brought under the coordination of HASHI. In December 1994, the sector agreement between the governments of Norway and Tanzania was signed for implementing the programme on Natural Resources Management and Environmental Planning (TAN, 092). The TAN 092 programme comprises of 12 projects including HASHI and RFPP. In 2000 the midterm review team among other things, recommended the upgrading of the HASHI and HASHI/ICRAF project to a National Resource and Competence Centre in Agroforestry. However, the centre has ultimately settled as the Natural Forestry Resources Management and Agroforestry Centre (NAFRAC).

Agroforestry research and development in Tanzania started way back 1980s, but to date only few farmers practice it despite the fact that many of agroforestry technologies have given positive results in terms of increased crop productivity, increased food security and ultimate poverty alleviation (Kyomo, 1994). It is hypothesized that many farmers are either not aware or lack the knowledge on agroforestry. The factors that contributed to low adoption and poor dissemination of agroforestry technologies are yet to be clear calling for the present research work. This article is an attempt to investigate the factors that contribute to the limited adoption of agroforestry technologies and delivery agroforestry information to the end users.

Materials and Methods

Study areas

The study was conducted in 2004 in RFPP and HASHI/ICRAF. RFPP is located within Ruvu North Forest Reserve (RNFR) (32,000 ha) in the Coast Region within Kibaha District at an altitude of 80 m above sea level, between latitudes 6^{o} 33' and 6^{o} 43' S and longitudes 38^{o} 48' and 39^{o} 03' E. RFPP covers about 6% of the area of RNFR and is currently managed by four villages (Msangani, Mwendapole, Mkuza and Kongowe) out of eighteen villages which border the reserve. Project offices are situated at Kibaha – Kongowe ward at about 60 km west of Dar es Salaam Region, about 3 km from the Dar es Salaam-Morogoro highway. The area is climatically characterized by a bimodal rainfall pattern with short rains falling between November and December and long rains between March and May. Mean annual rainfall ranges between 800 and 900 mm falling in an average of 81 days per year. Temperatures tend to be higher during the months of January and February, with mean monthly temperatures between 23^{0} C and 27^{0} C, having occasional maxima up to 36^{0} C and minima as low as 18^{0} C.

Soils are free draining, primarily sandy, sandy loam and gravel varying substantially over short distances. Clay soils are mostly found in valley bottoms and areas close to streams. The topsoil to 50 cm is dominated by pH 5.0 - 6.5 decreasing with increasing soil depth to 9.4 at 72 cm below earth surface (Maghembe, 1979).

HASHI/ICRAF activities covered the whole of Shinyanga Region, which is situated in the northwestern part of Tanzania between latitudes $2^{o} – 5^{o}$ S and longitudes $31^{o} – 35^{o}$ E. The altitude varies between 100 m and 1500 m a.s.l. The region falls under the semi-arid zone of the country with mean annual rainfall ranging from 600 mm in the East to 1200 mm in the West. Shinyanga Region is characterized by detached hills, great craggy masses of sharply angled rocks. In these outcrops, grassy "*Mbuga*" plains are flat, gentle and undulating covered with low sparse vegetation (MNRT, 2002b). Administratively, Shinyanga is divided into seven districts and is dominated by the Sukuma agro-pastoral community. For the purpose of this study, survey was conducted in Kahama and Kishapu Districts.

Sampling and Data collection

Both purposive and random sampling techniques were used whereby villages were purposively sampled and households were randomly selected for questionnaire interviews. The bases for purposive sampling were site variability, accessibility and concentration of project activities. Two villages in each study site were considered based on socio-economic variability and geographical characteristics. Msangani and Mwendapole were selected in RFPP site whereby in HASHI/ICRAF, Buzinza and Kagongwa were selected from Kishapu and Kahama Districts respectively. A number of data collection methods and techniques were used for triangulation of data and/or information.

Participatory Rural Appraisal (PRA) has been used as a method aiming at enabling local people to share, enhance and analyze their knowledge of life and conditions (Chambers, 1992). PRA techniques used included participatory mapping and modeling, Venn diagramming, wealth ranking, pair wise scoring and ranking and transect walk. The use of these techniques aimed at building rapport with the farmers and learn from them. Pair wise scoring and ranking enabled the analysis of problems hindering adoption and dissemination of agroforestry technologies. Transect walks enabled the team to appreciate what is really happening in the project area. That is actual project implementation in the field in line with a popular saying that "seeing is believing".

Semi-structured interviews (SSI) defined as guided conversation with topics of interest predetermined and questions or insights arise as a result of discussion and visualized analyses, were used to get information from key informants (individuals who are accessible, willing to talk and have great depth of knowledge about issues under discussion). Unlike structured or formal interviews, SSI concentrate not only on the questions asked, but also on the context in which the interview takes place (Mawe, 1998). In SSI the interview context is recognized to have a great or even greater influence on the quality of the information exchanged than the questions themselves. In order to remain focused and carefully controlled, a structured guide or checklist was used.

Participant observation (PO) is a qualitative data gathering method that requires direct observation of activities, behaviour, relationship and process in the field. In this context, PO involved observation of community, group, individual households and landscapes. PO method provided the context within which all other methods were applied and has functioned as the initial medium for learning about social and physical environment interrelationships. PO was primarily used to tie together the more discrete elements of data collected by other methods forming an iterative process between PO and other methods. The most important tools during PO were curiosity, willingness to learn from other people and ability to adapt to the rhythm and lifestyle of local people (Marin, 1995).

In questionnaire surveys, a structured questionnaire with both closed and open-ended questions was used. Questions asked were grouped into three categories: classification, factual and opinion. Classification questions covered aspects such as age, educational levels, wealth status and marital status. This type of questions was asked chiefly to provide information by which the respondents could be distinguished in the analysis. The majority of questions asked were concerned with facts. The word fact was used here in a wide sense, though describing questions as factual does not imply that the answers given are necessarily accurate. Opinion questions are sensitive to changes in wording and sequence than factual questions. They can be asked in different ways and tend to generate different aspects of the opinion. In this case, the questionnaire contained several repeated, but differently phrased opinion questions as a mean of checking the validity of the answers. The questionnaire was administered in 4 villages, two from RFPP and two from HASHI/ICRAF. A total of 80 households, 20 from each village were randomly selected for this survey. At RFPP, the first village Mwendapole, is located farthest from the project area compared to the remaining 3 villages participating in the project, whereas the second sampled village, Msangani, is the one closest to the project area. In the case of HASHI/ICRAF, the first village, Buzinza, was selected from Kishapu district, which has comparatively poor performance in adopting agroforestry technologies whereas the second village, Kagongwa, was taken from Kahama district which was distinguished as one of the best agroforestry adoption areas.

In secondary data, a number of published and unpublished documents were consulted at RFPP and AHASHI/ICRAF. Such pre-existing data were both qualitative and quantitative and served dual purposes, they first saved considerable time and expenses and secondly, acted as checkpoints for the primary data from the field.

Data analysis

Data collected by using PRA techniques were analyzed with the help of local people right in the field and feedback was given immediately to them for verification and custody. Most of the data collected through participant observation and SSI were analyzed by content analysis. In this case, the recorded dialogue was broken down into smallest meaningful units of information or themes and inferences were made. Data from questionnaire were coded and analyzed using the Statistical Package for Social Sciences (SPSS) and Microsoft Excel Spreadsheet. Descriptive statistics such as ranges, means and percentages were performed.

Results andDiscussion

Agroforestry technologies introduced

The AF technologies introduced in the study areas include rotational woodlots, boundary planting, improved fallow, fodder bank, scattered trees on farms and traditional and improved *ngitili* as summarized in Table 1. The main AF technology adopted at RFPP was rotational woodlots as practiced by all respondents (100%). In the case of HASHI/ICRAF, farmers acknowledged to practice a variety of technologies. Boundary planting, with 40% of the respondents practicing it, was the most popular or most preferred AF technology in the surveyed villages at Shinyanga. Other AF technologies were traditional *ngitili* (traditional fodder reserve) with regenerated or planted trees (17.5%), rotational woodlots (12.5%), scattered trees on farm (10%), improved *ngitili* (2.5%), improved fallow (2.5%), and fodder bank (2.5%). The popularity of rotational woodlots and other AF technologies in Shinyanga and other areas are intensively described by Nyadzi *et al*., (2003). The authors further indicated that the rotational woodlots is the potential AF technology to overcome shortage of wood to many parts of Sub Saharan Africa.

In Shinyanga boundary planting (40%), impacts a sense of ownership of land parcel, which is characteristic of a feudalist society. Apparently, from the land tenure system observed during the fieldwork, few landlords own land and a multitude of landless people survive through land renting. The results of having no land gives rise to uncertainity in investment. When studying AF and land tenure, Sinden and King (1990), indicated a similar situation that insecure or inequitable land ownership has high influence in AF technology adoption. In fact, there are no more general lands in Shinyanga.

Table 1: Percentage of respondents practicing AF technologies in the study areas

Agroforestry technology	RFPP (n=40)			HASHI/ICRAF (n=40)		
	Mwendapole	Msangani	Average	Buzinza	Kagongwa	Percentage
Boundary planting	NA	NA	NA	21	59	40
Traditional *ngitili*	NA	NA	NA	9	26	17.5
Rotational woodlots	100	100	100	7	18	12.5
Scattered trees on farm	NA	NA	NA	9	11	10
Improved ngitili	NA	NA	NA	1	4	2.5
Improved fallow	NA	NA	NA	2	3	2.5
Fodder bank	NA	NA	NA	2	3	2.5

NA = Not available

Dissemination methods

Basically, both RFPP and HASHI/CRAF have been employing three major agroforestry dissemination methods namely, the individual, group and mass methods, each with varying approaches (Figure 1). At RFPP, most respondents mentioned individual and group methods (67% and 87% of respondents respectively), while mass media was reported by few respondents (10%). At HASHI/ICRAF, mass media methods were most popular (100% of respondents) while group and individual methods accounted for 35% and 21% of the respondents respectively.

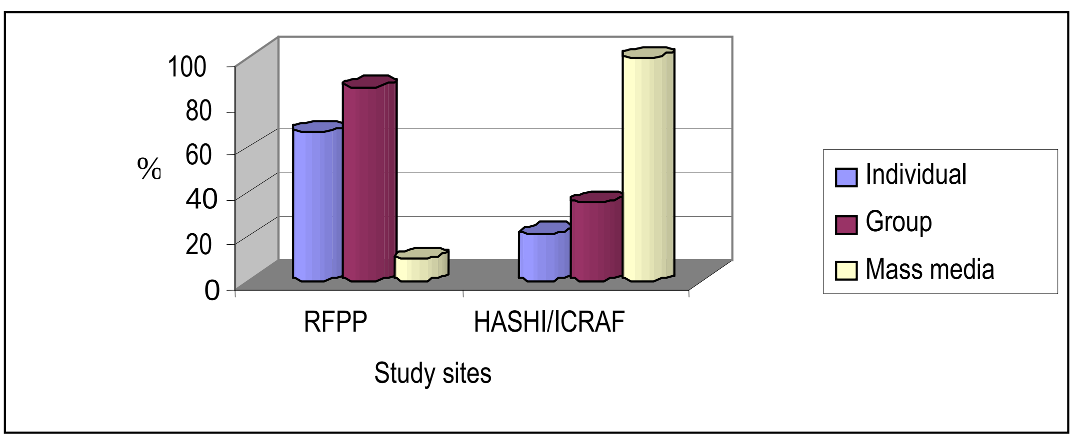

Figure 1: **Comparison of the dissemination methods between RFPP and HASHI/ICRAF (in percentages of respondents)**

Ranges of dissemination approaches, which may be individual, group or mass methods depending upon targets, were employed in both sites.

At HASHI/ICRAF, the approaches include:

- Farmer-to-farmer visits, interactive video shows (IVS), demonstration plots and farmers field day to research stations
- Workshops, meetings, seminars and training sessions to increase awareness and capacity on AF technologies
- Participatory deployment team (PDT) through various purposeful entertainment with drama groups such as *"Mbina ya Mabala"*, school pupils, local *ngoma* dancers and local theatre art for mobilization and sensitization of groups of farmers to participate in agroforestry. These three dissemination methods are commonly used in several other places (http://www.rirdc.gov.av/reports/AFT/oo-184sum.html)
- On-farm research increase involvement of farmers in technology development
- Audio-visual and print media like *"Watoto na Mazingira"* newsletter to disseminate AF options and providing forum for discussion
- PRA for problem identification and bottom-up planning for AF practices.

Some of these approaches such as farmer-to-farmer visits, video shows, PRA, meetings and seminars and workshops were also applied at RFPP though to varying intensities. For example, stakeholder farmers at RFPP have conducted visits to Kilimanjaro, Lushoto, HASHI/ICRAF, and the Tanzania Traditional Energy Development Organization (TaTEDO) in Dar es Salaam. Several PRA, meetings, video shows and seminars have also been carried out through RFPP Participatory Extension Team (PET).

Factors affecting adoption and dissemination of AF technologies

Inadequate extension services at individual level

A good number of respondents (68%) at RFPP complained that extension services were not adequate because there were fewer visits by extension agents to farmers than expected. A plausible explanation could be, either the extension officers' number is not enough or that the officers are not facilitated to the level of carrying out their duties effectively. This is similar to the observations reported by Sabban and Victoria (1993) who showed that inadequate access by farmers to inputs and other services has a negative impact in dissemination of AF technologies. This is also compounded by the fact that, some government extension services and traditional leaders are also not effective in the dissemination of some AF technologies (Kabwe, *et al*., 2004).

Value system of resources

At HASHI/ICRAF where majority of people are pastoralists, livestock are valued highly whereas in agricultural communities, crops are mostly valued. For instance, livestock keepers would prefer fodder trees and improved grass species while agriculturalists would be interested in trees, which improve soil fertility and compatible with crops. For the adoption to be successful, Sabban and Victoria (1993) observed a similar phenomenon in the Philippines that adoption has to go with the primary goal or priority requirement of the respective farmers. Therefore, depending upon which type of community one is dealing with, understanding their preference is important for successful adoption. In Shinyanga, for that matter boundary planting was more preferred whilst in RFPP, rotational woodlots were dominant. The most important thing in adoption of AF technologies is farmers' attitude and perception of values and meaning of the AF technology in place (Sabban and Victoria, 1993).

Land tenure system

Land ownership patterns affect tree investment especially when there are landless people in the community. Land tenure has also been noted to be a fundamental challenge not only in dissemination and adoption of AF technologies but also in developing a new farming system (Sabban and Victoria, 1993). This is a particular case with Kishapu district where livestock keeping is dominant and most farmers survive by purchasing or renting land from few landlords. Figure 2a shows that, the dominant mode of land acquisition at RFPP was the allocation by the project (RFPP) (41.9%), followed by purchasing (24.1%), borrowing (19.7%) and inheritance (14.3%). On the other hand, at HASHI/ICRAF project areas, the dominant form of land acquisition was through purchasing (55%), followed by inheritance (38.9%) and renting (6.7%) as shown in Figure 2b. Though not featured very much in questionnaire survey, land renting was reported by key informants to be the dominant mode of land acquisition in Buzinza village. People pay or rent for a piece of land of 1-2 acres (0.4 – 0.8 ha) a token fee of about 15,000/= and above. Observations made by Bakengesa *et al*. (2002) found the same thing that insecurity on land and trees tenure has resulted in low adoption of AF technologies by farmers in Shinyanga. On the other hand, the trading of land as a commodity implies a high demand for land and a strong sense of private land ownership among the respondents. This and the prevalence of land renting were pointed out as the main drawback towards tree planting and hence affected adoption of AF technologies. This is because it is not easy to plant trees on land that is definitely not yours as its ownership is uncertain. When studying land tenure and management of land and trees in Ghana, Keijiro *et al*. (2003) also observed that the decision to plant trees or leave land to fallow is highly affected by land tenure.

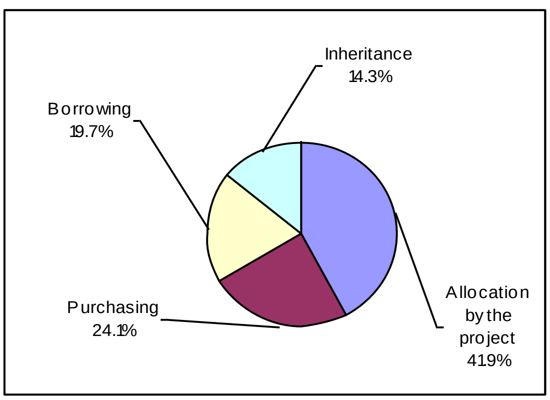

Figure 2a: Mode of land acquisition at RFPP

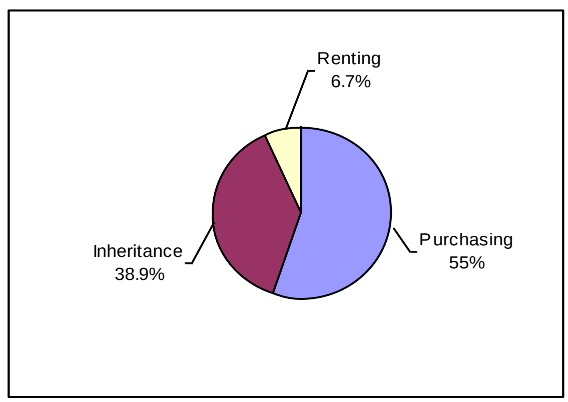

Figure 2b: Mode of land acquisition at HASHI/ICRAF project area

Poor institutional linkage

It was revealed during PRA (Venn diagramming for institutional analysis) and SSI that there was poor collaboration between district authorities and technical staff from HASHI/ICRAF. This could lead to suspicion of farmers on the project and hence affecting the adoption of AF technologies. As the way of improving adoption of AF technologies, collaborative meeting is required to develop strong linkages between local governments and project authorities. The importance of forming a dissemination network to coordinate research, training and dissemination of AF technologies is also reported by Kabwe *et al*. (2004) and Bakengesa, *et al..,*(2004).

Lack of frontline actors to link the projects extension officers and farmers

In terms of extension services, a link between project extension officers and the farmers was poor in both sites. However, active and innovative farmers who were respected by other farmers were observed in RFPP and HASHI/ICRAF. For example, a farmer called Enne Haule had planted *Crotolaria* sp. (*marejea*) in her plot and she managed to explain the reason for planting those plants as weed control. In discussion, other farmers were convinced to follow what Enne did. Therefore, farmers of this type could be considered as frontline actors for linking extensionists and other farmers. According to the experiences gained in Zambia, Kabwe *et al*. (2004) reports a similar experience where farmer trainers are the source of initial AF technologies information to 41% of farmers. The effect of missing these actors is slow adoption of AF technologies, as farmers tend to believe messages from their fellow farmers than from extension agents.

Language of extension materials

Most of the extension materials were written in English language, which is difficult to be understood by farmers. Therefore, while the project management in both study sites claimed to have written various materials as part of disseminating AF technologies, most of the respondents (74% and 69% in RFPP and HASHI/ICRAF respectively) claimed to have not heard and seen those materials. Elsewhere it has been noted that lack of well prepared publications and poor knowledge (Sabban and Victoria, 1993) and skills by extension workers is also limiting adoption of AF technologies (http://www.rirdc.gov.av/reports/AFT/oo-184 sum.html). There is a need to translate the extension materials to a language that is clearly understandable to farmers (local people).

In appropriate dissemination methods

Table 2: Strengths and weakness of AF dissemination methods

Method	Strengths	Weaknesses
Individual	• Builds confidence • Effective in message delivery • High farmer-extension linkage	• Difficult to implement (time consuming) • High farmer suspicion on criteria of selection of farmers to study visit • Risk of differential treatment of farmers • Costly and need many extension agents • Risk of perpetuating malpractices
Group	• Easy sharing of knowledge and experiences • Technologies reach many farmers at a time • Bring farmers together • Cost effectiveness and efficiency	• Risk of domination by few local elites • Lack of confidence to express ideas in a large group • Lack of sense of responsibility
Mass	• Repetitive • Easy grasping and memorable • More effective in rural areas since it triggers high attendance	• Generally is capital intense • With the exception of few approaches such as interactive video shows, no immediate feedback • High mass influence

Although mass media methods were popular in HASHI/ICRAF and group methods praised at RFPP, there is no single method that can be claimed to be the best for disseminating AF technologies. It has also been noted that to be effective the use of a particular method has to target specific group of operators or general members of rural economy (http://www.rirdc.gov.av/reports/AFT/oo-184 sum.html). Strengths and weaknesses of each method are as shown in Table 2.

Conclusion and Recommendations

It is concluded that, proper dissemination method is very crucial in success of adoption of any Agroforestry technology. There is a need for optimal combination of individual, group and mass methods for effectiveness in disseminating AF information.

The following recommendations have also to be considered;

- There is a need to analyze a number of factors which in one way or another affect dissemination and adoption of AF technologies before embarking into initiation of agroforestry programmes
- The priorities for extensionists should always be given to those technologies that have greater potential to solve farmers' problems than the ones which are easy to carry out.
- There is also a need for optimal combination of individual, group and mass methods for effectiveness in disseminating AF information.
- Frequent collaborative meetings between farmers, experts from different areas are necessary so as to develop strong linkages between them.
- Extension materials have always to be put in simple language consumable by farmers.

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21. IMPACTS OF SCALING UP SUCCESSFUL AGROFORESTRY TECHNOLOGIES ON RURAL LIVELIHOODS IN WESTERN TANZANIA.

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Abstract

ICRAF and partners since 1987 in collaboration with farmers and national institutions have developed promising agroforestry technologies that provide significant benefits to smallholder farmers. In order for agroforestry to have impact on rural poverty, food security and environmental conditions, these technologies need to be scaled up to many farmers, and spread widely across the landscape and to have a critical mass of capacity at grass root levels. In this paper we present results of work by ICRAF and partners that is helping farmers and their families take steps out of chronic poverty and gaining sustainable development towards Africa green revolution. Today over 417,503 farmers in Malawi, Tanzania, Zambia, Zimbabwe and Mozambique (189,854 farmers in western Tanzania) are enjoying benefits through agroforestry focusing on working trees grown on farms and rural landscapes, that include "Fertilizer" trees for land regeneration, soil health and food security, fruit trees for nutrition, fodder trees that improve small holder livestock production, timber and fuelwood trees for shelter and energy and trees that produce various products and medicinal trees that combat diseases.

Introduction

Agroforestry in Southern Africa started in 1987, through collaborative efforts between International Centre for Research in Agroforestry (ICRAF) now World Agroforestry Centre and national agricultural and forestry institutions in Malawi, Zambia and Tanzania. The programme later extended to Zimbabwe in 1989 and Mozambique in 2001. Major land use problems of declining soil fertility, shortage of fodder, fuelwood and environmental degradation were identified that could be solved by planting and integrating trees on farms.

Agroforestry Research and Development Project in Tanzania was initiated in 1986 and is part of the Southern Africa Development Community (SADC) regional programme (Agroforestry Project for Sustainable Rural Development in the Zambezi Basin) which is funded by CIDA, Canada and covers 5 countries namely Malawi, Tanzania, Zambia, Zimbabwe and Mozambique. It is implemented by the World Agroforestry Centre (ICRAF) in collaboration with government and non-governmental institutions. The project in Tanzania collaborates with the Ministry of Agriculture and Food Security and the Ministry of Natural Resources and Tourism.

The goals of the project are to promote food security, environmental resilience and improve income particularly of small scale, resource poor farmers through the use of agroforestry technologies and innovations.

In Tanzania the project was initiated to address the massive environmental degradation due to deforestation, specifically declining soil fertility which leads to poor productivity, fuel wood shortage, shortage of dry season fodder for domestic animals and deforestation of natural woodlands. In Tanzania, the project operates in Shinyanga and Tabora Regions. This paper presents the impacts of the scaling up effort in Tabora and Shinyanga, Tanzania.

Adoption and impact assessment

Strategies of scaling up

The purpose of scaling up is to increase the adoption of diversified and improved agroforestry options in order to reach more resource poor farmers with a particular emphasis on women farmers.

The scaling up strategies of the project are:

- Capacity building (including training) at all levels.
- Establishing and strengthening of strategic linkages and partnerships with public, private sector and civil society.
- Create sustainable seed delivery systems for agroforestry.
- Studying policy framework for adoption of agroforestry.
- Improving farmer experimentation and participation in agroforestry development while taking special focus on women involvement.
- Improving and adding value and marketing of agroforestry products and services so that greater socio-economic benefits can be derived.
- Resource mobilization.

Agroforestry options

Agroforestry (AF) options being promoted are;

- Rotational woodlot and boundary planting using leguminous trees species such as *Acacia crassicarpa, Acacia leptocarpa, Acacia julifera, Acacia polyacantha, Acacia nilotica, Leucaena* spp, and non-leguminous trees such as *Azadirachta indica* for rehabilitation of ecosystem and improving soil fertility and income.
- Improved fallows using *Gliricidia sepium, Sesbania sesban, Tephrosia vogeli* and *Tephrosia candida* for improving soil fertility and increase food production.
- Fodder banks using *Gliricidia sepium, Acacia angustissima, Leucaena pallida* and *Calliandra* spp for improvement of livestock nutrition.
- Processing and domestication of indigenous fruits for improving nutrition and income generation.
- Domestication of medicinal trees for conservation of valuable indigenous trees and improvement of health.
- Nutritional gardens for food security and improved nutrition and income generation.

Partners

Dissemination and adoption of agroforesry has been promoted through partnership, with national institutions, public, farmers, civil society and private sector. In Tanzania the project is collaborating with the following institutions.

Active partners

- Ministry of Agriculture and Food Security
  - National Agricultural Research Institutes, particularly Tumbi ARDI
  - National Extension Services
  - Projects such as Participatory Agriculture Development Empowerment Project (PADEP), Sasakawa Global 2000
- Ministry of Natural Resources and Tourism
  - Tanzania Forestry Research Institute (TAFORI)
  - Tanzania Tree Seed Agency

- District Councils (Uyui, Tabora Municipality, Nzega, Igunga and Shinyanga rural).
- Non governmental organizations;
    - World Vision Tanzania
    - Tanzania Women Leaders in Agriculture and Extension (TAWLAE).
    - MVIWATA (Network of farmers groups in Tanzania).
    - Heifer Project international
    - AFRICARE
- Association of Tobacco Traders in Tanzania (ATTT).
- Sokoine University of Agriculture
- VI Agroforestry Project Musoma
- VI Agroforestry Project Mwanza
- VI agroforestry Project Kagera
- Catholic Church (CARITAS)
- Tabora NGO Cluster (HIV/AIDS).
- Small Scale Industry Development Organisation (SIDO).

Potential partners

- Tabora Development Foundation Trust (TDFT)
- Moravian Church in Western Tanganyika (Development Projects Department)
- Mogabiri Extension and Training Centre
- Buhemba Rural Agricultural Training Centre (BRAC)
- Golden Pride Project (Resolute Tanzania Ltd).
- PELUM Tanzania.

Impact of agroforetry

Impact assessment of ICRAF's work on the ground in the five countries covered by the Zambezi Basin Agroforestry Project is an important means to document evidence for either positive or negative effects of agroforestry as introduced by ICRAF and its partners on people's livelihoods. This evidence is required for several reasons, among which include:

- ICRAF needs to know if it is doing the "right thing" by introducing agroforestry into people's lives; Does it lead to a positive "change of lives and landscapes" as envisioned by ICRAF mission?

- Evidence for such impact is also an important argument to justify and continue the financial and institutional support by various donors ICRAF has enjoyed in the past. If agroforestry as a sustainable means to positively change people's lives is working, then proof of this needed for justification of financial support.

Impact assessment was done in each of the five countries encompassing ICRAF's southern Africa regional programme namely Zimbabwe, Mozambique, Malawi, Zambia and Tanzania, in 2004.

Respondents were sampled using various methods that included stratified random sampling, systematic random sampling and cluster sampling. In cases where only a small group of farmers had adopted a particular technology, total enumeration was done. Depending on the specific country situation, the impact assessment was done in one site or several sites, targeting farmers from villages.

Table 1: Overview of agroforestry technologies assessed

Country	Agroforestry technology assessed
Malawi	Simultaneous intercropping
	Relay intercropping
Mozambique	Improved fallows
	Simultaneous intercropping
	Relay intercropping
Zimbabwe	Fodder banks
Tanzania	Woodlots
	Fodder banks
	Fruit processing
Zambia	Improved fallows
	Biomass transfer

In most of these countries it is evident that agroforestry has a positive impact on the livelihoods of the farmers and their families, in the following areas:

- Improved soil fertility and yields
- Increased income and savings
- Increased knowledge and experience related to agroforestry
- Improved food security and nutritional status
- Improved health status and increased health expenses
- Increased educational expenses
- Increased firewood supply
- Mitigation of the impacts of HIV/AIDS
- Improved family relations.

Results for western Tanzania

Woodlot Technology

Farmers were happy and are using woodlot technology because it is cheap and a good source of wood for construction, fuelwood for domestic use and tobacco curing, while some farmers appreciated the soil fertility improvement by the planted trees. Among the interviewed farmers responded that nowadays they use between 15 - 180 minutes to get fuel wood as compared to whole day before the establishment of woodlot technology. Most of the woodlots averaging between 0.25 - 2 ha were established near their homes, saving them walking long distances and time to collect wood.

Table 2. Time to collect fuel wood in Tabora area

Time	Frequency	Percentage
Takes 5 mins	9	29.0
Takes 15 mins	5	16.0
Takes 20 mins	6	19.0
Takes 30 mins	1	3.2
Takes 60 mins	2	6.5
Takes 120 mins	2	6.5
Takes 180 mins	5	16.1
Failed to estimate time	1	3.2
Total	31	100

Other benefits by farmers in Isikizya and Ulowa reported that they are now harvesting mushrooms growing under the woodlot fields. Both male and female farmers reported that they are now generating income through the sale of seeds especially from *Acacia crassicarpa* trees, while others are enjoying a pleasant environment and good scenery provided by the planted trees. Some farmers indicated that they are spending more money generated through the sale of products from the technology on education (44%) as compared to before the establishment of woodlot technology (56%). In Shinyanga some of the income has been spent on building schools.
Reasons for not adopting woodlot technology included lack of farmer's knowledge on the value of agroforestry trees and tree planting, laziness, ignorance and unavailability of seedlings.

The problems highlighted by farmers on woodlot technology included, attack by termites and expensive chemicals to control them, shortage of water due to drought to water seedlings was a major problem in Shinyanga. The farmers suggested that they needed training on the construction of wells or dams, other problems were uncontrolled grazing and bush fires.

Fodder bank technology

It involves planting of nutritious leguminous trees to supplement animal feed. This technology had high adoption near urban centres. Preferred fodder bank species differed among the respondents; *Leucaena sp* and *Gliricidia sepium* were dominant. Farmers at Lubaga in Shinyanga region reported improvement in income from the technology and were saving money from buying expensive animal feeds. Both men and women were involved in this technology and had acquired skills through training in planting fodder banks. The income is spent on education and house hold expenses.

Fruit processing technology:

This technology is very popular among women. Most of the fruit trees species both indigenous and exotics are readily available and are consumed by the communities. Majority of farmers get their fruits from natural forest (44%) while others buy from the market (36%).

In Tabora region, the most preferred fruits species readily available throughout the year and are consumed by the community. The preferred fruits and their fruiting callender are as shown in Tables 3 and 4.

Table 3. Most preferred fruit species in western Tanzania

Indigenous fruits	Exotic fruits
Vitex mombassae	Guava
Strychnos cocculoides	Pawpaw
Flaucortia indica	Mangoes
Vitex doniana	Oranges
Sclerocarya birrea	Banana

Table 4. The fruiting calendar of some fruits is as follows

Fruits	Duration to fruiting
Guava	March to June
Strychnos cocculoides	April to September
Vitex mombassae	April to June
Sclerocarya birrea	June to September
Flaucortia indica	March to June

Income generation

A total of 53 women (44 Tabora and 9 Shinyanga) were interviewed. Processing of both indigenous and exotic fruits had significant impact among women, who are now selling juice, jam and wine. In Tabora, 85% women are generating income through processing and selling of jam, wine and juice. Women are now earning between Tshs 12000 (US$12) to Tshs 30000 (US$ 30) with averages of Tshs 9,000 (US$ 9) per week through sales of juice. While selling of wine ranges from Tshs 12500 (US$ 1.2) to Tshs 45000 (US$45) with averages of per Tshs 13086.50 (US$ 13) per week.

In Shinyanga 17% women respondents are earning money from processing and selling juice, wine and jam. Their earnings from selling jam ranged from Tshs 2000 (US$ 2) to Tshs 20000 (US$ 20), with average of Tshs 7000 (US$ 7) per week. Earnings through sale of juice ranged from Tshs 1000 (US$ 1) to Tshs 50000 (US$ 50) with averages of Tshs 9157.10 (US$ 9) per week. The sale of wine generated earnings ranging from Tshs 2000 (US$2) to Tshs 20000 (US$ 20) with average money earned per week of Tshs 8166.70 (US$ 8). The extra money is now being used to improve family welfare through the purchase of food (17%), poultry (2%), paying school fees and school items (29%), domestic use (18%), purchase of equipment like fridge for preservation (5%) and buying clothes (21%).Spending on education was a significant impact among respondents. About 61.4% of the women respondents at Tumbi village (Tabora region) spent money on education now as compared to before adoption of processing technology, while in Shinyanga region 67% of the respondents spent money on education.

The women have bank accounts and are now saving money, something that they were not doing before adoption of fruit processing technology. Sixty eight per cent were saving their money earned through the sales of jam, juice and wine in the bank. About 6% of the women were saving their money at home because they do not have access to the banks and 26% of the respondents stated that the money they earn from processing is not enough for them to save in the bank, so it was mostly used at home to buy household items.

Women empowerment

In individual and focus group discussions (FGD) women farmers mentioned several social benefits arising from agroforestry resources, such as empowerment due to improvement in income, they now feel economically independent and can make decisions on how to spend incomes earned. This has improved their social statuses in the home as they now have a voice in the household regarding decisions on the use of incomes from agroforestry resources. All female farmers responded that relations at home were not affected and have a positive influence in form of unity among family members (100%). Their increased income through production and sales of processed fruit products has resulted in positive impact on household food security (have food throughout the year) and economic status.

Most of the women (53%) reported changes in their workloads due to processing and 45.5% stated that they are now spending more hours on processing fruit products. Improvement in nutritional and health status of men, women and children was reported by 84% of respondents due to processing. Family members in Tabora and Shinyanga are now getting nutrients that include essential vitamins from consuming juice and jam and are able to buy other types of food and medicines due to processing. The problems associated with processing fruits, include lack of enough knowledge about fruit processing, markets to sell their products, lack of capital and awareness.

The following testimonies were made by women whose livelihoods have changed through processing:

Mrs Stella Sichinga (Mama Mchungaji) from Tumbi women groups (16 km from Tabora town). "I was one of the first ten women who were invited to Agricultural Research Institute, Tumbi (ARI) for a seminar on processing of fruits conducted by ICRAF. At this one-week seminar we were taught how to make juice, wine and jam from matunda pori (wild fruits), that included Ntalali (*Vitex mombassae*), Ubuyu (Baobab, *Adansonia digitata*), Zambarau *Syzygium guineense,* Mbula *(Parinari curatellifolia), Vitex doniana*, Mtonga (*Strychnos cocculoides*), Guava (*Psidium guajava*), oranges, paw paw (*Carica papaya*), passion (*Passiflora edulis*) and mango (*Mangifera indica*). During this training I realised that the skills I was acquiring had the potential to improve my livelihood and offered me opportunities to generate additional income as a housewife. I decided to implement these skills; I now make juice and jam, as these two products are the most preferred by my family and people in the neighbourhood. In making juice and jam, I use local resources, which are not expensive and are within my income. The recipe includes lemon peals, lemon juice, sugar and clean boiled water. The whole process is done in my own house; sometimes I get help from my children and husband. I usually make about 50 litres of juice per day, which fetches about Tzshs 20,000/= (US$20). I sell my products here at Tumbi, but I also get orders from my customers at Tabora. I am really happy that the training has enabled me to process and sell product from fruits. I have managed to buy a big fridge, which helps me in my business, upgraded my kitchen equipment for my own use and for processing; I even bought a sofa set. My family now enjoys eating jam and drinking a variety of juices, these products were previously associated with the well to do in our societies. Every business has problems; my problems include the unreliability of electricity, electric failures often result in spoilage of my products, customer's failure to return my containers and failure to pay on time. All these affect my business. My future plans are to start a small scale processing plant using modern equipment and to sell my products beyond Tabora. My advise to other women is that this is a profitable enterprise which can be done by everyone without major problems to generate income. I urge them to pick up the trade, as it will improve their life".

Ms Lucy Manyegule from Tabora town. "I received training in processing of juice and jam from indigenous fruits by ICRAF at Tumbi in 2000. We were told that processing could improve the income of mothers. After this training I now make juice and jam for my own use and sell to various customers in different offices in Tabora. I make juice and jams from indigenous fruits which I normally buy from the local market. The fruits include Mtonga (*Strychnos cocculoides*), Mbula (*Parinari curatellifolia*), Mbuguswa (*Flacourtia indica*), Ntalali (*Vitex mombassae*), Zambarau (*Syzigium guineense*), Ubuyu (Baobab *Adansonia digitata*), Furu (*Vitex doniana*). The process of making juice is simple, for example making juice from Mtonga you need the mtonga fruits, sugar, lemon, clean boiled water and a white cloth for filtering the juice. The process for making jam is like for making juice, for example Ntalali jam you need Ntalali fruits, sugar, lemon, clean water clean bottle for packaging and saucepan for cooking. All the processing is done at my home. I normally make about 50 litres of juice per week, which I sell at Tzshs 2500 (US$2.5) per 5 litre, and about 20 bottles of jam, which I sell at Tzshs 2500 for 500 gms and Tzshs 3000 (US$3.0) for 1000 gms. I earn an average of about Tzshs 25,000/= (US$25) per week. This year (2004), I received a big order from Forest Resources Management Project (FRMP) of Ministry of Natural Resources and Tourism to make jam and juice, these products were displayed at the national Saba Saba show in Morogoro. My customers include cabinet ministers who have given me orders to made juice and jam for them. Through processing of juice and jam I have benefited in many ways. Apart from my own consumption, I bought a wardrobe, previously I used to eat from metal or plastic plates, but through processing I have managed to buy china plates and sauce pans. The income also helps me to pay rent and some school requirements for my children.

I plan to expand trade but am constrained by the lack of reliable markets and availability of packaging materials. I usually make my jams and juices based on definitive orders from my customers to reduce my losses. I have managed to share this in knowledge by teaching other individual farmers, women groups and my friends in Tabora town".

Mrs. Mwadawa Luziga of Mukombozi Womens group*, Mbola village."* I was part of the forty people from our village that attended a seminar at Tumbi. After the seminar we formed a group called Mukombozi group. This group was composed of men and women. The group nominated me to attend a two weeks training in processing conducted by ICRAF at Tumbi. "Mafunzo illinipatia elimu ya milele na milele" *(the training gave* *me permanent knowledge and skills which are with me forever).* I decided to implement my training skills by making jam and juices for my household needs and sales. My husband fully supports me, while my children like juice and jam. I usually make about 5 litres per day, which I sell, for a glass at Tzshs 50/= (US$0.05). I also make jam. The income helps me to meet some of my domestic costs such a buying salt and soap. Currently in Mukombozi group we are 20 women members remaining out of the original 40. The men withdrew from the group because jam and juice making normally involve cooking, an activity usually performed by women. Today 12 of us are making juice and jam, while six of us are selling and getting cash income. Through processing the group is now recognised and respected in the village, and around Tabora. We participated and displayed our products at the Dar es Salaam International Trade Fair (2002), where our products sold out. This year we participated in a regional Nane Nane show at Nzega. At first people were not interested in our juice and jam. We demonstrated on how to make juice and jam and showed the fruit samples that we had brought along. This education process and awareness creation made them understand that you can make better products from the wild fruits. When they realised that the products were from these wild fruits there was increased demand and all our products were sold out. People fought for the peanut butter I regretted why I had brought few bottles, I would have earned a lot of money if I had brought more bottles. At these two shows we realized that people are interested in our products. Now we urgently need a shop where to display and sell our products and we will be able to supply our products when this shop is available. In addition we need proper packaging materials and labels so that we can be competitive".

Elizabeth from Mpombwe village Sikonge district states that her husband feels ashamed and cannot eat guava in front of his children but if she makes guava juice he feels proud taking in front of his children. This confirms that value adding through processing improves consumption. This has also been observed with regard to other indigenous fruits, which people generally regard to be inferior and only fit to be eaten by children, but when processed into jam and juice they are widely accepted and consumed.

Constraints to scaling up

The main constraints to scaling up include:

- Lack of adequate human and financial resources for agroforestry research and development activities.
- Inadequate coordination of research and development activities
- Very few partners, unreliable and incapable
- Lack of awareness among stakeholders and farmers
- Long distance between sites
- Inadequate availability of quality germplasm (seeds and other planting materials)
- Drought
- Policy conflicts

Conclusion

The main conclusions are:

- Involvement of farmers in planning and implementation at grassroots is vital for success of the project.
- In order to sustain technology transfer special emphasis should be put on training of farmers as trainers and partner staff.
- Schools are very good learning centres for changing the communities and training farmers of the future
- Demonstration plots are practical and simple tools of effective training for rural communities.
- Activities that generate income and diversification are more attractive to farmers and likely to be adopted faster.

22. SCALING UP SUCCESSFUL AGROFORESTRY TECHNOLOGIES THROUGH SCHOOLS IN SHINYANGA AND TABORA REGIONS OF WESTERN TANZANIA

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Abstract

There is need for scaling up of agroforestry benefits to reach most of the population in Tanzania, in order to uplift their standard of living. Schools provide the right environment for scaling up, due to their strategic location among the rural communities. They are suitable grounds for training present farmers (adults) and building foundation for farmers of the future (young). Through the schools there is potential to reach directly 635 primary schools, 4225 primary teachers and 270,000 students in our target areas of Tabora and Shinyanga regions. In collaboration with World Vision (Nzega) and Education department, Tabora primary school teachers and farmers, participated in a study tour to Shinyanga, and Tabora regions in order to get practical experiences of agroforestry. The teachers and farmers were impressed and interested in most of the agroforestry technologies, that included, improved fallows for soil fertility, woodlots as sources of fuelwood, fodder banks for dry season fodder and domestication of fruit and medicinal trees. The teachers have now adopted some technologies in their schools and farms. Currently over 100 schools in Uyui, Nzega, Igunga, Tabora have agroforestry demonstrations of woodlots, improved fallows, fodder banks, fruit and medicinal trees in various configurations. There is a wider diversity of species, and some schools have started benefiting from the environmental services of wind erosion control, shade, while some from the established fruit orchards students are now enjoying fruits as snacks. These schools are serving as learning and training centers for surrounding communities.

Introduction

The natural vegetation in Shinyanga and Tabora is mainly miombo woodland, with trees belonging to the legume family, Caesalpiniaceae, dominating these woodlands. The dominant tree species belong to *Brachystegia*, *Julbernardia* and/or *Isoberlinia* genera. Fires are a characteristic feature of the miombo.

Shinyanga region is located in northwestern Tanzania, 3° S 10° E, covers 50,764 sq km with a population of 2.8 million. The altitude ranges from 1200 - 1500 m above sea level, receiving an average rainfall of 700 mm per year (November - April). The soil types are shallow red clay (*eutric cambisol*) and shallow black cotton soils (*vertisol)*. Most of Shinyanga region was cleared of natural woodlands in the past in an effort to eradicate tsetse fly and to expand livestock production. Main crops grown are maize, rice, sorghum, millet, cotton and tobacco.

Tabora region is located in western Tanzania, 30° S 33° E, covers 76,500 sq km, with a population of 1.7 million. The altitude ranges from 1100 – 1300 m above sea level and average rainfall is between 700 - 1000 mm (November – April). Soils are mostly sandy soils (*ferric acrisol*). Main crops grown are maize and tobacco. Both Shinyanga and Tabora region experience prolonged drought period of 7 months from May to November.

In general, both cropping as well as livestock keeping is practiced extensively. Measures to replenish soil fertility and to conserve the land are rarely taken into consideration in these traditional farming systems.

Today, the major constraints to farming in Shinyanga and Tabora Region are declining soil fertility, shortage of wood for fuel and construction, and limited supply of livestock fodder especially during dry seasons.

This paper describes the evolution and current status of agroforestry activities in schools, including benefits, problems and lessons learned in western Tanzania.

Agroforestry research and development in Tanzania

The main goal of agroforestry research and development project in Tanzania is to improve the economic and nutritional well being of resource poor farmers through the development and dissemination of appropriate technologies that reduce deforestation, improve food security and contribute to poverty alleviation.

ICRAF and its partners since 1987 in collaboration with farmers and national institutions have developed promising agroforestry technologies that provide significant benefits to smallholder farmers. For agroforestry to have impact on rural poverty, food security and environmental conditions, these technologies need to be scaled up to many farmers, and spread widely across the landscape and to have a critical mass of capacity at grass root levels, availability of germplasm, several products, diversity of species, technologies and options that can be adapted to a multitude of situations.

The government of Tanzania has favorable policies and strategies that encourage adoption of appropriate technologies to alleviate poverty, increase food security and improve environment management. Dissemination of agroforestry technologies requires the establishment of demonstration plots in strategic locations to serve as learning centers and farmer field schools. This will accelerate adoption of agroforestry technologies and also provide seed, which is required for scaling up. Schools provide the right environment to scale up agroforestry technologies in western Tanzania due to their strategic location among rural communities.

Scaling up activities through schools

Scaling up through schools, provides an opportunity to train boys and girls as future farmers, and helps to build the foundation for agroforestry at a young age in anticipation that it will have an everlasting impact in their life in future (a future farmer needs to be prepared for the future now). The teachers in these schools are the custodians or guardians for the farmers of the future. Schools in Tanzania have been involved in tree planting activities, act as communication centers for neighboring villages, have adequate land and have environment and agriculture in their curriculum.The promotion of agroforestry in schools is to, provide:

- Environmental services: shade and erosion control and beauty
- Nutrition: through planting of fruit trees and vegetable gardens
- Income: through sale of tree products such as poles, seed, and timber future
- Diversification of crop and tree varieties
- Learning centers for knowledge and skills

Agroforestry technologies being disseminated

The following agroforestry technologies are being disseminated to schools.

- Woodlots and boundary planting using leguminous trees such as *Acacia polyacantha*, *Acacia nilotica*, *Leucaena* spp, *Acacia crassicarpa*, *Acacia leptocarpa*, *Acacia julifera* and non-leguminous trees such as *Azadirachta indicaa*
- Improved fallows using *Sesbania sesban* and *Tephrosia vogelii, Tephrosia candida, Gliricidia sepium*

Table 1. Some basic statistics for schools in Tabora and Shinyanga Regions (2003)

District	Number of primary schools	Number of teachers	Number of students	Boys	Girls
Uyui	79	494	33,358	17,632	15,726
Tabora Municipality	58	799	35,903	18,138	17,765
Nzega	154	821	57,188	27,007	30,181
Igunga	112	1057	50,971	26,772	24,249
Shinyanga Rural	232	1054	92407	47,540	44,867
Total	635	4225	269827	137089	132788

- Improved *ngitili* (a traditional in-situ pasture conservation system) in agro-pastoral societies of Shinyanga rural and Igunga
- Fodder banks using *Gliricidia sepium*, *Acacia angustissima*, *Leucaena pallida*, *Centrosema pubescens*, *Macrotyloma axillare* and *Macroptilum atropurpureum*
- Domestication of indigenous fruits and medicinal trees
- Establishment of fruits orchards
- Nutritional vegetable gardens.

Exchange visits

In collaboration with World Vision and Education department Nzega and Igunga, 26 primary school teachers and 6 farmers trainers (1 from Nzega and 5 from Igunga), participated in a study tour to Shinyanga, and visit to MUVIWASHI, which is a network of farmers in Lubaga, involved in fodder banks and dairy animals, from 2 - 3 December 2002. The participants were teachers and farmers we intend to use as farmer trainers. Teachers were expected to train pupils in schools who are farmers of the future, while farmers are expected to train 5 farmers in their neighborhood. The teachers and farmers were very impressed and interested in *Gliricidia sepium* improved fallows, for soil fertility, woodlots as sources of fuelwood, fodder banks for dry season fodder and fruit trees. These teachers have since adopted some technologies in their schools and farms. The schools are now being used as training centers. ICRAF inputs in this partnership have included training and capacity building in tree planting skills and agroforestry, in general, provision of planting materials of seed and seedlings of fruit and medicinal species, improved fallow species, fuelwood species and polythene bags. ICRAF has also conducted exchange visits for the teachers. The schools contribution has been the provision of land, seed collection and labour for planting and maintenance of the demonstrations.

Establishment of demonstration plots

Depending on land availability in schools, demonstrations were established during the December 2002 and January 2003. Field visits have been conducted to assess performance and also seek views and feedback from the teachers on these demonstration plots.

- Woodlots minimum 100 trees per species spacing 4 x 4 metres (0.25 ha) or 2 x 3 m
- Improved fallows: 40 x 40 m at 2 x 2 metres
- Fodder species: 40 x 40 at 2 x 2 metres
- Fruit trees minimum 100 trees: include indigenous and popular exotics of paw paws, passion, and mangoes.

Current species in demonstrations

- The following species have been established in demonstrations
- Woodlots: *Azadirachta indica (Neem), A. crassicarpa, Senna siamea* and *A. auriculiformis*
- Improved fallows: *G. sepium, L. pallida* and *S. sesban*
- Fodder banks: *G. Sepium* and *L. Pallida*
- Seed orchards: *G. sepium, A. auriculformis, A. crassicarpa, S. siamea* and *A. indica*
- Boundary plantings: *A. crassicarpa, G. sepium* and *A. indica*
- Fruit orchards: Fruit trees: *Tamarindus indica, Adansonia digitata, S. birrea, Syzigium guineense, Psidium guava*, Passiflora edulis, *Mangifera indica Carica papaya*
- Medicinal trees: *Acacia nilotica, Kigelia Africana*
- Timber trees: *Afzelia quanzensis* and *Pterocarpus angolense*

The Uhuru torch visited some of the good performing schools of Lakuyi, Itobo, Ibologelo, Bulumbela, in recognition of their agroforestry activities this year 2004.

Diversity of tree species planted in schools.

Most of the schools are now involved in serious tree planting, some of the trees species now found in schools include: *Leucaena leucocephala, Leucaena pallida, Moringa oleifera, Acacia senegal, Mangifera indica, Sesbania sesban, G. sepium, Acacia nilotica, Azadirachta indica, Vitex mombasae, Terminalia sericea, Eucalyptus, Senna siamea, Carica papaya, Syzigium guinensee, Melia azaderach, Afzelia quanzensis, Psidium guava, Citrus spp, Acacia crassicarpa, Delonix regia, Passiflora edulis, Khaya anthotheca, Senna spectabilis, Jacaranda mimosifolia, Tamarindus indica, Kigelia africana, Tephrosia vogelli, T. candida, Adansonia digitata, S. birrea, A. mangium, Cedrela odorata* and *Pterocarpus angolense*.

Participation and attendance of international seminars

From 25 to 30 January 2004, four teachers from Tanzania, including one teacher trainer from Tabora Teachers College and teacher from Itobo Primary School in Nzega attended a farmers of the future training in Vumba, Zimbabwe. These teachers are now promoting agroforestry in schools and in surrounding villages. Teacher Luziga from Itobo has established a tree-planting group with over 20 members called KUMI (Kikundi Upandagi Miti Itobo), group for planting trees at Itobo.

Review workshops

A two day teachers review workshop was conducted from 30-31 August 2004 at Mwamala primary school, Nzega to review and exchange experiences in agroforestry activities in schools and surrounding villages and also plan for the next season. A total of 26 participants, 23 teachers (20 males, 3 females), one Ministry of Agriculture official, one Ministry of Natural Resources official and one Ministry of education official from Nzega participated in the workshop. The workshop included plenary presentations by ministry officials, teachers and group discussions that developed action plans for each school. In addition the participants had a field visit to Shigamba primary school.

Table 2. Schools and agroforestry technologies adopted in Western Tanzania

Name	Woodlots	Improved fallows	Fodder	Fruit orchards	Seed orchards	Medicinal	Ngitili	Boundary planting	Shade aesthetics	Indigenous tree
Igunga District										
Ushirika	X				X			X	X	
Usongo	X			X			X		X	
Bulyangombe	X	X		X					X	
Nyandekwa	X	X		X	X				X	
Simbo	X			X	X				X	
Ibologelo	X	X		X	X	X			X	
Bulumbela	X	X							X	
Nzega District										
Itobo	X	X	X	X	X	X			X	
Kagongwa	X	X	X						X	
Lakuyi		X							X	
Lububu	X		X	X					X	
Shigamba	X	X							X	
Bulunde	X	X							X	
Chamipulu	X	X							X	
Idubula	X	X							X	
Bulambuka	X	X							X	
Sigili	X	X							X	
Iboja	X	X		X				X	X	
Wela II	X	X							X	
Igusule	X	X							X	
Ilalo	X	X	X	X		X			X	X
Mwamala	X								X	
Kishili Mwaguguli		X						X	X	X
Udutu Ugembe 1	X	X		X		X			X	x
Ilagaja	X	X		X		X			X	x
Uyui District										
Ilolangulu	X	X								
Mbola	X									
Magiri	X			X					X	
Mayombo	X									
Imalampaka	X									
Isikizya	X									
Ilolansimba	X	X		X	X			X	X	
Ibiri	X									
Itobela	X	X								
Isenga	X									
Kipela	X									
Idete	X								X	
Tabora District										
Tumbi	X	X							X	
Mawiti (Malolo)	X									
Kazima	X									

Table 3. Status of tree planting in schools Mwakalundi Division, Nzega District

Year	Target	Trees planted	Survived	Number dried
2001	33,933	28,510	24,210	4800
2002	42,760	30,536	25,975	4561
2003	84,192	67,502	49,680	17822

Table 4: Performance of trees in woodlots at 19 months in Igunga and NZega Western Tanzania

School	*Acacia auriculiformis*		*Acacia crassicarpa*	
	Ht (m)	RCD (mm)	Ht (m)	RCD (mm)
Bulumbela (Igunga)	2.75	38	2.88	44
Ibologelo (Igunga)	2.31	29	1.72	21
Kagongwa (Nzega)			2.22	39

Table 5. Performance of fruit and medicinal trees at 19 months in Igunga and Nzega Western Tanzania

School	*Acacia nilotica*		*Adansonia digitata*		*Kigelia africana*		*Sclerocarya birrea*	
	Ht (m)	RCD (mm)	Ht (m)	RCD (mm)	Ht (m)	RCD (mm)	Ht (m)	RCD (mm)
Ibologelo (Igunga)	1.23	23	1.15	41	0.90	35	2.28	59
Itobo (Nzega)	1.39	51	0.74	38	1.01	51	2.66	81

Issues emanating from review workshop for ICRAF:

- ICRAF should continue collaboration and provision of skills in AF
- ICRAF to collaborate with government in training and provision of working tools
- ICRAF should train villagers in AF practices so that they can improve their crop yields
- ICRAF should conduct seminars at all levels on AF
- ICRAF should establish an office to be closer and within easy reach and consultations in the district
- Continue training and offer strategies that can be used to improve the environment through tree planting and livestock management
- Continue communication and maintain dialogue, which includes visits with workshop participants (teachers)
- Help in-group formation and follow up visits
- Training and skills to be extended to farmers and schools and all villages in Mwakalundi division and other divisions of Bukene, Nyasa and Puge
- Collaborate with government in digging wells in school to support nursery activities
- Frequent visits to school for advise on AF
- Supplying seed and seedlings
- Provision of technical support to train farmers in districts and divisions
- ICRAF to give motivation on tree planting by installation of sign boards in its areas of operations
- Advise on how to access credit
- ICRAF should provide them with promotional materials such as leaflets, T – shirts, caps so that they can promote agroforestry to a wider audience
- The good reading materials should be translated into Swahili so that they can be widely shared with others
- Link farmers and schools to projects that offer dairy animals.

The following issues concern the Government of Tanzania

- To support training on environment preservation through frequent seminars and multi media shows
- To provide space for ICRAF to build an office so that their services can be closer to the people
- To develop strategy to avail and distribute seedlings
- Local government should be at the forefront to promote AF
- Provision of credit from donors to support groups and individuals for working equipment
- Impose by laws to prevent environmental degradation
- Policies that support access to credit for tree growing
- Have central nursery to supply seedlings
- Support AF scaling up to benefit all Tanzanians
- By-laws to enforce people to plant trees
- Introduce competition among schools
- Government should contribute to AF and local government to allocate funds to support AF in schools
- Impose by laws that prohibit livestock in school and farmers fields in general
- Local government to support activities of seed purchases for soil fertility trees
- Dig wells and construct dams to support nurseries
- Promote ngitili in every village
- Offer credit to farmers and start the cattle loan system
- Use teachers to create agroforestry awareness in the villages
- AF should be the main agenda at all leaders meetings, the leaders should be at the forefront in promoting agroforestry technologies such as improved fallows, fodder banks, ngitili, woodlots and environmental conservation.

Impacts of schools

The following were the main impacts of schools

- On farmers around schools: farmers have started nurseries and have requested for training in agroforestry after visiting the demonstration plots in schools. Most of the farmer's requests are for trees for improved fallows and indigenous fruit and timber trees
- Schools are now being used as training ground for communities
- Some schools have started enjoying the provision of shade by the trees, while some have noticed reduced wind erosion in their compounds
- Mwalimu Luziga of Itobo primary School has trained farmers and has started a group called KUMI (Kikundi Upandaji Miti Itobo).

Problems

Most of these nurseries are seasonal due to water problems; a few schools (Itobo) maintain a nursery throughout the year. Sigiri and Igunga town schools are buying water, 20 lts costs Tshs: 200/=, to maintain their nurseries. Other problems encountered in these nurseries include, lack of polythene tubes, lack of watering cans, damage of seedlings by chicken, rats, cutworms, caterpillars, grasshoppers and termites, fungal diseases, theft of seedlings, lack of water, saline water at some sources (Igunga), labour shortage during watering, poor germination of tree seed, lack of markets for tree seedlings and generally lack of technical know how. Some schools are reluctant to start nurseries as may run out of water. Conflicts in schools between teachers involved in agroforestry. The other threat is from open grazing of livestock. These nurseries have received tree seeds, and technical backstopping form ICRAF staff.

Constraints to scaling up through schools

The main constraints to scaling up through schools include:

- Lack of adequate human and financial resources for agroforestry research and development activities
- Very few partners to support agroforestry activities
- Lack of awareness among other teachers
- Long distance between sites
- Inadequate availability of quality germplasm (seeds and other planting materials)
- Drought
- Policy conflicts

Lessons learnt

The following are the main lessons learnt:

- Involvement of teachers in planning and implementation at grassroots is vital for success of scaling up
- In order to sustain technology transfer special emphasis should be put on training of more teachers as trainers
- Schools are very good learning centres for changing the communities and training farmers of the future
- Demonstration plots are practical and simple tools of effective training for rural communities
- Activities that generate income and diversification are more attractive to farmers and schools and likely to be adopted faster
- Schools where environment teachers were females tended to do better than those with males.

Way forward

(i) Introduce agroforestry competition among schools
(ii) Involve the schools in participatory domestication of medicinal and fruit trees
(iii) Introduce fruit processing for health and nutrition
(iv) Intensify biomass transfer to support nutrition gardens
(v) Initiate and support agroforestry clubs in schools
(vi) Documentation and capture the composed songs and drama activities on agroforestry
(vii) Sensitization of all members of staff in schools
(viii) Translation of documents in Swahili
(ix) Participatory monitoring and evaluation
(x) Support exchange visits
(xi) Conduct review workshops for other districts
(xii) Develop a concept to support agroforestry in schools, to improve peoples welfare, nutrition and environment

SUB-THEME: NATURAL RESOURCES POLICIES ON AGROFORESTRY

23. NEED FOR POLICY ON AGROFORESTRY RESEARCH AND DEVELOPMENT IN TANZANIA

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Abstract

Agroforestry is a practice of growing trees and shrubs with crops or livestock. While its importance in terms of improving peoples' livelihood is well known, there is inadequate policy and legislation on Research and Development in Tanzania. This paper examines existing policies in agriculture and natural resources sectors with a view of checking how Agroforestry features in policy documents of agriculture and natural resources sectors. Past and recent Sector policy documents on agriculture and natural resources sectors were examined in order to find out to what extend the practice of growing trees and shrubs with crops or livestock features in these documents. Views/opinions of different stakeholders were collected through interviews and discussions with researchers and farmers. Additionally, several current and past Agroforestry projects were examined to see if they were motivated by government and local policies. The findings indicate that although there are currently a number of government and local policies aiming at improved both the agricultural sector and natural resources sectors, no distinct policy statements exist on agroforestry. In the forestry policy documents, though, there are many policy statements and directives on woodfuel, farm forestry and trade on forestry products but all these ostensibly refer to forestry. Farmers wanted assistance in getting inputs (seeds, seedlings) and information on markets of Agroforestry products. Researchers were worried about the low adoption rates of technologies so far developed. Traders want information about quality and safety of Agroforestry products. Due to importance of agroforestry in improving livelihood of Tanzanians, formulation of policy statements/directives to guide agroforestry development are suggested.

Introduction

Agricultural development is the cornerstone of Tanzania's rural development strategy. Agriculture is the mainstay of the economy and contributes about 50% of the GDP and more than 66% foreign exchange earnings. The natural resources sub-sector contributes about 3% of GDP and 10% of foreign exchange earnings. Important export crops include coffee, cotton, cashew, tobacco, tea sisal and pyrethrum. Agroforestry products include fuelwood, fruits, medicinal plants, crops, honey and animal feeds. These two sectors employ about 80% of the total labour force and supplies raw materials to the industrial sector and food to over 30 million people. It is estimated that 95 to 97% of the food consumed in the country is produced locally and only 3 to 5% is imported.

Policies, laws, rules or regulations, are always present at all levels in a society. Policies promote certain practices with the help of incentives, or they can influence actions through fines or taxes. Policies help shape how organizations, companies, communities or societies functions or operate. At national level, policies are statements of government goals and are often supported by incentives or sanctions which will help achieve the goal (s). Policy content includes policy statements and policy instruments (Mayers and Bass, 1999) which lay out the policy objectives, strategies of how the objectives can be achieved including incentives (resources to be mobilized, how they will be distributed, share of roles and responsibilities among the range of stakeholders) and dis-incentives (punitive sanctions which can be in form of legal instruments such as laws and by-laws).

Policy statements therefore start by indicating current position (*status quo*) then proceed to state the expected state (target, goals) and finally the strategy to reach the expected state. Additionally, especially in regulations, it is common to indicate incentives for positive action and penalties for defaulters.

In the agriculture and natural resources sectors, policies attempt to regulate either the supply side (the quantity and quality of produce) or the demand side policies help to manipulate market prices and influence the purchasing behavior of customers. In short policies are recognized or legislated rules that promote attainment of community goals and targets. For agroforestry the main areas of policy concern are: land tenure (access, proper use, degradation, fertility), inputs (availability, credit), planting materials (availability, quality, credit), species (adaptability, suitability, utility). The driving forces for setting policies include the need for food or survival, leading to livelihoods, desire for profit and comfort and world trends (protocols, cross-boundary). Government policies provide conditions which allow operators (farmers, private enterprise, consumers and social organizations) to act for the purpose of improving their welfare. The interest is directed towards understanding the policy factors that inhibit or enhance agroforestry technology development and adoption by farmers.

Effective development of agroforestry requires favourable policy at the community and governmental levels to ensure sustainable technology development and dissemination. This calls for a need to investigate the previous and existing policy environments and their impacts on agroforestry. This paper therefore seeks to identify policy issues that affect agroforestry in Tanzania. The approach adopted has focused on group discussion, key informant interviews and in-depth reading of past and present policies.

Results

In depth scrutiny of policy documents in the Agricultural Sector

Agricultural policies include Agricultural Policy (1973), the Agricultural and Livestock Policy (1983), Research Master Plan, Science and Technology Policy (1988), National Land Policy and the Agricultural Sector Development Strategy (2002). There are also a number of legislations governing crops and livestock which fall under the then: Ministry of Agriculture, Food Security and Cooperatives (MAFC) and the Ministry of Livestock Development (MLD).

The National Agricultural and Livestock Policy of 1997 recognized the need to utilize the national scientific and technological capacity in the promotion of agricultural production and productivity. The policy emphasizes the need to harness both new science and technology and indigenous knowledge in addressing existing production constraint. In the first ever Research Master Plan for Tanzania (1997), factor research (comprising of soil and water management and agroforestry) were among first priority research programmes. These programmes attracted incremental funding and human resources. However, as was observed later, emphasis was only on technology generation leaving aside agroforestry development aspects.

In October 2001, the *Agricultural Sector Development Strategy* (ASDS), an instrument for stimulating growth and reducing poverty was finalized. This is the main policy document which concerns the agricultural sector. It replaces the Agricultural, and Livestock Policy Document. It envisages an agricultural sector that, by 2025, becomes "modernized, commercial, highly productive and profitable, and utilizes natural resources in a sustainable manner". The strategy basically aims at revamping the sector by addressing a number of constraints, which affect the sector. The main objective of the ASDS is to accelerate growth in agriculture from the current 3.3% to 6% per annum by 2005. (Already, agricultural growth in 2001 was 5.5%). To achieve this target, the ASDS outlines three main strategies:-

(i) Establishment of a favourable environment to raise productivity and profitability in the sector.
(ii) Promotion of partnerships between private and public sectors and between agri-businesses and contract growers.
(iii) Implementation at district level, based on District Agricultural Development Plans (DADPs).
(iv) The ASDS also outlines a number of initiatives that are to be implemented, including:-
   - Promotion of private – sector driven production, processing, storage, input supply and marketing.
   - Improvements in rural infrastructure
   - Review of legislation that negatively affects private sector participation in agriculture.
   - Removal of fiscal and other disincentives and restrictions on trade at national, regional and district level and that restrict movement of food crops across districts, regional and national borders, cross-borders, etc.

The ASDS is the driving force for modernization of agriculture. It calls for research to be demand driven, responsive to the needs of the farmers and livestock keepers. Emphasis is placed on demand-driven and market-led technology development and adaptation. Research topics are derived either from specific requests by stakeholders during the regular Zonal Planning Meetings, or through participatory rural appraisals (PRAs). In ASDS, development and dissemination of high yielding and stable seed is well emphasized. The success of agricultural services provision, including research, extension and training programmes is tied to their responsiveness to the specific needs of the client (stakeholders) and market opportunities.

The role of the public sector is to be regulatory, facilitatory and supportive of private sector functions. The Agriculture Sector Development Programme (ASDP) has been formulated and approved whose role is to operationalize the ASDS.

The National Land Policy aims at promoting a secure land tenure system. It encourages the optimal use of land resource. The major theme of the policy is the conversion of land into an economic asset to which all citizens should have equal access. Thus the policy facilitates broad-based social and economic development without upsetting or endangering the ecological balance of the environment.

In depth scrutiny of policy documents in the Natural resources Sector

The natural resources sector has the following policy documents; National Forestry Policy (NFP, 1998), National Fisheries Policy (1998), National Wildlife policy (1998) and National Beekeeping Policy (1998) (MNRT, 1998). These policies have subsequently formed the basis for enacting a series of related Laws.

The Forest Policy admits that woodfuel is the main source of energy both in rural and urban areas and that lack of alternative and affordable sources of energy contributed to degradation of natural resources due to uncontrolled harvesting of trees for woodfuel. In the policy directive, the national forestry policy calls for private individuals to establish woodlots in their farms. It calls on research and extension to look for alternative affordable sources.

Forest Policy recognizes trade in wood and non-wood forest products as offering considerable potential for increased economic development through income and employment generation as well as export earnings. However, the policy warns that unregulated trade can instigate uncontrolled exploitation and has the potential of accelerating forest destruction and degradation through loss of biodiversity.

On private and community forestry, NFP says that shortage of land and unclear land and tree tenure, particularly for women, have hampered investments in forestry on private and village lands. Moreover, inadequate awareness of tree growing and of sustainable forest management, as well as lack of financial incentive have been constant obstacles for private and community forestry development.

The National Forest Policy is true in saying that planting and management of native species has not been adequately promoted as compared to planting of exotic species. The tradition of obtaining tree seedlings free of charge has also discouraged the establishment of private nurseries. By and large, farmers' general knowledge on tree management is inadequate for the establishment of agroforestry systems. Wood products from private farms have found limited markets due to free wood supply from public lands and, consequently, investment on tree growing has not been considered financially attractive.

In the National Forestry Research Master Plan (NAFORM) (1999), it is indicated that research programmes in such areas as indigenous forestry management and species have not been initiated due to inadequate human resources and low priority due to poor research funding and infrastructure. Demand driven research is underscored in the Forest Policy. Also recommended is private sector involvement in order to utilise the full potential as well as to domesticate and commercialise non - wood products (gums, resins, bee products, etc.) with high demand most of which remain undeveloped. Suitable Agroforestry practices as noted from East Asia, have a stake in the promotion of agroforestry products. However, suitable policies need be on place.

Observations from Farmers/researchers/Traders/Past agroforestry projects

In order to gauge the feelings of stakeholders about presence or absence of policy on agroforestry development, practising farmers, researchers, traders and representatives of past agroforestry projects were interviewed. Farmers were asked what they wanted from NGO's, joint programmes, and Government etc concerning agroforestry while researchers were asked what problems they experienced in carrying out agroforestry research. Traders were asked about issues they considered pertinent in dealing with agroforestry products. Additionally, representatives of few current and past agroforestry projects were asked if they were motivated by government and local policies in initiating these projects. The four agroforestry projects examined were HADO, HIMA, SCAPA/LAMP and SECAP.

Responses

Farmers in Uyui District, Tabora Region felt that agroforestry is gaining momentum but with inadequate assistance in getting inputs (e.g. seed, seedlings) the tempo will be scaled down. Availability of inputs in neighbourhood and at affordable prices are seen as pre-requisites for future scaling-out of agroforestry. Discussion with researchers indicated that there are several technologies at various research institutes conducting agroforestry research. However, these technologies are not able to spread fast to farmers and livestock keepers due to inadequate capital and weak extension service. Researchers felt that involvement of farmers ensures sustainability of projects since they consider them their property. By adopting a holistic and integrated approach to agroforestry rather than solving one problem at a time, and working in interdisciplinary and multidisciplinary teams ensures effective use of the available resources including human resources.

Researchers now realize that by working closely with the farmers they are able to continually reflect on their performance, learn and gain experience from the communities they worked with. Through feedback researchers are able to revisit their strategies and approaches in time thus minimizing chances of making mistakes. Traders are worried about inadequate availability of products, their quality and safety (shelf life) of products. Representatives of Agroforestry development projects were of the view that regional environment rather than national policies dictated nature and location of projects, and this influenced results.

General Discussions

There are many experiences which can be learnt from reading policy documents. Major policy documents of the two sectors comprise of the Agricultural and Livestock policy (1983), Research Master Plan and the Agricultural Sector Development Strategy (2002), the National Forestry Policy (NFP), National Forestry Research Master Plan –NAFORM 2000 – 2009, and National Forestry , and Beekeeping Programmes (NFP, and NBKP). These policies help shape how organizations, companies, communities or societies operate to reach/achieve set goals for the sectors. There are also strategy documents intended to address former policy weaknesses. In terms of agricultural research, close examination of these documents shows that they promote a holistic and integrated approach to research. ASDS for example encourages stakeholder participation in many activities in the agriculture sector (URT, 2001; URT, 2002). Grass-root level farmers' or community-based organizations and networks are very much encouraged to become key development partners.

However, many of the issues addressed are not specific to increased technology development and uptake in agroforestry. For example, most NFP policy statements and directives are focusing on policy in the ream of forestry not agroforestry. Although the National Research Master Plan for Tanzania (1999) show Community and Farm Forestry as second priority, it did not spell out policies and policy directions to guide agroforestry development. The effect is that to many farmers and livestock keepers agroforestry is perceived as a new practice which needs policy guidance. This is however, gradually changing following the enactment of the Land Act 1999, and National Agroforestry Strategy (NAS, 2002). The Land Act makes provision for women to own land. While NAS gives a framework for the scaling up and out of Agroforestry Technologies. However, there is need for harmonisation of sectoral policies and regulations being implemented.

Typically, the problems that agroforestry policy needs to address are as follows:

(i) How does agroforestry meet the key social values?
(ii) How can we reduce problems and costs in Agroforestry interventions?
(iii) How can agroforestry systems be tailored to respond to local conditions (institutional, cultural, environmental)
(iv) To what extend are motivations and interests of stakeholders met by agroforestry interventions?

In the case of farmers in Uyui District, Tabora Region what they want is guidance on how to get inputs (seeds, credit, seedlings) in the neighbourhood and at affordable prices. Researchers want policy guidance on how available technologies can be spread fast to farmers and livestock keepers to meet agroforestry goals. Traders are concerned about markets, inadequate availability of products and their quality and safety. These are some of the demands which need to be considered in formulating future agroforestry policies.

In order to be aware of further stakeholders' needs, the respective research institution must work very closely with them and communicate regularly with a view to create better relationship and understanding between both sides.

The dominant contemporary discourse is for policy to be effective (ability to meet the goals of the rural population), efficient (at a low cost without having a negative impact) and to be accountable (be institutionally responsive to those who are affected by the actions). Decentralization, de-concentration (both intended to increase local decision making and accountability) and the creation of partnerships with those who are perceived to have a better record of success in delivering services to farmers are perceived to be the way to go.

Conclusions and Recommendations

Current national government policies aim at improving both the agricultural sector and natural resources sectors. There are also many initiatives at the level of strategy formulation intended to address former policy weaknesses. However, many of the issues being addressed are not specific to increased technology development and uptake in agroforestry. Many issues confronting agroforestry e.g demand for inputs (seeds, seedlings) and information on markets of agroforestry products require policy guidance. Through this study we know that there is low adoption of available technologies and that traders in agroforestry products want information about quality and safety of products. Due to importance of agroforestry in improving livelihood of Tanzanians, we suggest formulation of policy statements/directives to guide agroforestry development in Tanzania.

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24 THE ROLE OF NON - GOVERNMENTAL ORGANISATIONS IN INTEGRATING GENDER ON LAND CONSERVATION IN REFUGEE AFFECTED AREAS IN TANZANIA: A CASE OF NGARA DISTRICT, IN NORTH WESTER TANZANIA

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Abstract

A study to examine the role of NGOs in integrating gender on land conservation in refugee affected areas of North Western Tanzania was conducted in Ngara district with the view to recommend strategies that would foster gender sensitive and responsive land conservation projects in these areas. A Cross Sectional Research Design (CSRD) was adopted. Data collection process made use of a structured questionnaires which were administered to a sample of 43 men and 43 women. Data were coded and analysed using Statistical Package for Social Sciences (SPSS) computer programme. Results showed that NGOs have been involving both men and women in land conservation initiatives through public meetings for awareness creation, training on land conservation and provision of forest inputs. The major land conservation activities in which men and women participated were tree nursery establishment and tree planting. Participation of men and women in these activities was significantly associated ($P<0.05$) with their awareness on land degradation and on land conservation project. The study also found that project planning process involving local communities in land conservation had not been adopted by NGOs. It was further revealed that the issue of establishment of Village Environmental Committees as part of empowering local communities was not seriously taken. Majority of men and women who were involved in land conservation participated at the level of implementation. The major factor which was found to limit full gender integration in land conservation was lack of regular mobilisation particularly for women. The study came out with the following recommendations: (i) mobilisation of rural men and women through regular and gender balanced public meetings, and training on land conservation initiatives (ii) NGOs land conservation activities should be co-ordinated and monitored by the District Natural Resources related departments (iii) encourage formation and/or strengthening of gender equity in Village Environmental Committees (iv) project planning process should ensure participation of intended beneficiaries and NGOs and (v) land conservation initiatives should focus more to rural communities than schools and church related institutions.

Introduction

Land degradation is one of the major environmental problems facing Sub-Saharan Africa (SIDA, 1993). Land tenure systems, poverty and rapid population growth has been singled out as principal social-economic causes of the land degradation critical environmental catastrophe (Cleaver & Shreiber, 1992; SIDA, 1993). The severity of the problem of land degradation in some parts of Africa, has further been aggravated and compounded to a greater extent by large influxes of refugees, fleeing their countries due to civil wars and armed conflicts (UNHCR, 1999). In places where refugees settle, land clearing for establishment of refugee camp sites and agricultural crop production take place. There is also need for construction materials and fuel-wood. All these activities pose a major threat to forest resources (Ashley, 1992; Babu and Hassan, 1995). Given the intensity and extent of the problem of land degradation (and other socio-economic problems) in Africa and the limited resource ability to halt it, the affected African governments have always been given tremendous support by international donor community directly and of more recent through NGOs (Braton, 1989) and have in many instances, recorded success in various places. Successes of NGOs' in land conservation and other rural development initiatives has been associated with their participatory approaches (Fowler, 1991; Clarke, 1996) which fundamentally ensure involvement of beneficiaries in development project planning and implementation.

In the recent years, our country has witnessed the mushrooming of local NGOs with different objectives. In Tanzania, NGOs (mainly foreign) play major roles in areas ranging from basic education to health care, from social welfare to agricultural extension, and of our interest, to environmental conservation, although literature on their involvement in these development endeavours is still not readily available (Marche and Ruvuga, 1994). On the aspect of environmental protection, these local NGOs in collaboration with foreign NGOs have been engaged in land conservation in different areas in Tanzania. Besides addressing environmental problems in areas which naturally degraded by indigenous population, several NGOs have notably been involved in land conservation in refugee affected areas. One of such areas are Ngara district, Kagera region, where, soon or later after the Burundi and Rwanda refugee episode of 1994, numerous local as well as international NGOs responded to its environmental rehabilitation. Amongst these many NGOs were Deutsche Gesellshaft fu Technische Zusammenarbeit (GTZ) and Ngara District Development Organization (NDDO).

It is widely taken for granted that people's participation involves naturally both men and women. But experience has shown that, very often, what is termed as people's participation, in many instances lack gender perspectives. Quite often, women who are the major users of land resources have not adequately involved in designing and implementation of development projects probably due to prevailing socio-economic and cultural factors in a given social setting or mobilisational on the part of the change agents factors.

Although NGOs have been involved in land rehabilitation in refugee affected areas in Tanzania, little is known on their role in integrating gender in this development process. The interest was rather on the area of coverage, quantity and quality of outputs more than on the gender integration process. Thus, the broad objective of this study was to investigate the role of NGOs in integrating gender in land conservation in refugee affected areas in Ngara district in an effort to generate useful information that will assist government and NGOs to design gender sensitive and gender responsive programmes in land conservation in refugee affected areas. Specifically, objectives of the study were to identify strategies adopted by NGOs in land conservation in refugee affected areas; established type of gender integration in land conservation; factors that influence gender integration in land conservation; and to assess the potential sustainability of land conservation initiatives promoted and supported by NGOs in the study area.

Materials and Methods

Study area

The study was conducted in Ngara District, situated in North-Western Tanzania. The district lies between Longitudes 30°15' and 31°15' East and between Latitudes 2°10' and 3°0' South. The district borders the countries of Burundi and Rwanda on the South-West and North, respectively. On the East and North-Eastern, Ngara borders Biharamulo and Karagwe districts, respectively, while on the extreme South, it is bordered by Kibondo District in Kigoma Region. Ngara District is administratively comprised of four Divisions, namely Kanazi, Murusagamba, Nyamiyaga and Rulenge. The district has an area of 3,744 km^2.

The economy in the study area depends largely on agricultural and livestock production. Major food and cash crops grown include banana, beans, cassava, millet, sweet and Irish potatoes, vegetables, fruits and coffee respectively. Livestock kept consist mainly of local cattle, goats, sheep and chicken. Dairy cattle keeping have currently been introduced (albeit on a small scale).

Research design and sampling procedures

The study made use of a cross-sectional design which allowed information to be collected at one point in time. The selection of this particular research design was justified by limited resources, including time scale. Target population of this study consisted of all men and women in Ngara district. To obtain the desired population sample, multistage sampling technique was used. Wards, villages and eventually households which provided the survey subjects made up the sampling phases. Simple random sampling was used to select four wards from the sample frame of 17 wards which make up Ngara District. The selected wards were Kabanga, Kibimba, Rulenge and Rusumo. Using the same method two villages were selected from each ward to obtain a total of eight villages. These villages were Kabanga and Djulaligwa selected from Kabanga Ward, Buhororo and Ruganzo (Kibimba Ward), Mbuba and Rulenge (Rulenge Ward), Kasharazi and Kasulo (Rusumo Ward). From each village six households were again randomly selected. Thus, 43 households were obtained for the present study, leading to a total of 86 respondents since male and female gender groups of each household were treated separately.

Data collection

Structured questionnaires were the major tools used in field data collection. Two types of questionnaires were designed, one for the household female and male members and another one for staff from two selected NGOs engaged in land conservation in the study area. Household female and male members' questionnaire focused essentially on respondents' socio-economic characteristics, environmental degradation and conservation awareness and their connection with their participation in land conservation initiatives. NGOs staff questionnaire on the other hand covered generally the organisation's strategies employed in land conservation with the view to discover how such strategies promoted gender integration. Gender integration in this study was defined as involvement of both men and women in land conservation activities by NGOs. To ensure validity the household questionnaire was subjected to pre-test at Buhororo village so as to allow necessary adjustments in some questions. Field observations were also made in an effort to supplement the information from the respondents that related to observable land conservation activities. Secondary data on land degradation/conservation, NGOs, gender and refugees were obtained from various sources.

Data analysis

The data that were gathered from field surveys were coded and analysed using Statistical Package for Social Sciences (SPSS) computer software. Frequencies and percentages were mainly the major descriptive statistics that were computed. However, where appropriate, Chi-square test was used to detect possible associations between gender and participation in issues related to land conservation initiatives and other qualitative parameters.

Results and Discussion

Strategies of NGOs on land conservation initiatives in Ngara district

Refugee episode of 1994 in Ngara District

Ngara district was the most affected district; with an estimated influx of over 480,000 refugees housed in the then five refugee camps of Musuhula, Lumasi, Lukole, Keza and Benaco. The later camp harboured more than 250,000 refugees (KEP, 1997). The refugee population outnumbered the district resident population which was estimated to be around 180,000 by that time (UNHCR, 1999). Official statistics indicate that, more than 16,000 ha of forest cover were completely cleared for refugee settlement and other land uses. As a result, areas surrounding refugee camps were severely faced with a serious decrease in vegetative cover, loss of biodiversity and land degradation (KEP, 1997).

In response to the negative impact of refugees on the environment in the study area, large number of local and international NGOs came in, some to provide initially humanitarian relief services and some interested to rehabilitate the environment that severely degraded. NGOs' involvement in environment rehabilitation is the primary reason that prompted the selection of the study area with the view to investigate their role in integrating gender in land conservation initiatives in this particular refugee affected area. Initially, two NGOs; namely, Co-operative American Relief Everywhere (CARE) International (Tanzania) and Karagwe Development Association (KARADEA) were proposed to be studied.

However, upon arriving in the field, CARE which provided support through CARE-KEPT had already left Ngara and its environmental conservation activities were taken over by GTZ, hence KEP-GTZ.

KARADEA on the other had changed its name and scope. It was then known as Relief for Development Society (REDESO) and its chief concern was to provide environmental services inside refugee camps and not with local communities. Therefore Kagera Environmental Project (KEP-GTZ) and Ngara District Development Organization (NDDO) were alternatively studied.

GTZ is a German NGO that has been co-ordinating and carrying out activities of Kagera Environmental Project (KEP-GTZ) which was started in July 1996 to operate in the refugee affected districts of Biharamulo, Karagwe and Ngara, with a long term goal to enable local communities and refugees carry out efficient natural resources practices in these districts through participatory approach (KEP-GTZ, 1998). The project was jointly funded by the European Union and the governments of Germany and Tanzania. NDDO on the other hand, is a local non-governmental organisation which was established in 1987, with an overall objective to improve the standard of living of the rural communities in Ngara district. To realise this broad objective, it has been undertaking among others, environmental conservation, promotion of energy saving rural technology and increasing participation of women in development activities through gender sensitisation and training.

Eighty nine percent of staff of surveyed NGOs mentioned that public meetings for awareness creation (mobilisation), training of both men and women on land conservation, provision of forest inputs and physical implementation of activities by men and women were the major strategies that were adopted by NGOs in carrying out land conservation initiatives in Ngara District.

A remarkable large number of men (79%) and women (84%) mentioned tree planting as the major activity that was carried out (Table 2). Another major activity that was mentioned by majority of respondents was tree nursery establishment (67% of men and 44% of women). The rest contributed less than 26 per cent.

Table 1. Distribution of respondents by initiator and activities of land conservation project by sex

Parameters	Men (n = 43)		Female (n = 43)	
	Frequency	%	Frequency	%
Initiator [a]				
District authority	6	14	4	9
Villagers	4	9	1	2
Village government leaders	6	14	5	12
NGOs	27	63	33	77
Total	43	100	43	
Project activities				
Tree nursery establishment	29	67	19	44
Tree planting	34	79	38	84
Agroforestry	11	26	10	23
Contour ridging	4	9	7	16
Improved stoves	1	2	4	9

[a] Applicable only to respondents who were aware of projects existence

Tree nursery establishment and tree planting were also mentioned by NGOs field staff who were interviewed as the major activities that were carried out in the land conservation projects, though some mentioned water catchment conservation and joint community based forest management which were carried out on pilot area basis. The results show that land conservation mainly involves tree planting and tree nursery establishment. These activities are similar to those carried out by numerous NGOs in Kenya (Buck *et al.,*1984) because in places where such NGOs were working had been severely deforested.

Gender integration in land conservation project

Findings of this study showed that 72% of male respondents (25%) who were aware of land conservation reported to be involved in land conservation project activities, whereas the proportion was 58% for their female counterparts (38%) (Table 2). This difference between gender was not statistically significant (P>0.05). This implies that NGOs engaged in land conservation in the study area to promote and involve women in such initiatives, although the degree of women involvement is still low compared to 90% reported by Helin (1989), in refugee affected areas of Luuq, Somalia that was promoted and supported by NGOs.

Generally, this study found out that respondents' participation in land conservation project activities was highly associated (P<0.05) with their awareness and knowledge on land degradation, and on land conservation project. This implies that, farmers adopt technologies that solve known problems and also due to expected benefits. In case of the present study, rural communities expected to solve their widespread problem of land degradation that threatened their subsistence production.

Table 2. Participation and level of participation in land conservation project activities by gender

Parameters	Male (n = 43)		Female (n = 43)	
	Frequency	%	Frequency	%
Participation				
Yes	31	72.09	25	58.14
No	12	27.91	18	41.86
Level of participation [a]				
Planning	7	22.58	8	32.0
Decision making	1	3.23	2	8.0
Implementation	23	74.19	15	60.0
Reason for not participating [b]				
Have other own activities	2	16.67	1	5.56
Not mobilised and educated	6	50.0	13	72.22
Not involved in group	4	33.33	4	22.22

[a] Applicable only to participants; [b] Applicable only to non participants

On the other hand, majority of men (74%) and women (60%) respondents who participated did so mostly at the level of project implementation other than in planning and decision-making. An overall assessment however, indicated clearly that involvement of men and women in planning and decision making on land conservation projects in the study area had not been well adopted by the NGOs. Involvement of men and women is very crucial for ensuring gender equity and sensitive planning of projects (Panda and Lund, 1998).

However, about 83% male non participants (21% of total male) and 94% female non-participants (35% of total female) do not participate because there were no mobilisation and education in land conservation, and group formation initiatives in their areas (Table 2). The results suggest that mobilisation was significantly associated (P<0.05) with gender integration. This implies that NGOs had not yet fully mobilised and educated rural women in issues covering land conservation, which is contrary to Helin (1989). The relative low level of mobilisation can partly be attributed by lack of enough and skilled staff in NGOs. For instance out of 6 KEP-GTZ staff, only one staff had university qualifications related to management of natural resources. The rest had education qualifications ranging from mere primary education to post secondary certificate in agriculture. Similar weaknesses were identified by Lewis (1992), in his study on the role of

NGOs in social development. Secondly, NGOs seemed not involving fully other development related departments in mobilising rural communities. For instance, Community Development Department that could have played a crucial role in mobilising local communities was not directly involved in the NGOs' land conservation initiatives.

Factors that influence gender integration in land conservation

Results indicate that about 46% and 38% of male and female respondents respectively, knew that there existed Village Environment Committees (VEC) in their villages (Table 3). However, the difference between gender was not statistically significant (P>0.05). VEC had not been clearly established as part of village development organs like other committees such as health, finance and planning, and were not functional and active in cases where they existed. Further more, NGOs did not seem to take trouble to promote such grassroots institutions, although they were expected to empower local communities through strengthening their grassroots institutions (Farrington *et al.,*1993) including village environmental committees. Given lack of strategy to strengthen local institutions related to land conservation/natural resources management, on the part of NGOs, sustainability of land conservation initiatives in the study area is objectively open to doubt.

Table 3 shows that out of respondents who admitted presence of VEC, 22% of female (8% of the total female) and 68% (31%of total male) said that they were members of such bodies. By Statistical considerations, membership to VEC was highly associated (P<0.001) with gender. These findings confirm the general situation in which women are underrepresented in different community decision making bodies in most African societies (Picard, 1996). The number of VEC members ranged from 5 to 8.

The study found that conducting public meeting, training on land conservation were modes of creating awareness among local committees on land conservation issues.

Results denoted that, about 67% of male and 50% cent of female respondents had knowledge on public meetings conducted by NGOs to create awareness among local communities on land conservation (Table 4). Statistical test revealed that there was no significant (P>0.05) difference between male and female on awareness on public meetings.

Findings show that more men than women had ample time to attend such meetings. While 75 % of male (50 % of total male) had attended these meetings regularly, 54 % of female (27% of total female) did attend them at the same rate. A small proportion of male (16 %) and a relatively large proportion of female (38 %)

Table 3: Knowledge on and membership to village environmental committees (VEC) by gender

Parameters	Male (n = 48)		Female (n = 48)	
	Frequency	%	Frequency	%
Presence of VEC				
Yes	22	45.83	18	37.50
No	17	35.42	17	35.42
Do not know	9	18.75	13	27.08
Membership to VEC [a]				
Yes	15	68.18	4	22.22
No	7	31.82	14	77.78

[a] Applicable only to respondents who were aware of the existence of VEC.

Table 4 Knowledge on, attendance to and contribution of ideas in public meetings conducted by gender

Parameters	Male (n = 48)		Female (n = 48)	
	Frequency	%	Frequency	%
Knowledge on Public Meetings				
Yes	32	67	24	50
No	6	13	9	19
Do not know	10	21	15	31
Attendance [a]				
Regularly	24	75	13	54
Occasionally	5	16	9	38
Not at all	3	9	2	8
Contribution of ideas [b]				
Yes	29	100	18	82
No	0	0	4	18

[a] Applicable only to respondents who were aware of conduction of public meetings. [b] Applicable only to respondents who attended public meetings.

had attended these meetings occasionally. However, statistical test did not reveal significant difference (P>0.05) between men and women who attended public meetings. Chi-square test revealed that there existed strong relationship (P<0.001) between awareness on public meetings on land conservation and attendance to them among respondents.

Out of respondents who attended meetings, 100 % and 82 % of male and female, respectively contributed their ideas. This results show that contribution of ideas in the public meetings was highly associated (P<0.001) with sex, indicating certainly that there was still gender disparity. Probable explanation could be that, some women in the study area might still be inclined to traditional outlook of not speaking out in front of men or change agents had not yet created self confidence in and among women or may be women were not given equal chances as men to contribute their ideas. These findings however, differ with those reported by Picard (1996) who contended that women in central Madagascar were playing a prominent role in local public meetings.

Table 5 denote that 63% and 56% of male and female respondents respectively agreed that training on land conservation had been provided to both men and women. No significant relationship (P>0.05) existed between sex and knowledge on provision of training on land conservation. Provision of training on land conservation was also affirmed by staff from KEP - GTZ and NDDO.

Out of respondents, 81% of female respondents who were aware of training on land conservation attended the training, while 77 % of male had attended the training. The study found strong association (P<0.001) between awareness on provision of training on land conservation and attendance to it. This suggests that most people, particularly women in the study area who were made aware of training on land conservation attended it.

The training on land conservation was provided through seminar (male and female 83% and 78 % respectively) (Table 5). As regards knowledge obtained, majority of (men and female) ranked awareness on land degradation (65 and 68%), and tree nursery establishment techniques (65% and 100%) as the first knowledge they obtained, followed by appropriate land use (61% and 41%). Agroforestry was least ranked by both men and women indicating that it was not likely given due attention. Women conceived highly knowledge in tree nursery establishment with expectation that tree nurseries and hence tree planting would produce trees that would reduce scarcity of fuel wood while men were interested in the availability of building poles.

Table 5. Training on land conservation: Awareness on, attendance, Mode of training, knowledge obtained and its usefulness by gender

Aspects	Male (n = 48)		female (n = 48)	
	Frequency	%	Frequency	%
Training to both gender				
Yes	30	62	27	56
No	8	17	10	21
Do not know	8	17	8	17
No response	2	4	3	6
Attendance to training [a]				
Yes	23	77	22	81
No	7	23	5	19
Mode of training [a]				
Workshop	5	17	6	22
Seminars	25	83	21	78
Knowledge obtained from training [a]				
Awareness on land degradation	15	65	15	68.18
Tree nursery establishment techniques	15	65	22	100
Types and uses of trees	11	47	12	55
Appropriate land uses	14	61	9	41
Agroforestry	6	26	9	41
Adequacy and usefulness of knowledge [a]				
Adequate and useful	8	33	2	9
Inadequate but useful	16	67	20	90

[a] Applicable only to respondents who were aware of provision of training on land conservation by NGOs. Respondents who were aware of training on land conservation conducted by NGOs were requested to say whether or not they attended such training and the results are shown in Table 5.

As for adequacy and usefulness of the knowledge obtained, 66% (33% of total men) of men and 91% (42% of total women) of women mentioned that the knowledge they had obtained was really useful but inadequate (Table 5). The underlying implication is that a need for continued and regular training of local communities particularly women on land conservation still existed.

It was found out that majority of men (58 %) and women (47 %) who were aware of provision of support by land conservation project reported that such support was mostly forest inputs (Table 6). The same was affirmed by NGOs staff who were interviewed. Forestry support included mainly tree seedlings, wheel barrows, water cans, insecticides, sieves, pangas and hoes. Another big proportion of men and women mentioned agricultural inputs support that was provided by other NGOs/governments agents involved in both environmental and agricultural improvement initiatives. A considerable proportion of women (26%) mentioned technical support (a reflection of the introduction of household energy saving technology particularly improved stoves by some NGOs in which women were interested), while financial support, provision of equipment and organisational support were the least mentioned.

Table 6: Institutional support provided by land conservation project by gender

Support	Male (n = 48)		Female (n = 48)	
	Frequency	%	Frequency	%
Technical	3	7	11	26
organisational	3	7	2	5
Financial	2	5	3	7
Equipment	6	14	5	12
Forest inputs	25	58	20	47
Agricultural inputs	13	30	12	28

The introduced land conservation methods in the study area were tree planting, mulching and use of manure/dung (organic fertiliser) and to a lesser extent agroforestry and contour ridging (Table 7). The reasons noted were that, those people who were not involved in the project, learnt these methods from their neighbours who had been participating in training on land conservation. It was further observed that most of peasants in the study area had traditionally been growing largely banana and coffee that require mulching for moisture retention, fertiliser and trees for windbreak and kept livestock mostly local cattle and goats which produced manure which was applied in the fields for fertilising these perennial crops. The study notwithstanding, did not find any evidence which show that practice of land conservation methods had an association ($P>0.05$) with socio-economic characteristics of the respondents

Table 7: Common land conservation methods and their practice by gender

Practice	Male (n = 43)		Female (n = 43)	
	Frequency	%	Frequency	%
Contour ridging	13	27.08	7	14.58
Mulching	22	45.83	28	58.33
Tree planting	31	64.58	30	62.50
Use of manure	21	43.75	19	39.58
Agroforestry	11	22.92	11	22.92
Reasons for practice				
To conserve land	25	52.08	24	50.00
To increase soil fertility	25	52.08	25	52.08
To increase food production	23	47.92	22	45.83

Most of the respondents mentioned increased soil fertility, soil conservation and increasing food production as the reasons for adopting land conservation practices (Table 7). Benefits that they expected from land conservation are presented in Table 8. Both gender ranked firewood/poles, increased soil fertility and soil erosion control ranked the highest, while medicine and fruits ranked the last.

This indicates that tree planting for medicinal trees or fruits were either not seriously considered or local communities were not aware of such important tree use (Table 7). It was also noted that a smaller percentage of respondents mentioned fodder for animals as a benefit expected, indicating that dairy cattle keeping (zero grazing) in the study area had not been effectively introduced. Field observation could hardly sight rural households with cattle at zero grazing, although on the contrary, most of households at the district headquarters practised in-house cattle keeping. Thus, cattle keeping left on a free grazing system might to a certain extent frustrate efforts towards land conservation and protection.

Table 8: Potential expected benefits from land conservation project by gender

Benefit	Male (n=48)		Female (n=48)	
	Frequency	%	Frequency	%
Firewood/poles	44	92	26	51
Soil fertility increase	28	57	26	51
Medicine	5	10	6	12
Control of soil erosion	25	51	21	41
Fruits	9	18	14	27
Fodder for animals	10	20	8	16

Status and sustainability of the land conservation projects

Results on this aspect indicate that 75% and 78% of men and women respectively held that the project was still going on (Table 8). The assertion by majority that the project was still going on was supplemented by field observations through which it was found out that most of the available NGOs staff that were to be interviewed were found on an appointment basis as they were in the field, away from their NGOs' head offices. Such could be an indication that they were in the field for making follow-up of project activities..

Table 9: The status of the land conservation project by gender

Project status	Male (n = 44)		Female (n = 46)	
	Frequency	%	Frequency	%
Complete	1	2.20	1	2.17
Going on	33	75.00	36	78.26
Abandoned	5	11.36	5	10.87
Do not know	5	11.36	4	8.70
Project Sustainability				
Sustainable	32	72.73	32	69.57
Unsustainable	7	15.91	11	23.91
No response	5	11.36	3	6.52
Reasons for sustainability				
Beneficiaries have educated	25	56.82	25	54.35
Government will take over	1	2.27	1	2.17
Reasons for non sustainability				
Many people were not involved	5	11.36	12	26.09
Donor dependent	2	4.55	1	2.17
Project was short lived	1	2.27	1	2.17

In terms of projects sustainability, around 73 % and 70 % of men and women who were initially aware of land conservation, maintained that land conservation activities were expectedly sustainable (the proportions represent 66.67 % of total male and female respectively) against less than 25 % of men and women who predicted them to be non-sustainable (Table 9).

Majority of men (around 57%) and women (54%) who held land conservation to be sustainable were of the opinion that they had obtained useful education and knew numerous benefits of land conservation that were liked by people. On the contrary, 11% and 26% of men and women respectively, who condemned them to be unsustainable held that many people had not been fully involved and educated in land conservation. This proportion of respondents who conceived land conservation activities unsustainable was not statistically significant (P>0.05).

Majority of men and women (83%) suggested that NGOs and government should regularly and continuously train and involve fully men and women in land conservation activities. Women respondents (13%) further went on to suggest that people should not burn and clear forests. This type of suggestion is considered important because if trees, as part of land conservation were sufficiently planted, but at the same time the traditional habits of bush fires and forest felling are not arrested or contained, then the whole exercise may become meaningless and useless.

Table 10: Recommendations for better and sustainable implementation of land conservation activities by gender

Recommendation	Male (n = 48)		Female (n = 48)	
	Frequency	%	Frequency	%
Train men and women	40	83	40	83
Not to burn and clear forests	-	-	2	4
None	8	17	6	13
Total	48	100	48	100

Conclusions and Recommendations

Conclusions

The study found that land conservation activities in refugee affected areas are largely dependent on the initiatives and support of local and foreign NGOs. However, local NGOs are financially weak and their capacity to undertake land conservation activities is dependent on availability of an external donor agencies' support. Public meetings for awareness creation, training on land conservation and provision of forestry inputs to some local communities, physical implementation of land conservation activities by men and women are the strategies that are used by NGOs in undertaking land conservation initiatives. But public meetings and training in land conservation as a tool of mobilisation of rural men and women are not conducted on regular basis.

Majority of men and women who are involved in land conservation project participate at the level of implementation rather than at all levels of project cycle. This type of planning can threaten sustainability of land conservation activities. Lack of regular gender equity mobilisation and education in land conservation initiatives to men and women contribute largely to less achievement of full gender integration in land conservation initiatives.

Village environmental committees which have an important role in monitoring environment conservation activities at the grassroots level have not been well established. NGOs seemed to have overlooked this essential grassroots institution which forms part of sustainable undertaking of land conservation initiatives and empowerment of the rural poor in this development process, of which they are expected to promote and strengthen. Sustainability of land conservation in refugee affected areas depends greatly on extent of awareness among, training and full involvement of men and women.

Recommendations

The study recommended that public meetings and training on land conservation promoted by NGOs as tool of mobilisation of rural communities be conducted on regular basis, with central focus on equal representation of men and women. Although there is insufficient number of staff and sometimes skills, NGOs should strive to involve all development related departments to play their traditional role of mobilising and creating awareness among rural communities on issues covering land conservation and development.

NGOs in collaboration with district government responsible authorities should facilitate equal representation of men and women, encourage formation and/or strengthen village environmental committees with and women so that these grassroots institutions take charge of monitoring sustainable land conservation, management and use at this local level. NGOs should adopt process planning that ensure participation of intended beneficiaries in designing, planning, implementation, monitoring and evaluation of land conservation project/initiatives, with full and equal involvement of men and women. NGOs' land conservation initiatives should direct focus more to rural communities than schools and church related institutions, because the former are more disadvantaged than the latter.

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ANNEXES

ANNEX 1: LIST OF WORKSHOP PARTICIPANTS

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ANNEX 2: OPENING SPEECH FOR THE SECOND NATIONAL AGROFORESTRY WORKSHOP, BY THE HON. MINISTER FOR NATURAL RESOURCES AND TOURISM, ANTHONY M. DIALLO (MP)

The Session Chair,
Distinguished Guests,
Workshop Participants,
Ladies and Gentlemen,

May I take this opportunity to welcome you all to Mbeya. For those coming from outside Tanzania, I welcome you to Tanzania and it is my hope that you will extend your stay after this workshop to have the opportunity to see the riches of Tanzania. I am sure during these 4 days you will be very busy deliberating on agroforestry research and development under the theme of Partnerships and Linkages for Greater Impact in Agroforestry and Environmental Awareness.

I wish to thank the organizers of the workshop that is; the Ministry of Natural Resources and Tourism and the Ministry of Agriculture, Food and Cooperatives. This workshop, I am told, got its major support from the Management of Natural Resources Programme (MNRP) which is co-financed by the Government of Norway and the Government of Tanzania. Let me on behalf of my Government thank the Government of Norway for its financial support not only to this workshop but also to many other areas of our development.

The Session Chair, Ladies and Gentlemen, Tanzania has an area of 945,200 km^2 and a population of 34.5 million people, of which over 80% depends on agriculture for economic development. However, agricultural productivity which accounts for 50% of the Gross Domestic Products (GDP). The low productivity is attributed to the use of insufficient and poor farm implements like hand hoe, low soil fertility due to continuous cultivation without nutrient replenishment, poor marketing systems and poor rural infrastructure. Low crop yields could be boosted by use of chemical fertilizers. However, about 50% of the population live below the poverty line with per capita income of US$ 210. A significant proportion of the population faces income poverty, food insecurity, poor nutrition and health, HIV/AIDS and environmental degradation. Most of the farmers cannot afford expensive farm inputs like inorganic fertilizers. It is therefore necessary to resort to technologies that will be affordable by the poor farmers.

The Session Chair, The government has made efforts to improve the livelihoods of the rural poor. These include, Rural Development Strategy 2001, Agricultural Sector Development Strategy 2001, The Tanzania Development Vision 2025 and National Strategy for Growth and Reduction of Poverty (NSGRP) 2005. However, specifically in 2002, the Government prepared a National Agroforestry Strategy document which envisaged that by year 2025, at least 4 million rural farming households should adopt and benefit from agroforestry interventions in a sustainable manner. We are informed that by year 2002, over 725,000 people were benefiting from agroforestry interventions in Tanzania. This shows how the government regards agroforestry in its development agenda. I am pleased to note that international institutions like the World Agroforestry Centre (ICRAF) and its partners are developing strategies to scale up agroforestry to reach and benefit more people.

The Session Chair, due to socio-economic and technological problems facing the small scale farmers in the region coupled with land degradation, high deforestation rate and population growth, agroforestry is considered one of the potential sustainable options in improving agricultural and livestock productivity, improve quality of life and contribute to sustainable equitable environment. Here we consider agroforestry to include all land use systems which integrate trees and agricultural crops and or livestock. In this context, we note that agroforestry is not new in the SADC countries, Tanzania included. These land use systems have existed for many years in different localities with different names. However, agroforestry research and development came in the mid seventies and was deliberately stepped up in the eighties and nineties, having realized its potential and its cost-effectiveness in contributing to sustainable productivity and development.

The Session Chair, I am informed that initially research and development emphasis was put in screening multipurpose trees for fodder, fuelwood and soil fertility improvement. I am also informed that in Tabora and Shinyanga for example, fodder banks, rotational woodlots and improved fallows for soil fertility improvement have been developed, tested by farmers and have shown positive results. As a result, in year 2003 about 700 women farmers in Shinyanga had adopted fodder bank technology which resulted in increased milk production significantly. Milk use in household also increased from less than 0.5 to 2 litres per day. Again in the same year, over 2626 farm families and 12 schools in Shinyanga had established and were evaluating rotational woodlots. Maize yield has increased from 0.8t/ha under natural fallow to an average of 1.4t/ha under legume fallow.

Recently emphasis has been put on indigenous fruit trees and their processing for value addition. The processing of indigenous and exotic fruits into high value products like jams, juices, wines, pickles and chutney is done by women in Tabora. These women can now afford 3 meals per day for the family, pay school fees for their children, buy medicines and clothes for their families. Similar results have been observed in Mbeya with improved fallows. These advances need more publicity and popularization. Lets not forget that food shortages being experienced almost countrywide could be easily addressed by popularizing such technologies.

The Session Chair, many stakeholders are involved in undertaking agroforestry research and development activities in Tanzania. These include Government Ministries, Research and Training Institutions, NGO's., Farmers, International Organisations, Universities, Councils etc. The list is long. To mention a few which are promoting Agroforestry (AF) technologies, we have The African Network for Agriculture, Agroforestry and Natural Resources Education (ANAFE) and its four regional Agricultural Forums for Training (RAFT) Branches. The World Agroforestry Centre; - (ICRAF), Natural Forestry Resources Management and Agroforestry Centre (NAFRAC), Agricultural and Forestry Research Institutions, and Sokoine University of Agriculture.
These institutions need to collaborate, coordinate and network to step-up effectiveness and to scale up the proven technologies.

The Session Chair, I am informed that this gathering is comprised of distinguished scientists from within and outside the country who have gathered here to:

1) Take stock on agroforestry research and development since the first workshop which was held at Sokoine University of Agriculture on 12th -16th October 1993.
2) Review and strengthen mechanisms for collaboration, coordination and networking among stakeholders in agroforestry research and development.
3) Identify gaps in research and development and set up priorities
4) Find ways to implement strategies for scaling up and out of appropriate agroforestry technologies
5) Review the current status of Agroforestry training in the country.

The Session Chair, the current policies and strategies strongly support establishment and strengthening partnerships with international, regional, national, NGOs, grass root communities and private sector in achieving the millennium development goals. In line with our policies the Government of Tanzania is committed to support agriculture in the context of agroforestry investments and other initiatives that will improve the livelihoods of the rural poor.

The Session Chair, I believe in the four days of the workshop, participants will review the technological inroads you have secured in agroforestry research and chart out and consolidate the way forward in agroforestry research and development agenda. Allow me, The Session Chair, to thank the two Ministries for organizing this important workshop and choosing Mbeya to be the venue. I am sure you will have the opportunity of seeing success agroforestry stories in Mbeya. These need in depth analysis leading to increased adoption elsewhere.

The Session Chair, invited guests, workshop participants, Ladies and Gentlemen, I wish you all fruitful deliberations, and at this juncture, I declare the Second National Agroforestry Workshop officially opened.

THANK YOU FOR YOUR ATTENTION

ANNEX 3: CLOSING REMARKS BY THE GUEST OF HONOUR PERMANENT SECRETARY FOR MINISTRY OF AGRICULTURE FOOD AND COOPERATIVES

Mr. Chairman,
Director Forestry and Beekeeping
Director General TAFORI
Representative of SADC Land and Water Management Programme
Representatives of ICRAF
Distiquished Guests, Ladies and Gentlemen.

It gives me much pleasure to get this opportunity to officiate at the closing of this important Second Workshop on Agroforestry and Environment in Tanzania.

I understand you had 4 very busy days here in Mbeya to discuss many issues on Agroforestry and Environment.

I am informed that you had some key note papers and several themes and sub-theme which included:

- Sustainable soil management
- Fodder production
- Domestication of indigenous fruits and medicinal plants
- Wood production
- Adoption, impact of agroforestry information and dissemination, and
- Natural resources policies on Agroforestry.

Mr. Chairman, Ladies and Gentlement

I am also told that you will have a full day trip to Mbozi District to learn experiences of farmers in Agroforestry and see adoption of Agroforestry in the district.

Mr. Chairman,

You have discussed in detail the experiences in research and dissemination and scaling up of Agroforestry in the country and have come up with several key issues regarding scaling up and out of Agroforestry technologies:

- That Agroforestry technologies can go a long way towards contributing to household incomes, food security and eradication of poverty

- That the adoption rate of Agroforestry technologies need some push from different stakeholders among which politicians should be at the front

- There is a pressing need for a clear policy on Agroforestry in the country including legislation to support the implementation of the policy

- Constant and sustainable efforts to popularize Agroforestry as a sustainable land use system

- Sustainable enhancement of Research and Development institutions by providing sufficient financial and human resources to continuously address current and emerging Agroforestry research issues so as to provide practicable solutions to such issues.

- Enhancement of internal and international collaboration between institutions and other stakeholders to share experiences to avoid duplication.

I am pleased to learn that you have not only agreed on these issues but also proposed strategies to address them. This is important because we always give resolutions in many workshops of this kind but no follow up action are given leading to these resolution remaining on paper.

Mr. Chairman,

This workshop would not be a reality without financial and logistical support of:

- The Ministries of Natural Resources and Tourism and Agriculture Food and Cooperatives
- NORAD
- Research and Training Institutions
- Office of the Regional Commissioner Mbeya.

I take this opportunity to thank these Institutions for this support.

Last but not least I thank the management of Mkapa Hall for the excellent services throughout the period of the Workshop.

May I also wish participants from within and outside the country a safe journey home.

Mr. Chairman, Distinguished Guests, Ladies and Gentlemen,

May I now take this opportunity to declare the 2nd National Agroforestry and Environment Workshop officially CLOSED!

THANK YOU

ANNEX 4: WORKSHOP RESOLUTIONS

Group Chairs & Raportuers

Achievements: research

- Sustainable soil management
    - Development of RWL for wood and soil.
    - Testing of IF, RC, biomass transfer and mixed cropping for soil improvement.
- Fodder production
    - Screening of fodder species as alternatives to *Leucaena leucocephala*
    - Use of AF species as animal feed supplements
    - Agronomic management of fodder species
    - Plant secondary compounds as feed and anti-nutritive factors
- Wood production
    - Use of woodlots for wood production and environment conservation
    - Use of agroforestry tree species for satisfying demand for fuelwood and construction materials, environment conservation, food and medicine
- Domestication and value addition of indigenous fruits and medicinal tree products

Achievements: Adoption

- Factors influencing adoption of AF have been articulated, which include:
    - Biological and biophysical aspects
    - Policy
    - Socio-economic
    - Institutional
    - Cultural
- AF adoption is about 1,000,000 farmers. More efforts in scaling up are necessary

Research gaps

- Limited work done on technologies appropriate for dry areas of the country
- Limited research done on second generation issues e.g.
    - Pests and diseases
    - Processing and marketing
    - Socio-economic aspects
- Limited research on water and nutrient dynamics
- More work on indigenous tree species
- Work on biotechnology aspect of AF

Constraints to adoption/scaling up of AF

- Inadequate policy statement on AF and conflicting policies on land management
- Inadequate coordination, collaboration, networking and poor linkage among stakeholders.
- Improper definition of responsibilities/roles on technology transfer and information exchange among stakeholders.
- Inadequate information on market outlets for AF products
- Inadequate number of extension staff
- Limited awareness on AF
- Inadequate frontline actors
- Inadequate skills among farmers, government and partners extension workers:
    - Processing and marketing
    - Tree management practices
- Slow processes of land ownership

- Inadequate credits/incentives for AF
- Inadequate germplasm and ineffective distribution system
- Inadequate communication skills to translate research findings to end users

A way forward

- Coordination of AF
  - Need to have effective AF research and development coordination mechanism
- Research
  - More research on arid and semi-arid land AF
  - More work on second generation issues
  - More research needed on indigenous trees
- Scaling up of AF
  - Formulation of clear policy statement on AF- R & D
  - Use the seven ICRAF prongs for AF scaling up
  - Finalization of AF business plan

ANNEX 5: OBITUARY

(Passport size)

Dr. Edward Laurent Ngatunga was born at Lituhi, Mbinga District on 20thJune, 1949. In 1973 he enrolled for a B.Sc. Agriculture degree course at the University of Dar es Salaam, Morogoro Campus where he graduated in 1976.

After graduating, he worked with the Agricultural Research Institute Mlingano, Tanga as Agricultural Research Officer undertaking research under Soil Management and Soil Fertility Section. In 1980 he joined the University of Dar es Salaam for a Master of Science degree in Soil Science which he attained in 1982. During this period 1976 – 1983 he wrote several scientific reports and presented papers in scientific conferences. He initiated a soil exchange programme with other laboratories (National and International) with the view of upgrading accuracy and reproducibility of laboratory results. Before he attended a M.Sc. Degree course, he had the opportunity to attend a one month course in Soil and Water conservation Research at IITA, Ibadan, Nigeria and 3 weeks course in the use of N15 in Soil Science and Plant Nutrition held in Leipzig, East Germany.

Later in 1983 he was promoted to a Senior Agricultural Research Officer and transferred to Naliendele Agricultural Research Institute, Mtwara where he worked as Head of the Soil Science Department and laboratory up to 1988. From 1988 – 1989 he was assigned officer in charge of Tobacco Experimental Station, Department of Research and Development Ministry of Agriculture and Food Security, in Tanzania.

In 1997 he went to Katholick University of Leuven, Belgium to pursue his Doctorate Degree in Soil Science. He got his doctorate degree in 2001 and was promoted to Principal Research Officer on Soil and Water Management and Agroforestry in the Department of Research and Development, Ministry of Agriculture and Food Security. He attended various courses related to his specialization.

During his carrier he worked in different capacities as organizer of workshops (e.g. the 1st National Agroforestry and Environment Workshop, held at SUA), Chair of Workshops and seminars, resource person in preparation of National Research Master Plan, National Coordinator of SADC Land and Water Management Research Programme, National Focal Point for Natural Resources. He worked very closely with the National Agroforestry Steering Committee (NASCO). Before his death he participated fully in the organizing committee for the 2nd National Agroforestry and Environment workshop held in Mbeya from 14 – 17th March 2006.

Dr. Ngatunga is a re-known scholar. He has published four papers in International Journals, eight in Scientific Conference Proceedings, Chapters in books and many Technical Reports.

Dr. Ngatunga died of sudden asthmatic complications at Mikocheni Mission on 4th April 2006. He was laid to rest at his home village Lituli on 7th April 2006, and is survived by a widow and ten children. May the Almighty God rest his soul in Eternal Peace. The late Dr. Ngatunga will be remembered as a hardworking, diligent and a faithful person.