ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES

THE BIOLOGICAL CHARACTERISTICS AND POTENTIALS FOR USE IN AGROFORESTRY OF TWO MIOMBO WOODLAND TREE SPECIES

A Thesis Presented to the School of Graduate Studies Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Dryland Biodiversity.

By

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June, 2003

DEDICATION

For my son Mabala

and my husband Kilomo.

ACKNOWLEDGEMENTS

I would like to sincerely thank my supervisors Professor Masresha Fetene, Dr. Zemede Asfaw and Dr. Hubert Lyaruu. Together they tirelessly guided and assisted me from proposal development through all stages of thesis write-up. I thank Dr. Lyaruu specifically for guiding me during field data collection in Tanzania and for facilitating the laboratory soil analyses. My sincere thanks also go to Prof. Nikundiwe at University of Dar-es-salaam, the RPSUD Country Coordinator, for facilitating my enrollment in this programme. I also thank him for assistance and encouragement during my field data collection time. At this point I would like to express my gratitude to Mr. Magambo, my Headmaster, Pugu Secondary School who facilitated my study leave so that I could join this programme. At Botany Department – University of Dar-es-salaam I owe gratitude to Mr. Kamwela who assisted me in field plant identification, Mr. Kweyunga Charles for his assistance during laboratory soil analysis and Mr. Ndangarasi for his guidance in data analysis. I am grateful to village leaders and villagers who willingly participated in completing the questionnaires. I am grateful to my parents; Mr. and Mrs. Kafumu for their moral support, encouragement and upbringing me in the moral of value and loving education. I would like to thank the family of Mr. and Mrs. Biswaro in Addis Ababa who in one way or another have contributed to my comfortable stay in this country. Many people have in one way or another contributed to the completion of this work and its impossible to mention all names here. However, I say ' Thank You Very Much all'. Finally, I wish to express my deepest gratitude to my husband Mr. Kilomo and our son Mabala for love and patience during the period of my fieldwork and during the period I have been away to Ethiopia for studies. Swedish Agency for Research Co-operation with Developing Countries (SAREC) funded this study through Research Program on Sustainable Use of Dryland Biodiversity (RPSUD).

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ABSTRACT

Two indigenous tree species of Tanzanian miombo woodland were studied to explore some of their biological characteristics and potential for use in agroforestry. These were selected by farmers from among four most frequently encountered tree species found within the study area using direct matrix ranking approach. The selection of the study species was based on degree of preference by farmers. Semi-structured interviews were administered on 60 informants to explore information on ecological aspects of the study sites, biological characteristics and multipurpose nature of the study species. Studies on the ecology and growth characteristics and their influence on the environment were conducted in four sites i.e. two sites for each study species. A total of 40 quadrats (50 by 20 m), 10 in each of the study sites, were established for study of vegetation information, tree characteristics and estimation of undercanopy vegetation cover. To investigate the influence of the study species on undercanopy soil, samples were collected from three study trees for each site. The soil samples were collected from 0–5 and 25–30 cm depths at 100, 250 cm and outcanopy distances along the transect radiating from tree bole. Bulk density, texture, pH, electrical conductivity, organic matter, total nitrogen, available phosphorus and exchangeable potassium of soil samples were analyzed. Vegetation cover and soil properties outside tree canopies were also investigated for comparison purposes. *Sclerocarya birrea* (A. Rich.) Hochst. Subsp. *caffra* (Sond.) Kokwaro. and *Brachystegia microphylla* Harms ranked first (1487) and second (1170) respectively in direct matrix ranking and hence were selected for this study. Site two study trees had highest average tree density. *B. microphylla* had higher mean tree height, canopy depth, and crown cover whereas *S. birrea* had higher mean DBH. In all sites undercanopy species diversity was significantly higher than species diversity outside the tree canopies. Soil mineral elements decreased with depth and distance from the tree bole. Significantly higher levels of nutrient elements under the tree canopies revealed an increase in input from the study trees. This indicates that the study trees enriched soil under their canopies thus creating suitable microenvironment, which promotes the development of understorey herbaceous layer. Comparison of levels of nutrients under the canopies of the two species indicated that *B. microphylla* had significantly higher percentage of total nitrogen at all depths than *S. birrea*. This may be due to the fact that *B. microphylla*, which is a leguminous tree, may fix nitrogen and hence increase nitrogen content under its canopy zones. *S. birrea* had a wide range of uses, indicating its multipurpose nature. It is concluded that both *B. microphylla* and *S. birrea* display high agroforestry potential and hence are recommended for use in agroforestry practices in miombo zones. However, the results of this study are subject to further verifications.

1. INTRODUCTION

1.1 Miombo ecosystems

1.1.1 Location

Miombo woodland is the largest single vegetation type covering 450 000 km^2 which is about 50% of the land surface of Tanzania (Rodgers, 1996). It occurs in two distinct blocks, in the southeast and west of the country (Lind and Morrison, 1974). Eastern Arc Mountains of Ukaguru and Udzungwa separate these blocks (Rodgers, 1996).

Miombo woodland is a distinctive physiognomy occurring in Africa south of the equator only (Walter, 1985). As a whole it covers an estimated 3.0 million km^2 of Zimbabwe, Mozambique, Angola, Malawi, Katanga province of Zaire and southern Tanzania (Rodgers, 1996). In the world ecosystem classification it is placed in the Zonobiome II i.e. Humido – Arid Tropical Summer – Rain Region with Deciduous Forest (Walter, 1985).

The miombo terminology comes from the Kinyamwezi vernacular name "Muyombo" (plural 'Miyombo') which refers to the tree *Brachystegia boehmii* (Lind and Morrison, 1974). *Brachystegia* is one of the commonest genera in miombo woodland (Lind and Morrison, 1974).

1.1.2 Geology and soil

The miombo woodland has moderately undulating landscape with broad, flat, gently sloping ridges alternating with shallow, flat-bottomed, seasonally inundated valleys called Mbuga (Lind and Morrison, 1974). Recurring ridges alternating with valleys lead to relative homogeneity of climate, which gives a distinctive relationship between geomorphology, soil and hence vegetation (Rodgers, 1996). Such distinctive interrelationship leads to the development of catenas of topographically related soils on this extensive undulating landscape (Herlocker, 1999). Due to this catena phenomenon, three types of soils are recognized in all miombo woodlands (Pratt and Gwynne, 1977). These are: soils of well-drained middle and upper slopes which are sand or sandy loams; valley floor Mbuga soils are poorly drained, dark, heavy clays that shrink and swell; and soils on the edge of seasonally fluctuating lakes which are always saline.

1.1.3 Climate

Miombo woodland occurs in elevation between sea level to 800 m in areas which receive unimodal rainfall between 500 to 1200 mm per annum (Lind and Morrison, 1974). Rainfall extends for five to seven months i.e. if it falls for five months it comes between December and April, and if for seven months, it falls between November and May (Herlocker, 1999). Miombo is characterized by long and severe dry seasons that take five to seven months (Paul *et al.*, 1997). The ratio of precipitation to potential evapotranspiration ranges between 0.50 and 0.75 (Paul *et al.*, 1997).

1.1.4 Vegetation

The miombo formation is described and mapped as the largest vegetation unit in the Zambezian phytochorion (White, 1983). Poor soil condition, unimodal rainfall, prolonged and severe dry seasons and severe and frequent fires are some of its main characteristics (Paul *et al.*, 1997). Despite such unfavorable conditions, miombo woodlands are not only rich in species composition but species are also generally very tolerant and well adapted to such harsh climatic and environmental conditions (Lind and Morrison, 1974; White, 1983).

Miombo woodland is generally fairly homogeneous in structure, function and species composition throughout its range (Rodgers, 1996). While miombo is relatively homogenous over large areas, there are notable differences in plant communities between sites; these are due to variation in habitat such as slope positioning, rockiness and soil depth (Rodgers, 1996). The catena concept, explains this phenomenon (Paul *et al.*, 1997).

Catena is a result of recurring of vegetation pattern, which is associated with valleys and ridges. This results into distinct relationships between geomorphology, soil and vegetation. Rodgers (1996) identified three catena series in miombo woodland which are: Chipya woodland on the top of the ridge; *Brachystegia* woodland on lower slopes and Valley communities on valley bottom.

Chipya woodland

It is called 'Chipya' in Zambia or 'Chao' in Tanzania. This catena represents a community influenced by greater fire intensities and hence the name 'Chipya' which means burning. Chipya is more open, less diverse and includes more fire tolerant species than the miombo proper (Rodgers, 1996). The common elements are species in the genera *Pterocarpus, Burkea, Terminalia, Erythrophleum, Pseudolachnostylis, Combretum* and *Pteleopsis myrtifolia* (Rodgers, 1996). Dominant genera of grasses are *Andropogon* and *Hyparrhenia.* These are course, taller and denser than in miombo proper.

Brachystegia woodland

Brachystegia woodland is also refered to as miombo proper. It has a numerous (various) tree species in which most of them are less tolerant to fire (Rodgers, 1996). Dominant tree species are those in genera *Brachystegia, Julbernadia* and *Isoberlina* (Paul, *et al.*, 1997).

Other genera that are associated with these dominant species are *Afzelia, Swartzia, Pterocarpus, Burkea, Amblygonocarpus, Uapaca,* and *Xeroderris* (Lind and Morrison, 1974). *Combretum* and *Terminalia* species dominate understory tree layers. Shrub layer, which is sparse, includes *Diplorhynchus, Condylocarpos, Xeromphis, Byrsorarpus, Tetracera, Combretum, Ximenia* and *Flacourtia* genera (Rodgers, 1996). Ground layer is shorter and less dense than in Chipya but is more diverse in grasses, sedges and herbs. Grasses include genera of *Panicum, Andropogon, Themeda* and *Sporobolus*. Termite mounds are very common in this community on which usually occurs under shade islands of bigger trees (Lind and Morrison, 1974). These are associated with climber tangles (*Landolphia*) and thicket precursors (*Leptactactina*).

Valley bottom communities

Rodgers (1979) discussed two types of valley communities, which are upper and lower valley communities. Upper valley communities are found in the broad flat valley bottoms which usually flood during the rainy season (Paul *et al.*, 1997). In Zambia, these are called Dambos while in Tanzania they are known as Mbuga (Rodgers, 1996). Dambos has the tendency of flooding during rainy season since soil drainage is impeded due to overland run-off of rain. It is associated with a riverine forest community along a streambed at the bottom of the valley. In Mbuga soil drainage is less impeded than in Dambos and hence develop more open woodland. This kind of woodland usually includes species in the genera of *Bahia, Pericopsis, Terminalia* and *Combretum* (Rodgers, 1979).

Lower valley community occurs when valley is broadened and merges into the wooded grassland that has less acid soils (Rodgers, 1979). On the impeded drainage, plant community becomes of more *Sclerocarya, Sterculia africana, Acacia,* and *Combretum hereoense and Combretum imberbe* (Rodgers, 1996).

1.2 Scope of the problem

A large proportion of the Tanzanian population benefits from miombo woodlands through the extraction of timber, fuelwood, building materials, honey, wild fruits, mushrooms and hunting and agricultural activities that are taking place in these woodlands (Munyanziza and Wiersum, 1999). In addition, there are other intangible benefits and services offered by miombo woodlands such as socio – cultural benefits and environmental services (Munyanziza and Wiersum, 1999).

The problem of deforestation of miombo woodland in Tanzania has a long history. The atlas map of 1971 shows that miombo was an extensive area, sparsely populated with much of its area being wildlife and forest estates (Herlocker, 1999). Currently it is being rapidly converted and the only wilderness areas left are the legal forests and wildlife reserves (Bisamda *et al.,* 1998). The large scale clearing was started by the colonial government for agricultural expansion and tse-tse flies control at around 1930s and 1940s (Rodgers, 1996). Recent, deforestation of Tanzanian miombo woodland has reached to an alarming state. It has been reported that between 1961 and 1984, expansion of cultivation land only caused a shrinkage of Tanzanian's forest land from 45.5 million ha to 42.2 million ha (TZ-DRT, 1991) and miombo is included.

Miombo conversion has been fueled by the rapid increase of Tanzanian population. Census of 1978 showed that the population of the country was 17.5 million people with growth rate farming methods, frequent bush fires and overstocking led to severe degradation especially for soil erosion (Bisamda *et al.*, 1998).

Responding to such rampant deforestation, a number of conservation programmes have been taking place in the country. Village Afforestation project, HADO (Dodoma land conservation program); HASHI (Shinyanga land conservation program) are among such conservation programs (Kerkholf, 1990). However, despite their potential contribution to conservation, these projects are on small-scale, slow and incapable of meeting the actual demand for service. To date, HADO, which was launched in 1974, has only managed to bring 1700 km^2 under conservation (Bisamda *et al,* 1998). For Tabora region to meet its fuelwood demand, Village Afforestation was required to plant trees at the rate of 15 000 to 20 000 ha per year but the actual planting was only 7 000 to 9 000 ha per year (FAO, 1986). In this situation, to meet the demand of consumption and conservation, combinations of approaches are needed (Eliapenda, 2000).

In a situation like this where the action of local-poor people is the major source of deforestation and degradation, integrated interventions are important (Barrow, 1991). Also, since the population of Tanzania is still largely agrarian, community based conservation programmes emanating from agricultural technologies and which are appropriate to farmers' management abilities offer feasible alternatives for sustainable land use (World Bank, 1978; TZ-DRT, 1992; URT-MOA, 1992). In line with this, agricultural technologies that can conserve soil fertility and increase land productivity can contribute significantly to conservation strategies (World Bank, 1978; Cook and Grut, 1989; TZ- DRT, 1992).

A number of comprehensive reviews of agricultural research activities have been conducted (Otsyina *et al.,* 1998). On the basis of these reviews, agroforestry was identified as one of the most promising technologies that could enhance land productivity and conserve soil fertility (King and Chandler, 1978; Otsyina *et al.,* 1998; Mulofwa *et al.,* 1999). Further, reviews on the potential of agroforestry in miombo zones of Africa, concluded that there are benefits to both sustainable agriculture and ability to reduce fuelwood crisis (Maghembe, 1994).

Past experiences show that, research priority still remains on the identification of suitable indigenous multipurpose tree species for different agroclimatic zones of the country (Kasembe *et al.*, 1984; Maghembe, 1994; Otsyina *et al.,* 1998). More significantly, it has been pointed out that in order to have successful agroforestry systems, there is a need to find ways to integrate scientific knowledge and the knowledge of traditional farmers (Cook and Grut, 1989). Such integration will bring about acceptability and widespread adoption of agroforestry innovation among smallholder farmers within the miombo zones and the country as a whole.

Before one attempts to establish an agroforestry system using certain tree species, specific knowledge on biological characteristics and potential for use in agroforestry of those species must be acquired (Vergara and Nair, 1985; Maghembe, 1994). While there are a large number of basic floristic and faunistic descriptions of the Tanzanian miombo ecosystems (Lind and Morrison, 1974; White, 1983), there are a limited number of ecological studies (Rodgers, 1996; Munyanziza and Wiersum, 1999), and much less have been done in miombo areas of the country as far as agroforestry is concerned (Maghembe, 1994).

As indicated above, the sustainable utilization of the Tanzanian miombo ecosystems through agroforestry, using miombo species can be achieved if specific ecological knowledge about them is acquired. More importantly, this knowledge should be integrated with farmers' knowledge, preferences and choices (Kerkholf, 1990). Therefore in this study the biological characteristics and potential use for agroforestry of two miombo woodland tree species were investigated. The farmers' preferences and choices were incorporated through the use of their preferences and choices in the selection of study species. Ethnobotanical methods were employed to gather the information on the knowledge of farmers on the study species.

1.3 Objectives of the study

The general objective of this study was to investigate the characteristics and potential for agroforestry of two tree species from the Tanzanian miombo forest using the combination of ethnobotanical and vegetation study methods.

Specific objectives of this study were:

- To investigate farmers' preferences and choices on indigenous tree species and their knowledge in agroforestry.
- To evaluate the multipurpose nature of the study species.
- To investigate the effects of the species under consideration on the composition of undercanopy vegetation.
- To analyze the effects of the species under consideration on the physical and chemical properties of the soil under the tree canopy.
- To evaluate the ability of the species under consideration to create favorable microenvironment and potential for use in agroforestry practice.

1.4 Description of the study area

1.4.1 Location

This study was carried out in Tanzania within southeast miombo woodland block in Kilosa district. The district is located between latitude $6^{0}04'$ and $7^{0}53''$ south of equator and longitude $36^{0}30'$ and $37^{0}30'$ east (URT 2000). Four sites were established within the district for this study (Fig. 1). For *Brachystegia microphylla,* site one was established at Kilosa Bomani (on the hill north of district headquarters) while the second site was located at Zombo in Kigunga village, which is found along the road to Mikumi National Park. For *Sclerocarya birrea* site three was established at Mbwade along the road to Morogoro (regional headquarter) and site four at Kilosa Bomani. The sites were selected after the study species were identified based on farmers' preference following the ethnobotanical survey conducted.

1.4.2 Climate

1.4.2.1 Precipitation

The study area receives two peaks of rainfall per year, which are fairly undifferentiated into seasons. This is a typical characteristic of miombo woodland as one advances towards the equator to 6^{0}S (Rodgers, 1996). Hence it could be categorized as an area that experiences unimodal rainfall pattern (Rodgers, 1996). A short rain peak is experienced between November and January while the highest peak is between March to May (URT 2000) (Fig. 2). The total rainfall received by the area is between 1000 mm and 1016 mm per year and the dry season is prolonged for five months between June to October (URT 2000).

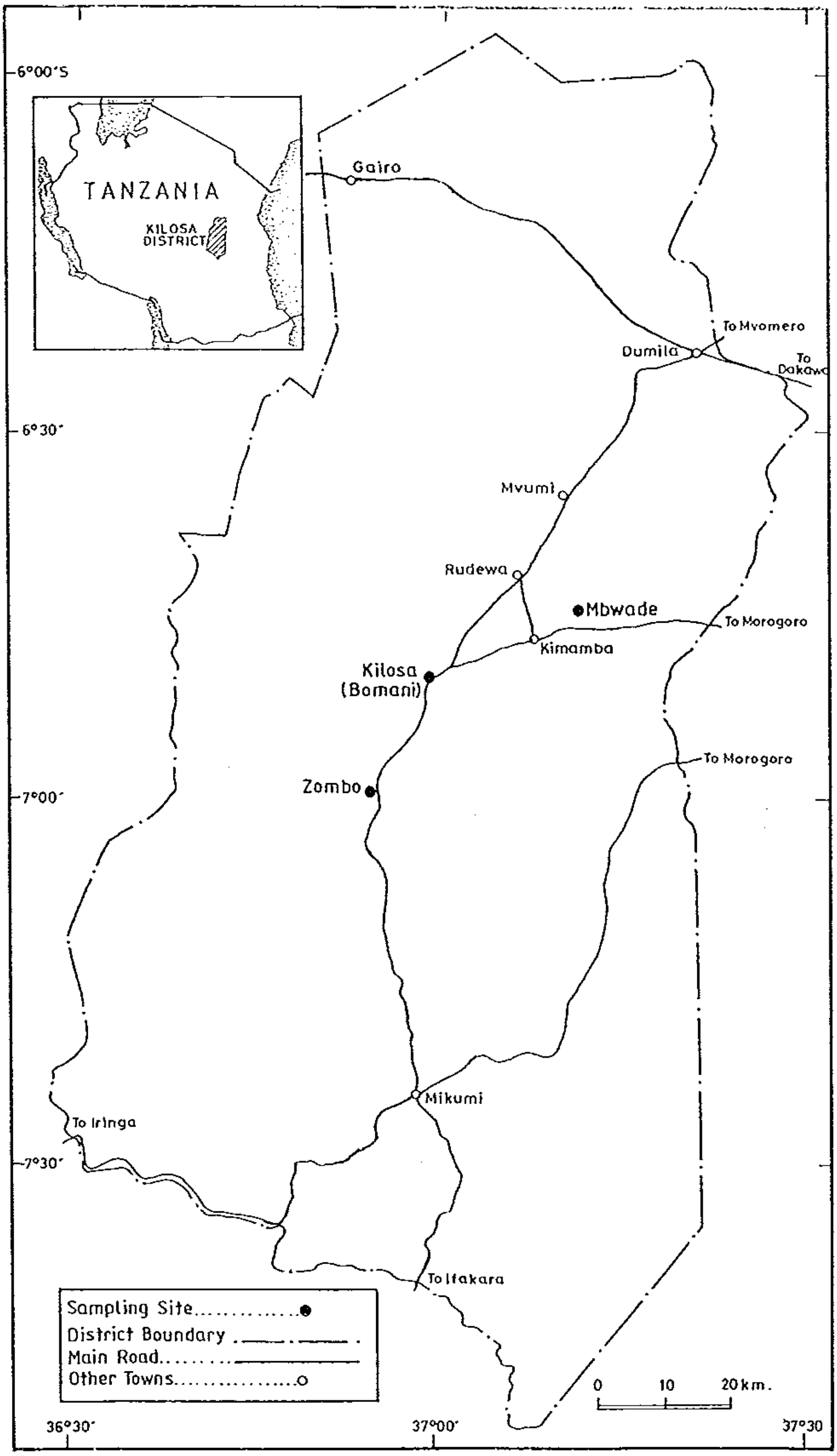


Figure 1. Map of the study area showing location and sampling sites

1.4.2.2 Temperature

The average temperature of the study areas is 24^0C whereas the minimum temperature is 18^0C in mountains and maximum temperature is 30^0C in lowlands (URT 2000). The coolest months are May, June and July while hottest months are September and October (URT 2000) (Fig. 2).

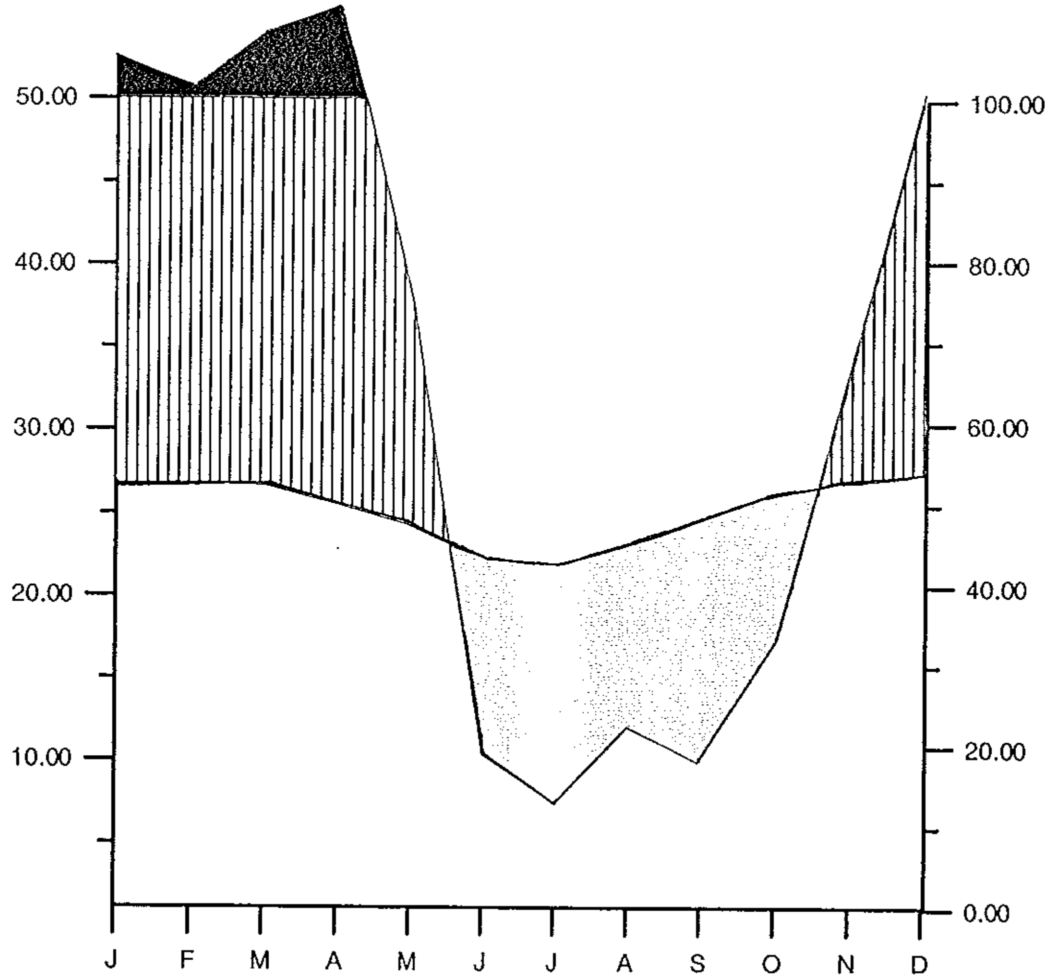
1.4.3 Land and people of the study area

Kilosa district is one among six districts of Morogoro region in the eastern zone of the country. According to the census of 1988 it had a total population of 346 575 (URT, 1988). The district's total land area is 14 245 km^2, of which 7 536 km^2 have potential for agriculture (URT, 2000).

Indigenous people of the study area belong to Wasagara ethnic group (URT, 2000), although pastoralist tribes were migrating into the district as it was observed during this study. The Wasagara people speak Kisagara language, the language for the local names of plants included in this thesis. Generally, Wasagara people depend on agriculture for their daily earnings as smallholder farmers. Their income in 1985 was estimated at 1.10 US$ per person per year (URT, 2000). Major crops grown in the study area are maize, rice, cassava, sweet potato, banana, groundnuts, beans and some cotton.

Ilonga station (506 m) (25.17°C) (1020 mm)

(16)



Source: Ilonga Agricultural Research Institute Meteorological Station (1987-2002)

Figure 2. The clima-diagram showing climate of the study area (Kilosa district)

2. MATERIAL AND METHODS

2.1 Ethnobotanical study methods

These are the techniques that are used to investigate the relationship between plants and humans (Cotton, 1996). Ethnobotany is a multidisciplinary subject, which gets its methods from different fields. These are fields of Botany, Linguistics, Ecology, Economics, Chemistry and Anthropology (Martin, 1995). In this study two ethnobotanical methods from the field of Anthropology were employed. These are direct matrix ranking tool and semi – structured interviewing.

2.1.1 Direct matrix ranking

The selection of study species was done using direct matrix ranking according to the farmers' choices and preferences following the description by Martin (1995). Direct matrix ranking method is based on multiple dimensions whereby informants order series of objectives considering several attributes at a time. In the table, criteria are listed along the left hand side and names of the items along the top. Individual respondents can rank the items according to each criterion, using numeral scale in which highest number is equal to 'best' objective and lowest number to the 'worst'. Total score of each item is obtained and rank of each item can be shown. At last the result of numerous individual responses can be added together to create the matrix that is a representative of the community.

In this study, nine criteria were given along the left hand side as tree quality and names of four suggested tree species as items along the top (Appendix 1). These were given to the farmers in a direct matrix ranking form for selection of two preferred species. The technique followed the work by Franzel *et al.* (1996). After filling the forms total score of each

2.2 Ecological study methods

2.2.1 Selection of four tree species suggested for direct matrix ranking

During reconnaissance survey the study area was stratified into three strata (valley, sloppy and hilly stratum). In each stratum, 30 quadrats of 20 by 20 m were randomly established following Mueller–Dombois and Ellenberg (1974). In each quadrat all trees encountered were counted and recorded. From all strata, total number of each tree species and their frequency of occurrence were calculated. The first four tree species with higher frequencies were picked and subjected to the direct matrix ranking.

2.2.2 Vegetation data collection

Vegetation data and soil samples were collected from randomly selected scattered trees of the study species. A total of forty trees of the study species for canopy features and vegetation studies and twelve trees for undercanopy soil analysis were selected for this study. For each site canopy features and undercanopy vegetation cover were recorded for ten study trees.

A total of forty quadrats of 50 by 20 m (1 000 m^2) were established i.e. 10 per site. The quadrat was established systematically to include at least one of the selected study trees. Selection of study trees for detailed investigation was made on the basis that only one matured enough study tree was studied per quadrat. For each of the quadrats the density of all tree species was recorded.

Canopy features: diameter at breast height (DBH), canopy diameter, tree height and canopy depth were measured using a meter tape. These were measured following Asferachew *et al.* (1998). DBH were measured approximately 1.5 m above the ground. Canopy diameter was measured by stretching the meter tape from one edge of the canopy to another. Tree height was recorded by measuring the distance from the base of the tree to the tip. Canopy depth was measured from the bole where bifurcation of branches begins to the tip of the tree.

Percentage cover of herbaceous vegetation under each of the study trees was estimated visually following Mueller-Dombois and Ellenberg (1974); Magurran (1988). Percentage cover of outside canopy herbaceous vegetation was also estimated from a 9 by 9 m quadrat. These quadrats were established on open space approximately 3 m away from the edges of canopy of the study tree. Percentage cover of undercanopy vegetation was compared with cover of outside canopy vegetation. This was done to assess the effect of canopy on undercanopy herbaceous layer for abundance and composition (Magurran, 1988). Total percentage cover of under and out canopy of each site was used to calculate species diversity indices using Shannon-Wiener Diversity Index formular following Magurran (1988):

$H' = - \sum pi \ln pi$ Where; H' = Shannon-Wiener diversity index

pi = the proportional abundance of the ith species (n_i/N)

ln = natural logarithm

2.2.3 Soil data

Soil samples for laboratory analyses were collected at a distance of 100, 250 cm from the tree bole and outside canopy at a depth of 0-5 and 25-30 cm. Outside canopy soil was collected from the open space approximately 3 m away from the canopy edges of the study trees. These samples were taken from three trees for each site i.e. a total of 72 samples was collected in this study. For bulk density, core samples were collected from each soil sampling point. Soil samples were kept in polythene bags, and properly sealed to avoid contamination and transported to the Botany Department at the University of Dar-es-salaam for analysis.

2.3 Laboratory soil analysis

The analysis of soil characteristics involved the measurements of bulk density, texture, pH, electrical conductivity, organic matter, total nitrogen, available phosphorus and exchangeable potassium.

2.3.1 Soil bulk density

The determination of bulk density was done using a known volume (core method) (Blake and Hartge, 1986). Soil was dried to 105^0C and weighed. The bulk density was obtained by using the oven dry weight of the sample divided by the sample volume.

2.3.2 Soil texture

Soil texture was determined by using the pipette method following Gee and Bauder (1986). The method involved a pre-treatment stage, separation of the sand sized particles and determination of silt and clay as described by Gee and Bauder (1986). The total weight was obtained from the formula:-

$$Ws + Wp + Wr = Wt$$

Where: Ws = weight of the sand fraction; Wp = weight of the fractions taken by pipette (silt and clay); Ws = weight of the remaining fraction; and Wt = total oven dry weight.

2.4 Data analysis

Information that was obtained through direct matrix ranking and questionnaires was summarized, described and tabulated. Species diversity of the herbaceous layer under the canopies of trees and outside their canopies were calculated by Shannon-Weaver diversity index following Goldsmith *et al.* (1976); Magurran (1988). Significance differences between undercanopy and outside canopy percentage covers for each site were compared using the special t-test following Magurran (1988).

Comparison on variation in soil properties between undercanopy and outcanopy were done by Analysis of Variance. Multiple comparisons of significantly different means were separated by Tukey High Significance Difference (HSD) as described by Fowler *et al.* (1998). Significant difference of means of tree characteristics and undercanopy soil properties between study species were compared using paired sample t-test (Zar, 1999). Mean values of a particular soil property were used to draw error bar graphs.

3. RESULTS

3.1 Ethnobotanical study

3.1.1 Selection of four tree species suggested in direct matrix ranking

A total of 19 tree species were recorded in the assessment of encounterbility frequencies. Table 1 indicates ten most frequently encountered tree species. From these, four species with higher frequencies of occurrance were picked for direct matrix ranking as most frequently encountered tree species. These are *Brachystegya microphylla, Brachystegia spiciformis, Sclerocarya birrea and Pterocarpus angolensis.*

Table 1. Ten most frequently occurring tree species in the study area

		Number of trees per stratum per species				
Tree species	**Family**	**Valley stratum**	**Sloppy stratum**	**Hilly stratum**	**Total no. per species**	**Frequency**
Brachystegia microphylla	Fabaceae	0	11	34	45	0.213
Brachystegia spiciformis	Fabaceae	0	16	21	37	0.175
Sclerocarya birrea	Anacardiaceae	20	16	0	36	0.171
Pterocarpus angolensis	Fabaceae	0	6	12	18	0.085
Acacia seyal	Fabaceae	14	0	0	14	0.066
Albizia herveyi	Fabaceae	3	10	0	13	0.062
Acacia nilotica	Fabaceae	10	0	0	10	0.047
Piliostigma thonningii	Fabaceae	8	0	0	8	0.038
Adansonia digitata	Bombacaceae	0	6	0	6	0.028
Acacia polyacantha	Fabaceae	3	2	0	5	0.024

3.1.2 Selection of study species

Results from direct matrix ranking are shown in Table 2. All scores from sixty respondents were added for each tree quality attribute against each suggested species. This created a matrix (Table 2) that is a representative of the community. Then total scores of each species were calculated. *S. birrea* ranked first followed by *B. microphylla* then *P. angolensis* and the last one was *B. spiciformis* with scores of 1487, 1170, 932 and 884 respectively. According to the results, *S. birrea* and *B. microphylla* were selected to be the study species.

Table 2. Direct matrices ranking of four suggested tree species

Scientific name	*B. microphylla*	*B. spiciformis*	*P. angolensis*	*S. birrea*
Local name (Kisagara)	**Mhini**	**Myombo**	**Mninga**	**Mng'ongo**
Family / **Tree quality**	*Fabaceae*	*Fabaceae*	*Fabaceae*	*Anacardiaceae*
Fuelwood	240	208	234	115
Charcoal	237	203	229	98
Shade	206	115	90	235
Fodder	28	1	1	91
Medicine	41	1	0	227
Furniture	185	199	240	207
Fruits (eaten)	11	0	0	226
Seeds (eaten)	4	0	0	72
Farm tree	218	157	138	216
Total score	**1170**	**884**	**932**	**1487**
Rank	**2**	**4**	**3**	**1**

Note: n = 60; scores for each attribute ranged between 0 and 4.

0 - represents unknown; 1 – very poor; 2 – fair; 3 – good; 4 – very good

3.1.3 Indigenous knowledge on the ecology of the study area

The knowledge of the indigenous people on the ecology of the area was recorded. This includes knowledge on climate (rain seasons and temperature fluctuations) and soil types. Seventy-two percent of respondents identified two rainy seasons while twenty-eight identified one season. According to the group who identified two rainy seasons, short rain season is between October and January while the second long season is between February and May. From the group with experience of one season usually rain comes between November and May.

According to indigenous people of the study area high temperatures are experienced during the late dry season to early rainy season between September and December while low temperature is during early dry season between May and July.

From the knowledge of local people who were interviewed, the study area has three types of soils, which are kichanga, mfinyanzi and tifutifu. While 32% of the respondents identified the three types of soil as kichanga, mfinyanzi and tifutifu, 68% of respondents identified two types. Of those who identified two types, 63% identified kichanga and mfinyanzi and 37% identified mfinyanzi and tifutifu. The approximate equivalents correlation between local soil types and International types was done following U.S. Department of Agricultural (U.S.D.A) (Van Wambeke, 1992) and FAO – UNESCO (1988) systems in Table 3.

3.1.4 Indigenous people and tree planting (agroforestry)

Seventy percent of the respondents planted trees recently, about three years ago. Out of them 79% planted trees around homesteads only, 7% planted on farms only whereas 14% planted both around homesteads and on farms. Table 4 shows types of trees planted by farmers of the study area; percentage of people who planted that particular species and their reasons for planting.

Table 3. Indigenous classification of the soils of the study area

Indigenous classification	Characteristics according to indigenous people	Approximate equivalents correlation to international classification systems	
		U.S.D.A	FAO- UNESCO
Kichanga	Whitish and shiny, big particles, hold water for very short time.	Alfisols	Lixisols/Nitisols
Tifutifu	Blackish in color, medium capacity of holding water, non elastic when wet.	Alfisols	Lixisols/Nitisols
Mfinyanzi	Blackish, small soil particles, hold water for very long time, when with water is elastic and swells, when dry shrinks and forms cracks.	Vertisols	Vertisols

Table 4. Tree species planted by farmers of the study area

Tree species	Local name	Family	Respondents who planted (%)	Reason for planting
Mangifera indica	Mwembe	Anacardiaceae	47	Fruits, shade
Cuppressus lusitanica	Msonobari	Cupressaceae	23	Medicine,shade, operation
Cocos nucifera	Mnazi	Palmae	17	Oil, economic earning
Citrus sinensis .	Mchungwa	Rutaceae	13	Fruits
Eucaryptus sp.	Mkaritusi	Myrtaceae	13	Building poles, operation
Elaeis guineensis	Mgazi	Palmae	8	Oil, economic earning
Azadrichta indica	Mwarubaini	Meliaceae	5	Medicine, shade
Terminalia catappa	Mkungumanga	Combretaceae	2	Shade

3.1.5 Indigenous knowledge on biological characteristics of study species

The respondents indicated that *B. microphylla* usually thrives well on mountainous and sloppy areas and in most cases preferring sandy soil. On the other hand, *S. birrea* mostly prefers to grow on valleys and gentle slopes on clay soil. Table 5 indicates the total response scores on a particular type of habitat and soil type for each study species.

Table 5. Indigenous knowledge on habitat of the study species

Habitat			Soil type		
	B. microphylla	*S. birrea*		*B. microphylla*	*S. birrea*
Mountains	43	0	Clay	5	30
Hills	0	9	Sand	31	5
Slopes	16	18	Loam	4	5
Valleys	0	27	Both types	20	20
Anywhere	1	6			

According to the respondents, average height at first flowering was estimated to be 4.6 m and 4.2 m for *B. microphylla* and *S. birrea* respectively. On the other hand average age at first flowering were suggested to be 8.4 years for *B. microphylla* and 9.7 years for *S. birrea*.

Respondents also managed to identify times in which the study species undergo certain biological dynamics such as shading of leaves, flushing of new leaves, flowering and fruiting (Table 6). *B. microphylla* starts shading leaves one month earlier than S. birrea whereas flushing is between October and November for both. *S. birrea* starts flowering one month earlier than *B. microphylla* whereby both undergoes fruiting between January and February.

3.1.6 Uses of the study species by the local people

Respondents listed different uses of each study species. Table 7 shows how local people use different parts of the study species with their respective response percentage listed for that particular use.

Table 6. Indigenous knowledge on phenology of the study species

	B. microphylla				*S. birrea*			
Months	**shading**	**flushing**	**flowering**	**fruiting**	**shading**	**flushing**	**flowering**	**fruiting**
Jan				X				X
Feb				X				X
March								
April								
May								
June	X							
July	X				X			
Aug	X				X			
Sep	X				X			
Oct		X				X	X	
Nov		X	X			X	X	X
Dec			X	X				X

Table 7. Uses of different parts of the study species

	B. microphylla		*S. birrea*	
Plant part	**Uses**	**Respondent score (%)**	**Uses**	**Respondent score (%)**
Leaves	Fertilizer	20	Medicine	28
	Fodder	12	Fodder	18
Branches	Firewood	100	Firewood	67
	Charcoal	100	Building poles	7
			Legs of beds	5
Barks	Local building ropes	82	Medicine	70
	Bee hives	37	Storage utensils	7
	Boats	31	Soap	2
	Storage utensils	72		
Roots	-	-	Medicine	52
Fruits	-	-	Food	98
			Beer	2
			Medicine	2
General use	Timber	68	Ritual tree	60
	Shade	37	Shade	57
	Slip way	23	Local utensils & furniture	35
	Farmland tree	10	Timber	5

3.2 Descriptions of the study species

Detailed description of features of *Brachystegia microphylla* Harms is given in Brenan (1967) and for *Sclerocarya birrea* (A. Rich.) Hochst. subspecies *caffra* (Sond.) Kokwaro. (Syn: *S. caffra* Sond.) in Kokwaro (1986); Mbuya *et al.* (1994).

B. microphylla is an indigenous tree of miombo woodland belonging to the family Fabaceae / *Leguminosae* subfamily *Caesalpinioideae*. At maturity, these trees attain heights ranging between 4 and 20 m. When the trees are young, barks are smooth, pale silver grey and as they age, barks become rough with dark grey to brownish. Crowns are spreading and flat topped with delicate upper branches. Leaves are closely pectinate (17-)25-60(-72) pairs of leaflets. Flowers are small, greenish, white or yellowish. Pods are thinly woody, smooth up to 12 x 3 cm.

Though *B. microphylla* does not produce high quality timber (as reported by indigenous people in this study), it remains ecologically important for miombo woodlands. It has been widely known for production of high quality charcoal and is preferred by many people for fuelwood (as reported by indigenous people in this study).

S. birrea is an indigenous tree belonging to the family *Anacardiaceae*. According to Mbuya *et al.* (1994) there are three subspecies of *S. birrea* in Tanzania, which differ in leaflet number and shape, length of flower spike and distribution. *S. birrea* subspecies *caffra* is one of the three subspecies of *S. birrea*. Others are *S. birrea* subspecies *birrea* and *S. birrea* subspecies *multifolialata*.

S. birrea subspecies *caffra* is a deciduous tree 10 – 18 m having a thick bole with large branches and a rounded crown. It grows in mixed deciduous woodland and wooded grassland from 100 to 1600 m above sea level. Leaves are alternate, compound and crowded at tips of branches. Leaflets are ovate to elliptic, dark green above, much paler and bluish – green below. Flowers can be on the same or separate trees. Male flowers are pale green in spikes whereas female flowers are green-pink and solitary. Fruits are rounded and fleshy to 3.5 cm across with cream to yellow color. They are edible, taste a bit like mango; having 2 – 3 large oily seeds inside.

S. birrea subspecies *caffra* is an important tree with diverse uses. Some of the uses are firewood, timber, utensils, carvings, drinks, bee forage, fodder, medicine, oil and cosmetics (Palgrave, 1983; Mbuya *et al.*, 1994).

3.3 Vegetation data

A total of 91 plant species from 38 families were recorded during field data collection in this vegetation study (Table 8). There was a variation in species composition, tree density and dominant species among study sites. Table 9 indicates three dominant (in frequencies of occurrance) tree species for each site and their densities. Site two had highest tree density for three dominant trees followed by site four then site three and site one had lowest tree density.

Three dominant tree species for site one were *B. microphylla, Albizia harveyi* and *Julbernadia globiflora* and for site two were *B. microphylla*, *B. spiciformis* and *Pterocarpus angolensis.* Three dominating tree species for site three were *S. birrea, B. spiciformis* and *B. microphylla* while for site four were *S. birrea, Acacia seyal* and *A. nilotica.*

Dominant shrubs at site one were *Margaritaria discoidea, Schrebera alata* and *Combretum zeyheri* while for site two were *Hoslundia opposita, Combretum apiculetum* and *C. zeyheri*. Shrubs of *Combretum zeyheri, Annona senegalensis* and *Diospyros usambarensis* dominated at site three. At site four, *Lonchocarpus capassa, Flueggea villosa* and *Harrisonia abyssinica* were dominating shrub species.

Grasses and herbs dominant in site one were *Heteropogon contortus, Hyparrhenia rufa, Orthosiphon suffrutescens* and *Rourea orientalis* while for site two were *Hyparrhenia rufa, Rottboellia cochinchinensis,* and *Commelina benghalensis*. For *S. birrea* sites grasses and herbs, which were dominant were *Heteropogon contortus, Hyparrhenia rufa* and *Hyptis suavelons* in site three. Site four was dominated by *Themeda triandra, Rottboillia cochinchinensis, Abutilon mauritianus* and *Sida alba.* Other tree, shrub, herb and grass species, which were present in each study site, are presented in Table 8.

Table 8. Plant species recorded from all study sites categorized in growth form

1 - 4 stands for study sites; + = Presence of a species; - absence of a species on that site

Species	Family	*B. microphylla*		*S. birrea*	
		1	2	3	4
Herbs					
Aristida rhiniochloa Hochst	Poaceae	+	-	+	-
Cynodon dactylon (L.) Pers.	Poaceae	-	-	+	+
Cyperus rotundus L.	Cyperaceae	+	-	-	+
Heteropogon contortus (L.) P. Beauv.ex Roem.& Schult	Poaceae	+	+	+	-
Hyparrhenia rufa (Nees) Stapf	Poaceae	+	+	+	-
Panicum maximum Jacq.	Poaceae	+	-	+	+
Rottboellia cochinchinensis (Lour.) Clayton	Poaceae	+	+	-	+
Themeda triandra Forssk.	Poaceae	-	-	-	+
Abrus precatorius L.	Fabaceae	-	-	+	+
Abutilon mauritianum (Jacq.) Medic.	Malvaceae	+	-	-	+
Achyranthes aspera L.	Amaranthaceae	-	-	+	+
Asparagus africana Lam.	Asparagaceae	+	+	-	-
Asystasia gangentica	Acanthaceae	+	-	+	+
Commelina benghalensis L.	Commelinaceae	+	+	+	-
Glinus oppositifolius (L.) A. DC.	Aizoaceae	+	-	+	-
Hyptis suavelons	Labiatae	-	-	+	-
Lippia spicata Bak.	Verbenaceae	+	-	+	+
Orthosiphon suffrutescens (Thonning) J. K. Motron	Labiatae	+	-	+	-
Rourea orientalis Baill.	Connaraceae	+	-	+	-
Sida alba L.	Malvaceae	+	-	+	+
Tephrosia villosa (L.) Pers.	Fabaceae	-	-	+	+
Tragia cilialis	Laneiaceae	-	-	+	-
Tridax procumbens L.	Asteraceae	-	-	+	+
Triumfetta rhomboidea Jacq.	Tiliaceae	+	-	+	-
Vernonia adoensis Walp.	Asteraceae	+	-	+	+
Waltheria indica L.	Sterculiaceae	+	-	+	+
Shrubs					
Deinbollia borbonica Scheff.	Sapindaceae	-	-	+	+
Solanum incanum L.	Solanaceae	+	-	-	+
Combretum zeyheri Sond.	Combretaceae	+	+	+	-
C. molle R. Br. Ex G. Don	Combrataceae	+	-	+	-
C. apiculetum Sond.	Combrataceae	-	+	-	-

Dalbergia melanoxylon Guill. & Perr.	Fabaceae	+	-	+	-
Annona senegalensis Pers.	Annonaceae	+	-	+	+
Calotropis procera (Ait.) Ait. f.	Asclepiadaceae	-	-	+	-
Lantana camara L.	Verbanaceae	-	-	+	-
Vangueria infausta Burch.	Rubiaceae	+	-	+	-
Pseudolachnostylis maprouneifolia Pax.	Euphorbiaceae	-	-	+	-
Markhamia acuminata	Bignoniaceae	-	-	+	-
M. obtusifolia	Bignoniaceae	-	-	+	-
Diospyros usambarensis F. White	Ebenaceae	+	-	+	-
Uvaria kirkii Oliv.	Annonaceae	-	-	+	-
Lonchocarpus capassa Rolfe	Fabaceae	-	+	+	+
Grewia forbesii Mast.	Tiliaceae	-	-	+	+
Ximenia americana L.	Olacaceae	+	-	+	-
Commiphora africana (A. Rich.) Engl.	Burseraceae	+	-	+	-
Boscia salicifolia Oliv.	Capparidaceae	+	-	+	-
Schrebera alata (Hochst.) Welw.	Oleaceae	+	-	+	-
Harrisonia abyssinica Oliv.	Simaroubaceae	+	-	+	+
Flueggea virosa (Willd.) Voigt	Euphorbiaceae	-	-	-	+
Pluchea dioscoridis DC.	Asteraceae	-	-	-	+
Antidesma venosum Tul.	Euphorbiaceae	+	-	+	+
Maerua angolensis DC.	Capparidaceae	-	-	-	+
Maerua kirkii (Oliv.) F. White	Capparidaceae	-	-	-	+
Clerodendrum myricoides (Hochst.) Vatke	Verbenaceae	-	-	-	+
Ochna mossambiscensis Klotzsch	Ochnaceae	+	-	-	-
Holarrhena pubescens (Buch.-Ham.) G. Don	Apocynaceae	+	-	-	-
Thylachium africanum Lour.	Capparaceae	+	-	-	-
Hoslundia opposita Vahl	Labiatae	+	+	+	-
Dichrostachys cineria (L.) Wight & Arn	Fabaceae	-	+	+	+
Suregada zanzibariensis Baill.	Euphorbiaceae	+	-	-	-
Dombeya shupangae	Sterculiaceae	+	-	+	-
Margaritaria discoidea (Baill.) Webster	Euphorbiaceae	+	-	-	+
Catunaregam spinosa (Thunb.) Tirvengadum	Rubiaceae	-	-	+	-
Stereospermum kunthianum Cham.	Bignoniaceae	+	-	-	-
Steganotaenia araliacea Hochst.	Umbelliferae	+	-	-	-
Senna singuaena (Del.) Lock	Fabaceae	+	-	+	+
Trees					
Acacia nigrescens Oliv.	Fabaceae	-	+	-	+
Acacia nilotica (L.) Del.	Fabaceae	-	-	-	+
Acacia polyacantha Willd	Fabaceae	-	-	-	+

Acacia seyal Del.	Fabaceae	-	-	-	+
Adansonia digitata L.	Bombacaceae	-	-	+	-
Albizia gummifera (JF Gmel.) C.A. Sm.	Fabaceae	-	-	+	-
Albizia harveyi Fourn	Fabaceae	+	-	+	+
Brachystegia microphylla Harms	Fabaceae	+	+	+	-
Brachystegia spiciformis Benth.	Fabaceae	-	+	+	-
Flacourtia indica (Burn. f.) Merr.	Flacourtiaceae	+	-	+	-
Hyphaene coriacea Gaertn.	Palmae	-	-	-	+
Isoberlinia angolensis (Benth.) Hoyle & Brenan	Fabaceae	-	+	-	-
Julbernadia globiflora (Benth.) Troupin	Fabaceae	+	+	-	-
Kigelia africana (Lam.) Benth.	Bignoniaceae	-	-	-	+
Lannea schweinfurthii (Engl.) Engl.	Anacardiaceae	-	-	-	+
Manilkara sulcata (Engl.) Dubard	Sapotaceae	-	-	-	+
Pericopsis angolensis (Bak.) Van Meeuwen	Fabaceae	+	+	+	-
Phoenix reclinata Jacq.	Palmae	+	-	-	-
Piliostigma thonningii Schumach	Fabaceae	-	-	-	+
Pteleopsis myrtifolia (Laws.) Engl. & Diels	Fabaceae	-	+	-	+
Pterocarpus angolensis DC.	Fabaceae	-	+	+	-
Sclerocarya birrea (A.Rich.) Hochst.	Anacardiaceae	+	-	+	+
Strychnos madagascariensis Poir.	Loganiaceae	+	-	+	-
Tamarindus indica L.	Fabaceae	-	-	+	-
Trichilia emetica Vahl.	Meliaceae	-	-	+	-

Table 9. Tree density and average density of three dominant species for each site (n=10)

Species	Site no.	Dominant species	Tree density / species / plot	Average tree density / species / ha	Average tree density / ha
B. microphylla	1	*B. microphylla*	2.4	240	350
		Albizia harveyii	0.8	80	
		J. globiflora	0.3	30	
	2	*B. microphylla*	3.4	340	700
		B. spiciformis	2.2	220	
		P.angolensis	1.4	140	
S. birrea	3	*S. birrea*	1.7	170	380
		B. spiciformis	1.1	110	
		B. microphylla	1.0	100	
	4	*S. birrea*	2.0	200	440
		Acacia seyal	1.4	140	
		A. nilotica	1.0	100	

3.4 Tree characteristics of the study species

Results indicate that there are variations in tree characteristics between these two study species (Table 10). Comparison of tree characteristics among study species revealed that *B. microphylla* had higher mean of tree height, canopy depth and crown cover than *S. birrea*. On the other hand, *S. birrea* had higher mean of DBH than *B. microphylla* as shown in Table 11. When subjected to the statistical test, only DBH was significantly different between study species at 0.05 level of significance (Table 11).

In comparing the characteristics of the study trees for all sites, trees at site two had highest mean tree height (19.80 $\pm$ 4.64), canopy depth (15.30 $\pm$ 5.76) and crown cover (178.11 $\pm$

90.5). Trees at site four had highest mean DBH (2.15 $\pm$ 0.72) followed by trees at site three (1.71 $\pm$ 0.55).

Table 10. Untreated data of tree characteristics of the study species at all sites Measurements are in m and m^2 for crown cover

a) *B. microphylla*

Tree no.	Site one				Site two			
	height	depth	DBH	Crown cover	height	depth	DBH	Crown cover
1	20.0	17.0	3.0	153.94	12.0	6.0	0.8	63.62
2	13.5	11.5	1.9	44.18	15.0	10.0	0.8	50.26
3	8.0	4.0	0.8	28.27	22.0	18.0	1.5	188.69
4	7.0	4.5	0.8	33.18	17.0	12.0	1.1	153.94
5	12.0	10.0	1.3	63.62	21.0	19.0	1.4	254.47
6	13.0	8.0	1.0	63.62	25.0	18.0	1.8	298.65
7	12.0	9.0	1.2	63.62	16.0	10.0	1.0	113.10
8	12.0	9.0	1.1	103.87	20.0	15.0	1.1	132.73
9	12.0	9.0	1.0	90.76	25.0	20.0	1.8	298.65
10	10.0	7.5	1.0	70.88	25.0	25.0	1.9	226.98

b) *S. birrea*

Tree no.	Site three				Site four			
1	15.0	12.0	1.9	132.73	15.0	12.5	2.4	132.73
2	10.0	6.0	1.0	283.53	16.0	14.0	2.3	201.06
3	18.0	12.0	2.3	298.65	9.0	6.0	1.3	86.59
4	12.0	7.5	1.9	70.88	18.0	13.0	3.0	201.06
5	15.0	12.0	2.0	226.98	20.0	15.0	2.5	254.47
6	7.0	5.0	1.0	23.76	12.5	15.0	1.1	113.10
7	15.0	7.0	1.9	113.10	10.0	8.0	1.1	33.18
8	15.0	7.0	2.5	153.94	20.0	16.0	3.0	201.06
9	10.0	6.0	1.6	113.10	19.0	17.0	2.5	153.94
10	12.0	8.0	1.0	95.03	20.0	17.5	2.3	103.87

Table 11. Mean values of tree characteristics of study species (mean ± SD; n = 10)

Tree characteristics	*B. microphylla*	*S. birrea*	P - value
Tree height (m)	16.74 (6.40)	15.66 (5.92)	> 0.05
Canopy depth (m)	13.06 (5.92)	11.99 (5.93)	> 0.05
DBH (m)	1.17 (0.46)	1.18 (0.38)	< 0.05
Canopy cover (m^2)	151.88 (83.32)	130. 64 (84.02)	> 0.05

3.5 Undercanopy vegetation

Diversity indices of undercanopy vegetation for each site were significantly higher compared to that of outside canopy of study trees (Table 12). Generally, *S. birrea* had higher species diversity index when compared with *B. microphylla*.

Comparison on diversity indices of undercanopy vegetation of study trees among study sites indicated that, study trees at site three had highest diversity index, followed by trees at site four, then followed by study trees at site one (Table 12).

B. microphylla trees had higher percentage cover per tree when compared with *S. birrea* trees. Comparison of mean percentage cover of study trees for each site revealed that site two had highest average percentage cover per tree of undercanopy vegetation (94.0%) followed by site three (79.2%), then site one (61.9%), and lastly site four (50.5%). Undercanopy and outcanopy percentage cover for each species per plot is presented in Appendix 4.

Table 12. Comparison of species diversity indices of under and outside tree canopy vegetation in each of the study site

Site no.	Undercanopy species		Outcanopy species		t - value	significance
	richness	diversity	richness	diversity		
1	*15*	1.665	*11*	1.484	2.6	**
2	*3*	0.888	*3*	0.840	2.1	*
3	*21*	2.112	*12*	1.018	16.4	**
4	*14*	2.068	*7*	1.615	7.2	**

Note: n = 10; Difference between under and outcanopy are tested by special t – test. * stands for significant at $p < 0.05$; and ** at $p < 0.01$

3.6 Laboratory soil analyses

3.6.1 Bulk density

Soil bulk density increased with depth as well as with distance from the tree bole (Fig. 3). For *B. microphylla* mean soil bulk density ranged between 0.96 ± 0.12 and 1.04 ± 0.14 g/cm^3 for topsoil (0–5 cm) and between 1.11 ± 0.10 and 1.04 ± 0.16 g/cm^3 for sub soils (25-30 cm). For *S. birrea* it ranged between 0.96 ± 0.14 and 1.08 ± 0.15 g/cm^3 for topsoil and 1.09 ± 0.17 and 1.18 ± 0.14 g/cm^3 for sub soil (Appendix 6). However the differences in bulk density of soils sampled under tree canopy was not statistically significant ($p< 0.05$) in comparison with those sampled from outside tree canopies.

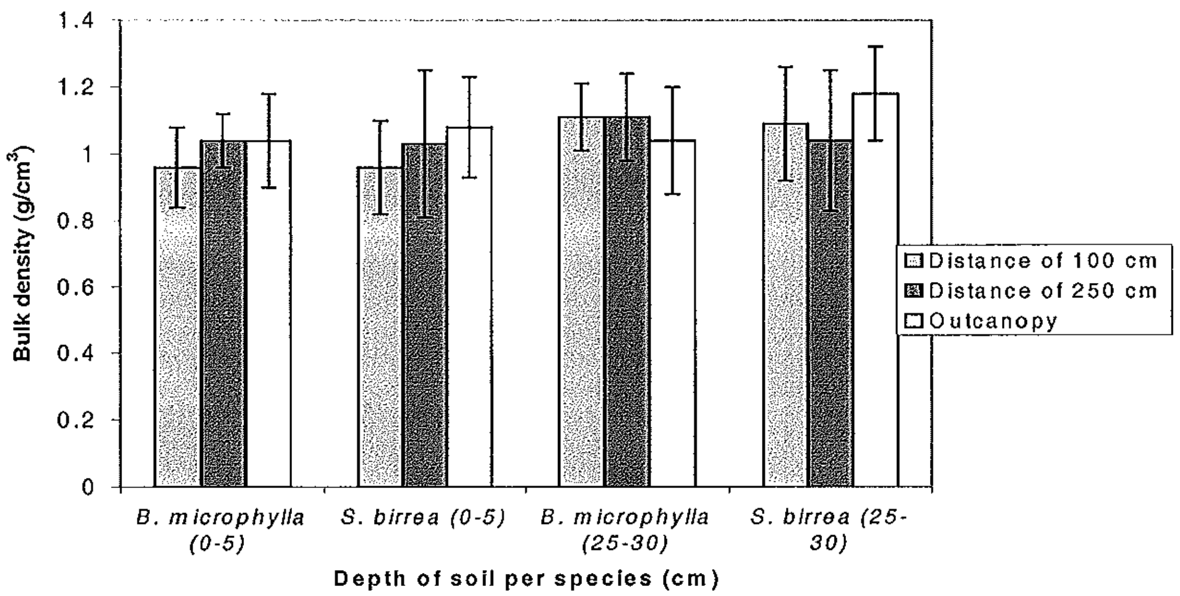


Figure 3. Variation in bulk density of soil samples (mean ± SD; n = 6)

3.6.2 Soil texture

Results on soil texture showed that site one, two and three were dominated by sand fraction without difference between under and outcanopy soils. Observed textural classes from these sites are sandy loam, loamy sand and loam (Table 13).

Soil texture at site four was mostly dominated by silt and clay particles. The observed textural classes were clay and clay loam without significant difference between under and outcanopy soils (Table 13).

Table 13. Mean percentage sand, clay and silt at each distance and depth for all sites Distance and depth are in cm (mean ± SD; n = 3)

a) *B. microphylla*

		Site one				Site two			
distance	depth	sand	clay	silt	Textural class	sand	clay	silt	Textural class
100	0 – 5	71	14	16	Loamy sand	67	12	21	Loamy sand
	25–30	69	14	17	Loamy sand	68	14	18	Sandy loam
250	0 – 5	69	16	15	Sandy loam	68	11	21	Sandy loam
	25–30	66	20	14	Sandy loam	64	14	22	Sandy loam
OC	0 – 5	70	12	18	Loamy sand	65	14	20	Sandy loam
	25–30	70	14	16	Loamy sand	65	15	20	Sandy loam

b) *S. birrea*

		Site three				Site four			
100	0 – 5	49	17	34	Loam	15	47	38	Clay
	25 – 30	67	16	19	Loam	22	46	32	Clay
250	0 – 5	70	13	17	Sandy loam	16	34	50	Clay
	25 – 30	70	12	18	Sandy loam	18	32	50	Clay
OC	0 – 5	68	12	20	Sandy loam	23	22	55	Clay loam
	25 – 30	70	13	17	Sandy loam	25	22	54	Clay loam

3.6.3 Soil pH

The soil pH decreased with depth and distance from the tree bole under all study trees (Fig. 4). For *B. microphylla* mean soil pH ranged from 6.11 $\pm$ 0.34 to 6.36 $\pm$ 0.22 for topsoil, and from 5.33 $\pm$ 0.55 to 5.97 $\pm$ 0.33 for subsoil, while for *S. birrea* it ranged from 6.32 $\pm$ 0.54 to 6.69 $\pm$ 0.47 for topsoil and from 6.00 $\pm$ 0.75 to 6.47 $\pm$ 0.43 (Appendix 6). Statistically, pH values of soils sampled under canopy were not significantly different ($p < 0.05$) from those sampled from outcanopy for all study trees.

3.6.4 Electrical conductivity (EC)

The EC decreased from topsoil to subsoil and away from tree bole in all study trees (Fig. 4). There was a significant difference in EC between under and outcanopy soil for soils sampled under *B. microphylla*. The mean EC of undercanopy in site one ranged from 53.06 ± 14.77 to 220.81 ± 98.65 µs/cm for topsoil (0-5 cm depth) and 26.48 ± 8.66 to 152.17 ± 88.69 µs/cm for subsoil (25-30 cm depth) (Appendix 6). Variations in EC among sampling points for all sites were very high.

Comparison of EC between study species showed a significant difference between the study species. *S. birrea* had higher EC values without significant difference between under and outcanopy soils. EC at site four was exceptional high compared to other sites. It ranged from 663 to 345 µs/cm for topsoil and from 415 to 261 µs/cm for subsoil of undercanopies. Outcanopy soil had EC levels from 347 to 268 and 234 to 164.9 µs/cm for topsoil and subsoil respectively (Appendix 7).

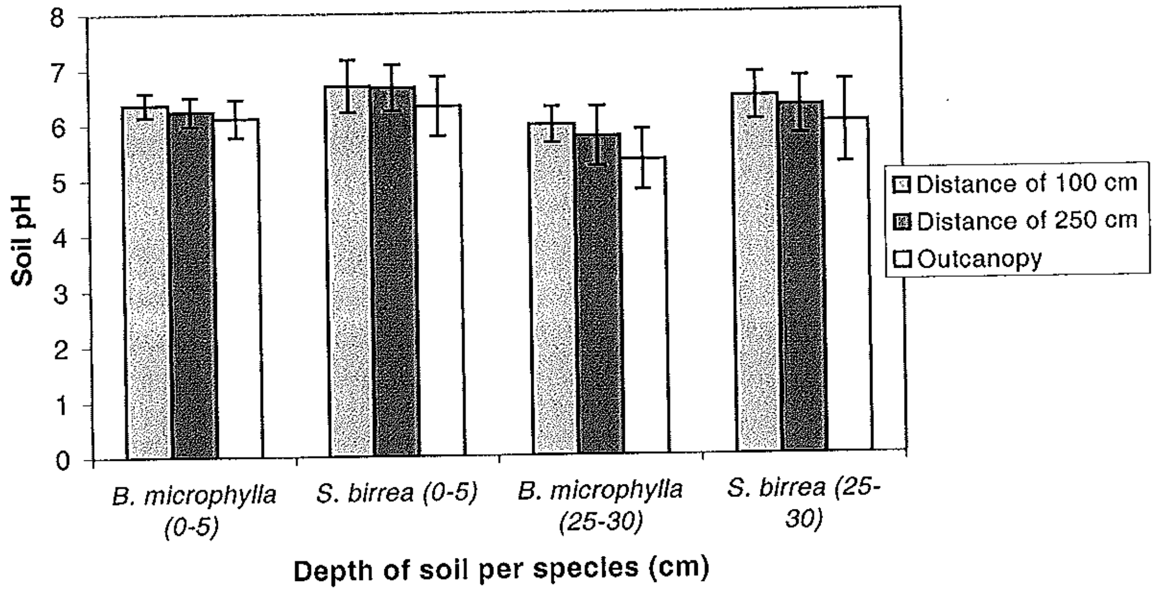


Figure 4. Variation in pH of soil samples (mean ± SD; n = 6)

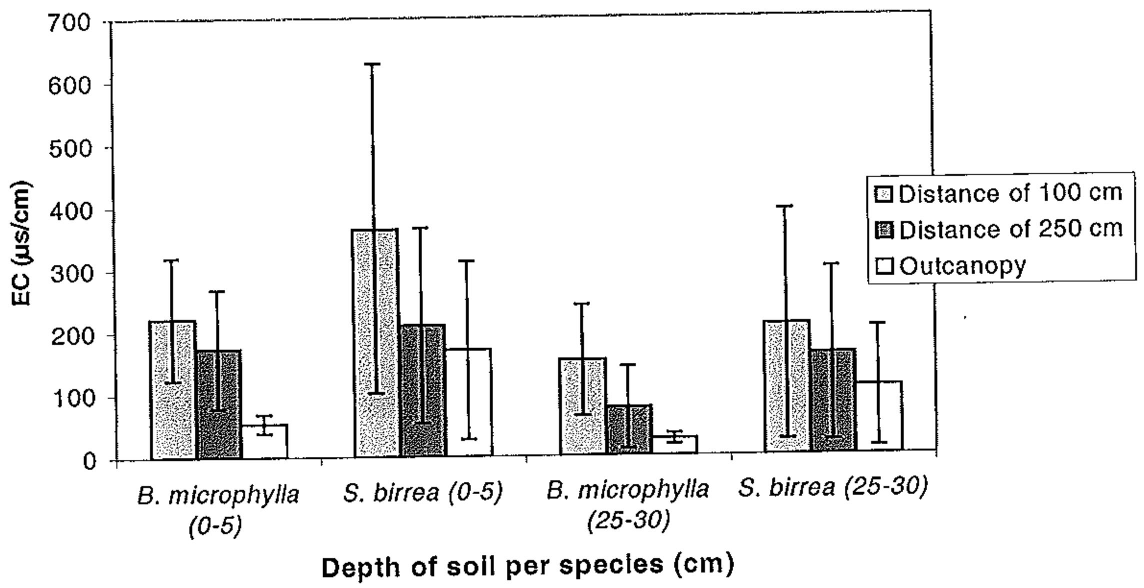


Figure 5. Variation in electrical conductivity of soil samples (mean ± SD; n = 6)

3.6.5 Organic matter

Organic matter decreased with increase in depth for both species at all study sites. The same trend was observed with distance from the tree bole (Fig. 6). In this study mean percentage of organic matter for soils collected under *B. microphylla* trees ranged from 6.62 $\pm$ 1.46 to 12.97 $\pm$ 1.45% for topsoil and from 4.33 $\pm$ 0.94 to 10.33 $\pm$ 1.43% for subsoil. Mean percentage of organic matter of soils collected under *S. birrea* canopies ranged from 10.21 $\pm$ 1.82 to 16.31 $\pm$ 0.62% for topsoil, while for subsoil were from 7.51 $\pm$ 1.51 to 12.64 $\pm$ 1.49% (Appendix 6). Generally soils collected from undercanopies of *S. birrea* had higher organic matter content than those from *B. microphylla*. Statistically, organic matter of soils sampled under tree canopy were significantly different from those sampled from outcanopy as shown in Appendix 6.

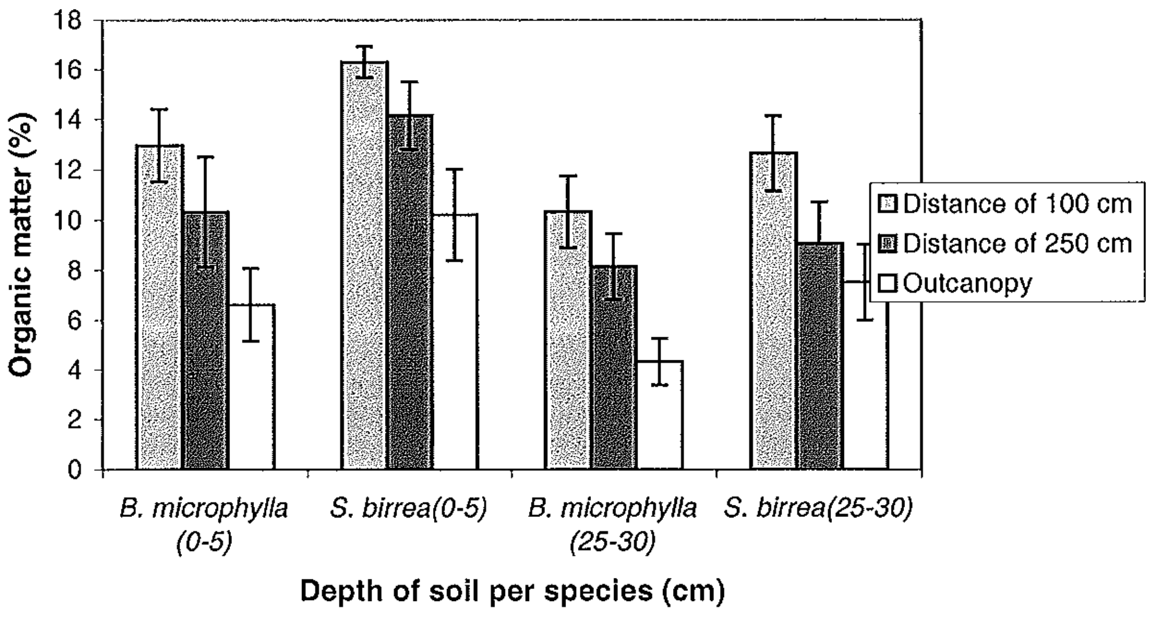


Figure 6. Variation in organic matter percentage of soil samples (mean ± SD; n = 6)

3.6.6 Total nitrogen

There was a general tendency for total nitrogen to decrease with depth as well as away from the tree bole. This was for all study trees (Fig. 7). Observation revealed that topsoils under *B. microphylla* had higher mean percentage nitrogen than those of *S. birrea*. It ranges from 0.26 ± 0.04 % to 0.53 ± 0.10 %; and 0.13 ± 0.04 % to 0.32 ± 0.05 % for *B. microphylla* and *S. birrea* respectively (Appendix 6). Statistically, mean percentage nitrogen of soils sampled under canopy were significantly higher from those sampled from outcanopy of study trees.

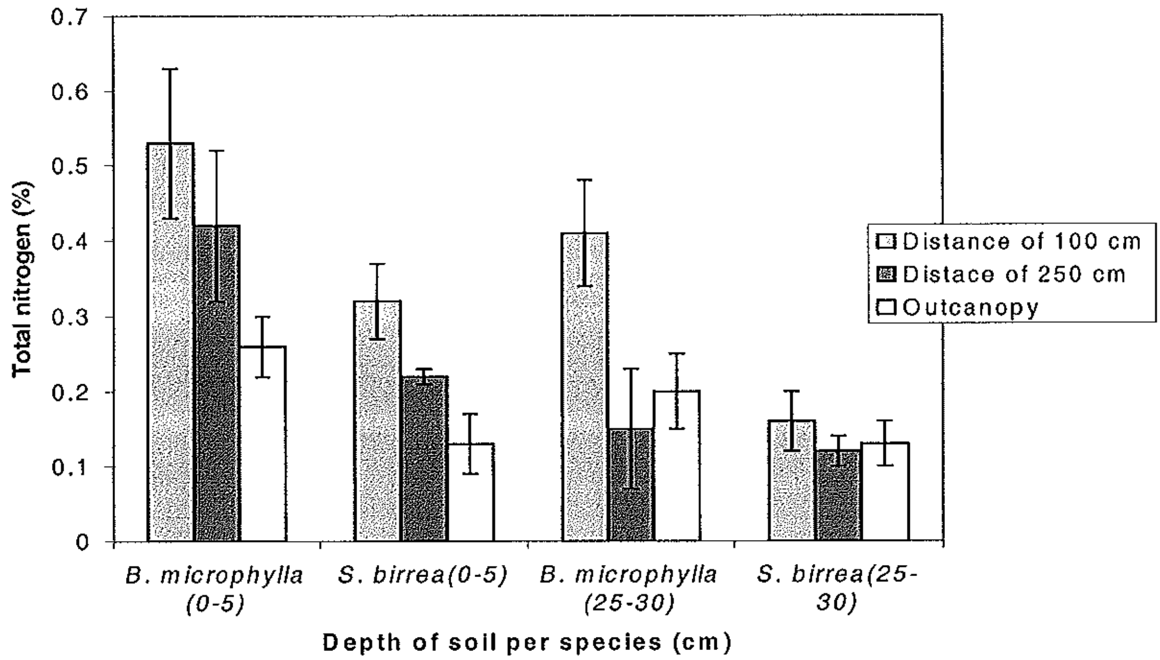


Figure 7. Variation in total nitrogen of soil samples (mean ± SD; n = 6)

3.6.7 Available phosphorus

Available phosphorus declined with distance from the tree bole and with increase in depth (Fig. 8). The mean available phosphorus of topsoil for *B. microphylla* ranged from 0.07 ± 0.04 to 0.18 ± 0.07 mg/100g and for *S. birrea* from 0.08 ± 0.03 to 0.21 ± 0.11 mg/100g. For subsoil it ranged from 0.04 ± 0.03 to 0.07 ± 0.04 mg/100g and 0.06 ± 0.02 to 0.09 ± 0.05 mg/100g for *B. microphylla* and *S. birrea,* respectively (Appendix 6). Available phosphorus levels were significantly higher under tree canopies compared to outside canopies for all study species.

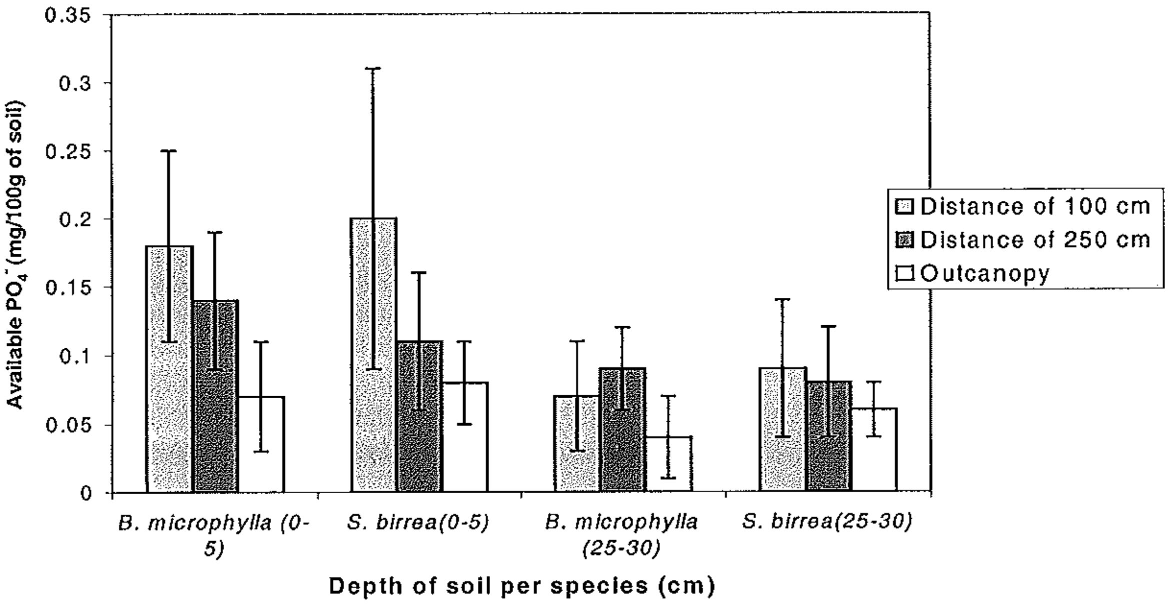


Figure 8. Variation in available phosphorus of soil samples (mean ± SD; n = 6)

3.6.8 Exchangeable potassium

Exchangeable potassium decreased away from the tree bole and also with increasing soil depth (Fig. 9). Statistically, exchangeable potassium levels were significantly higher under tree canopies from those outside canopies for all study species. It was observed that topsoils sampled from undercanopies of *S. birrea* had higher mean exchangeable potassium which ranged from 2.15 ± 1.20 to 3.83 ± 0.61 meq/100g compared to those sampled from undercanopies of *B. microphylla,* which ranged from 1.67 ± 0.55 to 2.66 ± 0.45 meq/100g (Appendix 6).

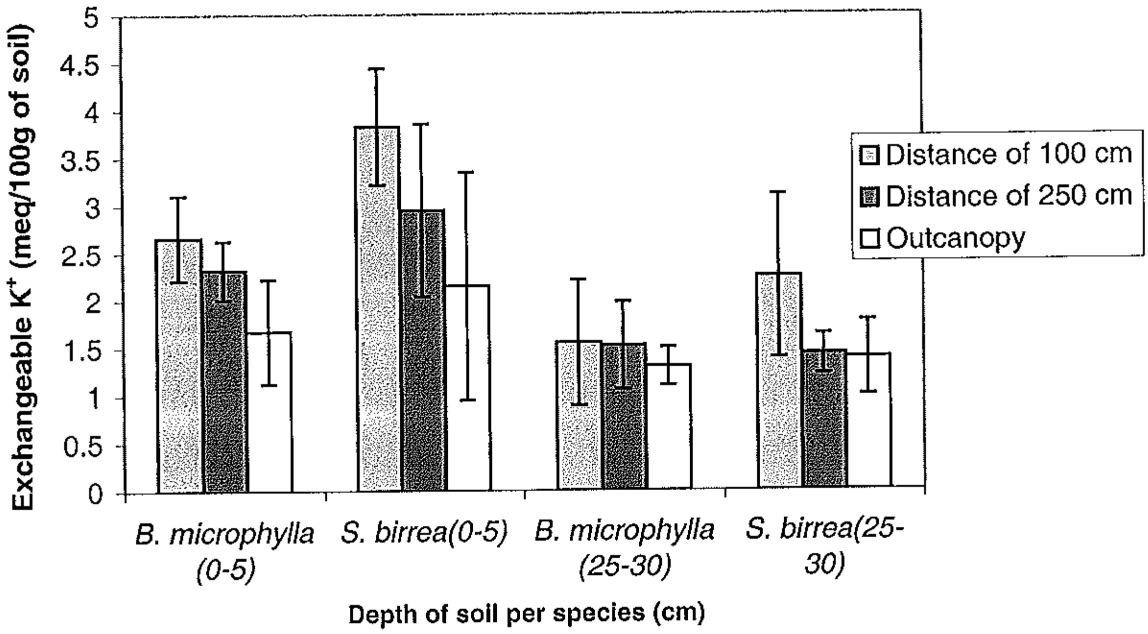


Figure 9. Variation in exchangeable potassium of soil samples (mean ± SD; n = 6)

4. DISCUSSION

4.1 Indigenous knowledge

Assessment of indigenous knowledge on agroforestry revealed that most planted trees were exotic and found around homesteads. Also from this survey it has been noted that farmers prefer to plant fruit trees from which they enjoy its shade and sometimes sell those fruits for economic earnings. Whenever farmers plant trees of quality apart from fruit, economy earnings and shade, they mostly comprise species supplied by the government as it was observed during village afforestation project in Tanzania (Kerkholf, 1990).

Most of the indigenous tree species, which are found scattered around homesteads and farmlands are naturally regenerated and protected during tillage or building operations. This was similar to what was reported by Kerkholf (1990) and Mulofwa *et al.* (1999). This situation applies also to the study species as it was noted that no planting was carried out for the study species, but the community rely completely on supply from natural sources. However, local people do not plant these study species probably because still they can find them plenty around their surrounding (Baumer, 1990), and/or they are not aware of the economic value they have (Kerkholf, 1990), or because they grow more slowly compared to exotic species. According to Mulofwa *et al.* (1999) the absence of nurseries with indigenous tree species for supply of seedling to local people could also contribute. But it is high time that indigenous tree species should be planted as they offer social, economic and ecological advantages without altering the environment (Oba *et al.*, 2000).

Referring to indigenous knowledge both study species were indicated to have diversified uses. Comparatively *S. birrea* has more uses than *B. microphylla*. Diversity of uses for *S.*

birrea was also noted by Palgrave (1983); Mbuya *et al.* (1994); Maundu *et al.* (1999); and Mulofwa *et al.* (1999). Diverse uses of *B. microphylla* and *S. birrea* imply their multipurpose nature. According to King and Chandler (1978); Franzel *et al.* (1996); Rhoades (1997) multipurpose nature is one of the central tenets for tree species demanded for agroforesty.

4.2 Tree characteristics

B. microphylla trees at site two had highest tree height and average number of trees per hectare. *S. birrea* at site four had the highest mean DBH with moderate number of trees per hectare. At site two there is probably competition for resources and light, which resulted in the thinning and lengthening tendency of trees. This observation is in line with the reports of Rhoades (1997); Scholes and Archer (1997). With moderate number of trees per hectare, *S. birrea* trees at site four have moderate mean tree height with well-developed trunks. This observation is a challenge for agroforesters to determine maximum number of trees of study species to be incorporated in the farming system so that positive tree effects will accumulate simultaneously within active farming systems.

4.3 Undercanopy vegetation

Species diversity indices of undercanopy vegetation were significantly higher in all study sites compared to those of outside canopy. This trend was also observed by Belsky *et al.* (1989); Grouzis and Akpo (1997) and Asferachew *et al.* (1998). Significantly higher undercanopy species diversity could be interpreted to be a result of the presence of greater soil fertility and better microclimatic condition under tree canopies (Scholes and Archer, 1997). Greater soil fertility within the canopy zones may have been due to minerals transported from surrounding soils by tree roots (Kellman, 1979; Belsky *et al.*, 1989) and subsequently through increased inputs from trees through litterfall and biomass production (Browaldh, 1995). Dust from the surroundings accumulated on tree leaves, branches and stem when washed down to undercanopy soils during stemflow and throughfall could be also contributing to the high fertility undercanopy (Kellman, 1979).

Better microclimatic condition perhaps is caused by reduced soil and air temperature (Belsky *et al.*, 1989) and improvement in surface water availability (Grouzis and Akpo, 1997). Grouzis and Akpo (1997) noted that tree canopy significantly reduces total solar radiation where tree foliage showed high potential to reflect to the atmosphere and/or to intercept absorbable incoming radiation. Also tree canopies reduce air temperature, soil temperature and wind velocity (Belsky *et al.*, 1989). Thus reduction of total solar radiation, temperature and wind velocity result in lowering Potential Evapotranspiration (PET) (Le Houérou and Popov, 1981). Decreased PET, better water infiltration together with active absorption and transfer of water by roots located in deep horizons towards the superficial horizons improves water availability under tree canopies (Grouzis and Akpo, 1997).

4.4 Soil properties

Significant difference in EC between under and outcanopy of soils sampled under *B. microphylla* probably implies the influence of these trees on the chemical composition of the soil under its canopies. This could be the result of accumulation of soluble salts (Smith and Doran, 1996; Asferachew *et al.*, 1998).

Site three and four were noted to have very high values of EC with insignificant difference between under and outcanopy soil. This could mean that the soil in these sites has naturally higher EC (saline) (Pratt and Gwynne, 1977). Thus its implication probably could mean that *S. birrea* can tolerate saline soils.

EC is associated with determining soil salinity as it is related to the total ions in the soil. At the EC below 0.4 dS/m (mmhos/cm) indicates good nutrient availability for plants whereas, above this, it leads to the salinity problem (Smith and Doran, 1996). Salinity is an accumulation of excess cations on top soils. This indicates nutrients poor soils that is structurally unstable and disperses readily (Smith and Doran, 1996).

Nitrogen was observed to be higher under the study trees than outcanopies. This was also noted by Browaldh (1995). The mechanism under which nitrogen concentration is improved by trees is complicated. This might be explained by the combined effect of increased mineralization and nitrate uptake by the trees. Browaldh (1995) demonstrated that the high concentration of Ammonia lower concentration of Nitrate and consistently lower NO_3^- / NH_4^+- N- ratio under tree canopies than outcanopy as it was observed.

Under tree canopies there is high concentration of microorganisms. Moderate range of pH, reduced temperature and improved water moisture undercanopies favors these microorganisms (Rhoades, 1997). High concentration of microorganisms under tree canopies is responsible for high rate of mineralization of litter materials under tree canopies than outcanopies (Kamprath, 1978 and Smith and Doran, 1996). Microorganisms function as important catalyst for transformation and cycling of nitrogen and other nutrients (Rice *et al.*, 1996). Nutrients released during turnover of the microorganisms are often plant available. Hence microorganisms are significant source and sink of nitrogen (Rice *et al.*, 1996).

Significantly higher concentration of nitrogen under *B. microphylla* compared to that under *S. birrea* could be interpreted as the result of *Rhizobium*-Legume symbiosis (Keya, 1978; Marques *et al.*, 2001). *B. microphylla* are classified as members of subfamily *Caesalpinioideae* belonging to the family *Leguminosae* (Brenan, 1967). Marques *et al.* (2001) demonstrated that members of this family form symbiotic relationship with *Rhizobium* bacteria. Thus the higher nitrogen content under *B. microphylla* might be attributed to nitrogen fixation.

Significantly higher percentage of organic matter was observed on undercanopy than that on outcanopy for both study species. These data are consistent with previous research results of Weltzin and Coughenour (1990); Asferachew *et al.* (1998) and Yeshanew *et al.* (1999). Higher organic matter percentage undercanopy could be a result of input of litter from the tree in the zone under the tree canopy (Campbell *et al.*, 1994; Rhoades, 1997). The accumulation of dust on rough tree canopies due to reduced wind velocity on which, through stemflow and throughfall is washed down undercanopy (Kellman, 1979; Belsky *et al.*, 1989). Such dust may also be contributing to the greater soil organic matter percentage under the study trees (Kellman, 1979; Belsky *et al.*, 1989). Faecal droppings of birds and other animals utilizing the tree shade during hot days might also be contributing to the undercanopy soil organic matter (Belsky *et al.*, 1989).

Significantly higher organic matter percentage under *S. birrea* than *B. microphylla* may be explained by several factors. Higher organic matter concentration in fine–textured soils probably is due to tendency of organic matter to incorporate into soil aggregates (Campbell *et al.*, 1994; Sikora and Scott, 1996). This tends to reduce decomposition or eluviation, resulting in higher organic matter percentage in fine-textured soil as observed in this study (Campbell *et al.*, 1994).

Litter quality could also influence the organic matter percentage among study species. According to Campbell *et al.* (1994) chemical quality of litter inputs regulate organic matter decomposition rate and the formation of stable soil organic matter. Perhaps litter from species with recalcitrant fractions does not mineralize completely resulting in a build up of soil organic matter (Campbell *et al.*, 1994; Rhoades, 1997).

Potassium and phosphorus were noted to decline with profile depth and distance from the tree bole. This may indicate that the tree rather than parent rocks have contributed to the input of these nutrients. Significantly higher concentration of PO_4^- and K^+ in the undercanopy soil than outcanopy perhaps implied ability of these species to enrich soils under the canopy. Litter inputs, root residue decay, nutrient pumping by long tree roots, throughfall and stemflow may be mainly responsible for higher concentration of undercanopy soils (Kellman, 1979; Belsky *et al.*, 1989; Browaldh, 1995; Rhoades, 1997). More important, the level of these two elements found undercanopy of study species is in normal range for the growth of many crops (Kamprath, 1978).

Greater concentration of nutrients under tree canopies than outcanopy generally may be interpreted as a result of effects of study trees on soil through different processes carried out by the tree (Kellman, 1979). These are tree input, output and turnover or catalytic processes (Weltzin and Coughenour, 1990). Thus these processes could be responsible for creation of microenvironments observed under study trees on this study.

5. CONCLUSION

Both *B. microphylla* and *S. birrea* are typically deciduous tree species. They prefer dry to subhumid environments with moderate temperatures. *B. microphylla* is strictly indigenous to miombo thriving well on steep escarpments on sandy soils. *S. birrea* occurs in miombo woodlands as well as in open woodlands on lowlands and mostly preferring fine textured soils.

B. microphylla and *S. birrea* showed high potential to create microenvironment under their canopies. Their positive influence on undercanopy environment i.e. improvement of chemical nature of soil and increasing soil fertility, promotes the growth of undercanopy herbaceous layer. Thus, this indicates their potential for use in agroforestry.

Furthermore, these two study species are multipurpose and therefore can be qualified as suitable for agroforestry. *B. microphylla* if introduced as an agroforestry tree can be useful in rehabilitating severely degraded and eroded sloppy areas and can prevent soil erosion in steep slopes. Because of its ability to fix nitrogen, if incorporated in agroforestry system it can supply nitrogen to the poor soils and at the same time its leaves can supply fodder for animal keeping societies. It can also offer a continuous supply of high quality fuelwood, building materials for the local community and shade for crops, animals and people during sunny days.

S. birrea if promoted and planted on large scale as an agroforestry tree in Tanzania, it will be easily and widely accepted by local people due to its social value such as medicinal, ritual and supply of local raw materials for household utensils. From its delicious edible fruits, fresh juice rich in vitamin C and famous alcoholic liquor (Amarula) can be produced commercially on a large scale. Thus it would significantly contribute to the economy of smallholder farmers and the nation at large. Apart from ecological, social and economical advantages, *S. birrea* leaves are palatable which can be used as fodder by animals and the tree can offer good shade when with leaves.

From this study the investigated species, *B. microphylla* and *S. birrea* both displayed a high agroforestry potential and hence are qualifying to be used in agroforestry practices. The present study concentrated only on exploration of some biological characteristics of the trees, screening of their multipurpose nature, their ability to grow undercanopy vegetation, to enrich undercanopy soils and to create microenvironment. The study species needs thus to be subjected to further monitoring studies such as environment tolerance limits and combination trials, so as to establish the conditions under which these species can be incorporated in the farming systems, for optimal cumulative positive tree effects.

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7. APPENDICES

Appendix 1. Direct matrix ranking form of four suggested study species

Tree quality	Species X	Species Y	Species Z	Species W
Fuelwood				
Charcoal				
Shade				
Fodder				
Medicine				
Furniture				
Fruits (eaten)				
Seeds (eaten)				
Farmland tree				
Total score				
Rank				

Scores: 0- unknown; 1- very poor; 2- fair; 3- good; 4- very good

Appendix 2. Questions for semi-structured interviews

(To be translated into Swahili whereby it will be responded and recorded by this language)

1. Date_______________

2.Site number__________ village name_______________

a) Personal information

3.Name of interviewer_______________

4.Name of informant_______________ sex__________

5.Occupation_______________average age__________

6.For how long have you been living here? _______________

b*) Climatic information*

7.How many seasons of rainfall do you receive per year? __________

In which months? _______________

8.The temperature is highest and lowest in which season?

Highest_______________

Lowest_______________

c) Information on tree planting

9. Have you ever planted any tree(s)? YES__________NO__________

If yes, where? Around homestead or on farmland? __________

10. What are the names of these trees?

Vernacular name __________ Botanical name__________

-do- __________ -do- __________

-do- __________ -do- __________

-do- __________ -do- __________

d) Habitat of the study species

11.Usually these species commonly grow in which areas and on which type of soil? (According to local classification)

Species1: habitat_______________

Soil type_______________

Specie2: Habitat_______________

Soil type_______________

12. How many types of soil are found in this area? __________

Vernacular name__________characteristics__________,

__________, __________

f) Biological dynamics of the study species

13. In which seasons usually the trees shade their leaves? Usually is in which months?

Species1:season__________months__________,__________

Species 2:season__________months__________, __________

14.Which months are the flowering and fruiting period of these tree species?

Species 1: Flowering months__________, __________

Fruiting months__________, __________

Species 2: Flowering months__________, __________

Fruiting months __________, __________

15.Approximately, how long does these tree species take since germination to the first flowering or fruiting period?

Species 1: ____________________

Species 2: ____________________

16. What is the average size of the trees when they are fully mature? (referring to the first flowering and/or fruiting stage)____________________

Species 1:____________________

Species 2: ____________________

h) The uses of the trees

17. How do you use these trees?

Species 1:

Leaves__________, __________, __________

Fruits__________, __________, __________

Roots__________, __________, __________

Branches__________, __________, __________

Barks__________, __________, __________

Other uses for the whole tree

____

____

Species 2:

Leaves__________, __________, __________

Fruits__________, __________, __________

Roots__________, __________, __________

Branches__________, __________, __________

Barks__________-, __________, __________

Other uses for the whole tree

____

____

Appendix 3. List of respondents with their respective age and sex

No.	Respondent's name	Age	Sex
1	Khadija Ramadhani	65	F
2	Jacob Thumuni	53	M
3	Marthias Nzubunze	55	M
4	Ibrahimu Hobwe	75	M
5	Anthonia Ndema	50	F
6	Ally Shaaban	52	M
7	Willium John	61	M
8	Theresia Telesifori	55	F
9	Bakari Kapona	70	M
10	Chalesi John	45	M
11	Esdori Tomasi	70	M
12	Said Suleiman	75	M
13	Daniel Mwaja	60	M
14	Zakayo Tomotheo	40	M
15	Jonas Keneth	38	M
16	Stephano Kapande	70	M
17	Ally Mwinyimvua	60	M
18	Zena Rajabu	40	F
19	Katisha Juma	65	F
20	Magreth Emili	50	F
21	Mohamed Musa	58	M
22	Siwema Abdallah	42	F
23	Maneno Daniel	35	M
24	Juma Kindamba	45	M
25	Issa Salum	40	M
26	Zubeda Malinze	42	F
27	Zaituni Marigwe	50	F
28	Maria Kindamba	60	F
29	Zebedayo Kulwa	55	M
30	Juma Mrisho	45	M
31	Shomari Kibikigala	42	M
32	Shamila Mohamed	23	F
33	Agnes Ulele	33	F
34	Mwanaisha Mwinyimkuu	50	F
35	Salumu Juma	30	M
36	Gabriel Tupa	74	M

37	Maurid Kisile	46	M
38	Ali Matimbwa	35	M
39	Lediani Macha	51	M
40	Yohana Makawa	36	M
41	Huba Chuma	55	F
42	Rashid Kindahele	42	M
43	Abdalla Kahaya	46	M
44	Felician Likanga	45	M
45	Husseni Makonga	52	M
46	Robert Chilongola	43	M
47	Maurid Malenda	40	M
48	Mohamed Bogwa	59	M
49	Ramadhani Madohola	60	M
50	Ndanga Waziri	43	M
51	Maika Chiseo	47	M
52	George Chuma	55	M
53	Hemed Kipengele	70	M
54	Rashid Sefu	52	M
55	Hamis Bogwa	31	M
56	Zena Kindamba	60	M
57	Mwinda Chiseo	63	M
58	Karimu Lipumula	78	M
59	Hamisi Alani	65	M
60	Mwahija Mlinji	48	F

Appendix 4. Percentage covers of undercanopy and outcanopy herbs encountered from each study tree

a. Site one

		Percentage cover / plot / species										Percentage cover / species / site
	Undercanopy vegetation	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
1	*Heteropogon contortus*	-	30	40	40	20	-	50	45	60	-	285
2	*Hyparrhenia rufa*	-	40	35	30	50	-	-	-	-	-	155
3	*Panicum maximum*	-	-	-	-	-	20	-	-	-	-	20
4	*Aristida* sp	-	10	10	-	-	-	-	-	-	-	20
5	*Commelina benghalensis*	10	-	-	-	-	-	-	5	2	-	17
6	*Asparagus africana*	5	-	-	-	-	-	-	-	-	-	5
7	*Vernonia adoensis*	-	-	-	-	-	3	5	-	-	-	8
8	*Triumfetta rhomboidea*	-	-	-	3	-	-	5	3	-	-	11
9	*Asystasia gangentica*	-	-	-	-	-	-	-	5	-	-	5
10	*Sida alba*	-	-	-	-	-	-	10	-	5	-	15
11	*Waltheria indica*	-	-	-	-	-	-	-	-	-	5	5
12	*Rourea orientalis*	-	-	5	5	-	-	-	-	-	-	10
13	*Glinus oppositifolius*	-	-	-	5	-	-	-	-	-	-	5
14	*Abutilon glandiflora*	-	-	-	-	-	-	-	-	-	20	20
15	*Lippia spicata*	-	-	-	-	-	-	-	-	-	8	8
	Total percentage cover / site											**589**
		Percentage cover / plot / species										Percentage cover / species / site
	Outcanopy vegetation	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
1	*Heteropogon contortus*	10	80	80	-	-	-	70	40	90	-	370
2	*Hyparrhenia rufa*	-	-	-	60	50	-	-	-	-	-	110
3	*Panicum maximum*	-	-	-	-	-	50	-	-	5	-	55
4	*Asparagus africana*	10	-	-	-	-	-	-	-	-	-	10
5	*Sida alba*	10	-	-	-	-	-	15	-	-	-	25
6	*Waltheria indica*	-	-	-	-	-	-	-	5	-	-	5
7	*Orthosiphon suffrutescens*	-	-	-	-	-	-	-	-	2	-	2
8	*Rourea orientalis*	-	-	3	5	-	-	-	-	2	-	10
9	*Triumfetta rhomboidea*	-	-	-	5	-	-	-	-	-	-	5

10	*Rottboellia*	-	-	-	-	-	-	-	-	-	30	30
11	*cochinchinensis*	-	-	-	-	-	-	-	-	-	40	40
	Cyperus rotundus											
	Total percentage cover / site											**662**

b. Site two

		Percentage cover / plot / species										Percentage cover / species / site
	Undercanopy vegetation	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
1	*Rottboellia cochinchinensis*	80	40	30	30	55	60	60	50	45	45	495
2	*Hyparrhenia rufa*	20	40	50	60	45	15	-	50	55	45	380
3	*Commelina benghalensis*	-	-	20	-	-	15	30	-	-	-	65
	Total percentage cover / site											**940**
		Percentage cover / plot / species										Percentage cover / species / site
	Outcanopy vegetation	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
1	*Rottboellia cochinchinensis*	70	30	55	50	30	40	40	45	40	40	440
2	*Hyparrhenia rufa*	10	65	45	45	60	50	45	35	40	55	450
3	*Commelina benghalensis*	20	-	-	-	-	-	-	20	-	-	40
	Total percentage cover / site											**930**

c. Site three

		Percentage cover / plot / species										Percentage cover / species / site
	Undercanopy	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
1	*Panicum maximum*	50	-	5	30	-	-	30	-	-	-	115
2	*Heteropogon contortus*	-	20	-	-	50	80	40	-	10	30	230
3	*Hyparrhenia rufa*	-	-	-	-	10	5	20	70	70	40	215
4	*Aristida* sp	-	-	-	-	-	-	-	10	10	-	20

5	*Sida alba*	50	-	5	-	-	-	-	-	-	-	55
6	*Orthosphon suffrutescens*	-	1	5	-	-	-	-	-	-	5	11
7	*Abrus precotorius*	-	-	10	-	10	-	-	-	-	-	20
8	*Lippia spicata*	-	10	5	-	-	-	-	-	-	-	15
9	*Achyranthes aspera*	-	-	5	-	-	-	-	-	-	-	5
10	*Hyptis suavelons*	-	-	5	5	10	-	-	-	-	-	20
11	*Tragia cilialis*	-	-	3	-	-	-	-	-	-	-	3
12	*Asystasia gangentica*	-	-	10	-	-	-	-	-	-	-	10
13	*Commelina benghalensis*	-	-	-	10	-	-	-	-	-	-	10
14	*Asparagus africana*	-	-	-	10	3	-	-	-	-	-	13
15	*Triumfetta rhomboidea*	-	-	-	5	-	-	-	-	-	-	5
16	*Deinbollia borbonica*	-	-	-	5	-	-	-	-	-	-	5
17	*Calotropis procera*	-	-	-	-	10	-	-	-	-	-	10
18	*Tridax procumbens*	-	-	-	-	5	-	-	-	-	-	5
19	*Tephrosia villosa*	-	-	-	-	-	-	5	-	-	-	5
20	*Vernonia adoensis*	-	-	-	-	-	-	-	-	-	5	5
21	*Waltheria indica*	-	-	-	-	-	-	-	-	-	15	15
	Total percentage cover / site											**792**
		Percentage cover / plot / species										Percentage cover / species / site
	Outcanopy vegetation	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
1	*Heteropogon contortus*	80	50	-	30	50	90	70	60	35	-	465
2	*Hyparrhenia rufa*	-	-	-	-	30	-	-	-	30	40	100
3	*Aristida* sp	-	-	-	-	-	-	5	5	-	-	10
4	*Sida alba*	5	-	-	-	-	-	-	-	-	10	15
5	*Tephrosia villosa*	5	-	-	-	-	-	5	-	-	-	10
6	*Commelina benghalensis*	-	1	-	-	-	-	-	-	-	-	1
7	*Hyptis suavelons*	-	-	-	-	5	-	-	-	-	-	5
8	*Achyranthes aspera*	-	-	10	-	-	-	-	-	-	-	10
9	*Waltheria indica*	-	-	10	-	-	-	-	-	-	-	10
10	*Tridax procumbens*	-	-	-	-	2	-	-	-	-	-	2
11	*Orthosphon suffrutescens*	-	-	-	-	-	-	-	-	-	1	1
12	*Rourea orientalis*	-	-	-	-	-	-	-	-	-	10	10
	Total percentage cover / site											**639**

d. Site four

		Percentage cover / plot / species										Percentage cover/species / site
	Undercanopy vegetation	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
1	*Themeda triandra*	-	30	20	-	30	35	15	-	50	-	180
2	*Rottboellia cochinchinensis*	-	10	15	-	-	20	20	-	-	-	65
3	*Panicum maximum*	-	10	-	-	-	20	20	-	10	-	60
4	*Cyperus rotundus*	-	10	-	-	-	-	-	-	-	-	10
5	*Cynodon dactylon*	-	-	-	-	-	-	-	10	-	-	10
6	*Asparagus africana*	-	-	-	40	-	-	-	-	-	-	40
7	*Sida alba*	-	-	10	5	-	-	-	-	15	-	30
8	*Deinbollia borbonica*	-	-	-	5	-	-	-	-	-	-	5
9	*Glinus oppositifolius*	-	5	10	-	-	-	-	-	-	-	15
10	*Abutilon glandiflora*	-	5	-	-	-	5	3	8	-	3	24
11	*Achyranthes aspera*	10	-	-	-	-	5	-	-	-	-	15
12	*Asystasia gangentica*	10	-	-	-	-	-	-	-	-	-	10
13	*Vernonia adoensis*	-	-	-	-	-	-	-	5	-	-	5
14	*Lippia spicata*	-	-	-	-	-	-	-	-	8	3	11
	Total percentage cover / site											**480**
		Percentage cover / plot / species										Percentage cover /species/site
	Outcanopy vegetation	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
1	*Rottboellia cochinchinensis*	-	40	-	40	40	-	25	-	5	20	170
2	*Themeda triandra*	-	-	40	-	-	-	-	20	40	-	100
3	*Panicum maximum*	-	-	-	-	-	20	30	-	40	-	50
4	*Cyperus rotundus*	-	-	-	-	-	-	-	-	-	35	35
5	*Sida alba*	-	-	-	10	-	20	-	-	-	-	30
6	*Abutilon glandiflora*	-	-	-	-	-	-	5	20	-	-	25
7	*Achyranthes aspera*	-	-	-	-	-	10	-	-	-	-	10
	Total percentage cover / site											**420**

Appendix 5. Botanical collections

1.	*Brachystegia microphylla*	MKK 0001 - 02
2.	*Sclerocarya birrea*	MKK 0002 - 02

At a depth of 25-30cm

Tree no.	100cm	250cm	Outcanopy	100cm	250cm	Outcanopy
Tree 1	8.60	8.94	5.50	14.10	9.12	9.46
Tree 2	11.35	9.12	4.13	13.76	9.80	7.57
Tree 3	9.96	7.24	3.10	17.37	16.34	6.88
Tree 4	9.00	6.54	4.30	10.49	6.02	5.16
Tree 5	10.70	7.22	3.61	13.59	8.60	7.22
Tree 6	12.38	9.80	5.33	12.73	10.15	8.77

d. Electrical conductivity (μs/cm)

At a depth of 0-5cm

Tree no.	100cm	250cm	Outcanopy	100cm	250cm	Outcanopy
Tree 1	159.6	119.3	52.4	200.1	97.22	60.21
Tree 2	139.4	72.1	41.7	114.3	46.5	32.5
Tree 3	109.7	85.6	68.9	76.6	60.9	35.4
Tree 4	276	257	60.9	663	359	277
Tree 5	360	302	30.2	607	350	268
Tree 6	280.17	201	64.28	523	345	347

At a depth of 25-30cm

Tree no.	100cm	250cm	Outcanopy	100cm	250cm	Outcanopy
Tree 1	79.7	38.2	14.5	80.16	42.16	20.11
Tree 2	70.7	32.5	39	30.1	35.8	40.1
Tree 3	66.5	31.5	25.1	33.5	29.4	12.4
Tree 4	254	95.4	27.9	414	261	179.9
Tree 5	210.1	200.21	20.24	415	316	234
Tree 6	232	61.26	32.16	279	283	164.9

e. Total nitrogen (%)

At a depth of 0 – 5 cm

Tree no.	100cm	250cm	Outcanopy	100cm	250cm	Outcanopy
Tree 1	0.436	0.308	0.25	0.301	0.21	0.197
Tree 2	0.506	0.34	0.232	0.381	0.241	0.112
Tree 3	0.425	0.375	0.201	0.238	0.214	0.121
Tree 4	0.569	0.467	0.305	0.328	0.226	0.113
Tree 5	0.529	0.444	0.243	0.306	0.236	0.101
Tree 6	0.702	0.592	0.309	0.355	0.207	0.152

At a depth of 25 – 30 cm

Tree no.	100cm	250cm	Outcanopy	100cm	250cm	Outcanopy
Tree 1	0.439	0.075	0.109	0.142	0.12	0.172
Tree 2	0.338	0.086	0.173	0.15	0.114	0.112
Tree 3	0.324	0.073	0.189	0.203	0.114	0.124
Tree 4	0.497	0.208	0.21	0.177	0.122	0.181
Tree 5	0.474	0.249	0.226	0.103	0.154	0.1
Tree 6	0.403	0.185	0.264	0.184	0.113	0.111

f. Available phosphorus (mg/100g)

At a depth of 0- 5 cm

Tree no.	100cm	250cm	Outcanopy	100cm	250cm	Outcanopy
Tree 1	0.265	0.067	0.03	0.26	0.182	0.12
Tree 2	0.126	0.164	0.064	0.399	0.144	0.103
Tree 3	0.216	0.216	0.104	0.133	0.089	0.074
Tree 4	0.244	0.13	0.011	0.197	0.109	0.108
Tree 5	0.125	0.113	0.1	0.146	0.038	0.032
Tree 6	0.116	0.124	0.097	0.093	0.074	0.051

At a depth of 25 – 30 cm

Tree no.	100cm	250cm	Outcanopy	100cm	250cm	Outcanopy
Tree 1	0.039	0.051	0.012	0.103	0.123	0.058
Tree 2	0.072	0.094	0.014	0.157	0.095	0.063
Tree 3	0.134	0.131	0.1	0.118	0.075	0.088
Tree 4	0.052	0.11	0.01	0.088	0.1	0.071
Tree 5	0.048	0.095	0.033	0.023	0.016	0.028
Tree 6	0.098	0.08	0.051	0.069	0.069	0.046

g. Exchangeable potassium (meq/100g)

At a depth of 0-5cm

Tree no.	100cm	250cm	Outcanopy	100cm	250cm	Outcanopy
Tree 1	2.63	2.58	1.34	1.24	4.316	4.316
Tree 2	3.014	2.146	1.21	1.16	2.141	2.141
Tree 3	2.117	2.581	2.7	1.101	3.751	3.751
Tree 4	2.13	1.96	1.84	1.533	2.561	2.561
Tree 5	3.16	2.01	1.62	1.2	2.89	2.89
Tree 6	2.89	2.63	1.321	1.545	2.04	2.04

At a depth of 25-30cm

Tree no.	100cm	250cm	Outcanopy	100cm	250cm	Outcanopy
Tree 1	1.44	1.23	1.24	2.817	1.55	1.99
Tree 2	1.21	1.672	1.16	1.11	1.55	1.311
Tree 3	1.07	2.393	1.101	2.971	1.467	1.74
Tree 4	1.44	1.322	1.533	1.18	1.127	1.006
Tree 5	2.861	1.281	1.2	2.67	1.66	1.21
Tree 6	1.291	1.244	1.545	2.744	1.22	1.11

h. **Percentage sand, clay and silt**

			S. birrea			*B. microphylla*		
Tree no.	**distance**	**depth**	**sand**	**clay**	**silt**	**sand**	**clay**	**silt**
1	100	0-5	61	10	29	72	14	14
		25-30	70	13	17	70	15	15
	250	0-5	70	15	15	70	10	20
		25-30	71	15	14	68	20	12
	outcanopy	0-5	72	10	18	69	11	20
		25-30	70	10	20	71	18	11
2	100	0-5	50	10	40	70	12	18
		25-30	72	12	16	70	14	16
	250	0-5	72	13	15	72	10	20
		25-30	70	10	20	70	14	16
	outcanopy	0-5	72	11	17	70	15	15
		25-30	70	15	15	70	14	15
3	100	0-5	40	26	34	70	15	15
		25-30	50	25	25	67	13	20
	250	0-5	70	10	20	65	20	15
		25-30	70	10	20	60	26	14
	outcanopy	0-5	60	15	25	70	10	20
		25-30	70	15	15	68	10	22
4	100	0-5	15	45	40	52	30	28
		25-30	34	40	26	53	30	27
	250	0-5	16	45	39	51	23	25
		25-30	20	40	40	54	22	24
	outcanopy	0-5	32	41	27	51	24	25
		25-30	34	41	25	52	24	24
5	100	0-5	12	46	42	70	11	19
		25-30	13	46	41	70	9	21
	250	0-5	13	45	42	70	10	20
		25-30	15	45	40	69	11	20
	outcanopy	0-5	18	13	69	69	9	22
		25-30	19	13	69	71	9	20
6	100	0-5	19	48	33	80	5	15
		25-30	20	50	30	80	5	15
	250	0-5	18	12	70	75	10	15
		25-30	20	9	71	80	10	10
	outcanopy	0-5	20	9	71	72	10	18
		25-30	21	12	70	73	11	16