ELSEVIER

Forest Ecology and Management 64 (1994) 171-182

Forest Ecology and Management

Performance of multipurpose trees for agroforestry two years after planting at Makoka, Malawi

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Abstract

Forty-nine accessions of multipurpose trees belonging to 37 species were planted at Makoka, Malawi, on a ferric lixisol at 1030 m altitude, unimodal rainfall (average 1044 mm per annum) and a dry season lasting 6 months. Two years after planting, 25 accessions showed >90% survival and mostly fast growth and high biomass production. The ranges of growth parameters in these accessions were 3.2–7.1 m height, 7.0–15.4 cm collar diameter, and 18–40 t ha^{-1} total above ground biomass. Potential biomass production obtained from coppice regrowth in the best accessions was 5.0–13.7 t ha^{-1} per year.

The best performing species were *Calliandra calothyrsus, Acrocarpus fraxinifolius, Gliricidia sepium, Cassia spectabilis, Cassia siamea, Flemingia congesta* and *Albizia falcataria*. Of the 18 Australian species tested, only *Acacia auriculiformis, Acacia shirleyi* and *Acacia julifera* showed satisfactory growth. *Cassia brewsterii, Acacia ampliceps* and *Acacia victoriae* failed to grow. Other species showing poor performance included *Prosopis* species and *Robinia pseudoacacia*.

Key words: Multipurpose tree species; Growth; Biomass; Performance

1. Introduction

A large number of multipurpose trees and shrubs with potential use in agroforestry exist throughout the tropics and subtropics (Boland and Turnbull, 1981; Burley and Von Carlowitz, 1984). However, the paucity of information on their natural variability, adaptability and growth rate in different ecological zones has restricted their utilization (Venkatesh, 1988). Therefore most agroforestry programmes in the tropics use a limited number of well-known and widely introduced multipurpose trees, especially *Leucaena leucocephala* and *Prosopis* species. Recent experimental evidence shows that some of the problems currently associated with *Leucaena leucocephala*, including lack of drought/frost tolerance, poor growth in acid soils and susceptibility to the psyllid, may be largely a consequence of the narrow genetic base of the *Leucaena* germplasm used (Brewbaker, 1985; Brewbaker and Sorensson, 1986; Hughes, 1988). Therefore the identification, introduction and testing for adaptability, growth and development of alternative and new multipurpose tree species should be given special attention in any agroforestry programme.

This report examines survival, growth and biomass production of 49 accessions of potential multipurpose tree species for agroforestry in the

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0378-1127/94/$07.00
SSDI 0378-1127(93)06048-A

unimodal plateau ecozone of southern Africa. The germplasm was established at Makoka near Zomba (Malawi) in December 1988. Many species were considered because many agroforestry technologies have potential in the ecozone (Ngugi, 1987), while each agroforestry technology has distinct requirements for multipurpose tree attributes.

2. Materials and methods

2.1. Study area

The experimental area is located at Makoka Agricultural Research Station, near Zomba, Malawi, at 15°30′S latitude, 35°15′E longitude and 1030 m altitude. The annual total rainfall at Makoka varies from 850 to 1250 mm with a mean of 1044 mm. The rainy season lasts from November to April followed by a dry season from May to October. The potential annual evapotranspiration is 1360 mm. The mean daytime temperatures at Makoka vary from 16 to 24°C with extremes of 11°C in July and 30°C in November.

The experimental area is on a slope of 7.5%, with sandy loams as top soil and sandy clay loams in subsurface horizons (a ferric lixisol). Some of the chemical characteristics of the soils are presented in Table 1.

2.2. Experimental design and management

Thirty-seven multipurpose tree species comprising 49 local and exotic seed sources were evaluated in this study (Table 2). Seedlings of the different species were raised in polyethylene containers and planted out in December 1988 after attaining about 20 cm height. Land preparation before planting included ploughing, harrowing and ridging. Ridges were parallel to the contour and 75 cm apart.

The experiment was arranged in a 7×7 triple lattice design and replicated three times. The field randomization procedure outlined by Cochran and Cox (1957) was adopted. Each tree accessions constituted a plot of 10 m×7.5 m with 25 trees planted on ridges at 2.0 m within and 1.5 m between rows (3333 trees ha^{-1}). In 1988 and 1989, a cover crop of beans was planted for soil conservation. Plots were kept free from weeds at all times.

2.3. Data collection and analysis

The trial was assessed at 3 month intervals in the first year. Data are presented for assessments at 15 and 26 months after planting. In each assessment, survival, height, root collar diameter, number of stems and branches and the width of the crown (crown characteristics) were measured. The occurrence of pests and diseases was monitored and is the subject of a separate report. All parameters were based on a complete assessment of all surviving trees in each plot.

At 15 months biomass production was assessed by cutting half the number of trees in each plot (12 or 13 trees) at 30 cm above the ground. Harvesting was performed systematically so that distances between trees within rows were 4 m and staggered between rows. Harvested trees were

Table 1
Soil chemical characteristics in the multipurpose tree screening experiment at Makoka, Malawi

Profile depth (cm)	pH in water	Organic carbon (%)	Total nitrogen (%)	Bray I available P (ppm)	Exchangeable cations (mequiv per 100 g soil)					
					K	Na	Ca	Mg	H	CEC
0–10	6.0	1.03	0.093	8	0.41	0.03	3.93	1.67	1.3	7.37
11–30	6.0	0.93	0.082	7	0.47	0.03	3.50	2.06	1.2	7.29
31–50	6.1	0.76	0.063	7	0.38	0.04	4.80	1.78	1.7	8.12
51–70	6.3	0.58	0.050	7	0.42	0.04	4.92	2.31	0.9	8.62

CEC, cation exchange capacity.

Table 2
Seed sources for multipurpose tree species under screening at Makoka, Malawi

Accession no.	Species name	Seed origin	Latitude	Longitude	Altitude
1	*Vangueria infausta*	Lushoto, Tanzania	4°47'S	38°17'E	1400
2	*Cassia siamea*	Isiolo, Kenya	0°20'N	37°36'E	1104
3	*Acacia shirleyi*	Dally Wales, Australia	16°19'S	133°23'E	225
4	*Robinia pseudoacacia*	Florence, Italy			
5	*Prosopis juliflora*	Madhya Pradesh, India	22°16'N	78°23'E	200
6	*Prosopis chilensis*	Taveta, Kenya	3°23'S	37°40'E	1000
7	*Acacia auriculiformis*	Noogoo Swamp, Australia	12°23'S	131° 0'E	28
8	*Gliricidia sepium*	Los Amates, Mexico	18°28'N	89°25'W	100
9	*Acacia trachycarpa*	Degrey River, Australia	20°12'S	199°10'E	50
10	*Acacia albida*	Mua, Dedza, Malawi	14°16'S	34°30'E	1000
11	*Prosopis cineraria*	Mombasa, Kenya	4°04'S	39°37'S	55
12	*Prosopis tamarugo*	Pampa Tamarugal, Chile	20°30'S	70°30'W	950–1100
13	*Gliricidia sepium*	Mariara, Venezuela	10°17'N	67°43'W	520
14	*Acrocarpus fraxinifolius*	Zomba, Malawi	15°20'S	35°20'E	1390
15	*Prosopis palida*	Mombasa, Kenya	4°04'S	39°37'E	55
16	*Acacia ampliceps*	Yilyarra, Australia	22° 2'S	123° 7'E	350
17	*Gmelina arborea*	Bunda, Malawi	14°10'S	33°54'E	1440
18	*Acacia zulacocarpa*	Garioch, Australia	16°40'S	145°18'E	400
19	*Acacia pachycarpa*	Billiluna Stn., Australia	19°33'S	127°41'E	300
20	*Maesopsis eminii*	Lushoto, Tanzania	4°47'S	38°17'E	1400
21	*Cassia spectabilis*	Zomba, Malawi	15°20'S	35°20'E	1390
22	*Albizia schimperiana*	Lushoto, Tanzania	4°47'S	38°17'E	1400
23	*Calliandra calothyrsus*	KEFRI, Muguga, Kenya	1°13'S	36°38'E	2096
24	*Gliricidia sepium*	Boaco, Nicaragua	12°23'N	85°45'W	200
25	*Acacia julifera*	128 km N. Hughenden, Australia	19°54'S	144°16'E	930
26	*Cassia siamea*	Kwale, Mombasa, Kenya	4°10'S	39°27'E	200
27	*Acacia stenophylla*	Newcastle Creek, Australia	17°15'S	133°27'E	500
28	*Acacia albida*	Mombasa, Kenya	4°01'S	39°37'E	55
29	*Acacia victoriae*	Borewa, Australia	18°32'S	118°27'E	90
30	*Albizia falcataria*	Sri Lanka	8°23'N	81°45'E	250
31	*Acacia murrayana*	Wilcannia, Australia	32°00'S	144°00'E	120
32	*Flemingia congesta*	Kasama, Zambia	10°10'S	31°11'E	1384
33	*Acacia burrowii*	Goondiwindi, Australia	28°49'S	150°43'E	260
34	*Acacia cyanophylla*	KEFRI, Mugaga, Kenya	1°13'S	36°38'E	2096
35	*Gliricidia sepium*	Guatemala			
36	*Cassia brewsteri*	Marborough, Australia	22°52'S	149°28'E	120
37	*Gliricidia sepium*	Gualana-Zacarpa, Guatemala	15°05'N	89°20'W	50–200
38	*Calliandra calothyrsus*	Patulul Suchitepequez, Guatemala	14°25'N	91°10'W	600–900
39	*Cassia siamea*	Machinga, Malawi	15°09'S	35°17'E	1276
40	*Acacia eriopoda*	Broome, Australia	17°57'S	122°14'E	10
41	*Acacia salicina*	Mitchel, Australia	26°29'S	148°02'E	325
42	*Acacia tumida*	Fitzroy Crossing, Australia	18°18'S	125°37'E	130
43	*Acacia difficilis*	Lake Evella, Australia	12°24'S	135°44'E	55
44	*Cassia spectabilis*	Kibwezi, Kenya	2°25'S	37°57'E	1000
45	*Acrocarpus fraxinifolius*	Lushoto, Tanzania	4°47'S	38°17'E	1400
46	*Gliricidia sepium*	KEFRI, Muguga, Kenya	1°13'S	36°38'E	2096
47	*Acacia melanoxylon*	Witselbos, South Africa	33°59'S	24°07'E	277
48	*Schizolobium excelsum*	Zomba, Malawi	15°22'S	35°20'E	1390
49	*Acacia albida*	Kitui, Kenya	1°22'S	38°01'E	1090

partitioned into the tree biomass components—foliage (leaves, twigs, flowers and pods), branches and stems—and then weighed green. Samples of each tree component were collected on a plot basis and oven-dried at 70°C to equilibrium moisture content and used to estimate the dry weight of each harvested tree component. Plot totals were then established and expanded to a hectare basis. A further assessment was made at 26 months and included tree heights, root collar diameter and crown characteristics for the trees not harvested at 15 months.

Four trees were harvested as before, to determine biomass production and the nutrient content of the most promising species, at about 2 years. For nutrient analysis, subsamples were taken from the foliage, branches and stem components and sent for oven drying. Dried foliage materials were ground in a Wiley mill for nutrient analysis. Woody samples were obtained by sawing through branch and stem materials and using the sawdust for nutrient determination. Total nitrogen was determined by the macro-Kjeldahl procedure. To determine all the other nutrients, samples were ashed in a muffle furnace at 450°C and the ashes dissolved in 6 N HCl. Portions of this solution were used to determine phosphorus colorimetrically, potassium and sodium by flame photometry and calcium and magnesium by titration with etylenediamine tetraacetic acid.

At each cutting time, advantage was taken to evaluate coppicing after cutting. Six months after the first cutting (i.e. 20 months after planting), the number of coppice shoots on each stump in a plot was counted and the coppices were harvested for biomass determination. A further harvesting of coppice was done at 26 months (at the time of the second biomass evaluation) and biomass partitioned as at earlier harvest.

Data are presented for survival at 15 months and for growth and biomass production 26 months after planting. The measurements at 15 months were also used to establish the rate of growth and accumulation of biomass in the second year of growth. All quantitative data are subject to analysis of variance for 7×7 triple lattice (ALPHANAL, 1987). Significant means are separated by the least significant difference.

3. Results and discussion

3.1. Survival

Twenty-four accessions of the multipurpose trees studied showed excellent survival (>90%) and an additional four had survival levels above 80% (Table 3). The accessions surviving well included those of *Acrocarpus fraxinifolius*, *Gliricidia sepium*, *Calliandra calothyrsus*, *Cassia spectabilis*, *Cassia siamea*, (*Senna siamea*), *Acacia albida*, *Maesopsis eminii*, *Albizia falcataria*, *Flemingia congesta*, *Schizolobium excelsum*, *Gmelina arborea*, *Acacia aulacocarpa*, *Acacia auriculiformis*, *Albizia schimperiana*, *Acacia salicina* and *Vangueria infausta*.

In general, many Australian accessions showed poor survival, *Acacia ampliceps*, *Acacia victoriae*, *Acacia cyanophylla*, *Acacia murrayana* and *Acacia pachycarpa* showed less than 25% survival. Other poorly surviving (<65%) species included *Acacia burrowii*, *Acacia difficilis*, *Acacia tumida*, *Acacia trachycarpa*, *Acacia stenophylla*, *Acacia julifera*, *Cassia brewsterii*, *Prosopis chilensis*, *Prosopis cineraria*, *Prosopis julifera* and *Robinia pseudoacacia*. *Prosopis tamarugo* was a complete failure.

The ability of a multipurpose tree species to survive in an ecozone is a key factor in selecting it for agroforestry. Low survival in *Prosopis* species and especially the total failure of *Prosopis tamarugo* was unexpected. This is especially in view of their reported adaptability and high production in subhumid and semi-arid environments (Felker et al., 1981; Food and Agriculture Organisation, 1981; Maghembe et al., 1983). Elsewhere within the Miombo ecozone, we have been able to obtain high survival and satisfactory early growth by *Prosopis chilensis* (Jonsson et al., 1988). All the *Prosopis* species studied are known to nodulate (Allen and Allen, 1981), although nodulation in the seedlings used for this study was not confirmed. The poor survival of many of the Australian acacias may also be a re-

Table 3
Performance of the multipurpose tree species 26 months after planting at Makoka, Malawi

Accession no.	Species	Survival (%)	Height (m)		Root collar diameter (cm)	Branching characteristics		
			Total	MAI		No. stems	No. branches	Crown width (m)
Promising accessions								
45	*Acrocarpus fraxinifolius*	100	7.14	3.29	15.4	1	3	2.32
14	*Acrocarpus fraxinifolius*	100	5.78	2.66	13.2	1	1	2.52
38	*Calliandra calothyrsus*	96	5.54	2.55	10.2	3	30	3.88
23	*Calliandra calothyrsus*	100	5.19	2.39	10.1	3	40	3.96
39	*Cassia siamea*	100	4.71	2.17	11.3	2	45	3.85
27	*Gliricidia sepium*	100	4.59	2.11	9.4	4	31	3.55
46	*Gliricidia sepium*	100	4.51	2.08	9.9	5	30	3.58
17	*Gmelina arborea*	100	4.37	2.01	14.3	1	23	3.31
13	*Gliricidia sepium*	100	4.35	2.00	10.7	4	37	3.76
2	*Cassia siamea*	96	4.22	1.94	9.3	2	43	3.59
8	*Gliricidia sepium*	96	4.21	1.94	9.9	6	36	4.12
35	*Gliricidia sepium*	100	4.04	1.86	9.2	3	36	3.69
24	*Gliricidia sepium*	96	4.00	1.84	9.7	4	28	3.42
30	*Albizia falcataria*	100	3.96	1.82	7.2	1	17	3.39
32	*Flemingia congesta*	96	3.95	1.82	7.8	10	35	2.62
26	*Cassia siamea*	92	3.90	1.80	9.6	2	41	3.38
22	*Albizia schimperiana*	88	3.86	1.78	7.0	2	13	3.19
48	*Schizolobium excelsum*	92	3.79	1.75	9.1	1	2	3.11
44	*Cassia spectabilis*	100	3.42	1.58	9.7	5	34	3.62
21	*Cassia spectabilis*	100	3.23	1.49	6.8	3	43	2.88
20	*Maesopsis eminii*	92	2.99	1.38	6.9	1	16	1.77
Australian germplasm								
7	*Acacia auriculiformis*	88	4.18	1.92	8.2	2	38	3.07
3	*Acacia shirleyi*	67	3.99	1.84	7.9	2	41	2.38
25	*Acacia julifera*	64	3.98	1.83	7.0	2	33	3.19
33	*Acacia burrowii*	36	3.86	1.78	6.0	1	36	2.24
18	*Acacia aulacocarpa*	96	3.72	1.71	6.8	2	37	2.80
43	*Acacia difficilis*	60	3.17	1.46	7.5	4	41	3.21
40	*Acacia eriopoda*	76	3.10	1.43	4.3	2	29	2.09
34	*Acacia cyanophylla*	16	2.81	1.29	7.0	4	23	1.89
42	*Acacia tumida*	56	2.65	1.22	3.7	2	19	2.11
47	*Acacia melanoxylon*	76	2.34	1.09	3.8	1	26	1.09
9	*Acacia trachycarpa*	52	2.28	1.05	4.7	3	26	3.06
41	*Acacia salicina*	80	1.64	0.76	4.5	1	17	1.20
27	*Acacia stenophylla*	56	1.41	0.65	2.0	2	6	0.78
36	*Cassia brewsterii*	44	Failed to grow					
29	*Acacia victoriae*	8	Failed to grow					
16	*Acacia ampliceps*	24	Failed to grow					
19	*Acacia pachycarpa*	12	Failed to grow					
31	*Acacia murrayana*	24	Failed to grow					
Other accessions								
49	*Acacia albida*	100	2.97	1.37	4.4	1	48	2.22
28	*Acacia albida*	100	2.33	1.07	4.6	1	44	2.05
15	*Prosopis palida*	76	2.21	1.02	3.1	2	18	1.70
1	*Vangueria infausta*	84	2.06	0.95	5.7	1	15	1.76
10	*Acacia albida*	100	1.97	0.91	3.7	1	38	1.67
6	*Prosopis chilensis*	48	1.69	0.78	2.6	2	24	2.04
4	*Robinia pseudoacacia*	67	1.62	0.75	3.4	3	7	0.79
5	*Prosopis juliflora*	56	1.35	0.62	1.6	2	24	1.32
11	*Prosopis cineraria*	64	Failed to grow					
12	*Prosopis tamarugo*	0	Failed to grow					
LSD 0.05		NA	0.91	NA	2.3	1	15	0.82
CV (%)		NA	14.8	NA	17.4	25.4	31.1	18.0

MAI, mean annual increment; LSD, least significant difference; CV, coefficient of variation; NA, not analysed.

sult of poor or lack of nodulation with native rhizobia. Further tests are therefore recommended with artificially inoculated seedlings. Yet for some species like *Acacia victoriae*, *Acacia pachycarpa*, *Cassia brewsterii* and *Robinia pseudoacacia*, the Miombo ecozone seems to be out of range.

3.2. Growth and production in promising multipurpose trees

3.2.1. Height, diameter and branching

In general, species showing excellent survival also demonstrated the best growth in height and diameter (Table 3). As early as 15 months after planting, 15 accessions of the multipurpose trees tested showed promise for use in agroforestry technologies based on fast growth (mean annual increment (MAI) >2.0 m per year). These accessions included *Calliandra calothyrsus*, *Acrocarpus fraxinifolius*, *Gliricidia sepium*, *Cassia spectabilis*, *Cassia siamea* and *Flemingia congesta*. The accessions continued to show outstanding growth at 26 months when they attained 3.2–7.14 m height. They were closely followed by *Albizia falcataria*, *Albizia schimperiana*, *Schizolobium excelsum* and *Maesopsis eminii*.

The two accessions of *Acrocarpus fraxinifolius* were the fastest growing, with mean heights of 7.14 m (MAI of 3.29 m) and 5.78 m respectively and basal diameters of 15.2 cm and 15.4 cm. The species develops a single stem with a clear bole (very few if any branches) making it a candidate for poles and fuelwood production under short rotation and coppice regeneration. *Calliandra calothyrsus*, *Gliricidia sepium*, *Cassia spectabilis* and *Flemingia congesta* developed multiple stems, heavy branching with wide crowns. They attained total mean heights between 3.20 to 5.50

Table 4
Above ground biomass production (dry weight) for promising accessions of multipurpose tree species 26 months after planting at Makoka

Accession no.	Species	Biomass (t ha^{-1})			
		Foliage	Branches	Stems	Total
[illegible]	*Acrocarpus fraxinifolius*	6.2	5.7	21.6	33.6
14	*Acrocarpus fraxinifolius*	8.4	4.4	20.5	33.3
38	*Calliandra calothyrsus*	8.4	15.2	16.4	40.1
23	*Calliandra calothyrsus*	7.0	11.5	10.2	28.7
39	*Cassia siamea*	9.9	11.4	8.3	29.6
37	*Gliricidia sepium*	7.6	6.7	8.3	22.6
46	*Gliricidia sepium*	5.3	7.2	8.6	21.1
13	*Gliricidia sepium*	5.4	5.0	9.1	19.6
2	*Cassia siamea*	8.6	12.1	6.2	26.8
8	*Gliricidia sepium*	6.5	6.2	9.7	22.4
35	*Gliricidia sepium*	7.3	5.1	5.7	18.2
24	*Gliricidia sepium*	3.6	3.8	5.2	12.5
30	*Albizia falcataria*	8.0	8.6	7.0	23.6
32	*Flemingia congesta*	3.7	9.6	5.0	18.3
26	*Cassia siamea*	8.4	11.1	5.8	25.3
22	*Albizia schimperiana*	2.5	2.4	3.0	7.9
48	*Schizolobium excelsum*	4.9	0.8	8.5	14.2
44	*Cassia spectabilis*	7.8	5.7	10.9	24.4
21	*Cassia spectabilis*	6.1	4.3	8.0	18.3
20	*Maesopsis eminii*	2.3	3.6	2.5	8.4
LSD (0.05)		3.3	4.4	4.6	–
CV (%)		56.2	52.2	39.2	–

Abbreviations as in Table 3.

m and basal diameters of 6.9–14.3 cm. The growth of *Cassia siamea* was constrained by the powdery mildew caused by *Erysiphe acacia* (N.S.W. Chipompha, personal communication, 1989). The impact of the powdery mildew was severe on coppice shoots but uncut trees recovered almost completely during the rainy seasons. In spite of the disease the three accessions of *Cassia siamea* tested attained mean heights of 3.90–4.71 m and basal diameters between 9.3 and 11.3 cm, with single stems and multiple branching.

3.2.2. Biomass production and coppicing

Estimates of biomass production for the promising species were generally high (Table 4). The best 20 accessions yielded between 12 and 40 t ha^{-1} total biomass on a dry weight basis. Only *Albizia schimperiana* and *Maesopsis eminii* produced less than 10 t ha^{-1} total biomass.

Calliandra calothyrsus (38) yielded 40 t ha^{-1} including 8.4 t ha^{-1} foliage and 31.6 t ha^{-1} woody biomass. The species is a well-known fodder and has high potential as a hedge in alley cropping, a source of green manure, bee forage and fuelwood production (National Academy of Sciences, 1980). The two accessions of *Acrocarpus fraxinifolius* yielded over 33 t ha^{-1} of total biomass each followed by the three accessions of *Cassia siamea* which yielded 25.3–29.6 t ha^{-1}. Five of the *Gliricidia sepium* accessions tested yielded 18.2–22.6 t ha^{-1}.

The biomass yields for the promising species in this study are very high considering that these accessions were only 26 months old (Art and Marks, 1971). The MAI for biomass of the 16 fastest growing accessions ranged from 8.4 to 18.5 t ha^{-1} per year. Data reported for biomass production in high density (5000–40 000 stems ha^{-1}) plantations of *Leucaena leucocephala* range from 4.5 to 25 t ha^{-1} per year (Gueverra et al., 1978; Visuttipitakul et al., 1983; Glumac et al., 1987; Goudie and Moore, 1987). Similarly some high density plantings of *Prosopis* species under irrigation (Felker et al., 1983) and high density *Pinus radiata* plantations in New Zealand (Madgewick and Oliver, 1985) have reported biomass production levels comparable with ours. However, our yield data are lower than those reported for irrigated *Acacia nilotica* in Pakistan (35–41 t ha^{-1} per year; Maguire et al., 1990) and *Prosopis juliflora* growing in a cement quarry with subsurface water at Mombasa, Kenya (36 t ha^{-1} per year; Maghembe et al., 1983). These comparisons should be made with due regard for the differences between the species and stands compared in stocking, site fertility, cultural treatments applied (like fertilization and irrigation) and age of the stands. At 26 months, the MAI for most of the multipurpose tree species tested are still increasing and in many accessions will continue to increase for some more years (Maclaughlin et al., 1987). There is therefore a good reason to allow the remaining trees in this trial to grow for a few more years to observe trends in growth rate and the potential yield within the ecozone.

In most accessions, coppicing was vigorous (> 5 coppice shoots per stump) and the production of biomass was very high (Table 5). In 1 year, when the same stumps were harvested twice, *Calliandra calothyrsus* (23) and *Cassia spectabilis* (44) produced the highest coppice biomass (12.9–3.7 t ha^{-1} per year. *Acrocarpus fraxinifolius*, *Gliricidia sepium*, *Flemingia congesta* and *Cassia siamea* (2) yielded over 5.4 t ha^{-1} per year of coppiced biomass. The ability to coppice and yield high biomass is an important criterion for selecting multipurpose trees for green manure and for fodder production. Green manures from these species are therefore under close evaluation for use as fertilizer supplements for growing maize (H. Prins and J.A. Maghembe, unpublished data, 1989). Although *Albizia schimperiana*, *Albizia falcataria* and *Maesopsis eminii* formed coppices, the biomass from these coppices is very low, making them unsuitable for technologies such as alley cropping under present conditions.

3.2.3. Nutrient content

The nutrient concentrations in the leaves, branches and stems of the most promising multipurpose tree species (Table 6) are comparable with multispecies averages reported for tropical forest ecosystems (Stark, 1971; Golley et al., 1975; Lundgren, 1978) and to other leguminous

Table 5
Coppicing ability and coppice biomass (dry weight) following harvesting of promising multipurpose tree species at 15 months

Accession no.	Species	No. of coppice shoots	Coppice biomass at 6 months ($t\ ha^{-1}$)		Coppice biomass at 12 months ($t\ ha^{-1}$)		Total ($t\ ha^{-1}$)
			Foliage	Wood	Foliage	Wood	
45	*Acrocarpus fraxinifolius*	4.0	1.2	2.0	2.0	1.8	7.1
14	*Acrocarpus fraxinifolius*	3.0	1.4	2.7	2.4	2.0	8.4
38	*Calliandra calothyrsus*	10.0	1.3	1.1	3.1	4.2	9.7
23	*Calliandra calothyrsus*	7.0	2.8	4.0	2.4	4.5	13.7
39	*Cassia siamea*	7.0	0.8	0.7	1.4	1.3	4.1
37	*Gliricidia sepium*	12.0	1.9	1.9	3.1	3.2	10.1
46	*Gliricidia sepium*	18.0	0.9	0.8	1.5	1.7	5.0
13	*Gliricidia sepium*	14.0	1.1	0.7	2.3	2.5	6.5
2	*Cassia siamea*	9.0	0.7	0.8	2.1	1.7	5.4
8	*Gliricidia sepium*	17.0	0.6	0.4	1.8	2.0	4.8
35	*Gliricidia sepium*	14.0	1.1	0.8	2.5	2.6	7.0
24	*Gliricidia sepium*	16.0	0.7	0.7	1.4	2.5	5.2
30	*Albizia falcataria*	4.0	0.3	0.2	0.4	0.2	1.1
32	*Flemingia congesta*	18.0	1.2	2.9	1.5	1.6	7.2
26	*Cassia siamea*	7.0	0.7	0.7	1.5	1.3	4.3
22	*Albizia schimperiana*	7.0	0.4	0.2	0.7	0.6	1.8
48	*Schizolobium excelsum*	3.0	0.8	0.8	1.6	1.1	4.3
44	*Cassia spectabilis*	17.0	1.8	3.2	3.6	4.3	12.9
21	*Cassia spectabilis*	15.0	0.8	0.8	1.8	1.6	5.0
20	*Maesopsis eminii*	NM	0.2	0.1	0.4	0.4	1.1
LSD (0.05)		–	0.3	0.6	0.7	1.1	–
CV (%)		–	34.0	44.5	33.9	44.4	–

The coppices were harvested 6 months and again at 12 months after cutting.
LSD, least significant difference; CV, coefficient of variation; NM, not measured.

trees and forages (Ahmed and Quilt, 1980; Maghembe et al., 1983, 1986; Glumac et al., 1987).

For all species and nutrients studied, concentrations were highest in the foliage and lowest in stems. This concentration gradient is important in forestry as it allows the harvesting of wood with only limited export of nutrients from the site (Boyle et al., 1973; Madgwick et al., 1981; Ahimana and Maghembe, 1987). This trend would hold true for the most promising species reported here. Thus, in the case of *Calliandra calothyrsus* (38), the foliage constitutes only 21.05% of the total above ground biomass; yet it contains 70% of all the nitrogen accumulated by the above ground biomass. If pooled together, the branches and foliage of *Calliandra calothyrsus* accumulated 89.5% N, 63.9% P, 64.8% K, 79% Ca and 63.3% Mg. Unlike tree utilization in forestry, however, harvesting of multipurpose trees like *Calliandra calothyrsus* in agroforestry may include removal of the foliage for fodder as well as branches and stems for fuelwood. Complete resource utilization excludes wastage and optimizes labour utilization in addition to increasing the total product mix from land. However, such utilization of fast growing multipurpose trees followed by repeated harvesting of coppices may affect long-term productivity unless the leaves and twigs are applied in situ as green manure. The promising accessions of these multipurpose trees are recommended for use in agroforestry under total as well as partial utilization of biomass. Further research should therefore address nutrient depletion and long-term productivity of agroforestry systems based on fast growing multipurpose trees under short production cycles and coppice regeneration.

Table 6
Nutrient concentrations in tissues of some promising multipurpose tree species planted at Makoka, Malawi

Multipurpose tree species	Tissue	Nutrient concentration (%)					
		N	P	Ca	K	Mg	Na
Calliandra calothyrsus	Leaves	2.60	0.21	0.96	0.51	0.31	0.05
	Branches	0.40	0.17	0.38	0.47	0.20	0.02
	Stems	0.20	0.15	0.22	0.33	0.20	0.07
Gliricidia sepium	Leaves	3.70	0.25	1.80	1.05	1.70	0.05
	Branches	0.55	0.15	0.45	0.94	0.50	0.05
	Stems	0.04	0.15	0.38	0.63	0.20	0.02
Acrocarpus fraxinifolius	Leaves	3.10	0.19	1.40	0.86	0.57	0.05
	Branches	0.45	0.17	0.58	0.74	0.40	0.02
	Stems	0.35	0.15	0.32	0.55	0.20	0.02
Cassia spectabilis	Leaves	2.50	0.25	0.96	0.94	0.93	0.02
	Branches	0.40	0.15	0.22	0.55	0.02	0.02
	Stems	0.04	0.13	0.16	0.31	0.31	0.02
Cassia siamea	Leaves	2.50	0.21	0.70	0.86	0.82	0.02
	Branches	0.40	0.15	0.36	0.74	0.48	0.02
	Stems	0.30	0.15	0.21	0.33	0.38	0.02
Flemingia congesta	Leaves	2.60	0.25	0.68	1.17	0.30	0.07
	Branches	0.30	0.15	0.23	0.98	0.16	0.05
	Stems	0.20	0.13	0.12	0.86	0.06	0.02
Schizolobium excelsum	Leaves	2.20	0.23	0.40	0.74	0.51	0.07
	Branches	0.65	0.17	0.39	0.51	0.21	0.05
	Stems	0.40	0.15	0.14	0.40	0.21	0.05
Albizia falcataria	Leaves	2.50	0.23	0.48	0.75	0.90	0.05
	Branches	0.45	0.15	0.32	0.51	0.20	0.02
	Stems	0.35	0.15	0.32	0.51	0.45	0.02
Albizia schimperiana	Leaves	2.30	0.19	0.48	1.33	0.45	0.02
	Branches	0.55	0.17	0.26	0.86	0.25	0.02
	Stems	0.45	0.15	0.22	0.33	0.14	0.02

3.3. *Performance of Australian acacias and other multipurpose trees*

3.3.1. *Height, diameter and branching*

The Australian germplasm generally performed poorly (Table 3). Of the 17 Australian *Acacia* species studied, only *Acacia auriculiformis* and *Acacia aulacocarpa* showed good survival and growth. *Acacia shirleyi, Acacia julifera, Acacia burrowii* and *Acacia difficilis* showed good growth (MAI > 1.5 m), but generally survived poorly. *Acacia victoriae, Acacia ampliceps, Acacia pachycarpa, Acacia murrayana* and *Acacia brewsterii* failed to grow. All of the species tested (except *Acacia difficilis* and *Acacia cyanophylla*) had single stems associated with many branches and small crowns.

Poor performance was also shown by *Prosopis* species. All the four *Prosopis* species tested basically failed (Table 3). *Acacia albida* accessions generally showed a slow start with MAI > 0.90 m. *Vangueria infausta*, a popular indigenous fruit species, reached maturity and produced large fruits in less than 2 years. The species has clearly demonstrated its potential to be cultivated as a fruit tree in view of its short growth period before yielding the desired products.

3.3.2. *Biomass production and coppicing*

At 26 months, only *Acacia auriculiformis, Acacia shirleyi* and *Acacia julifera* had high biomass production (>12 t ha^{-1}) (Table 7). *Acacia salicina, Acacia eriopoda, Acacia difficilis* and *Acacia aulacocarpa* yielded biomass in excess of 6 t ha^{-1}. Biomass production by the other species was insignificant.

Table 7
Biomass production (dry weight) for coppiced and uncoppiced accessions of Australian acacias and other multipurpose tree species 26 months after planting at Makoka

Accession no.	Species	Biomass uncoppiced ($t\ ha^{-1}$)			Biomass coppiced ($t\ ha^{-1}$)	
		Total	Foliage	Wood	Total	Foliage
Australian germplasm						
7	*Acacia auriculiformis*	15.8	5.7	10.1	1.2	0.8
3	*Acacia shirleyi*	12.3	4.5	7.7	1.1	0.6
25	*Acacia julifera*	12.8	3.1	9.7	1.5	0.8
33	*Acacia burrowii*	4.6	1.4	3.2	Did not coppice	
18	*Acacia aulacocarpa*	6.5	1.4	5.0	1.4	0.8
43	*Acacia difficilis*	6.9	1.8	5.1	1.0	0.6
40	*Acacia eriopoda*	6.7	3.0	3.7	0.9	0.5
34	*Acacia cyanophylla*	0.7	0.2	0.5	Did not coppice	
42	*Acacia tumida*	2.2	0.8	1.4	1.1	0.6
47	*Acacia melanoxylon*	1.9	0.5	1.4	0.6	0.2
9	*Acacia trachycarpa*	6.4	3.3	3.2	0.9	0.5
41	*Acacia salicina*	8.0	2.8	5.2	1.6	0.9
27	*Acacia stenophylla*	0.2	0.2	0.1	0.8	0.3
36	*Cassia brewsterii*				Failed to grow	
29	*Acacia victoriae*				Failed to grow	
16	*Acacia ampliceps*				Failed to grow	
19	*Acacia pachycarpa*				Failed to grow	
31	*Acacia murrayana*				Failed to grow	
Other accessions						
49	*Acacia albida*				NM	
28	*Acacia albida*				NM	
15	*Prosopis palida*	2.7	0.4	2.3	0.7	0.1
1	*Vangueria infausta*				NM	
10	*Acacia albida*				NM	
6	*Prosopis chilensis*	0.7	0.2	0.5	NM	
4	*Robinia pseudoacacia*	0.1	0.0	0.0	NM	
5	*Prosopis juliflora*				Failed to grow	
11	*Prosopis cineraria*				Failed to grow	
12	*Prosopis tamarugo*				Failed to grow	
LSD (0.05)		12.3	3.3	4.5	2.7	1.0
CV (%)		56.2	52.2	58.2	39.2	33.9

The coppice biomass is the total of two harvests—at 20 and at 26 months after planting.
LSD, least significant difference; CV, coefficient of variation; NM, not measured.

Following the three cuttings at 15, 20 and 26 months, coppicing of Australian acacias was very poor or non-existent. In *Acacia auriculiformis*, where limited coppicing occurred, this did not grow well because of severe attack by the powdery mildew *Erysiphe acacia*. The testing and artificial regeneration of *Acacia* species endemic to Australia (on a large scale) is a recent phenomenon (Boland and Turnbull, 1981; Turnbull, 1987). High hopes are placed on these Australian multipurpose tree species because of their potential for nitrogen fixation, their lack of thorns (making them easy to manage in farming systems) and expectations of fast growth in foreign sites as demonstrated by Australian eucalypts abroad. Many of the species tested in this trial have shown poor performance. However, most of the germplasm originates from semi-arid environments where they may have developed special mechanisms and symbioses to cope with water stress, nutrient availability and environmental periodicity. The failure of pines to grow in east Africa until the introduction of their obligate mycorrhizae partners is well documented (Mikola, 1970; Maghembe and Redhead, 1980). Testing of Australian *Acacia* species and related germplasm should therefore include introduction and inoculation of the planting stock with their native endophytes before their potential is ruled out.

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