Growth and yield estimates in natural stands of leleshwa (*Tarconanthus camphoratus*)

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ABSTRACT

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Leleshwa (*Tarconanthus camphoratus*, Compositae) is a tropical and subtropical shrub that grows in semi-arid Africa. Its coppicing ability and rapid production of high quality fuelwood make it an ideal candidate for sustained yield cropping. A study of its regrowth in natural stands in highland Kenya was carried out in 1989. Wet and dry woody biomasses of individual stems were found to be highly positively correlated with stem diameter 30 cm above the ground, allowing accurate estimates of woody biomass from stem measurements. Analysis of sites of increasing age since last cutting indicated that woody biomass increased at a rate of 2.3 t dry weight ha^{-1} year^{-1}, but that the biomass of larger, more useful size classes of wood initially increased exponentially. The best temporal predictor of biomass and maximum stem diameter was the number of months since cutting with more than 50 mm of rain. Maximum stem diameter of regrowing clumps was positively correlated with the diameter of the largest stem before cutting. Total biomass of useful wood was positively correlated with mean maximum stem diameter, independent of stand age and clump density.

INTRODUCTION

Fuelwood is the primary energy source for the majority of the world's people. Woody vegetation is used locally as firewood, and is converted to charcoal for transport to areas without sufficient wood production, such as cities, where it is often a less expensive cooking fuel than gas or electricity. Over large areas of the world, woody vegetation has been severely depleted by this demand, and fuelwood shortages are becoming critical (Chidumayo, 1987; Kalapula, 1989).

Considerable attention has been given to alleviating these shortages through agroforestry, the planting of fast growing woody plants in an agricultural setting (Allen et al., 1988; Bradley, 1988). However, little research has been

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done on the sustained cropping of indigenous vegetation (see Gustafsson, 1987; Chidumayo, 1988). This option is particularly attractive in arid and semi-arid areas with extensive stands of coppicing shrub species. Conventional agro-forestry projects in arid lands are hindered by long cropping intervals and the need to maintain the fuelwood plot for many years in the face of local loss of interest and the lack of agricultural skills among the pastoral peoples that inhabit these areas. Sustained-yield cropping of indigenous vegetation minimizes these difficulties.

Here we report the results of a preliminary study of one such shrub, leleshwa (*Tarconanthus camphoratus*, Compositae). We present estimates of standing biomass and growth rates (productivity) in natural populations of leleshwa previously harvested for fuelwood.

SPECIES AND STUDY SITE

Leleshwa is a multi-stemmed shrub that occurs in Africa and Arabia. In East Africa it occurs in habitats that are high, cool and dry. Most East African records are from altitudes between 1500 and 2200 m (Fig. 1), in areas with 500–1000 mm of rainfall. It prefers deep, rich soil on more or less level ground, but not soils of impeded drainage (e.g. black cotton). It often replaces dry cedar (*Juniperus procera*) or olive (*Olea africana*) forest when these disappear through burning, clearing or drought (Pratt and Gwynne, 1977; Lamprey, 1984). In many places it produces nearly pure stands, excluding other woody species and preventing the re-establishment of forest (Pratt and Gwynne, 1977). Leleshwa is fire tolerant, dying back to the ground, but coppicing readily after fire or cutting.
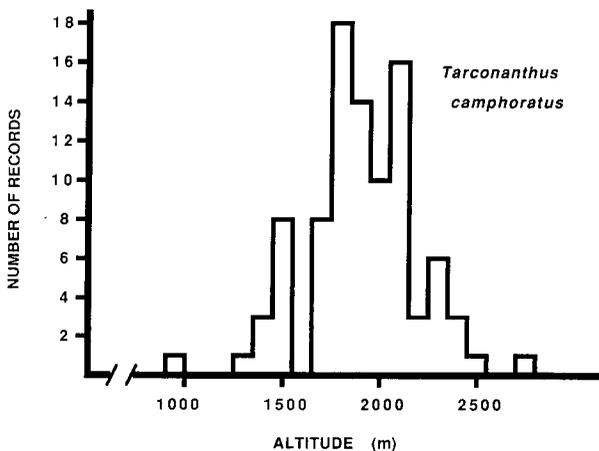

Fig. 1. Altitudinal distribution of *Tarconanthus camphoratus* in East Africa, based on records of sheets at the Herbarium of the National Museums of Kenya.

Leleshwa is generally unpalatable to both stock and wildlife, including browsers with broad tolerances (Pratt and Knight, 1971; Oloo, 1988). However, during extreme drought, leleshwa leaves can become a life-saving fodder for cattle (J. Hewett, personal communication, 1988). The eating of normally unpalatable plant species during drought in East Africa has been previously documented (Young, 1985; Hauser, 1987; Oloo, 1988). Its invasive nature and unpalatability to stock have caused leleshwa to be considered a pest of rangeland (Pratt and Gwynne, 1977). Clearing of leleshwa for rangeland, although difficult (Pratt, 1966; Parker and Parker, 1966; Pratt and Knight, 1971), is commonly practised. Sometimes scattered stems are left to provide shade and protection from drying winds (C. Francombe, personal observations; J. Hewett, personal communications, 1988).

Leleshwa is ideally suited for sustained fuelwood management. Its wood is hard, and it is locally favoured for charcoal production (Pratt and Gwynne, 1977). As an adaptation to recovery after fire (Lamprey, 1984), it coppices readily and grows quickly after harvest. As indicated by its specific name, *Tarconanthus camphoratus* produces strongly aromatic leaves, and may be a commercially exploitable source of camphor and/or menthol (P. Waterman, personal communication, 1990). Quantitative estimates of growth and standing biomass for leleshwa are necessary for informed management and conservation of leleshwa bushland. However, these characteristics have not previously been measured.

Ol Ari Nyiro ranch is located on the western edge of the Laikipia plateau, overlooking Lake Baringo (36° 25' E, 0° 35' N). Leleshwa occurs over much of the southern half of the ranch at altitudes of 1800–2000 m (Young, 1991). This area is thought to have been covered by olive forest in the past, and still contains small patches of olive forest and thicket (Young, 1991).

Since 1983, leleshwa management on the ranch has taken three forms: (1) complete removal of leleshwa and other woody species to produce grass leys; (2) removal of leleshwa leaving single stems to produce a grassy leleshwa woodland; (3) sustained yield charcoal production. In all cases the initial cutting was made into charcoal, but in the latter, shoots were allowed to regrow to provide future harvests. Charcoal production was usually done by outside contractors on a share-cropping basis. Five stands of leleshwa cut at different times since 1983 were available for resurvey. A single set of surveys of these stands in 1989 provided the basis for growth and productivity estimates over a period of 6 years.

All of the sites in this study are located within 2 km of the central compound of Ol Ari Nyiro ranch, at an altitude of 1870 m. Daily rainfall records for this site have been kept by ranch management since 1957. Mean annual rainfall has been 790 mm over the past 30 years. Mean maximum and minimum temperatures are approximately 30 and 14°C (Odingo, 1971, p. 16). The land is flat (<1% slope) and the soil is a red clayey luvic phaeozem

throughout the study area (Ahn and Geiger, 1987). The area is subject to cattle grazing and herbivory by wild animals, ranging from insects and rodents to elephants and rhinos. The five study sites are as follows.

Site 1. 0.3 km W of the manager's house. Cut in February 1983, stumps up to 40 cm tall left. An area of nearly pure leleshwa.

Site 2. 1.0 km NNW of manager's house. Cut in November–December 1983, no stumps left. An area of nearly pure leleshwa.

Site 3. 1.6 km SW of manager's house. Cut in December 1986–January 1987, some stumps left. An area consisting of pure stands of leleshwa interspersed with mixed stands of leleshwa, *Euclea divinorum* and *Acacia gerrardii*. Measurements were taken only in areas of pure leleshwa.

Site 4. 1.7 km NW of manager's house. Cut in August–September 1988, stumps and single stems left. An area of mostly leleshwa, with occasional *Acacia brevispica* shrubs.

Site 5. 1.6 km NNW of manager's house. Cut in December 1988, stumps and some single stems left. An area of nearly pure leleshwa.

METHODS

Destructive sampling

This work was carried out in February–March 1989. To estimate standing biomass of leleshwa stands, we destructively sampled 17 leleshwa stems ranging in diameter from 0.6 to 8.6 cm. We intentionally sampled a variety of sites and clump sizes: from rich flat soils to rocky slopes, pure to mixed stands, and young to old individuals. The diameter of each stem was measured 30 cm off the ground, taking the mean of minimum and maximum measurements. Larger stems in particular were oblong rather than circular in cross-section. All leaves were removed from each stem, and the wood cut into size classes based on diameter, in 1 cm cross-sectional increments. For all 17 stems we weighed the wood in each size class greater than 1 cm (i.e. excluding twigs and leaves). For 12 of these stems, we also weighed the twigs (wood < 1 cm diameter) and leaves, air-dried all samples for 1 month in the dry season, and weighed them again. In all, 84 samples were weighed fresh and 78 samples were weighed air-dry. Of these, 24 were then oven-dried to constant weight and weighed again.

We carried out linear regression analysis of stem diameter vs. total fresh biomass for all size classes, and stem diameter vs. total dry biomass.

Biomass estimates of leleshwa sites

At each of the five sites of varying age, the leleshwa stands were assessed for standing biomass. At the three oldest sites, four 10 m × 10 m plots were

randomly located in representative stands. Each stem over 1 cm diameter was measured at 30 cm from the ground on each of the 107 clumps (individuals) in these 12 plots. For 24 clumps, the number of stems less than 1 cm diameter was also counted, and for four of these clumps, each of these smaller stems was measured.

At the youngest site, there had not yet been any regrowth. At the second youngest site, fresh growth had just begun, and all clumps were very similar. Ten clumps were randomly selected. On each clump, the total number of stems was counted, and the largest two stems measured at 30 cm from the ground. The density of clumps was estimated by counting clumps in three 10 m × 10 m plots. Three samples of 10 stems each were collected from three clumps for fresh, air-dry and oven-dry biomass measurements of leaves and wood separately.

A total of over 2000 individual stems were counted and measured. For each stem, the biomass in different wood size classes was estimated using fitted regressions from the destructive sampling (c.f. El Fadl et al., 1989). Total fresh and dry biomasses were estimated, and fresh biomass in each size class was estimated for each clump, each plot and each site. For each plot, the mean of the largest stem in each clump was calculated. For all of these variables, a grand mean ($n=4$) was calculated for each site.

Rainfall records were analysed. For each site, the number of months since cutting during which rainfall exceeded 25, 50, 75 and 100 mm was calculated, as well as absolute age in months, and the total amount of rainfall since cutting. These variables were regressed against mean stem diameter and biomass estimates.

RESULTS

Destructive sampling

Stem diameter at 30 cm from the ground was an excellent predictor of fresh and dry biomass in leleshwa. Fitted linear regressions between stem diameter and the square root of biomass explained 97–99% of the observed variance in biomass in all size classes (Table 1). Nearly all of the observed values of biomass fell within 10% of the regression line. This relationship was considerably stronger than that of several arid land trees and shrubs in Kenya (see Lamprey, 1983), but with a slope (0.472) for total dry woody biomass very similar to the slope (0.486) that was estimated from published figures for *Acacia tortilis* (Lamprey, 1983). The fitted regression lines were used to estimate biomass for stems of known diameter in the plots. The relationship between total leaf biomass and with stem diameter is less strongly correlated, with a much lower slope (Table 1).

The ratios of air dry to fresh biomass were 0.582 ± 0.013 (s.e.) for leaves,

TABLE 1

Relationships between stem diameter (cm) and the square root of fresh biomass (kg) of various plant parts in *Tarconanthus camphoratus*

Plant part	Slope	Intercept	r	r^2	n
Leaves	0.078	+0.19	0.883	0.78	12
Total wood	0.552	−0.25	0.994	0.988	12
Wood					
>2 cm	0.637	−0.92	0.996	0.992	12
>3 cm	0.657	−1.25	0.994	0.988	9
>4 cm	0.698	−1.76	0.985	0.97	5
>5 cm	0.685	−1.89	0.997	0.994	4

TABLE 2

Regression coefficients for several variables vs. leleshwa growth (total fresh woody biomass) in five plots differing in the time since cutting. The outlier in Fig. 2 was omitted from the stem diameter analysis

	Stem diameter ($n=4$)	Residual variance (%)	Fresh woody biomass	Residual variance (%)	Dry woody biomass	Residual variance (%)
Total months	0.99972	0.056	0.9965	0.70	0.9949	1.02
Months with more than:						
25 mm rain	0.9953	0.94	0.9972	0.56	0.9970	0.60
50 mm rain	0.99988	0.024	0.9993	0.14	0.9988	0.24
75 mm rain	0.9953	0.94	0.9954	0.92	0.9922	1.56
100 mm rain	0.988	2.4	0.9860	2.8	0.9842	3.13
Total rainfall	0.972	5.5	0.9927	1.4	0.9909	1.81

0.704±0.021 for twigs (<1 cm diameter), 0.739±0.015 for wood 1–2 cm diameter, and 0.792±0.009 for all larger wood classes, independent of size. Sample sizes ranged from 10 to 15. The ratio of oven dry to air dry weight was 0.927±0.006 for all classes combined ($n=17$). There were no significant differences among classes for this ratio. This compares with a value of 0.93 reported for *Acacia tortilis* in Kenya (Lamprey, 1983).

Biomass estimates for leleshwa sites

The total number of months with rainfall exceeding 50 mm (about 2 in) was the best predictor of total fresh and dry woody biomass and the square of mean largest stem (Table 2). The next best variables had four times the residual variance for fresh biomass, and over twice the residual variance for dry biomass and stem diameter.

Mean largest stem had a striking squared relationship with age as measured
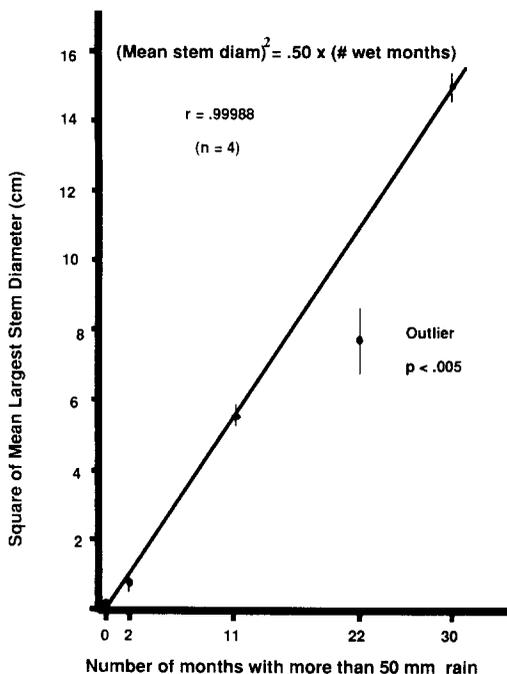
Fig. 2. The relationship between stand age in months receiving at least 50 mm rain, and mean largest stem diameter. Mean largest stem diameter is the average diameter of the largest stem in each clump.
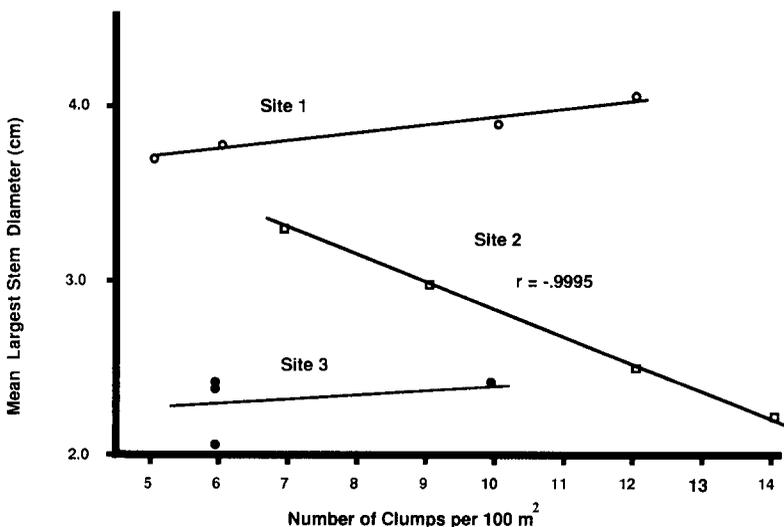

Fig. 3. Crowding in leleshwa. Only in Site 2 did plots with more clumps have smaller maximum stem diameters.
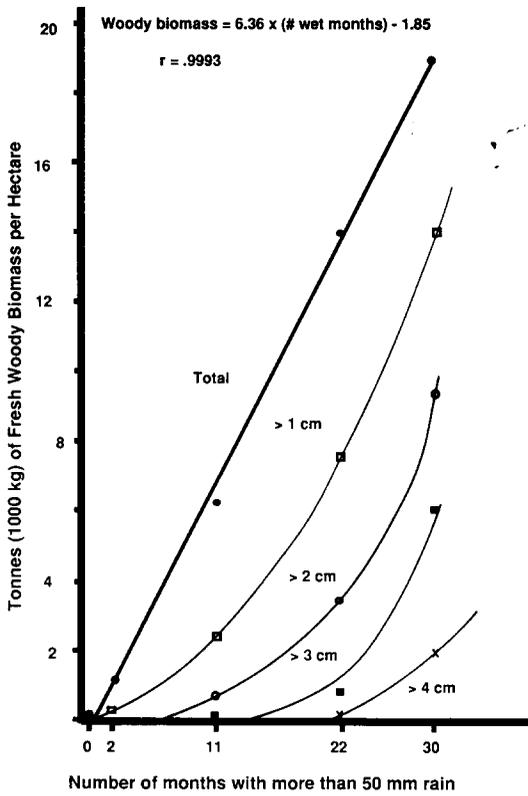
Woody biomass = 6.36 x (# wet months) - 1.85

r = .9993

Total

> 1 cm

> 2 cm

> 3 cm

> 4 cm

Number of months with more than 50 mm rain

Fig. 4. Increase in estimated fresh woody biomass of different summary stem diameter classes in leleshwa stands of increasing age.
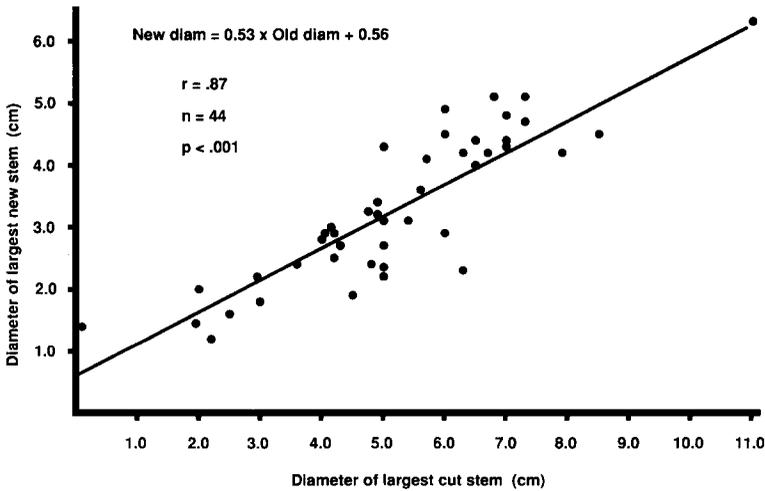
New diam = 0.53 x Old diam + 0.56

r = .87

n = 44

p < .001

Diameter of largest cut stem (cm)

Fig. 5. Relationship between the diameter of the largest stump in a clump cut in February 1983, and the diameter of the largest new stem in that clump in February 1989. Each point represents a single clump in Site 1.

in wet months (Fig. 2). However, the data for Site 2 represent a significant outlier ($P<0.005$), and were not included in the regression. Site 2 did not differ in soils or rainfall from the other sites; it was less than 500 m from Site 1. Site 2 did differ from all of the other sites in two ways. First, it was the only site in which no stumps were left. Leaving stumps can increase the subsequent growth of coppice shoots in teak (Wyatt, cited in Ola-Adams, 1975), and may also have this effect in leleshwa. Second, Site 2 was the only site to show statistical evidence of crowding. Sites 4 and 5 had little or no above-ground biomass. For Sites 1, 2 and 3, we plotted mean stem diameter against the
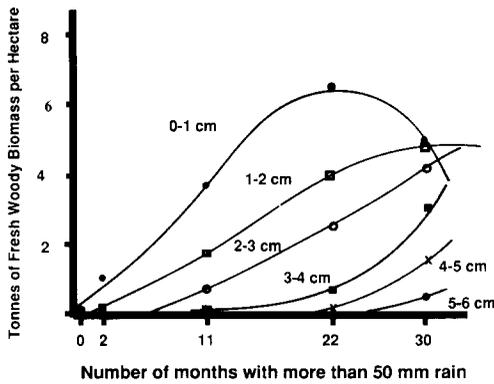

Fig. 6. Changes in the amount of fresh woody biomass in different incremental stem diameter classes in leleshwa stands of increasing age.
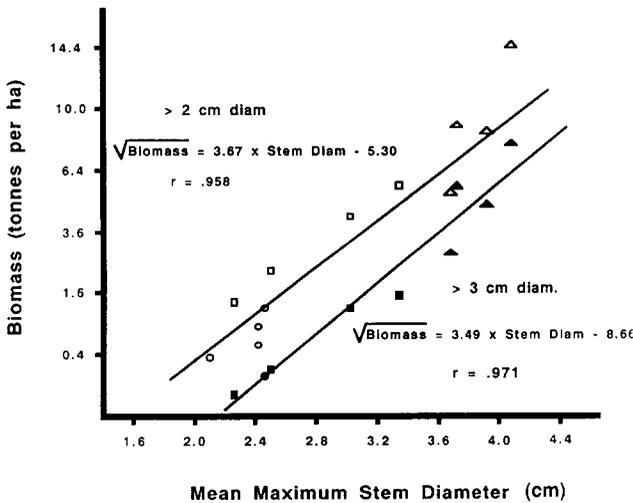

Fig. 7. Estimated fresh woody and oven dry biomass of wood in two summary size classes for plots differing in mean maximum stem diameter. Solid symbols, wood > 3 cm diameter; open symbols, wood > 2 cm diameter. Triangles, Site 1; squares, Site 2; circles, Site 3. Biomass is on a squared scale.

number of clumps in each plot (Fig. 3). Site 2 was the only site showing a negative relationship ($P < 0.001$), implying that crowding was a factor limiting maximum stem growth. Site 2 had 25–33% more clumps per hectare than Sites 1 and 3. The fact that Site 2 falls on the regression line for biomass vs. age (Fig. 4) indicates that more stems and more clumps compensated for the production of smaller stems.

The size of the largest living stem in each clump at Site 1 was significantly positively correlated with the diameter of the thickest old cut stump (Fig. 5). This may be because larger stumps inherently produce faster growing stems (El Houri, 1977; Neelay et al., 1984) or because larger stems were indicative of larger pre-harvest plants, with greater root systems or underground storage.

Total woody biomass increased linearly with time, at a rate of 600 kg of fresh wood per hectare per rainy month (Fig. 4). On average, there have been five rainy months per year since 1983, so the mean yearly increase in fresh woody biomass was 3 t (2.3 t dry biomass) per hectare. Although woody biomass increases linearly with time, the same is not true for particular size classes of wood. As clumps grow, the amount of wood in larger size classes increases exponentially (Figs. 4 and 6), at the expense of wood in smaller size classes (Fig. 6). The proportion of wood in the smallest size class (< 1 cm, 'twigs') steadily declines with age from 92% to 25%. Even the absolute amount of wood in this class is less in Site 1 than in Site 2.

Obviously, larger wood cannot continue to increase exponentially while total biomass increases linearly. Most likely, the lower curves in Fig. 4 will begin to ease off in older stands. Unfortunately, dated sites over 6 years old were not available in this study.

Mean maximum stem diameter in each 10 m $\times$ 10 m plot was a fair predictor of woody biomass over 2 cm and over 3 cm (Fig. 7). This relationship holds over all 12 older plots, and is not directly dependent on the age of the stands. Even more surprising, this relationship is independent of the number of clumps per plot. It is worth noting that the data for Site 2, the only site with evidence of crowding, are the most internally consistent with the overall trend.

DISCUSSION

Leleshwa (*Tarconanthus camphoratus*) growth is the result of stand age, rainfall, individual plant history and competitive interactions among and within individuals. Although leleshwa clumps produce new shoots throughout their lives (after the rains), larger shoots continually and increasingly suppress the success (growth and survival) of these shoots, a phenomenon not uncommon in coppicing plants (see Young, 1984). The results are plants that become more and more dominated with age by one or a few large stems.

Sustained yield

It is these larger stems that are of particular interest for sustained fuelwood management. Table 3 shows the uses of various leleshwa wood sizes. As can be seen in Fig. 4, it is only after 6 years (averaging five wet months per year) that there was appreciable wood in the preferred larger size classes. At this age, the amount of larger wood was increasing rapidly.

Although we were only able to gather data on stands up to 6 years old, we would suggest that a cutting cycle of around 10 years would be reasonable at this site, based on the trends in Fig. 4. Such a preliminary estimate is of course subject to further investigation of older stands.

The results in Fig. 7 indicate a possible easy technique for estimating the standing biomass of any pure stand of leleshwa, independent of age (on this soil). It would be necessary to measure only a few (10–15) stems, the largest single stems in randomly selected clumps, and then estimate biomass per hectare from Fig. 7. Ideally, the relationship shown in Fig. 7 should be further investigated, including plots with larger stems, to assess its generality.

Generality of results

There is reason to believe that some of these results are somewhat site-specific. Leleshwa individuals on rockier slopes are noticeably stunted compared with individuals on flat deep soils such as those in the study sites (T. Young and C. Francombe, personal observations, 1989; P. Oduol, personal communication, 1989). However, the stems used in the destructive sampling were chosen from a broad range of clumps and sites, including rocky slopes, and all fell on the same regression lines (see Buech and Rugg, 1989). In addition, the use of wet months to age the plots should produce a more general result, at least partly robust against regional variation in rainfall. Leleshwa in rockier

TABLE 3

Fuelwood uses for different diameter sizes of leleshwa (*Tarconanthus camphoratus*). Information summarized from interviews with several charcoal makers

Wood size (diameter) (cm)	Use
0–1	Fuel for kiln, kiln spacers
1–2	Fuel for kiln, kiln spacers, (firewood)
2–3	Kiln spacers, marginal (poor) charcoal, firewood
3–4	Fair charcoal, firewood
4–5	Good charcoal, firewood
> 5	Excellent charcoal, (firewood)

sites may grow more slowly than in deep level soils with the same rainfall. However, the relationship in Fig. 7 may turn out to be fairly robust against variations among sites.

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