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Growth, biomass estimates, and charcoal production of *Acacia drepanolobium* in Laikipia, Kenya

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Abstract

Charcoal is a major source for cooking energy in most African countries, for which demand from a burgeoning human population has sometimes outstripped the supply of wood from forests and woodland. Therefore, there is need to explore the potential of indigenous trees and shrubs for sustainable charcoal production.

Acacia drepanolobium is an ideal candidate for sustained charcoal production because (a) it occurs in almost mono-specific stands in high densities over vast areas, (b) it coppices readily when harvested or top killed by fire, (c) it's hard wood makes good quality charcoal, (d) income from its charcoal is an attractive source of supplemental revenue. Information on its biomass, charcoal yield, and regrowth rates are needed for informed management and its conservation for sustainable charcoal production, but this information is currently lacking. Suitability of *A. drepanolobium* for sustained charcoal yield in Laikipia, Kenya, was evaluated by developing predictive equations for standing biomass and charcoal production, and by undertaking a chrono-sequence analysis of its regrowth. Woody biomass was strongly related to stem diameter ($Y=3.77\,x+1.17$, $R^2=0.96$, $P<0.001$). Mean charcoal production from earthen kilns was 2.83 Mg ha^{-1}. Height and stem diameter in coppicing stands increased at a mean rate of 28.6 cm year^{-1} and 0.7 cm year^{-1} respectively. Biomass in coppicing stands accumulated at a mean rate of 1.3 Mg ha^{-1} year^{-1} in a 14-year period, yielding dry biomass of 18.26 Mg ha^{-1} useable wood that can produce a minimum of 3.0 Mg ha^{-1} of charcoal. We propose that *A. drepanolobium* can be harvested for sustainable charcoal yield over a 14-year cycle. Production should be commercialized using modern kilns to improve efficiency and maximize yields.

Keywords: Chrono-sequence; Fuel-wood; Harvesting; Sustainable; Rangelands

1. Introduction

Fuel-wood is the primary source of cooking energy for the majority of the world's population (Young and Francombe, 1991; Lew and Kammen, 1997; Kennedy, 1998). In Kenya, over 75% of the people use fuel-wood in either firewood or charcoal form, as it is the cheapest and most accessible source of energy (Bradley, 1988). Most of the charcoal comes from forests in the rural areas and is later transported for use mostly in the urban areas (Chidumayo, 1978). This practice has resulted in a massive depletion of woody vegetation (Young and Francombe, 1991) and fuel-wood shortages are becoming critical (Baumer, 1990).

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Barnes (1990) estimated that Kenya, which by then had an annual deforestation rate of 1.5%, stood to loose most of its indigenous forests by the year 2040. Harvesting trees and shrubs for charcoal production may eventually result in the degradation of vegetation and land resources, and the start of the desertification process (Baumer, 1990). Selective extraction of woody species for either charcoal or firewood may induce fundamental changes in the composition and physiognomy of forests and woodlands, while indiscriminate extraction may lead to undesirable ecological consequences.

There is an urgent need to develop environmentally sound methods of sustainable fuel-wood production and exploitation. In Kenya, considerable effort has been expended to alleviate fuel-wood shortage through the introduction of fast growing exotic trees, agroforestry, and use of energy saving stoves (Bradley, 1988; Lew and Kammen, 1997). Conventional agroforestry approaches have met with little success because of inappropriate species, long cropping intervals and inadequate husbandry techniques used by the harvesters, mostly the rural poor (Young and Francombe, 1991). Although short rotation forestry has received considerable attention elsewhere, and detailed models of biomass production have been produced (reviewed in Senelwa and Sims, 1997; Verwijst and Telenius, 1999), little attention has been paid to the sustained cropping and improvement of indigenous trees and shrubs for fuel-wood production.

Exploring the possibility of using indigenous trees and shrubs for sustained yield harvesting is a very attractive and potentially viable economic and ecological alternative. This is especially so in arid and semiarid areas, which have numerous and often extensive stands of tree and shrub species. Young and Francombe (1991) proposed *Tarchonanthus camphoratus* L. (leleshwa) as a candidate for sustained charcoal production. We propose that *Acacia drepanolobium* Sjostedt (whistling thorn) is also ideally suited for sustained harvesting because it appears to (1) coppice readily after harvesting, (2) be fire tolerant, (3) occur in mono-specific stands at relatively high densities, (4) have hard wood, (5) be of relatively low forage value to herbivores. Also, (6) harvesting *A. drepanolobium* for charcoal production can help pay for the costs of clearing it and, provide employment because income from charcoal is an attractive supplemental source of revenue. In order to propose a species for such usage, there is need for quantitative estimates of its growth before and after harvesting, and its biomass and charcoal yield. Such information will be invaluable for its informed management, conservation, and sustainable utilization.

We report the results of a study for evaluating the suitability of *A. drepanolobium* for sustained charcoal production. Our specific objectives were to develop predictive equations for yield of woody biomass and of charcoal, and to study the rate of regrowth of coppicing stands through chronosequence analysis.

2. Materials and methods

2.1. The species

Acacia drepanolobium is the dominant tree species in arid uplands with impeded drainage where it forms nearly mono-dominant stands especially on black cotton soils (Young et al., 1997, 1998). It has a wide distribution and can be found in the rangelands of Sudan, Ethiopia, Somalia, Kenya, Tanzania, Uganda, and Zaire. Its altitudinal range is 600–2550 m above sea level (Coe and Beentje, 1991; Beentje, 1994).

Acacia drepanolobium is a shrub or a tree that grows to a height of 7.5 m but maximum height averages 3–5 m over much of its range. It is either a short robust tree or a slender tree with a rounded canopy. Its bark is black, rough, and fissured. *A. drepanolobium* also has pairs of long and narrow stipular spines (hereafter thorns), that grow to 7.5 cm long, but average 3.5 cm in many areas. Some thorns have swollen bases that confluence into large hollow pseudo-galls (hereafter galls), which are red when young and fade to black and grey-white when old. Obligate ants (*Crematogaster nigriceps*, *C. sjostedti*, *C. mimosae*, and *Tetraponera penzigi*) (Madden and Young, 1992; Young et al., 1997), occupy these swollen thorns.

Acacia drepanolobium is eaten by a large number of mammalian herbivores including giraffe (*Giraffa camelopardalis* L.), eland (*Taurotragus oryx Pallas*), elephant (*Loxodonta africana* Blumenbach), Jackson's hartebeest (*Alcelaphus buselaphus jacksoni*

Pallas), Grants gazelle (*Gazella granti* Brooke) and goats (*Capra hircus* L.). However, its utilization by herbivores is hampered by the presence of ants that live in its galls. Together with the thorns (Milewski et al., 1991), the ants are believed to ward off herbivores by their stings and bites and to irritate feeding herbivores (Madden and Young, 1992; Young et al., 1997).

In the Laikipia ecosystem of Kenya, many ranchers in *A. drepanolobium* areas believe that it has increased its density over the past 30 to 40 years. Some ranchers have labelled it a problem species because it a) coppices readily in response to top kill by fire or harvesting, b) is of low forage value since it is heavily defended against herbivory, c) is increasing in density, and d) has not been successfully controlled by chemical and physical means.

On many ranches large strips of *A. drepanolobium* are cleared for roads, paths, and to create grass leys, with most of the wood being used in traditional earthen kilns for charcoal production or as firewood (pers. obser.).

2.2. Study area

This study was carried out at Mpala Research Center, Laikipia, north-central Kenya (0° 18′30″N, 26° 54′28″E), at an altitude of 1800 m above sea level. The area receives a mean annual rainfall of 500–550 mm with a weak trimodal tendency. The peak rainy season is April–May, with most of the remainder falling between July and November. The rainfall is characterized by a large spatial and temporal variation (Young et al., 1997, 1998). Maximum temperatures range from 25°C to 33°C, and minima from 12°C to 17°C. The soils of the study area are black cotton (vertisols) soils (Ahn and Geiger, 1987; Young and Okello, 1998; Young et al., 1998).

The woody vegetation of the study area is dominated by *A. drepanolobium*, which accounts for up to 97% of overstorey tree and shrub density. Other overstorey species include *Rhus natalensis* Krauss, *Grewia similis* K. Shum., *Grewia bicolor* Juss., *Scutia myrtina* (Burm. f.) Kurz, *Lycium europaeum* L., and *Cadaba farinosa* Forssk. *Acacia brevispica* Harms ssp. *brevispica* and *Balanites aegyptiaca* (L.) Del. are uncommon (Young et al., 1997, 1998). The topography is generally flat with slopes less than 5%. The major land use is livestock ranching although some ranches concentrate on wildlife tourism or combine both wildlife/livestock enterprises. It is an important wildlife area because it has the largest herbivore biomass outside national parks and games reserves in Kenya.

2.3. Procedure

2.3.1. Destructive sampling

Sixteen *A. drepanolobium* trees ranging in diameter (at the base) from 0.6 to 14.2 cm were harvested from natural stands. Sampling was designed to ensure a representative range of diameters. The harvested trees were sectioned into classes based on 1 cm increments of diameter. For each section, the leaves, galls, fresh growth, twigs (<2 cm diameter), and woody material (>2 cm diameter) were separated and air-dried to constant weight. These sections were weighed to the nearest gram for leaves, galls, fresh growth and twigs and to the nearest 50 g for woody biomass using electronic scales. The lengths of all the twigs and stems were measured to the nearest centimeter to estimate the total running length of twigs and stems in each tree.

2.3.2. Charcoal yield

Local charcoal burners were contracted to harvest trees of *A. drepanolobium* and burn the wood for charcoal. Before harvesting, an overstorey vegetation inventory was undertaken in order to estimate species composition and density using 15 randomly sampled belt transects (50 by 5 m). The heights and diameters (25 cm above ground) of all trees and shrubs falling within the transects were recorded.

Plots of 0.17 ha from which *A. drepanolobium* were to be harvested for charcoal were marked out. Only *A. drepanolobium* trees were put into the kilns. For each piece of wood used, (a) length of stem, (b) circumferences at the tip and at the base of the stem (these were later converted to diameters), and weight of stem to the nearest 50 g were measured using an electronic scale. Charcoal operators then arranged the wood horizontally into earthen kilns and lit them using methods that represented current practice. The charcoal produced was harvested and weighed to the nearest 50 g. Eight kilns were used in this study. The entire process from harvesting the wood to charcoal production varied between 6 and 8 weeks. Charcoalers made all decisions concerning type of kiln, arrangement of woody stacks, pieces to go in, and time of pyrolysis.

2.3.3. Chrono-sequence regrowth of coppicing stands

Four stands from which *A. drepanolobium* had been harvested, respectively, in 1984, 1993, 1994, and 1995 were relocated and used for determining rate of regrowth. For each stand, the density, species composition, and stand structure (heights and diameters) were estimated by means of three belt transects (50 by 5 m) in November of 1996. An unharvested stand adjacent to the 1984 plot was also inventoried. The number of coppice stems per individual in each regrowing stand was recorded. These measurements were repeated in 1998.

3. Analysis

Dry weight and diameter measurements were transformed to natural logarithms (Ln (x+1) to standardize for zero values) and least squares linear regression analysis of the relationships between biomass of each plant component, leaves, fresh growth, thorns, galls, twigs (woody biomass <2 cm diameter), woody biomass (>2 cm diameter), total biomass, and stem diameter were undertaken. Only the equation for woody material (>2 cm) was used to estimate biomass available for charcoal yield because the smallest piece of wood that was used in the kilns had a diameter of 2 cm. Distribution of biomass among the plant parts was calculated on a percentage basis.

Total biomass of each regrowing stand was calculated as the sum of estimated biomass of each individual using the predictive equation derived above. Linear regression analysis for the relationship between charcoal yield per hectare and woody biomass was undertaken. Growth rates of the coppicing stands per year were calculated based on the mean increase in heights and stem diameters per site. Growth rate (height and diameter) and increase in woody biomass were calculated for each stand based on relationships derived from the destructive sampling. The regrowth data enabled estimation of time taken for a harvested stand to recover to harvestable levels.

4. Results

4.1. Allometric relations

Basal diameter of a tree was an excellent predictor of its dry weight for *A. drepanolobium* (Fig. 1). The relationships between dry weights of different tree sections and their respective stem diameters were strong and positive for galls (y=1.91 x+2.71, R^2= 0.92) and thorns (y=1.79 x+2.55, R^2=0.91), but weak for leaves (y=0.92 x+3.96, R^2=0.17) and fresh growth (y= 1.01 x+2.98, R^2=0.24) (Fig. 2). Regression analysis for the harvested wood that went into the kilns showed that stem diameter by length of stem had a strong relationship with the cube root of fresh weight of the trees (R^2=0.86). Useful woody biomass varied from 43 to 69% of the entire tree biomass.

4.2. Charcoal yield

Charcoal yield from *A. drepanolobium* was strongly related to the biomass of woody material (wet weight) that went into the kilns (Fig. 3). A total of 24.3 Mg of wood was placed in the earthen kilns yielding 3.4 Mg of charcoal at an average of 2.8 Mg ha^{-1} (1.5–4.6 Mg ha^{-1}). Efficiency of conversion from wood to charcoal was low in the kilns used ranging from 10.2 to 18.2% (mean=14.2%, S.E.=±0.90).

Linear regression equations between charcoal yield and density of *A. drepanolobium* from harvested plots were weak (R^2=0.31–0.55). Similarly, the relationship between biomass yield (wet weight) and density was weak, with fitted linear regression accounting for less than 20% of the observed variance.

4.3. Chrono-sequence of regrowth

The density of coppicing *A. drepanolobium* in the four plots of different ages was 1156, 967, 933, and 933 (trees per ha) in 1, 2, 3, and 12-year-old stands, respectively (mean density of 997 trees per hectare). This figure is similar to density figures from nearby sites and is consistent with *A. drepanolobium* density for Laikipia rangelands (Young et al., 1998).

Coppicing trees took approximately 12–14 years to grow back to pre-harvest heights (Fig. 4). Growth in both diameter arid height was almost linear. However, there were years during which growth was evidently

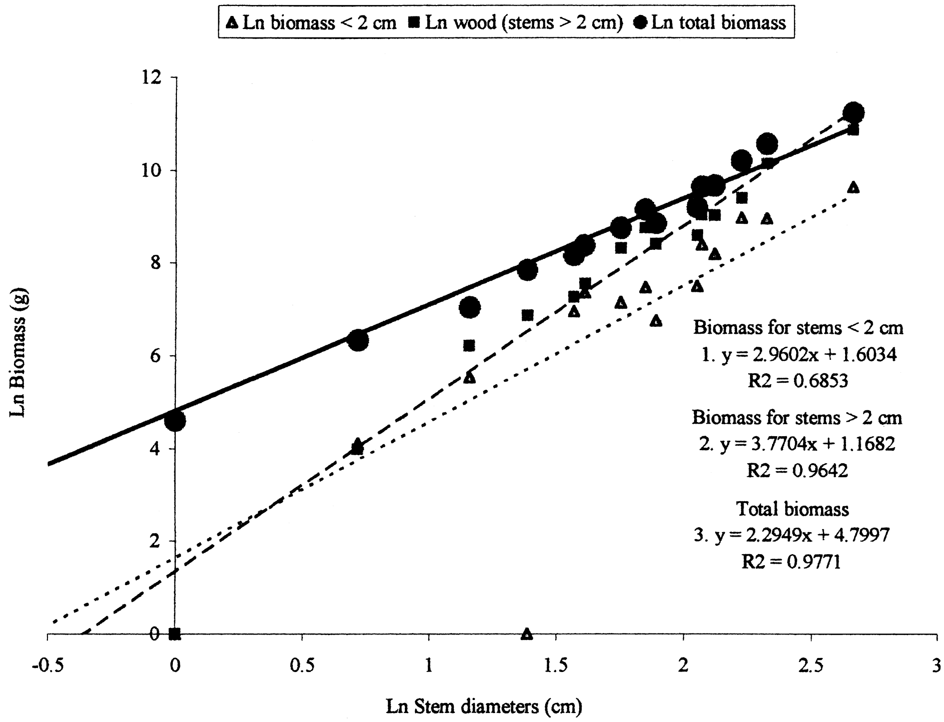

Fig. 1. Natural log–log relationship between the basal diameter of a tree and its dry woody biomass components. Within each category, each point represents a sampled tree. Solid line with big black blots represents relationship between total biomass and diameter, the broken line with squares is woody material >2 cm diameter, and the thin line with triangles is biomass from twigs <2 cm. Regression equations and the R^2-values are inset.

disrupted. The 3- and 4-year-old plots have similar mean diameters, suggesting that the 4-year-old plot had stunted in growth at some time. These stands were harvested in 1994 and 1995, respectively. Laikipia experienced a major drought in 1994 and this could have adversely affected coppicing in the 1994 stand. Growth in height was slow for the first 2 years, increased in the second, and slowed in the 5th year. Similarly, the months between the two censuses were abnormally wet, and characterized by rapid growth. Increase in mean diameter within the coppicing stands mirrored that of mean heights (Fig. 5). Stem diameter increased at mean rate of two centimeters in the first year. Increase in diameter is at a mean rate of 0.7 cm per year, with the maximum rate at 2.9 cm per year recorded between the 12th and 14th years. Height increased at a mean rate of 28.6 cm per year, with a maximum rate of 100 cm per year.

In the early years of regrowth, the plant also invests in a large number of coppicing stems (a max of eight stems in the first year) which may affect its vertical growth. It took 3–4 years for the dominant stem(s) to emerge (Fig. 6). Some trees continue growing to maturity with two or more stems. However, most trees have only one stem left by the fifth year. The number of stems per individual tree decreases with age from a mean of 2.8 stems after the first year to 1.2 stems after 14 years. The number of stems stabilizes between the 4th and 6h years when one or two stems remain (Fig. 6).

As coppicing stands age, the diameter size classes spread out for each age group with more diameter classes being represented in subsequent years (Table 1). The modal diameter class increases with time by about one centimeter per year. No seedlings were recorded in coppicing stands. The youngest plots had the largest proportion of small diameter stems while the older plots had a reduced proportion of small diameter classes and a greater representation of large stems.

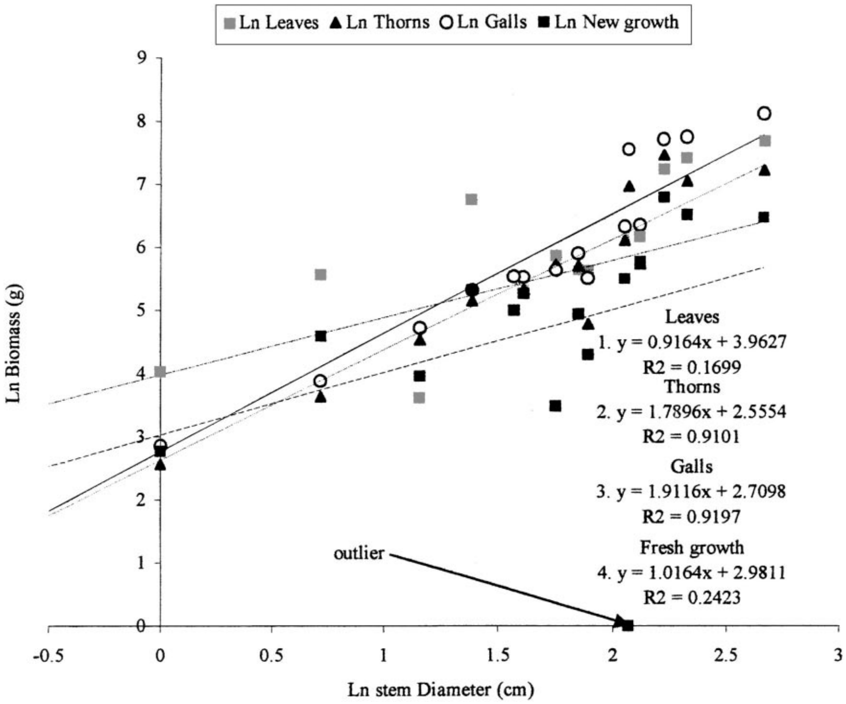

Fig. 2. Natural log–log relationship between the basal diameter of a tree and its dry non-woody biomass components. Within each category, each point represents a sampled tree. Solid line with circles represents relationship between gall biomass and diameter, the finely-dotted line with triangles is for thorn biomass and diameter, the dashed-dotted line with a cross in a shaded square represents relationship between leaf biomass and diameter, while the dashed line with black squares is for fresh growth. Regression equations and R^2 are inset.

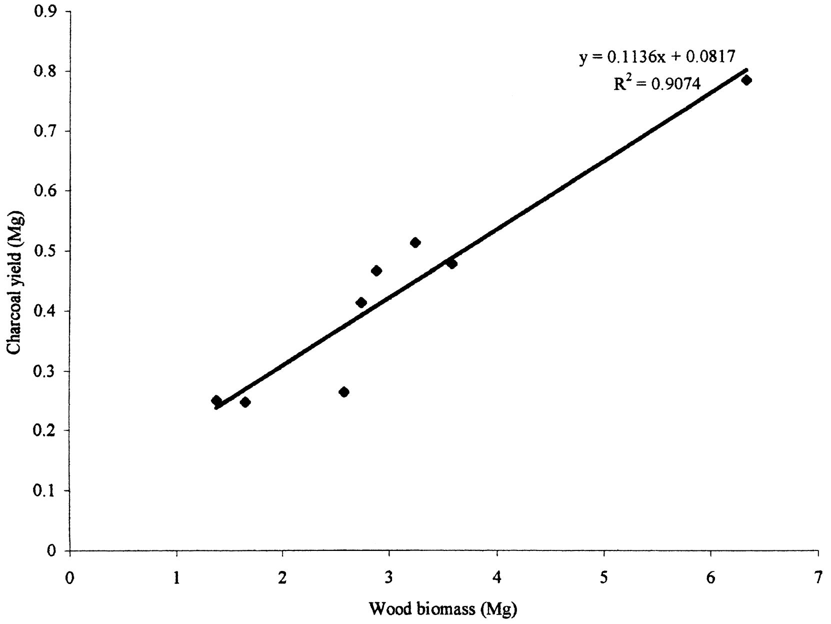

Fig. 3. Relationship between charcoal yield and woody biomass that went into the kilns.

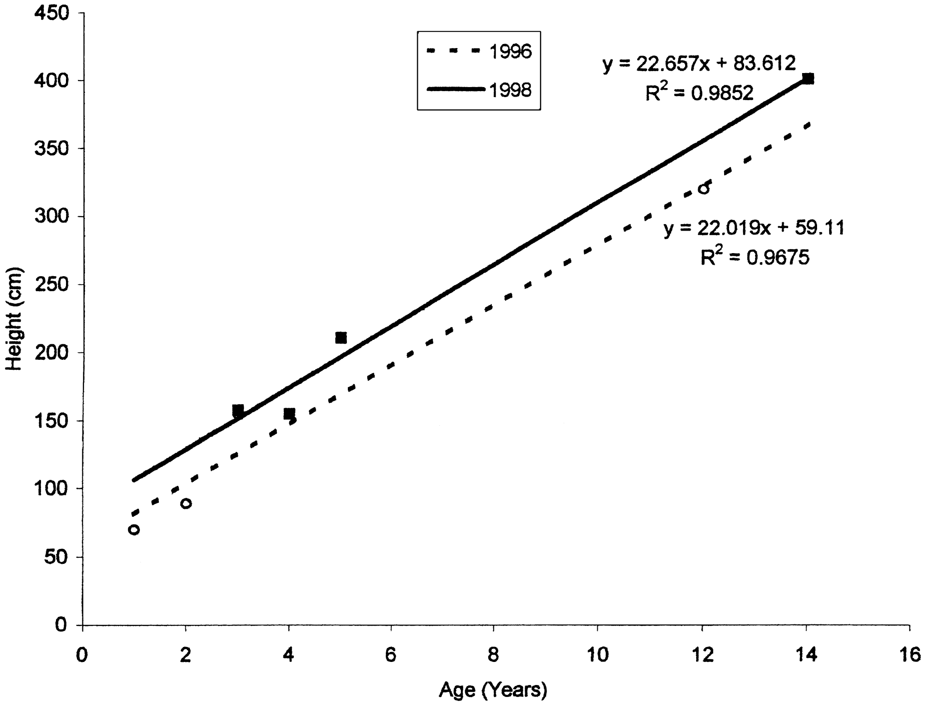

Fig. 4. Growth in mean height of coppicing stands of *A. drepanolobium* sampled in 1996 and 1998.

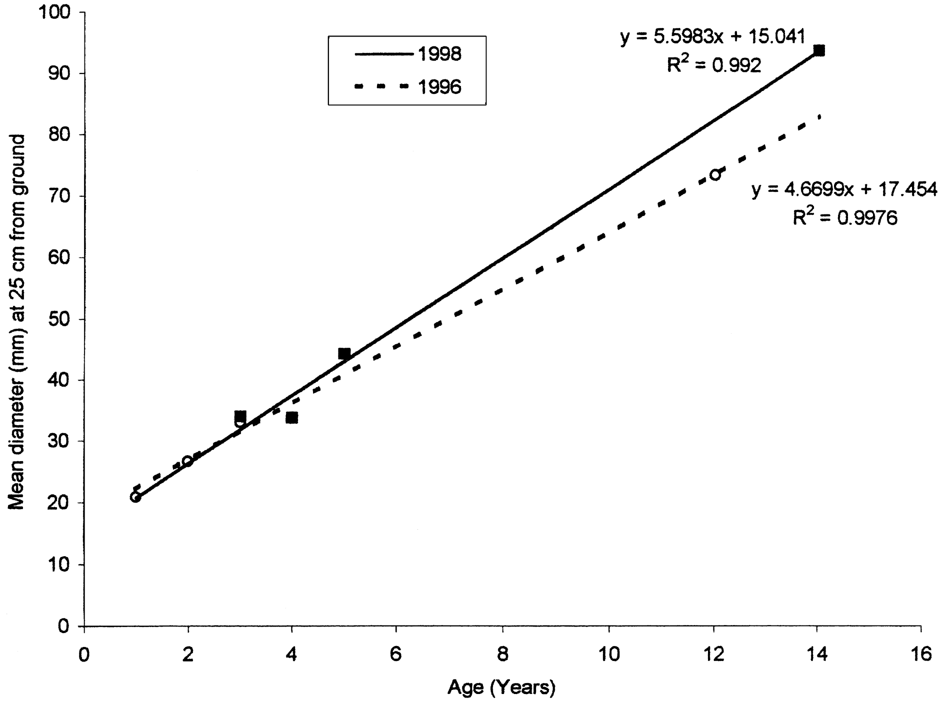

Fig. 5. Growth in mean stem diameter at 25 cm from the ground, of coppicing stands of *A. drepanolobium* sampled in 1996 and 1998.

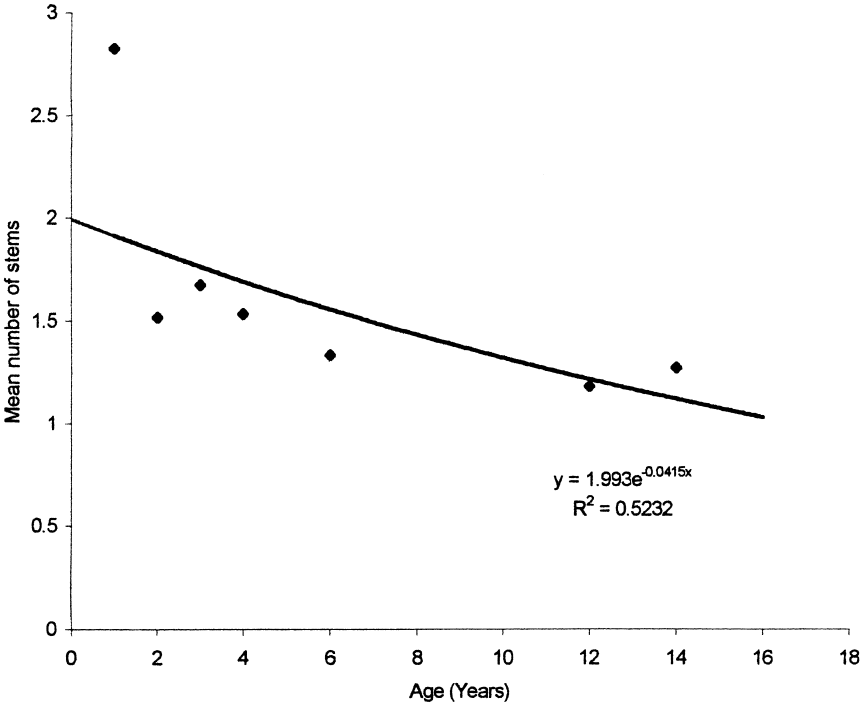

Fig. 6. Change in the mean number of stems per tree of coppicing *A. drepanolobium* trees over time.

Table 1
Mean percent distribution of diameter size classes (cm) in coppicing *A. drepanolobium* stands of different ages in 1996 and 1998. Percent contribution of each diameter size class is indicated in brackets

Diameter class	Year of sampling and age of stand								
	1996				1998				1996 Control
	1	2	3	12	3	4	5	14	
<1	1 (1.9)								12 (12.9)
1–2	23 (44.2)	6 (20.7)	2 (7.1)						14 (15.1)
2–3	23 (44.2)	14 (48.3)	10 (35.7)		12 (40)	12 (40)			15 (16.1)
3–4	5 (9.6)	6 (20.7)	10 (35.7)		11 (36)	12 (40)	11 (36.7)		9 (9.7)
4–5		3 (10.3)	5 (17.9)	2 (7.1)	5 (16)	5 (16)	13 (43.3)		3 (3.2)
5–6			1 (3.6)	3 (10.7)	2 (6)	1 (3)	4 (13.3)	1 (3.3)	6 (6.5)
6–7				7 (25.0)			2 (6.7)		4 (4.3)
7–8				4 (14.3)				7 (23.3)	11 (11.8)
8–9				9 (32.1)				9 (30.0)	5 (5.4)
9–10				2 (7.1)				4 (13.3)	1 (1.1)
10–11								4 (13.3)	3 (3.2)
11–12								3 (10.0)	2 (2.2)
12–13				1 (3.9)					1 (1.1)
13–14								2 (6.7)	3 (3.2)
14–15									2 (2.2)
15–16									1 (1.1)
18–19									1 (1.1)

Table 2
Estimated diy woody biomass yield (Mg ha^{-1}) of coppicing *A. drepanolobium* stands at different ages distributed by diameter size class sampled in 1996 and 1998

Diameter class	Year of sampling and age of stand.								
	1996				1998				1996 Control
	1	2	3	12	3	4	5	14	
2–3	005	0.05	0.05		0.03	0.06			0.02
3–4	0.04	0.06	0.11		0.09	0.14	0.14		0.05
4–5		0.08	0.16	0.06	0.10	0.16	0.42		0.03
5–6			0.05	0.18	0.07	0.05	0.26	0.09	0.18
6–7				0.86			0.26		0.23
7–8				0.80				1.57	1.06
8–9				2.63				3.22	0.73
9–10				1.13				2.04	0.25
10–11								3.14	1.02
11–12								3.08	0.89
12–13				1.65					0.64
13–14									2.68
14–15									2.15
15–16								5.83	1.32
18–19									2.86
Total	0.09	0.19	0.27	7.31	0.29	0.41	1.08	18.97	14.11

Biomass estimates showed that coppicing stands had at least 18.97 Mg ha^{-1} of dry wood (Table 2) at 14 years or 23.71 Mg ha^{-1} (wet weight) with a mean weight loss of 10% during drying. The largest diameter class recorded (15–16 cm) in the 14-year plot contributed one third of the total woody biomass within the plot. This estimate for 14 years of regrowth, therefore, falls within the range of 15.05–142.21 Mg wet weight ha^{-1} of wood used in kilns. The estimated woody biomass data suggests that it increased at an increasing rate with an increase in diameter. There was a greater increase in woody biomass per unit increase in diameter for larger (older) trees than for smaller (younger) ones. Increase of dry woody biomass averaged 0.007–0.051 Mg month^{-1} for the first 12 years then increased to 0.113 Mg month^{-1} by the 14th year. The rate of woody biomass assimilation was lower in the smaller sized diameters and increased rapidly as more trees reached ‘maturity’.

5. Discussion

Allometric measurement is a common technique for non-destructive estimation of plant biomass. Fitted linear regression equations after log transformations were excellent predictors of biomass from stem diameters. Many savanna species have been reported to have strong relationships between their weights and stem diameters: *Acacia tortilis* (Lusigi, 1983), *Acacia senegal* (Lamprey, 1983), *T. camphoratus* (Young and Francombe, 1991), and *A. etbaica* (Okello, 1996). Buech and Rugg (1989) concluded that site and species specific models improved goodness of fit significantly although general models for all trees work well in most cases.

From 43 to 69% of the biomass for trees with diameters greater than 4 cm can be used for charcoal production. The remainder is used as fuel for kilns, kiln spacers, and firewood (<2 cm diameter). Most twigs and leaves not used for charcoal production are used in covering denuded areas to encourage revegetation.

Variation in biomass that went into the kilns can be attributed to differences in tree density and population structure. Where trees were large, biomass accumulated could be greater than in plots with smaller trees, other factors being constant. Our results suggest that greater wood yield was obtained from stands with a lesser density of larger trees than from stands with a greater density of smaller trees. Regression equations suggest that even in instances where the density is high and the population has relatively smaller trees compared to plots where trees are few but large, the overall woody biomass yield would be greater for the latter. Woody biomass was not significantly related to tree density or to maximum and minimum stem diameters within a stand. It can, therefore, be expected that an improved woody yield can be expected from a larger tree if it is left to regrow after first harvesting.

In many African countries, charcoal is produced in earthen or brick kilns, enclosures in which wood is burnt with a limited air supply. About half the wood is burnt completely to ash and the heat given off during this combustion is sufficient to carbonize the remaining wood and thereby form charcoal. This method of charcoal production obviously causes a great deal of pollution and is extremely wasteful, with almost acrid smoke billowing off, and lots of other gases and tar wasted. The tar and gasses released contain about half the total available energy of the wood in its uncarbonized form (Cunningham, 1996).

Charcoal yield from the present study was low but similar to yields from earthen kilns in many studies (Lew and Kammen, 1997). Efficiency was low (maximum 18.2%) and varied between kilns, which though similar in design, are usually different because the size and composition of wood used as well as the time taken for carbonization, are different. More technologically advanced kilns such as the Mark IV, Cusab Kiln, and Gayland Batch charcoal retort give efficiency rates of 25–32% (Cunningham, 1996; Lew and Kammen, 1997). These kilns could significantly improve charcoal production in the rural areas. However, such kilns are usually out of the financial reach of most charcoal burners.

Coppicing in *A. drepanolobium* begins shortly after the trees have been cut, usually within 3 months especially if rains fall shortly after harvest. The phenomenon of a reduction of number of stems with increasing age has been reported elsewhere (Young, 1984). It has been postulated that large shoots continuously and increasingly suppress the success of smaller shoots (Young, 1984; Kennedy, 1998). In *A. drepanolobium*, the stems appear to regenerate almost at the same time, and the reasons why some drop off is not yet understood.

The mean annual rate of increase in height of 28 cm for the coppicing stands is higher than for non-coppicing stands (18 cm, Okello and Young, 2000 unpubl. data). This is a reasonable rate for a high-density wood tree in a rainfall gradient of 550 mm year^{-1}. Maximum growth in height recorded was 100 cm, and this followed the heavy El Nino rains of December 1997–January 1998. Young and Francombe (1991) predicted that *T. camphoratus* would take about 7 years to grow back to maturity. However, they did not indicate the mean heights of mature stands they sampled. Kennedy (1998) suggested that coppicing woody species have a higher growth rate than seedlings. Coppicing stems grow vertically due to strong apical dominance (Cannel, 1983). Trees that coppice still protect the soil since the root stock remains in place, and for nitrogen fixing trees, fertility is maintained since root nodules are still present. Population structure in coppicing stands is more or less even, there seems to be little recruitment of seedlings (Table 1). As stands mature, larger diameter size classes are increasingly represented and smaller ones phased out.

The rate of diameter increase in coppicing stands is slow initially but increases with time. Rate of increase in stem diameter by regrowing trees is important in determining the time it takes a stand to be ready for re-harvesting. Larger stems have more biomass and at a certain stage seem to assimilate biomass at a faster rate than smaller ones possibly because of a large amount of photosynthetic material and a large root system.

The total harvestable dry woody biomass was 18.97 Mg ha^{-1} for a 14-year-old stand, higher than 8 Mg ha^{-1} reported for mopane (Cuningham, 1996), although the rain averages 380 mm per annum in the latter study. This gave a minimum of 3.6 Mg of charcoal ha^{-1}, assuming 15% conversion efficiency. We consider this to be an under-estimate of the potential charcoal yield from coppicing stands of *A. drepanolobium*. Given the regrowth rates of *A. drepanolobium*, we suggest a minimum of 12–14 year-harvest cycle. Being a relatively small tree, *A. drepanolobium* is ideal for sustained charcoal production since no expensive machinery is needed for harvesting as machetes and axes suffice, and it does not have any special handling needs.

For sustainable charcoal yield from whistling thorn trees to be a reality, charcoal burners must turn to kilns that are more efficient and commercialize the production process. Increased efficiency would lead to higher yields, and probably lengthen the period before a stand is re-harvested.

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