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Weed removal improves coppice growth of *Daniellia oliveri* and its use as fuelwood in traditional fallows in Benin

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Abstract *Daniellia oliveri* is an indigenous tree with multiple coppicing that is harvested as firewood by local people from savannas and traditional fallows in West Africa. We investigated the effects of periodic weed removal on *D. oliveri* resprouting and growth in traditional fallows and its use for firewood production by smallholder harvesters. Protected plots were established in *D. oliveri* dominated fallows at four sites with contrasting soil types. The weedy control plots experienced periodic fires and grass competition. Sizes of firewood logs were surveyed on local markets and used to estimate the quantity of marketable firewood for each treatment. The species sprouted vigorously, forming pure stands. Leading shoot density on weed-free plots was three times higher, reaching 7,250 ± 454 shoots ha^{-1} 34 months after land clearance when compared to 2,425 ± 215 shoots ha^{-1} on weedy plots. The weed removal treatment increased shoot height from 18 to 34 months after land clearance, while shoot diameter was not affected. After 24 months, 50% of the shoots were of marketable size for the weedy treatment, while this was reached at 18 months for the weed-free treatment.

Keywords Resprouting · Traditional fallow · Fuelwood · Weed control · Guinea-Sudanian zone · *Daniellia oliveri* · Benin

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Introduction

Traditional fallows are major components of small-scale traditional farming systems in the Sudanian and Guinean zone of Africa (Peltier 1993; Gleave 1996; Floret and Pontanier 1999; Manley et al. 2004). They contribute to soil fertility restoration and provide farmers with a wide range of products such as fuelwood, fodder, fruits and wild leafy vegetables (Peltier 1993; Aweto 1999; Buresh and Cooper 1999; Szott et al. 1999). Fuelwood particularly is of critical importance to the welfare of rural and urban people in the region as it represents 70–90% of the total energy consumption depending on the specific country (Arnold et al. 2003). Fuelwood exploitation generates income for the majority of smallholders, rural households and traders who depend on harvesting and marketing firewood for their livelihoods (Wickens et al. 1995; Arnold et al. 2003; Cooke et al. 2008).

Traditional fallows produce wood resources mostly from vegetative regrowth by coppicing from stumps or root masses (Nyerges 1989; Buresh and Cooper 1999; Manley et al. 2004). In minimal cultivation with little soil disruption and short cropping period conditions, stumps and root masses of some felled tree species are conserved in the soil. Then, they resprout at the beginning of the fallow period and regenerate new shoots used as firewood (Nyerges 1989; Manley et al. 2004; Dalle and de Blois 2006).

Over the past decades, increasing population density, agricultural intensification and changes in land tenure in Sub-Saharan Africa, have led to the shortening of fallow cycles (Buresh and Cooper 1999; Szott et al. 1999; Ngobo et al. 2004; Manley et al. 2004). This, associated with extended cropping periods, may damage stumps and root masses and limit resprouting, as well as fuelwood productivity (Dvorak 1992; Manley et al. 2004; Dalle and de Blois 2006). Dry season bushfires also threaten the sustainability of traditional fallowing in the Sudano-Guinean region by limiting tree and shrub growth for woody resource production (Peltier 1993; Higgins et al. 2000; Sankaran et al. 2008) and burning litter biomass, thus inhibiting soil fertility restoration (Peltier 1993).

Although the role of traditional fallows in fuelwood supply is recognized, few studies focused on the mechanisms involved in wood production and the methods that could be used to improve wood yields from these ecosystems. Scientific knowledge on the ecology, biology and physiology of most successional local woody species as well as on recovery processes of these fallows is limited. There is also a lack of information on methods to vegetatively reproduce local tree species at low costs (Bellefontaine 1997; Bellefontaine et al. 2000). Despite most of the woody savanna species of the Sudano-Guinean zone can reproduce vegetatively and this mode of reproduction may dominate over sexual reproduction in fallows, it received very little attention (Nyerges 1989; Bellefontaine et al. 2000; Bond and Midgley 2001). Vegetative regeneration of Sudano-Guinean savanna species may be a very cheap option that should be explored and intensified (Bellefontaine 1997, 2005; Bellefontaine et al. 2003). For instance, *Anogeissus leiocarpus*, *Bombax caustatum*, *Daniellia oliveri*, *Detarium microcarpum*, *Isoberlinia doka*, etc. are all multipurpose tree species widespread in Sudanian and Guinean woodlands and fallows that are used as fuelwood by local communities. The coppicing abilities of these species have been reported (Bellefontaine 1997; Bellefontaine et al. 2000, 2003; Sawadogo et al. 2002). However, only limited studies on their resprouting performances and their potential use in forest management and agroforestry systems have been carried out. Despite the many studies on multipurpose uses of some local species, few of them assessed the potential of these species for fuelwood production. Most studies aiming at improving the sustainability of traditional fallow systems focused on soil fertility restoration, wood production and other ecological services such as fodder, through planting with fast-growing exotic legumes species (e.g., *Acacia auriculiformis*, *Gliricidia sepium*, *Leucaena leucocephala*, etc.). These agroforestry approaches are effective but their adoption by farmers is limited because of many factors such as the lack of consideration for local needs and the costs of improved agroforestry technologies (Buresh and Cooper 1999; Franzel 1999). Thus, traditional fallowing is still widespread throughout the region.

In this paper, we assess the resprouting performances (plant density, number of shoots per plant, shoot growth) of *Daniellia oliveri* (Rolfe) Hutch. & Dalz. in traditional fallows under two different vegetation management regimes: (1) no weeding and (2) periodic weeding. Weed management is a key factor in coppice management and effective weed controls may increase significantly the growth of coppices (Buhler et al. 1998; Mitchell et al. 1999; Szott et al. 1999). In the Sudano-Guinean savanna and fallow environments, weeds consist mostly of grasses and their interactions with trees include three major effects (Scholes and Archer 1997; Sankaran et al. 2004). First, weeds may compete with trees for soil nutrients (Szott et al. 1999). Second, intensive fires favored by dry biomass of grasses may also affect tree growth, density and coppicing (Szott et al. 1999; Higgins et al. 2000; Scholes and Archer 1997). Third, frequent dry season bush fires constitute a factor of major concern in fallow lands and plantations since fire, by burning the grass biomass, may impede organic matter accumulation in the soil (Peltier 1993; Szott et al. 1999). We hypothesized that the periodic removal of the weeds (left as mulch on the soil surface) would overcome these limiting factors and improve coppicing performances (plant density, number of shoots per plant, shoot growth) of

D. oliveri. The improvement of coppicing performances would result in a shorter rotation cycle and an increased proportion of marketable firewood for smallholder harvesters.

Methods

Study areas and species

The study was carried out in Benin (6°20′–12°25′N and 1°–3°40′E). Benin is located in the Dahomey Gap (Salzmann and Hoelzmann 2005), a savanna corridor interrupting the zonal West African rain forest block and including three contrasting ecological zones: the Guinea-Congolian affinity zone, the Sudano-Guinean transition zone and the Sudanian zone (Wezel and Böcker 2000). The study area is located in the Sudano-Guinean transition zone. Annual rainfall ranges between 900 and 1,200 mm, and occurs mostly during April through October. Vegetation consists of fallows dominated by *D. oliveri* and *Andropogon gayanus*, and mosaics of dry dense forests, woodlands, tree and shrub savannas with abundant *D. oliveri*. Herbaceous biomass in these fallows and savannas may grow at a monthly rate of 0.8–1.5 tonnes of dry matter per ha during the rainy season and reach an annual biomass of 4–8 tonnes of dry matter per ha (Boudet 1977; Mordelet and Menaut 1995). Natural vegetation is being converted rapidly into croplands and fallows (Wezel and Böcker 2000). In addition, the widespread traditional exploitation of woodfuel may be an important factor in the reduction of woodland areas (Wezel and Böcker 2000). The area experiences frequent bushfires during the dry season from December to April. Vegetation in our study sites burnt approximately twice during that period.

Four major soil types differing in their texture are found in the study area: (1) alluvial and heavy clay soils, that are frequently flooded during the rainy season but that dry out and form crusts during the dry season, (2) lateritic soils with small concretions and medium clay content, (3) ferralitic soils without concretions and with low clay content and (4) sandy soils with low water retention capacity. Clay soils are the most fertile with the highest organic matter content, while ferralitic soils are the least fertile with the lowest organic matter content. Sandy and lateritic soils have medium fertility.

Daniellia oliveri (Rolfe) Hutch. & Dalz. is a multipurpose medium-sized tree species from the *Caesalpiniaceae* family. It grows up to 15 m high with a dense inverted cone-shaped crown. The species is widespread in Sudano-Guinean woodland savannas in areas scattered between Gambia and Uganda. It is particularly abundant in the Guinean region, especially in inhabited and cultivated regions where it can form pure stands (Aubreville 1970). It has vigorous stump sprouting and root suckering abilities and thus tends to invade forest fallows (Aubreville 1970; Bellefontaine 1997; Bellefontaine et al. 2003). However, it can also reproduce through seeds. The seeds are light and can be easily dispersed by wind over long distances (Cuny et al. 1997). Its wood is well appreciated as firewood in the Sudanian and the Sahelian regions of Africa (FAO 2001), and used in construction. The foliage is used as fodder and in medicinal recipes (Lykke 2000; FAO 2001; Jegede et al. 2006).

Study design and data collection

The four major types of soil of the area were considered in this study: the clay soil in the area of Zogbodomey, the lateritic soil in the area of Agbangnizoun, the ferralitic soil in the area of Zagnanado, and the sandy soil in the area of Abomey In each area, homogenous 6–12–month-old *D. oliveri* dominated fallows in village lands were selected based on history of cultivation (length of last fallow periods, number of cycles) and species composition. Species present consist mostly of grasses. The dominant grass species in all sites is *Andropogon gayanus*, which constitutes almost 70–90% of the herbaceous layer cover. Each selected site had to be far from natural vegetation to avoid seeds from mature trees to be dispersed onto the plots. In each site, four plots of 10 m × 5 m protected with wooden fences against browsers and firewood harvesters were established for the application of the two vegetation management treatments: (a) the weed-free treatment, that is removal of all weeds from the plots twice a year until canopy closure at approximately 24 months (two plots per site) and (b) the weedy control treatment where the natural vegetation was conserved but protected from grazing (two plots per site). Grass biomass accumulated in the weedy control plots, which burnt approximately two times during dry season bushfires. Weed regrowth after these intensive dry season fires was very weak. Weed removal from weed-free plots was performed every year by hoeing 2–3 months after the beginning (in June) and at the end (in November) of the rainy season and biomass was left on the field. During November weeding operations, firebreaks were made around plots to protect them from fires. Each plot was cleared at the inception of the experiment in October 2005, corresponding to the end of the rainy season. Vegetation was removed and *D. oliveri* shrubs were cut down to ground level (Bellefontaine et al. 2000). The total number of sprouting shoots per plot was counted 6 months after land clearing. The dominant shoots were counted and their height and basal diameter were measured 12, 18, 24 and then 34 months after land clearance. Diameter measurements were distributed to 1-cm class intervals. Height measurements were attributed to 40, 50, 55, 60 and 80-cm class intervals starting at 0–40, 10–60, 15–70, 40–100 and 90–170 cm, respectively, for 6, 12, 18, 24 and 34 months after land clearance. The number of coppice shoots per individual plant was counted after 34 months and the length of all secondary shoots, that are the less developed shoots on each plant, was measured.

Market survey for size of marketed firewood

A market survey was conducted to assess the size of marketed bundles of firewood in four markets located exactly in the same districts where were established the experimental sites: the market of Zogbodomey (6°58′N, 2°10′E), the market of Abomey (7°11′N, 1°59′E), the market of Agbangnizoun (7°4′N, 1°57′E) and the market of Zagnanado (7°16′N, 2°21′E). Ten vendors were selected randomly and one bundle of firewood sampled randomly from each vendor, for a total of ten bundles in each market. The number of pieces of firewood in each bundle was counted and length and butt diameter of each piece were measured. Vendors were asked about the age of fallows from which they harvested the firewood. The sizes of firewood pieces in the market were compared to those of shoots in the experimental plots to determine the rotation time required for shoots to reach the marketable size. The lower bounds of the 95% confidence interval of mean sizes were used as minimum marketable sizes.

Data analysis

We used the mixed model analysis of variance with the first-order autoregressive covariance matrix to test if the weeding treatment (fixed factor) impacted on plant density (12–34 months) and shoot density (at 6 months). Time and site (soil type) were considered within-subject factors (Crawley 2007). *F* statistics with associated *P* values was interpreted to assess significance of various effects.

To test the effect of the weeding treatment and plant size on the distribution of the number of shoots per plant, we used the generalized linear mixed model with Poisson error structure and the log-link function, random factor being the site (Crawley 2007).

To test the effects of the weeding treatment on height and diameter class distribution, we used for each sampling date a generalized linear mixed model, with the Poisson distribution and the log-link function, random factor being the site (Crawley 2007). Means and medians were computed to compare size class distributions.

Kruskal–Wallis *H* tests were used to test if the length and diameter of pieces of firewood within bundles vary according to surveyed markets. To test the effects of weeding treatment on the proportion of marketable shoots for each sampling date, we used the generalized linear model with the binomial error structure and the logistic link function. The mixed model analysis of variance with site as random factor was used to compare the weeding treatments with respect to the density of marketable shoots for each sampling date. All effects were assessed at a 0.05.

Results

Shoot density and growth 6 months after land clearance

Six months after land clearance, *D. oliveri* sprouted vigorously but plant differentiation was barely noticeable, as many shoots emerged directly from the soil. In addition, no dominant coppice shoot was distinguishable for most plants. There was no significant effect of weed removal on shoot density (ANOVA, $F = 0.750$, $P = 0.401$). The average shoot density was 23,875 ± 2,437 shoots ha^{-1} on weed-free plots and 26,500 ± 1,803 shoots ha^{-1} on weedy plots. Most shoots were little developed with a median diameter of 1.5 cm and a median height of 21 cm. However, shoot height was higher on weed-free plots (29 ± 1 cm) than weedy plots (26 ± 1 cm, $G^2 = 9.02$, $P = 0.029$).

Density of dominant shoots 12, 18, 24 and 34 months after land clearance

Density of dominant shoots was two to three times higher on weed-free plots than on weedy plots for all four sampling dates (ANOVA, $F = 158.12$, $P < 0.001$, Fig. 1). It decreased significantly between 12 and 18 months (ANOVA, $F = 21.03$, $P < 0.001$) for both treatments. Thereafter, it remained relatively steady between 18 and 34 months for both treatments (Fig. 1).

Number of shoots per plant at the end of the experiment

Sprouting was weak at plant level with very few plants showing more than one shoot after 34 months (Fig. 2), with a mean of 1.7 ± 0.1 shoots per plant. The number of shoots per plant was dependent on the weeding treatment ($G^2 = 6.18$, $P = 0.013$) and on the size of dominant shoots ($G^2 = 10.91$, $P = 0.028$). Weed-free plots showed a lower mean number of shoots per plant than weedy plots (respectively, 1.6 ± 0.1 and 1.9 ± 0.1 shoots, Fig. 2). Mean number of shoots per plant was 1.6 ± 0.1, 1.4 ± 0.1, 1.7 ± 0.1, 2.5 ± 0.5 and 1.8 ± 0.3, respectively, for the 4.1–5.0, 5.1–6.0, 6.1–7, 7.1–8 and 8.1–9.0-cm classes.

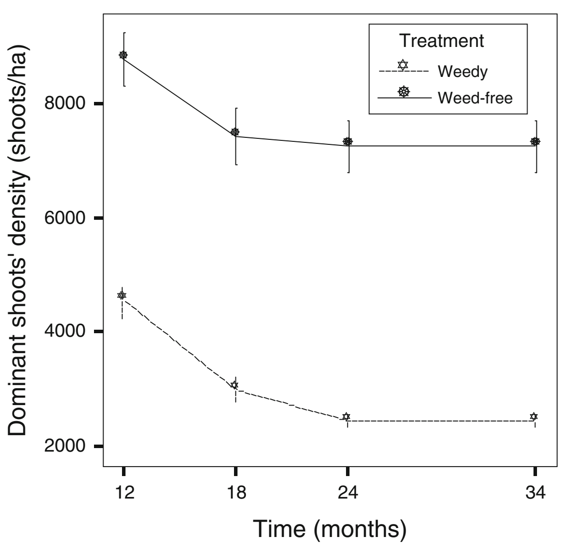

Fig. 1 Density of dominant *D. oliveri* shoots (means ± 1 SE) in weedy and weed-free plots 12, 18, 24 and 34 months after land clearance

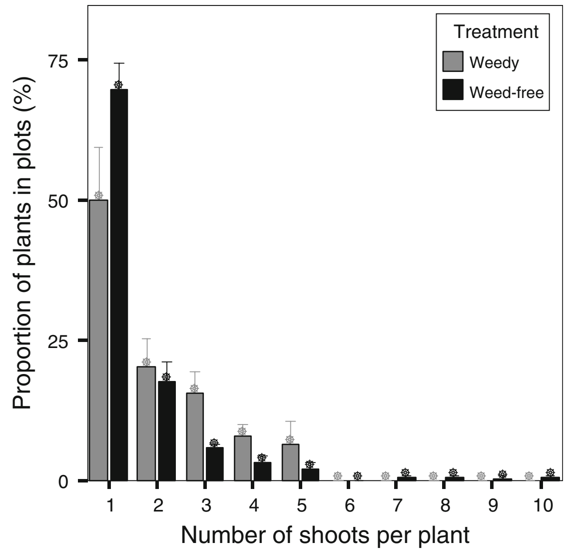

Fig. 2 Distribution of the number of shoots per *D. oliveri* plant (means ± 1 SE) in weedy and weed-free plots

Furthermore, where there was more than one shoot per plant, only one grew normally and emerged as the dominant shoot on the plant, the others showing very weak growth: after 34 months, the mean height of secondary and less developed shoots (46 ± 2 cm on weedy plots and 26 ± 2 cm on weed-free plots) was 4–9 times lower than that of dominant shoots (184 ± 6 cm on weedy plots and 236 ± 4 cm on weed-free plots). Secondary shoots' height was almost two times higher on weedy plots (46 ± 2 cm) than on weed-free plots (26 ± 2 cm).

Effect of weed removal on height and diameter class distribution of dominant shoots over time

Twelve months after land clearance, there was a marginal effect of weed removal on height class distribution of the dominant shoots ($G^2 = 7.74$, $P = 0.052$, Fig. 3). The weed-free treatment tended to show a higher proportion of individuals in the 35-cm class than the weedy treatment while no significant difference was observed in other classes. Shoot height ranged from 17 to 250 cm, while median height was 63 and 71 cm for weed-free and weedy treatment, respectively (Table 1).

Between 18 and 34 months after land clearing, weed removal significantly improved height growth ($P < 0.05$ for all periods, Fig. 3). There were higher proportions of medium and large size shoots in weed-free plots than in weedy plots, which had significantly higher proportions of small size shoots (Fig. 3). The mean and median heights were higher for the weed-free treatment than the weedy control treatment (Table 1).

Contrary to height, there was no significant effect of weed removal on diameter class distribution of the dominant shoots from 12 to 34 months ($P > 0.05$ for all periods, Fig. 4). After 12 and 18 months, the median diameter was 2.0 and 3.0 cm, respectively, no matter what the weeding treatment was; while after

Table 1 Descriptive statistics for the height and diameter of the dominant shoots of *D. oliveri* plants in weedy and weed-free plots 12, 18, 24 and 34 months after land clearance

Months	Treatment	Height (cm)		Diameter (cm)	
		means ± 1 SE	Median	means ± 1 SE	Median
12	Weedy	74 ± 2	71	2.2 ± 0.1	2.0
	Weed-free	86 ± 3	63	2.1 ± 0.1	2.0
18	Weedy	81 ± 4	68	3.1 ± 0.1	3.0
	Weed-free	117 ± 3	115	3.3 ± 0.1	3.0
24	Weedy	117 ± 5	110	3.6 ± 0.1	3.2
	Weed-free	152 ± 3	147	4.0 ± 0.1	4.0
34	Weedy	185 ± 6	174	4.8 ± 0.1	4.0
	Weed-free	236 ± 4	235	5.2 ± 0.1	5.0

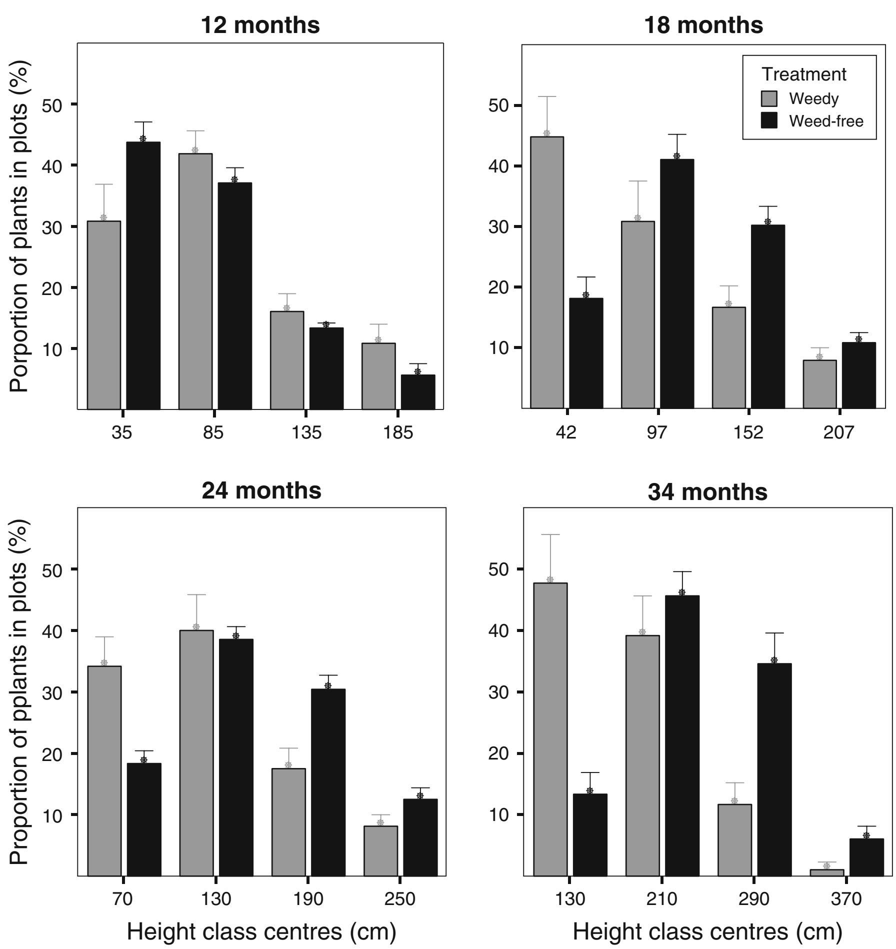

Fig. 3 Height class distribution of dominant *D. oliveri* shoots in weedy and weed-free plots 12, 18, 24 and 34 months after land clearance (means ± 1 SE)

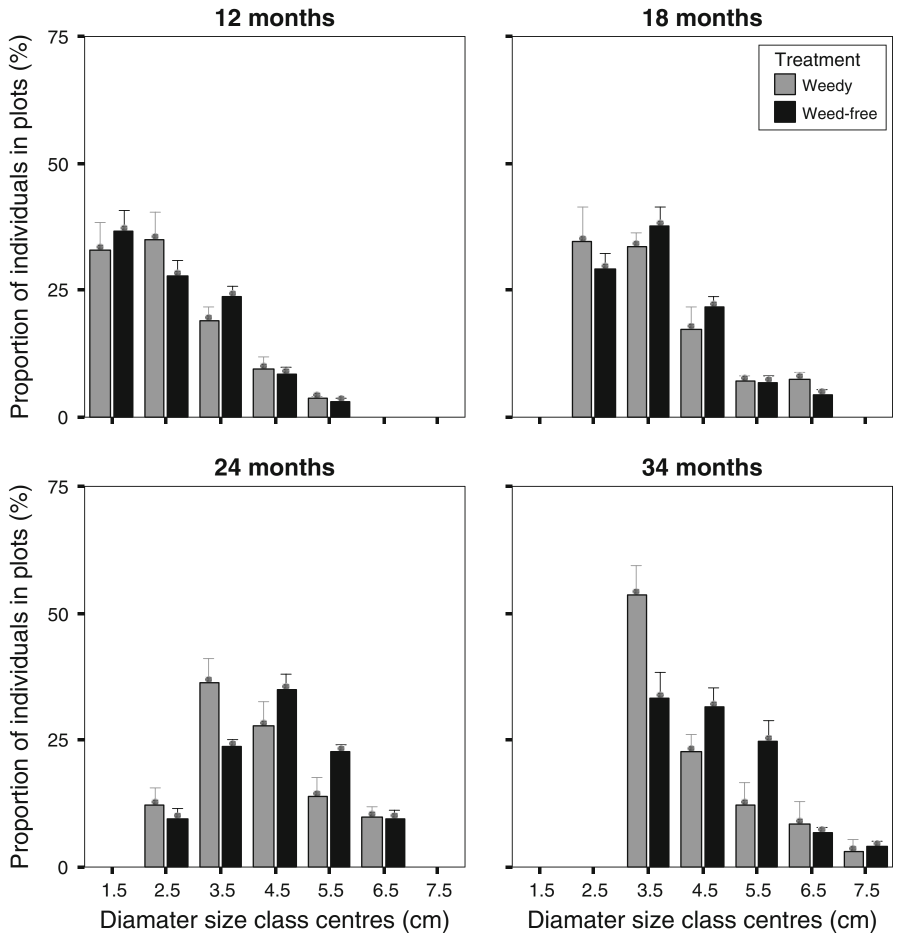

Fig. 4 Diameter class distribution of dominant *D. oliveri* shoots in weedy and weed-free plots 12, 18 24 and 34 months after land clearance (means ± 1 SE)

24 and 34 months it was 3.2 and 4.0 cm, respectively, for weedy plots and 4.5 and 5.0 cm for weed-free plots (Table 1).

Size of firewood bundles on local markets

The length and butt diameter of sticks within bundles of firewood differed significantly between markets (Kruskall–Wallis test, $H = 484.45$, $P < 0.001$ and $H = 37.90$, $P < 0.001$, respectively, Table 2). The 95% confidence intervals of the mean length and butt diameter of sticks are 80–105 and 2.3–5 cm, respectively. The median length ranged between 86 and 100 cm. The median diameter was 3.0 cm for all surveyed markets. According to surveyed vendors, firewood with these sizes can be obtained in 2- to 3-year-old *D. oliveri* fallows.

Effect of weeding on the quantity of marketable shoots

Six and twelve months after land clearing, there was no effect of weeding on the proportion of marketable shoots (respectively, $G^2 = 2.25$, $P = 0.1300$ and $G^2 = 1.75$, $P = 0.1900$, Table 3). However, marketable shoots' density was significantly higher on weed-free plots than on weedy plots at 12 months (Anova, $F = 6.94$, $P = 0.0196$). Eighteen and 24 months after land clearing, weed removal increased the proportion of marketable shoots (respectively, $G^2 = 161.45$, $P < 0.0001$ and $G^2 = 46.96$, $P < 0.0001$, Table 3), as well as marketable shoots' density (Anova, $P < 0.0001$ for the two dates). The time required for 50% of the leading shoots to reach marketable size is 18 months on weed-free plots, when compared to 24 months on weedy plots. After 34 months, almost

Table 2 Size of sticks of *D. oliveri* within bundles of firewood on local markets

Markets	Butt diameter		Length	
	means ± SE (cm)	Median (cm)	means ± SE (cm)	Median (cm)
Zogbodomey	3.3 ± 0.1	3	99 ± 1	100
Abomey	3.3 ± 0.1	3	85 ± 1	86
Zagnanado	3.0 ± 0.1	3	89 ± 1	89
Agbangnizoun	3.4 ± 0.1	3	88 ± 1	88
Mean ± 1 SE	3.2 ± 0.1	3	91 ± 1	90

Table 3 Density and proportion of marketable shoots of *D. oliveri* plants in weedy and weed-free plots 6, 12, 18, 24 and 34 months after land clearance

Months	Treatment	Density of marketable shoots (means ± 1 SE shoots ha^{-1})	Proportion (%) of marketable shoots (means ± 1 SE)
6	Weedy	650 ± 219	2.9 ± 1.2
	Weed-free	850 ± 343	4.8 ± 2.0
12	Weedy	1,275 ± 141	35.4 ± 4.9
	Weed-free	3,025 ± 369	33.9 ± 2.9
18	Weedy	1,587 ± 136	39.7 ± 2.3
	Weed-free	4,200 ± 270	50.8 ± 4.3
24	Weedy	1,637 ± 199	50.5 ± 3.1
	Weed-free	5,845 ± 867	84.6 ± 3.4
34	Weedy	2,350 ± 188	99.8
	Weed-free	7,175 ± 451	99.9

all dominant shoots reached harvestable sizes for both treatments (Table 3).

Discussion

Sprouting and growth of *D. oliveri* in relation to the presence of grass and other species

This study investigated whether weed removal improves the resprouting of *D. oliveri* and its use as firewood in traditional fallows in Benin. The results suggest that weed removal influences the number of shoots per plant. Plants in weedy plots, which experienced grasses and other species competition and periodic fires, showed a higher mean number of shoots than plant in weed-free plots. According to Bond and Midgley (2001), this increasing number of shoots per plant (two or more in the case of *D. oliveri*) may be indicative of disturbance stresses, especially fire and grass competition. From 12 months, however, only one dominant shoot developed per plant for both treatments resulting in single-stemmed individuals with no or weak secondary shoots.

Contrary to number of shoots at plant level, weed removal increased two to three times the density of dominant shoots. This effect of weed removal on shoot density was more noticeable after 12 months. No difference in shoot density was observed after 6 months, likely because lands were cleared at the inception of the experiment for both types of plots. The drop in leading shoot density observed between 12 and 18 months on both types of plots may be indicative of competition among plants as they grow.

Weed removal also improved height growth by increasing the proportion of individuals in the larger height classes. The improvement was more significant from 18 months after land clearing. This result is consistent with findings of Hardwick et al. (1997) and Dungan (2000), who observed that weeding around trees and fire prevention may promote the growth of trees for species such as *Beilschmiedia* sp and *Prunus cerasoides*.

Diameter growth was not affected by weed removal over the 34 months of the experiment. This may be due to the fact that height growth in savanna trees is more important than diameter growth during the first phases of growth (Higgins et al. 2000). However, diameter increased from an average of 2 cm after 12 months to more than 4 cm after 34 months.

Two combined factors, both related to grass biomass accumulation, may explain the positive effects of periodic weeding on shoot density and height growth. First, periodic bushfires occurred in the weedy control plots as a result of the accumulated grass biomass that constitutes a fuel load for the dry season bushfires (Higgins et al. 2000). Such fires are known to increase the mortality and decrease the growth of plants, what may result in lower shoot density and prevent them to reach larger height classes (Higgins et al. 2000). Second, mulching and reduced competition for light and soil nutrients through the removal of the grass biomass and selective thinning of undesired woody species (Szott et al. 1999) may have favored *D. oliveri* stand growth. The issue of knowing which of the two factors was more determinant of height growth needs further study.

Despite the negative effects of the presence of weeds, *D. oliveri* maintains a density of about 2,000–2,700 shoots ha^{-1}, forming almost pure stands. This high natural density confirms the invasive behavior of the species (Aubreville 1970) and also compensates for the low number of secondary shoots at individual plant level.

By improving the shoot density and height growth of coppices of *D. oliveri*, a pioneer species, weeding has proven to be an effective tool for acceleration of the regeneration of fallow species. Previous studies have reported the use of weeding techniques in assisted natural regeneration of degraded forests as a way to overcome several growth limiting factors such as fire disturbance and weed competition (Hardwick et al. 1997, 2004; Dugan 2000). For instance, fire prevention, ring-weeding of naturally grown seedlings and saplings of pioneer trees and lodging of grasses (e.g., *Imperata cylindrica*, *Saccharum spontaneum*) and other vegetation that compete with the pioneers have been used to stimulate forest regeneration (Dugan 2000).

Exploitation of *D. oliveri* coppices as fuelwood by smallholder harvesters

On local markets, pieces of firewood are of small size, averaging approximately 3 cm for butt diameter and 90 cm for length. These dimensions are shorter than those reported in other regions for other species and people. For instance, Shackleton (2001) reported mean length and diameter two-fold higher for *Terminalia sericea* in South African savannas (respectively, 194.3 and 6–11 cm) and Abbot and Lowore (1999) reported a mean diameter of 5 cm for many other indigenous coppicing fuelwood species in Malawi. However, these small sizes are suitable for domestic firewood. They also show the advantage of easy harvesting and handling by collectors, especially women and children (Abbot and Lowore 1999) who are the main collectors of domestic firewood in most African societies (Williams 1992).

Based on the growth performances recorded in our experiment, these marketed logs of firewood can be obtained from 24-month-old fallows in weedy conditions. Then, 50% of the leading shoots (about 1,500–2,000 shoots ha^{-1}) in weedy plots have reached sizes equal or superior to those of the pieces of firewood marketed in the study area. Weed removal improved these performances by shortening the time required to obtain similar characteristics by approximately 6 months and by increasing the quantity of marketable shoots three times. Thus, with weed control, substantial quantities of marketable firewood can be obtained from *D. oliveri* fallows within 18 months. These findings suggest that *D. oliveri* fallows may be valuable firewood production systems if additional management strategies are employed to reduce weed competition and avoid uncontrolled bushfires.

Conclusion

Daniellia oliveri is a woody species of savannas and fallows that shows a great potential for firewood production. It coppices vigorously in fallows and shows a relatively rapid growth. A well-managed shoot production from fallows, especially through weed control, may be a valuable fuelwood source for local people. Further research should explore the sustainability of this exploitation over time. Specifically, the impact of repeated harvesting on the resprouting behavior and soil fertility restoration, and the response of the species to other basic silvicultural treatments such as thinning should be investigated.

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