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Full Length Research Paper

Growth response of *Anogeissus leiocarpa* coppices to prescribed fire and weeding after plantation harvesting in the Sudanian zone of Mali, West Africa

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A nineteen-year-old plantation of *Anogeissus leiocarpa* in Zangasso forest was coppiced in order to study the sprouting and shoot growth according to cutting intensity and management mode. Two intensities of cutting (clear cutting and selective cutting) and two management modes (weeding and early fire) were experimented. Clear cutting was found better than selective cutting regarding the percentage of stump bearing shoots (97% versus 87%). The mean number of shoots per stump (12) was the same for the two cuttings. There was no significant interaction between cutting and management mode. The percentage of stump bearing shoot (97%) observed with early fire was slightly higher than that observed with weeding regarding (94%). The mean number of shoots per stump (11 and 12 stumps) was almost the same for the two management modes. For mean height and mean collar girth, clear cutting was better than selective cutting while no significant difference was observed between early fire and weeding. According to these results, coppicing artificial stand of *A. leiocrapa* is feasible. Either fire or weeding did not compromise the ability of sprouting and shoots growth.

Key words: South sudanian zone, coppice, early fire, stump shoots, weeding.

INTRODUCTION

Sahelian countries of Africa are facing serious processes of environment and forest ecosystems degradation. Many complex factors are contributing to theses processes. Successive droughts, irregular rainfall, demographic growth, inadapted resources exploitation modes are the main factors (FAO, 1995). Harvesting forest stands to satisfy their needs in fuel and timber wood and for medicinal uses is one of human main activities.

Nowadays, the entire humanity faces the reduction of forest superficies due to large extension of cultivated lands (Giraudy, 1996; Berthe et al., 1991) and over exploitation of forest products (Bailly et al., 1982; Leloup and Traoré, cited in Berthe et al., 1991; Bazile, 1997). The resulting consequences are numerous: poor natural regeneration, reduction of the biodiversity due to the extinction of some species in the south sudanian zone of Mali as reported by Grase (1999), and a global climate change. To encounter the problem, programs were developed throughout the world regarding regeneration and management issues of forest stands particularly in the sahelian region of Africa. For instance, regarding forests regeneration, planting forest tree species is one option on which many governments of Africa Sahelian countries were focused on (FAO, 1995).

Research activities on forest tree species were

Abbreviations: CNRA, Comité National de la Recherche Agronomique; **CRRAS,** Centre Régional de la Recherche Agronomique de Sikasso; **Ef,** Early fire; **IER,** Institut d'Economie Rurale; **OARS,** Opération Aménagement et Reboisement de la Région de Sikasso; **PASAOP,** Projet d'Appui au Secteur Agricole et Organisations Paysannes; **SC,** Selective cutting; **CC,** Clear cutting; **We,** Weeding.

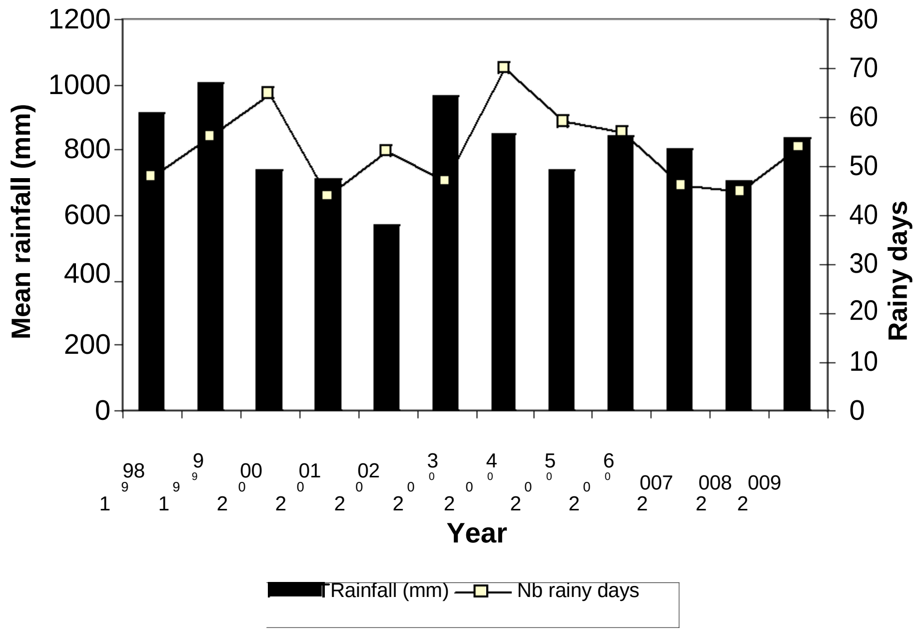


Figure 1. Variation of rainfall at the site of Zangasso from 1998 to 2009. Source of data: CMDT- Zangasso (Compagnie Malienne de Développement des Textiles).

undertaken to support governments' initiatives and to develop regeneration techniques (Louppe and Ouattara, 1993; Louppe and Ouattara, 1996; Kelly and Cuny, 2000). Others activities were also undertaken regarding the management of natural forest stands investigating various modes of disturbance such as clearing, fire, weeding etc. (Nouvellet, 1993a, b; Bellefontaine, 2000, Kelly and Diallo, 2000; Sawadogo et al., 2002, Zida 2007; Ky-Dembelé et al., 2007). Most of the early research activities in the sahelian region of Africa were focused on planting trees species mainly exotic species and on the management of natural forest stands including the traditional methods of natural forests management like burning or weeding. More recently, accent is to be made on planting local forest tree species. Hence, scientific knowledge regarding the management of artificial stands of local forest tree species is scarce or even lacking. Therefore, it is important to identify appropriate management methods of planted stands of forest local tree species for sustainable production. This is also important for conservation strategies and for improving vegetal materials as reported by Teissier (1999). In the same order, identifying appropriate management methods of planted stands of forest local tree species strengthened the recent enthusiasm of rural populations toward these species.

This paper relates experiment on coppicing a nineteen years old plantation of *Anogeissus leiocarpa,* a forest local tree species, in the south sudanian zone in southern Mali. The objective of the study was to assess the effect of cutting intensity and prescribed fire and weeding on sprouting ability and shoots growth of a coppiced artificial stand of *A. leiocarpa*.

MATERIALS AND METHODS

Study area

The study was carried out in Zangasso's forest (12° 10'N, 5° 38'W), Koutiala district, southern Mali. The climate is south sudanian. For the last twelve years (1998 to 2009), the observed mean rainfall was 806.42 mm ± 35.17 (SE). The mean number of rainy days for this period was 53.66 days ± 2,37 (SE) . The variation of rainfall encountered during this period is shown in Figure 1. Soils of this site are hydromorphics with a high water retention capacity and a pH varying from 5.2 to 5.7. The ratio C/N is high at the surface (17 to 21) and satisfactory in inferior layers (10 to 12) allowing well decomposition of organic maters and easy release of the nitrogen (Doumbia et al., 1992) . The types of vegetal stands varied from shrub savannas (2/8 of the forest area) to woody savannas (1/8 of the superficies). In between stands are covering 5/8 of the area (Kelly, 1995). The total area of this forest is 5135 ha.

Species

A. leiocarpa (DC.) Guill and Perrot, called "ngalama" in the local language (bamanan), is a forest local tree species belonging to the family of Combretaceae. It is an evergreen shrub or small to medium- sized tree up to 15 to 30 m tall, with straight, slightly grooved bole and open crown with gracefully drooping, pubescent branches (Andary et al., 2005). The species has exceptional wide range (Andary, 2005), occurring from Senegal to Sudan and from Ethiopia to Democratic Republic of Congo (Cuny et al., 1998). It is found from the driest savannas to the wetter forest borders, in wooded grassland and bush land and on riverbanks where annual

Table 1. Number of trees and number of felled trees by cutting intensity

Number of trees	Number felled trees	Felling rate (%)
458	458	100
448	248	55

rainfall is 200 to 1200 mm. It often grows gregariously on fertile soil in moist situations, from sea level up to 1900 m altitude (Andary et al., 2005).

The leaves serve making yellow dye used to make "bogolanfini", a traditional Malian mud cloth (Arbonnier, 2004). The inner bark is used as human and livestock anthelmintic for treating worms and for treatment of protozoan diseases in animals (Bizimana, 1994). Bark, leaves and roots serve also for traditional tanning of hides to leather. The wood is an excellent timber and fuel wood and yields good charcoal.

Experimental design

The stand used for this study was planted in 1987. The experimental design was a complete randomised block design composed of plots of 10 x 10 trees as experimental units. The spacing between trees was 3 x 3 m and the survival rate at the start of this study (2006) was 90%. The layout of the design for the experiment in 1987 is shown in Annex 2. Parcels of *A. leiocarpa* in group III were used for coppicing experiment. This group has sufficient number of parcels of *A. leiocarpa* allowing implementing our design.

The first studied factor is the intensity of cutting which has two levels. Level 1 was Clear cutting (CC) where all trees in the plot were cut. Level 2 was Selective Cutting (SC) where about half of the trees in the plots were cut. The preserved trees were selected based on the rectitude of their trunk and their vigour (without any attack or apparent disease). Cutting was done in July 2006 and trees were cut at 10 cm above ground level. Table 1 shows the number of trees felled down for each intensity of cutting.

The second studied factor is the management mode, which also has two levels, which were weeding (We) and early fire (Ef). The weeding consists in removing all grasses and shoots of other tree species in the subplots receiving this treatment. It was done each year in August. Early fire consists in burning the whole subplots receiving this treatment at a period when the vegetation is not too dry and when fire harmful effects are limited. It was applied each year in December. These two treatments were applied during four years. The design is a factorial experiment with two factors, each one having two levels giving four treatments replicated three times.

Data collection and analysis

To assess the effect of studied factors, counting and measurements were conducted during the four years of the study. Each year in December, the number of stumps bearing shoots and the number of shoots per stump were counted. The measurements were done at the same period and it concerned the total height and the collar girth of the tallest shoot of each stump. These data were analysed using SYSTAT9 for Windows. Descriptive statistics and two-way analysis of variance were conducted at a single time point that is 18, 30 and 48 months after cutting. Repeated measures analysis was also conducted to investigate time effect as well as the inter action between time and studied factors. Chi-squared test was carried out to investigate the relationship between sprouting ability and studied factors. For data in the form of counts, square root transformation was used before analysis.

RESULTS

Ability of sprouting of *A. leiocarpa*

Cutting intensity

The percentage of stumps bearing shoots was high for all intensity of cutting at all stages (age of coppice). The clear cutting showed significant higher percentage (P = 0.000 for chi-squared test) . This percentage also varied very little according to age for this level of cutting. More variation of this percentage was observed for selective cutting and for the number of shoots for both levels of cutting. This last variable showed a decreasing trend ending by the same number of shoots (12 shoots) for the two intensities of cutting at 42 months (Figure 2). The effect of cutting intensity was not significant regarding the number of shoots likewise the interaction between cutting intensity and management mode (Tables 2 and 3).

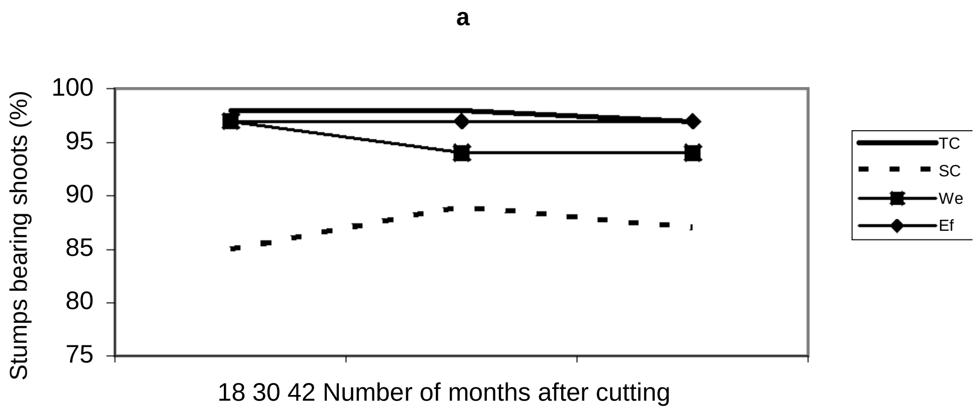
Management mode

The percentage of stumps bearing shoots was high (97%) for early fire and did not vary according to age (Figure 2) . It was higher than that for weeding and decreased little bit between 18 and 30 months. The ability of sprouting was however found not dependent of the management mode (P = 0.538 for chi-squared test). The effect of management mode was not significant regarding the number of shoots. The mean number of shoots was almost the same for the two modes at all ages but decreases according to age (Figure 2). At 42 months after cutting, the mean number was 6 shoots for both management modes.

Growth of shoots of *Anogeissus*

leiocarpa Cutting intensity

The analysis of variance on height and collar girth at 42 months showed a highly significant effect of cutting



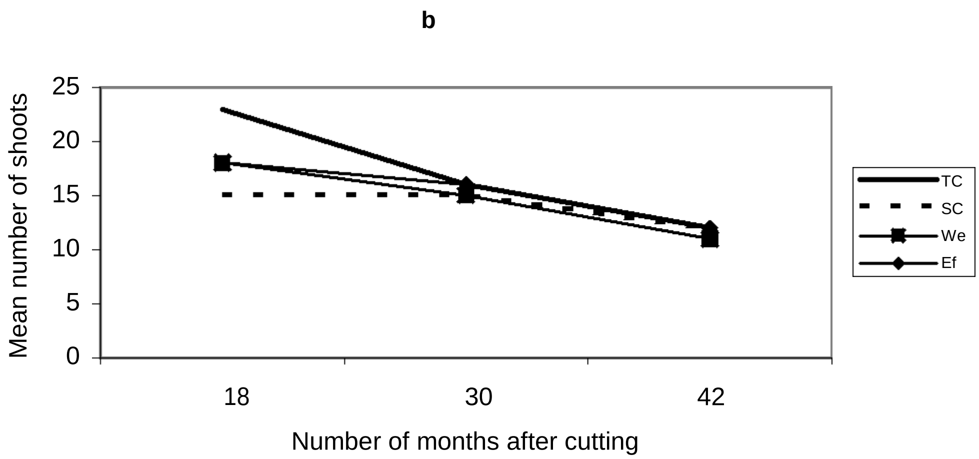


Figure 2. Evolution of the percentage of stumps bearing shoots (a) and mean number of shoots per stump (b) by cutting intensity (CC, SC) and by management mode (Ef, We).

Table 2. Results of analysis of variance on height

Source	Sum-of-squares	df	Mean-square	F-ratio	P
Cuttings$	937012.050	1	937012.050	151.146	0.000
Management$	1022.450	1	1022.450	0.165	0.685
Cutting$*Management$	14814.939	1	14814.939	2.390	0.124
Error	1091091.422	176	6199.383		

Variable = height measured at 42 months.

Table 3. Results of analysis of variance on collar girth

Source	Sum-of-squares	df	Mean-square	F-ratio	P
Cuttings$	2698.939	1	2698.939	218.887	0.000
Management$	0.006	1	0.006	0.000	0.983
Cutting$*Management$	20.672	1	20.672	1.677	0.197
Error	2170.133	176	12.330		

Variable = collar girth measured at 42 months.

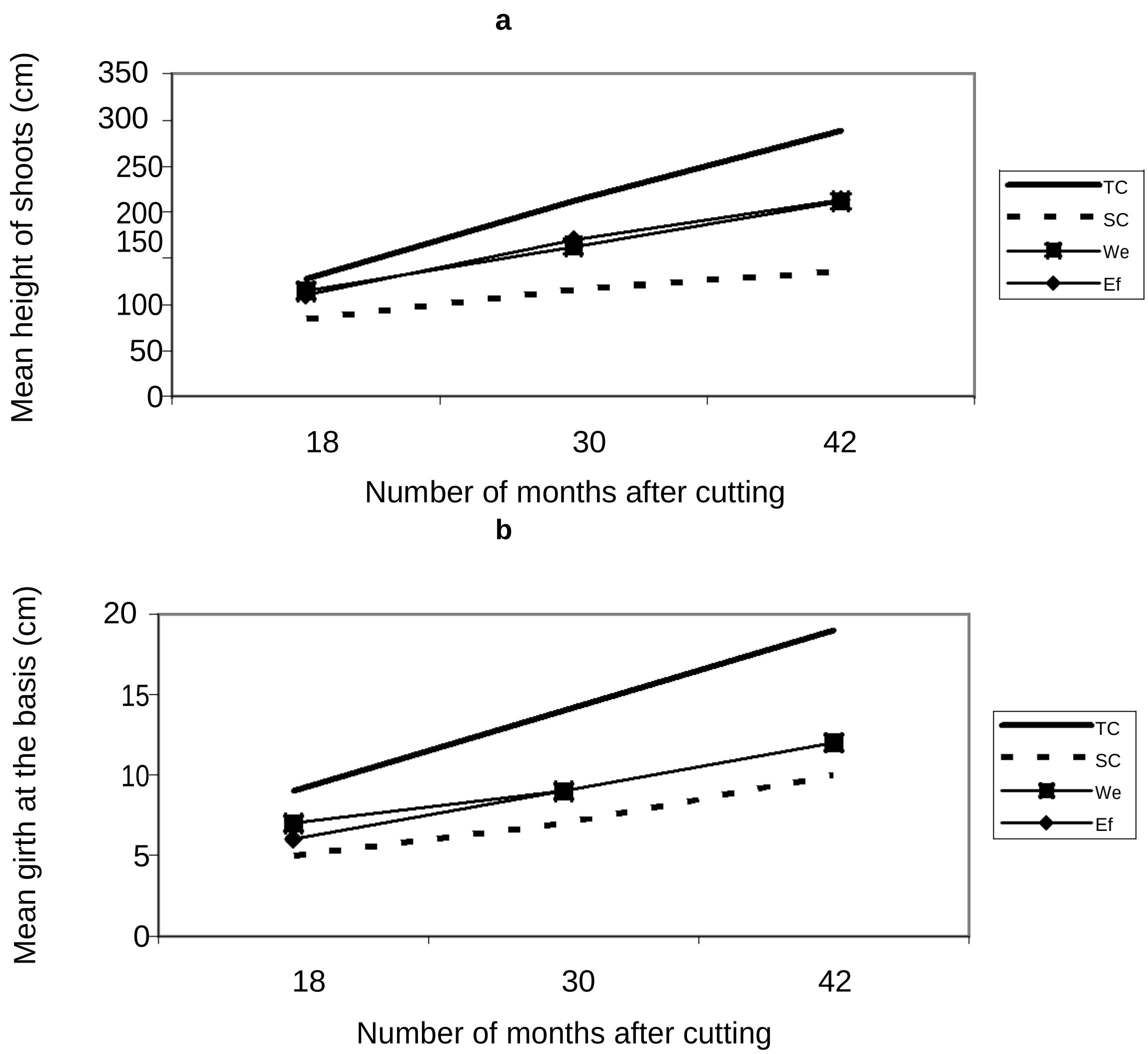


Figure 3. Evolution of mean height (a) and mean collar girth (b) by cutting intensity (CC, SC) and by management mode (Ef, We). Intensity of cutting: CC = Clear cutting, SC = Selective cutting, Management mode: We = Weeding, Ef = Early fire.

intensity ($P < 0.001$) for both variables (Tables 2 and 3). At 42 months after cutting, clear cutting gave better growth compare to selective cutting. The same result was obtained with data of previous time points that is 18 and 30 months (analysis not shown). For clear cutting, height growth was noticeable with current annual increments of 85 cm at 30 months and 75 cm at 42 months. This cutting offered twice the mean annual increment in height obtained with selective cutting (41 cm/year) 42 months after cutting.

Management mode

The analysis of variance on height and collar girth at 42 months showed a non-significant effect of management mode for both variables (Tables 2 and 3). Nonetheless, Ef showed a slightly higher mean height of shoots over the last two assessments. The observed mean height over intensity of cutting was respectively 214 cm and 212 cm for early fire and weeding, 42 months after cutting. The growth of height and collar girth according to management mode was regular (Figure 3). Mean annual increment of the height was 61.14 cm/year for early fire and 60.57 cm/year for weeding. That for collar girth was 3.42 cm/year for the two modes. The repeated measures analysis showed for both components (between and within subject), that only cutting, time (year) and their interaction were significant for all variables. An extract of these significant effects was given in Table 4 and the entire output of the repeated measures analysis was given in Annex 1.

Table 4. Significant effects from repeated measures analysis.

Variable	Component	Source	F	P
Height	Between subjects	Cutting	169.88	< 0.001
	Within subjects	Year	298.09	< 0.001
		Year*cutting	59.83	< 0.001
Girth	Between subjects	Cutting	307.91	< 0.001
	Within subjects	Year	299.40	< 0.001
		Year*cutting	51.47	< 0.001
Shoots #	Between subjects	Cutting	5.86	0.016
	Within subjects	Year	10.85	< 0.001

The interaction year*cutting was not significant.

DISCUSSION

Sprouting of *A. leiocarpa*

The ability of forest tree species (particularly *A. leiocarpa*) in natural stands to sprout well was known and reported by many authors (Anderson et al., 1992; Kelly and Diallo, 1992; Nouvellet, 1993a, b; Kelly, 1995; Kelly and Diallo, 2000). Based on the results of this experiment, planted *A. leiocarpa* was found to have high ability of sprouting suggesting that artificial stand of this tree species also sprouts well when coppiced.

The variation in time of the percentage of stumps bearing shoots was low for clear cutting and early fire (Figure 2) suggesting that these treatments provide good survival of stumps.

Effect of cutting intensity

A significant cutting effect was observed and clear cutting appeared to favour the sprouting. The biological explanation of this result is that, *A. leiocarpa* is a light species and clear cutting exposing more the stumps to sun light stimulates the sprouting. The number of shoots (12 shoots per stumps, 42 months after cutting) was high despite the self thinning. This mean number of shoots was a bit higher than that obtained by authors from previous studies in the case of natural stands. Bonkoungou and De Framond (1988) reported a mean of 8 shoots per stump five years after clear cutting, 4.5 shoots per stump were reported by Nouvellet (1993), five years after clear cutting and Sawadogo et al. (2002) trees observed 6 shoots, six years after selective cutting.

A decreasing trend of the mean number of shoots was observed for all treatments. The process leading to this trend is the natural selection (self-thinning) which is a biological phenomenon regulating life in the ecosystems. Sawadogo et al. (2002) as well as Bastide and Ouedraogo (2008) observed similar trend for several forest tree species. In a study of regeneration by selective coppicing in relation to land use, Luoga et al. (2004) found that 90% of harvested species sprouted in public land and 83% did so in reserve forest. The number of shoots per stump was respectively 4.9 ± 1.6 (SE) and 3.1 ± 1.4 (SE) for public land and reserve forest. They explained the better performance of public land compare to reserve forest by a release of self-thinning dynamic, reserve forest having a much higher tree biomass.

The number of shoots obtained from coppicing an artificial stand of *A. leiocarpa*, offered a wide range of choices according to future management objectives (production of fuel wood, timber wood, etc.).

Effect of management mode

The effect of management modes (early fire and weeding) on the ability of sprouting of a coppiced artificial stand of *A. leiocarpa* was found not significant. The percentage of stumps bearing shoots as well as the mean number of shoots did not differ significantly according to the levels of management mode. The result of this experiment was therefore in accordance with what authors observed in the case of natural stands of forest species including *A. leiocarpa.* For instance, the observed mean number of shoots (6 shoots per stump) was closed to results obtained by Kelly and Diallo (2000) which observed for all species confounded, respectively 5 and 4 shoots per stump for early fire and weeding, 30 months after clear cutting of natural forest stands in southern Mali.

Sawadogo et al. (2002) did not find significant difference between three treatments (early annual fire, total protection against fire and protection against fire two years after cutting) regarding stumps survival and shoots number per stump (all species confounded). These authors stated, "it seems that, a low intensity early fire does not endangered even young shoots and therefore their study does not support the idea of suppressing immediately the fire after cutting".

Growth of shoots of *A. leiocarpa*

The evolution of growth variables (height and collar girth) was regular. The trend was almost the same for the two management modes for the two variables (Figure 3).

Effect of cutting intensity

An important effect of cutting intensity was observed for shoots growth. Clear cutting showed higher mean height and mean collar girth. We still can explained this result by the fact that this type of cutting provides more light to shoots and also they are not in competition with adults trees for nutrients like in the selective cutting. The height increment with clear cutting is close to that observed for planted trees of this species in 1987 (96 cm/year) with big cube-shaped holes (50 x 50 x 50 cm) as manual soil preparation, forty eight months after planting (Kelly, 1995). It is superior to the increment observed for another plantation of the same species in the same site realised in 1993 with the same methods of soil preparation (big and small cube- shaped holes) which varied from 62 to 64 cm/year seven years after planting (Kelly and Cuny, 2000). In term of shoots growth of *A. leiocarpa*, Sawadogo et al. (2002) observe a mean height of 265 cm, six years after selective cutting in the sudanian savanna of Burkina Faso.

Effect of management mode

Regarding the growth of shoots, there was no significant difference between the two management modes (early fire and weeding). Some results were obtained by authors regarding the effect of fire and weeding on the growth of shoots of forest tree species. Kelly and Diallo (2000) found no significant difference between early fire and weeding regarding the growth of shoots of forest tree species in reserve forest in southern Mali. These treatments however were significantly better than the control treatment (no intervention).

Bastide and Ouedraogo (2008) also did not find any difference between a control treatment (protection against fire) and another treatment (early fire applied yearly) regarding the mean height of shoots of a local tree species (*Detarium microcarpum,)* seven years after selective cutting. These authors however found that the control treatment was significantly better than early fire regarding the growth of collar girth. They conclude, "the use of early fire as practiced nowadays at Burkina Faso seems to be an adapted technique". Houehounha et al. (2010) found that weed removal increased shoot height of *Daniellia oliver*i, another forest tree species.

Conclusion

A. leiocarpa is a local forest tree species successfully planted. Clear cutting appears to be an appropriate option for coppicing this tree species since it offered a high percentage of stumps having sprouted, a high number of shoots per stump and a good growth of shoots. Selective cutting appears to affect coppiced shoots of *A. leiocarpa* by slowing down there growth. It cannot be recommended for this kind of artificial stand with narrow spacing (3 m x 3 m) unless the aim of the management required doing so. Difference was found between the levels of the studied management mode for all measured variables. Nevertheless, it appears that these treatments (early fire and weeding) did not compromise the ability of sprouting of a coppiced artificial stand of *A. leiocarpus*. They did not compromise the growth of shoots too. They can therefore be advised in the sense to minimise the negative consequences of potential late fires, which are very frequent in the Sudanian zone of Africa.

In other way, by the removal of weeds, both are contributing to reduce competition and could therefore favour shoots growth as it was observed by authors in previous studies in the case of natural stands. Finally, on the light of these results, an artificial stand of *A. leiocarpa* can be managed by coppicing. The choice of the intensity of cutting will depend on the objectives of the management.

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ANNEX 1: OUTPUT OF REPEATED MEASUREMENTS ANALYSIS

Repeated analysis on height (HEIGHT07, HEIGHT08, HEIGHT09)

Table 1. Between subjects section.

Source	SS	df	MS	F	P
CUTTING$	1398479.408	1	1398479.408	169.884	0.000
MANAGEMENT$	1533.168	1	1533.168	0.186	0.667
CUTTING$*MANAGEMENT$	29616.775	1	29616.775	3.598	0.060
Error	1440594.400	175	8231.968		

Table 2. Within subjects section.

Source	SS	df	MS	F	P	G-G	H-F
Year	893595.817	2	446797.909	298.093	0.000	0.000	0.000
Year*CUTTING$	179379.178	2	89689.589	59.839	0.000	0.000	0.000
Year*MANAGEMENT$	4466.438	2	2233.219	1.490	0.227	0.229	0.229
Year*CUTTING$* MANAGEMENT$	7402.992	2	3701.496	2.470	0.086	0.104	0.103
Error	524598.234	350	1498.852				

Greenhouse-Geisser Epsilon: 0.7114; Huynh-Feldt Epsilon: 0.7279.

Repeated analysis on girth (GIRTH07, GIRTH08, GIRTH09)

Table 3. Between subjects section.

Source	SS	df	MS	F	P
CUTTING$	4822.243	1	4822.243	307.910	0.000
MANAGEMENT$	8.446	1	8.446	0.539	0.464
CUTTING$*MANAGEMENT$	36.232	1	36.232	2.313	0.130
Error	2740.713	175	15.661		

Table 4. Within subjects section.

Source	SS	df	MS	F	P	G-G	H-F
Year	2393.356	2	1196.678	299.403	0.000	0.000	0.000
Year*CUTTING$	411.450	2	205.725	51.471	0.000	0.000	0.000
Year*MANAGEMENT$	13.680	2	6.840	1.711	0.182	0.188	0.187
Year*CUTTING$*MANAGEMENT$	14.148	2	7.074	1.770	0.172	0.179	0.178
Error	1398.909	350	3.997				

Greenhouse-Geisser Epsilon: 0.8137; Huynh-Feldt Epsilon: 0.8344.

Repeated analysis on number of shoots (NBSHT07, NBSHT08, NBSFT09)

Table 5. Between subjects section.

Source	SS	df	MS	F	P
CUTTING$	8.093	1	8.093	5.868	0.016
MANAGEMENT$	0.057	1	0.057	0.041	0.839
CUTTING$*MANAGEMENT$	0.197	1	0.197	0.143	0.706
Error	241.351	175	1.379		

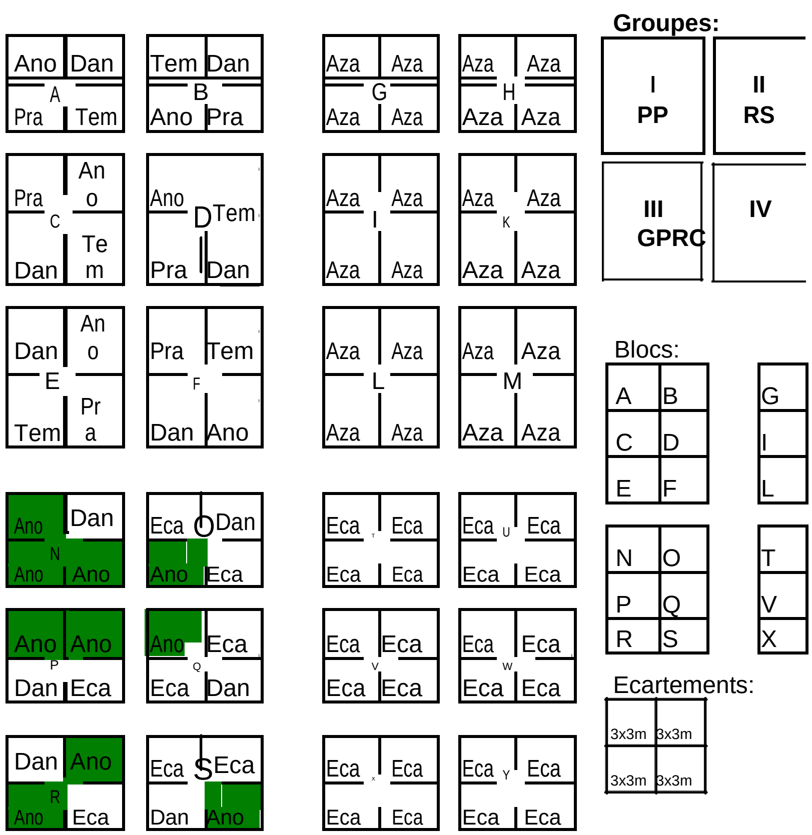
Table 6. Within subjects section.

Source	SS	df	MS	F	P	G-G	H-F
Year	12.084	2	6.042	10.856	0.000	0.000	0.000
Year *CUTTING$	2.538	2	1.269	2.280	0.104	0.118	0.117
Year *MANAGEMENT$	0.633	2	0.316	0.569	0.567	0.519	0.523
Year *CUTTING$*MANAGEMENT$	0.983	2	0.491	0.883	0.414	0.388	0.391
Error	194.792	350	0.557				

Greenhouse-Geisser Epsilon: 0.7518; Huynh-Feldt Epsilon: 0.7699.

ANNEX 2: DESIGN OF THE FIRST EXPERIMENT IN 1987 (PARCELS OF ANOGEISSUS IN GROUP 3 WHERE USED FOR COPPICING EXPERIMENT)

Dispotif expérimental essai C12 (Zangasso 1987)



Espèces:

Ano: *Anogeissus leiocarpa*
Aza: *Azadirahta indica*
Dan: *Daniellia oliveri*
Eca: *Eucalyptus camaldulensis*
Pra: *Prosopis africana*
Tem: *Terminalia macrotera*