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Original article

Effects of livestock and prescribed fire on coppice growth after selective cutting of Sudanian savannah in Burkina Faso

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Abstract – Can livestock grazing and/or fire regimes be used to promote coppice growth in Sudanian savannah silviculture? Effects of livestock and prescribed fire regimes on stool sprouting after selective cutting were followed during 6 years. Half the initial basal area (at stump height) of 10.8 m^2 ha^{-1} (500 stems ha^{-1}) was cut on 48 plots of 0.25 ha each. In a split-plot design with and without livestock, the effects of annual "early fire" (as soon as possible after end of the rainy season), no fire and 2 years without fire were tested. With moderate (50% of the potential) grazing of 0.7 TLU ha^{-1} stump mortality decreased and basal area per stool (stems > 10 cm GBH) increased, which we assume was due to reduced sprout/grass competition. Fire regimes had no major impact and no significant interaction was found. Six years after cutting, coppice basal area was 1.1 m^2 ha^{-1}, corresponding to a recovery of 20% of the initially removed area.

grazing / browsing / early fire / stool sprouting / fuelwood

Résumé – Effets du pâturage et du feu prescrit sur l'évolution d'un taillis après coupe sélective d'une savane soudanienne au Burkina Faso. Le pâturage et/ou le régime de feu peuvent-ils être utilisés pour promouvoir la croissance des rejets de souche après coupe en savane soudanienne ? Les effets du pâturage et d'un régime de feu prescrit, sur l'évolution d'un taillis après coupe sélective, ont été étudiés pendants six années. La moitié de la surface terrière initiale (à hauteur de souche) de 10,8 m^2 ha^{-1} (500 tiges ha^{-1}) a été coupée sur 48 parcelles de 0,25 ha chacune. Dans un dispositif split-plot avec et sans pâturage, différents régimes de feu, à savoir un feu précoce annuel (appliqué le plus tôt possible après la saison pluvieuse), pas de feu et deux ans sans feu ont été étudiés. Avec un pâturage modéré (50 % de la capacité de charge) de 0,7 unités de bétail tropical par hectare, la mortalité de souche a diminué et la surface terrière (tiges > 10 cm DHP) par souche a augmenté. Les régimes de feu n'ont pas eu d'impact majeur et il n'y a pas eu d'interactions significatives. Six années après la coupe, la surface terrière des rejets était de 1,1 m^2 ha^{-1}, correspondant à un taux de recouvrement de 20 %.

pâturage / pâturage aérien / feu précoce / régénération par rejet de souche / bois de feu

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1. INTRODUCTION

Silviculture in savannah ecosystems must take timing, frequency as well as intensity of fire and grazing into account. In the Sudanian Zone it is estimated that 25 to 50% of the area is burnt annually [11], and all areas burn every 2–3 years primarily due to anthropogenic causes [21]. However, temporary suppression of fire could also be considered human disturbance, since "natural" fires would occur every 5–10 years [21]. The probability of fire occurrence increases proportionally to the amount of grass fuel available, with a maximum effect above 3 t ha^{-1} [36]. Late fire (fire at the end of the dry season) when biomass is dry, is more fierce and devastating for woody shoots than early fire (i.e. as soon after the end of the rainy season as possible) when the vegetation moisture content is still high. The effects of fire are not homogeneous, in particular early fires create a spatial heterogeneity because of a spatial variability of the moisture content in the vegetation. For instance annual and perennial grasses dry out after different time lapses after the end of the rainy season. Moreover, there are strong interactions between fire and termites affecting decomposition of grasses, nutrient cycles, hydrology and spatial heterogeneity of biomass [14, 22]. It has been proposed to adopt the use of early fire in national forest policies to reduce intensity or avoid late fire by creating a spatially discontinuous (patchy) supply of herbaceous fuel load [9, 11, 21]. Moderate cattle grazing and trampling may also reduce grass in a patchy manner, thus creating discontinuous fuel load and vice versa [14].

Foresters recommend annual early burning, because total fire exclusion is considered difficult to achieve [4, 21], as in any case, burning is needed in pasture management [34, 35]. Recurrent fires however, cause a shift in the species composition, favoring species capable of vegetative reproduction [14, 17, 20]. Factors like bark properties and wood basic density vary among savannah species [1, 27] and together with coppice growth rates they define strategies for fire resistance in the reproduction stage of savannah trees [9, 16]. Before sprouts reach the free to grow stage above the grass layer, they will sit in the fuel bed where there is a risk of damage. Some species may resist almost any fire condition, while others rely on rapid stem growth and re-sprout vigorously after stems have been killed by fire [16]. Recurrent fires could limit growth of above as well as belowground structures [31]. In a savannah prone to recurrent fires, seasonal translocation of carbohydrates between shoots and roots could be an essential prerequisite for sprouting [10]. The ecological and economic importance of sprouting for survival or reproduction after wood harvesting [1, 4, 7, 23, 26, 30], fires [19, 20, 33] and shifting cultivation [18, 25] has been well documented.

Co-existence of woody and herbaceous plants in savannah ecosystems enhances the possibilities for multipurpose management, such as continuing grazing and wood production. Grass production is confined to the rainy season but woody plants flush some months before the first precipitation of the rainy season and the young foliage constitutes valuable fodder when grass is scarce, although browsing (livestock eating woody leaves and shoots) is an important source of protein also in the rainy season [24]. This difference in the phenology of woody and herbaceous plants ensures the availability of quality fodder throughout a large part of the year [9]. The savannah ecosystem, characterized by the co-dominance of two different life forms, grasses and trees, is a biome with a physiognomy that is neither grassland nor forest. From a manager's point of view, the balance between trees and grass can be tipped in favor of grasses by burning, low grazing pressure or tree cutting; or in favor of trees by excluding fire and intensive grazing [32]. Browsing may prevent seedlings from establishing [3] and reduce height growth of coppice stems, thus suppressing their recruitment into the adult stage where buds are "safe" [16] from fire. Limited browsing of coppice stems per se without fire will rarely cause stool mortality. In an experiment in Cameroon, Peltier and Eyog-Matig [29] found higher wood production with, than without livestock grazing, which they believe was due to reduced grass competition and less intensive grass fires.

Can livestock grazing and/or fire regimes be used to promote coppice growth in Sudanian savannah silviculture? Following cutting, sprouts are vulnerable to fire and intensive fire is likely to seriously damage or kill sprouts. Total fire suppression for longer time periods than a few years is not a realistic forest management option in a savannah environment where fire is used in agriculture and livestock production. Fire suppression is needed in particularly the first years following cutting until stems have reached the free to grow stage above grasses. Early fire might be a way to reduce fuel load and to create discontinuous herbaceous layer, which could prevent late fire frequency and intensity. We assume grazing reduces grass/sprout competition, but there is a risk of livestock browsing seriously damaging sprouting. Further we assume there are interaction effects between livestock grazing and fire regimes. For instance livestock grazing could reduce fuel build-up when total fire protection is used during the initial stage following cutting.

In order to study coppice growth with regard to management options discussed above, a split plot experiment with selective cutting and the following fire management options with and without livestock fencing were analyzed: (1) prescribed annual "early fire"; (2) permanent fire protection; (3) fire protection for two years, and thereafter annual early fire. Coppice growth was studied using following parameters: stool mortality, development of shoot height, basal area growth as well as number of stems per stool.

2. MATERIALS AND METHODS

2.1. Study area

The experimental site is located on a flat area in Tiogo state forest (12º 11' –12º 24' N, 2º 39'–2º 52' W) at an altitude of 300 m a.s.l. in Burkina Faso, West Africa. The reserve covers 30 000 ha close to the only permanent river in the country (Mouhoun). Phyto-geographically, it is situated in the Sudanian regional centre of endemism [37] in the transition from the north to south Sudanian Zone [15]. The unimodal rainy season lasts 6 months (May to October). The mean annual rainfall for the study period (1994–99) at the site was 830 ± 177 mm yr^{-1} with a large inter-annual variability and the number of rainy days yr^{-1} was on average 54 ± 5 (*table I*). Mean minimum and maximum temperatures were 16 ºC and 32 ºC in January and 26 ºC and 40 ºC in April, resulting in an aridity index [6] of 3.7. The most frequently encountered soils are tropical hardened leached ferruginous soils and the main properties according to FAO [13] classification of the soils in the experimental site were: clay (24.8 ± 7.7%), fine silt (15.0 ± 4.3%), coarse silt (25.4 ± 3.0%), fine sand (21.7 ± 6.7%), coarse sand (13,1 ± 4.2%), total organic matter (1.8 ± 0.7%), total N (0.1 ± 0.0%), C/N (11.4 ± 4.6%), available P (1.4 ± 0.7 ppm), pH H_2O (6.2 ± 0.5) [28]. The vegetation is tree and shrub savannah with a grass layer dominated by the annual grasses (Poaceae) *Andropogon pseudapricus* and *Loudetia togoensis* and the perennial grass (Poaceae) *Andropogon gayanus* [15]. Out of the 137 grass species encountered, annuals (101) dominated but perennials (36) had the largest biomass. Annuals were most frequently found on shallow soils and perennials dominated on deeper soils. A total of 74 woody species were encountered and one third of these were considered to have tree stature and two thirds are considered bushes with some few lianas. Identification of species and families of plants were made according to Guinko [15]. Mean basal area at stump level (20 cm) was 10.8 m^2 ha^{-1}, the corresponding figure at breast height (130 cm) was 5.9 m^2 ha^{-1} and stand density was around 500 woody individuals ha^{-1} having at least one stem > 10 cm GBH (girth at breast height) (*table II*). *Mimosaceae* and *Combretaceae* dominated the woody layer and in terms of basal area, the main species were *Entada africana*, *Lannea acida*, *Anogeissus leiocarpus* and *Vitellaria paradoxa* (*table II*). The livestock carrying capacity in Tiogo state forest was 1.4 TLU (tropical livestock unit) ha^{-1} [34] and the grazing pressure in the experimental site was estimated to about half of this capacity based on number of livestock in surrounding villages. Grazing was dominated by cattle although sheep and goats were present. The site was occasionally visited by elephants but they had no major impact. Tiogo state forest was delineated by the colonial administration in 1936 but cultivation has taken place for centuries and fuelwood has been transported to a town at 50 km distance for the last decades.

Table I. Mean annual rainfall and number of rainy days measured at the experimental site during the study period.

Year	Rainfall (mm yr^{-1})	Number of rainy days yr^{-1}
1993	748	45
1994	1130	60
1995	719	55
1996	872	58
1997	692	57
1998	652	49
1999	995	55
Mean	830	54
Standard deviation	177	5

2.2. Experimental design

This is a split-plot experiment with 4 replications. The experimental site of 18 ha was split into two contiguous main plots where livestock was excluded in one of them by fencing. Each main plot was further divided into 4 half-blocks (2.25 ha) containing 9 sub-plots of 0.25 ha (50 by 50 m) each separated by 20–30 m fire-barriers, to

Table II. Species composition, local use (U), growth form (GF), maximum height (H), as well as mean basal area and stand density before and after selective cutting. P stands for protected species; Po for timber and poles; PF for poles and fuelwood; F for fuelwood and others; T for tree; B for bush; S number of small individuals (stem < 10 cm girth at breast height (gbh) ha^{-1}; N number of large individuals (stem > 10 cm gbh) ha^{-1}; *Ba20* for basal area at stump level; *Ba130* basal area at breast height (130 cm) m^2 ha^{-1}. The category "others" includes a total of 34 species.

Species	Family	U	*GF*	*H* (m)	before cutting *S*	*N*	*Ba20* (m^2 ha^{-1})	*Ba130* (m^2 ha^{-1})	after cutting *N*	*Ba20* (m^2 ha^{-1})	*Ba130* (m^2 ha^{-1})
*Entada africana Guill. et Perr.**	Mimosaceae	F	B	4	178	88	1.35	0.74	7	0.01	0.02
Lannea acida A. Rich.	Anacardiaceae	P	T	12	126	29	1.02	0.68	29	1.02	0.68
*Anogeissus leiocarpus (DC) Guill. et Perr.**	Combretaceae	PF	T	15	139	22	0.92	0.31	15	0.46	0.09
Vittelaria paradoxa	Sapotaceae	P	T	15	212	20	0.90	0.58	19	0.71	0.52
*Detarium microcarpum Guill. et Perr.**	Caesalpiniaceae	PF	T	12	115	43	0.85	0.48	26	0.26	0.06
Terminalia avicennioides Guill. et Perr.	Combretaceae	P	T	15	157	18	0.52	0.33	16	0.30	0.18
*Piliostigma thonningii (Schum.) Miln-Red.**	Caesalpiniaceae	F	B	4	76	34	0.51	0.28	0	0.04	0.05
Tamarindus indica L.	Caesalpiniaceae	P	T	16	18	5	0.47	0.31	5	0.47	0.31
*Acacia macrostachya Reichenb. ex Benth.**	Mimosaceae	F	B	5	444	43	0.45	0.21	11	0.13	0.08
*Combretum nigricans Lepr. ex Guill. et Perr.**	Combretaceae	PF	T	12	212	35	0.37	0.18	27	0.22	0.12
Sclerocarya birrea (A. Rich.) Hoschst.	Anacardiaceae	P	T	15	94	8	0.28	0.20	8	0.28	0.20
Combretum micranthum G. Don	Combretaceae	F	B	5	80	20	0.23	0.11	12	0.15	0.07
Pterocarpus erinaceus Poir.	Papilionaceae	P	T	17	219	3	0.23	0.11	3	0.23	0.11
*Combretum glutinosum Perr. ex DC.**	Combretaceae	F	T	10	67	10	0.22	0.08	2	0.06	0.03
Mitragyna inermis (Wild.) O. Ktze.	Rubiaceae	Po	T	12	3	2	0.21	0.12	1	0.13	0.07
Combretum ghazalense Engl. et Diels	Combretaceae	F	T	12	94	14	0.19	0.09	6	0.04	0.04
Terminalia laxiflora	Combretaceae	P	T	12	70	7	0.18	0.12	7	0.17	0.11
Balanites aegyptiaca (L.) Del.	Balanitaceae	P	T	8	30	8	0.17	0.09	8	0.16	0.09
*Ximenia americana L.**	Olacaceae	F	B	4	83	12	0.15	0.05	6	0.08	0.03
Others					1242	86	1.61	0.87	50	0.82	0.50
Total					3656	509	10.82	5.93	255	5.76	3.30

* Species coppice growth investigated in this study.

which 9 treatments were randomly assigned *(figure 1)*. On 6 out of the 9 subplots, selective cutting was performed resulting in a net experimental area of 1.5 ha per half-block. In this study only 3 treatments per half-block were considered. On each half-block the following 3 treatments were applied on 2 sub-plots each: (A) annual early fire, (B) permanent fire protection (no fire), and (C) initial fire protection for two years and annual early fire thereafter (2-year initial fire protection). Prescribed early fire was applied simultaneously on all plots each year at the end of the rainy season (October–November) when the grass layer humidity was approximately 40%.

Establishment of experiments in "natural" forest ecosystems involves a number of difficulties with regard to the initial heterogeneity of the vegetation. We assumed there was a random distribution of species, soil conditions and livestock feeding habitats. Moreover, a disturbance factor like the selective cutting makes conditions more homogeneous (a baseline). Preferably, blocks should have been placed in different parts of the forest but due to practical reasons (fencing and fire-barriers), one large fenced-off area was put in place resulting in four contiguous half-blocks, which precluded randomization of fencing within each block. Blocks were situated along a gentle slope where the soil depth varied.

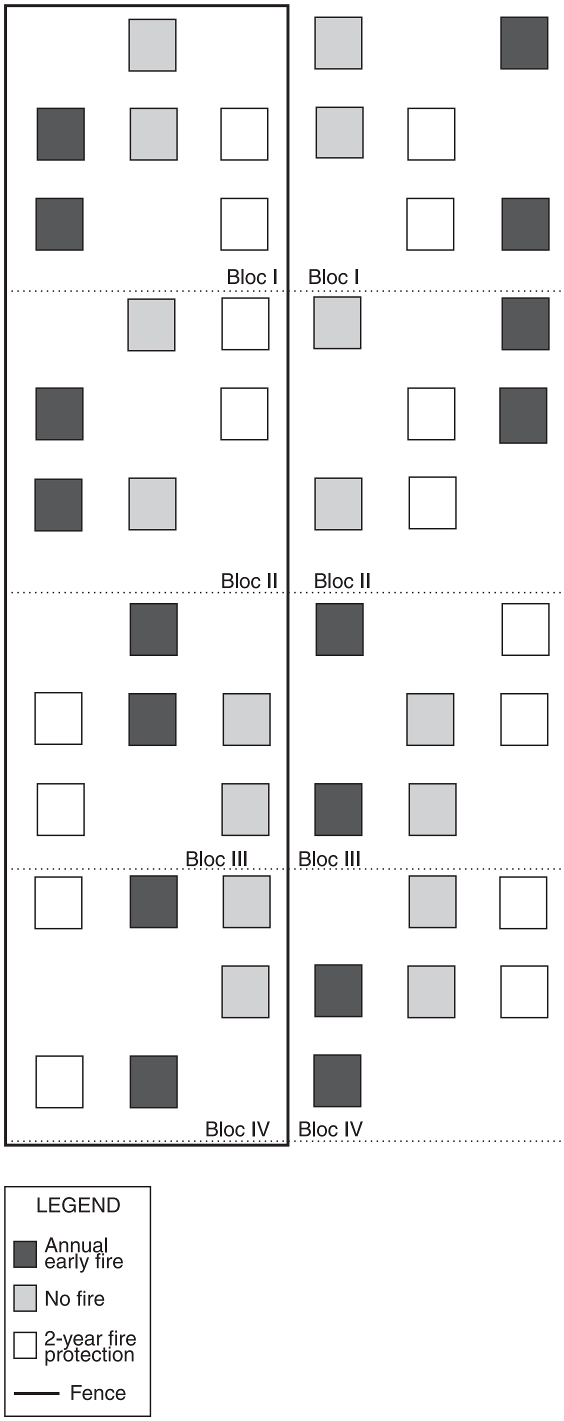

Figure 1. Experimental design (split plot) with and without livestock on main plots and three fire regimes on sub-plots: (1) annual early fire, (2) no fire, (3) 2-year fire protection followed by annual early fire.

2.3. Characteristics of the selective cutting

All woody (tree and bush) species were grouped into four categories depending on their local uses [35]: (1) protected species, (2) timber and poles (3) poles and fuelwood, (4) fuelwood and others (*table II*). *Vitellaria paradoxa* (shea butter tree) and *Pterocarpus erinaceus* (forage) were the main protected species. The other categories were cut according to butt diameter size: timber > 30 cm; poles and fuelwood > 14 cm; and fuelwood and others > 8 cm. *Detarium microcarpum, Anogeissus leiocarpus* and *Terminalia avicennioides* were the most common fuelwood species. All damaged individuals were cut irrespectively of dimension or species. Cutting was performed during December 1993 in the dry season using local axes and machetes. About half the number of stems per ha (corresponding to 44% of the basal area at breast height) for 52 species out of 74 on the experimental site were cut. *Entada africana* and *Detarium microcarpum* were the most common species making up 26% and 12% respectively (*table II*) of the 5.8 m^2 ha^{-1} at stump height that were cut.

2.4. Data collection and analysis

Every stool was surveyed at the end of the dry season (May) during six consecutive years (1994–99). The following parameters were recorded:

- stump mortality (stumps have not sprouted or the shoots have died),
- height (or length along the stem if the shoot is leaning) of stems,
- girth (stems > 10 cm GBH) at stump height (SH) and at breast height (GBH).

We assume a stem > 10 cm GBH, which corresponds to a height of about 2 meters, could withstand browsing and fire. This threshold value is based on the assumption that self-thinning takes place among stems < 10 cm GBH and therefore girth and basal area has not been measured for these stems. In analogy with seedlings and saplings in sexual reproduction the number of stems below this threshold value (< 10 cm GBH), represents the recruitment of "future stems" per stool.

Stump mortality for each year was calculated as number of stools recorded dead divided by number of stumps at the start in 1993. Girth (stems > 10 cm GBH) was measured in centimeters with a tailor-tape and the basal area was calculated per stool. Stem height was measured with a graded pole. Statistical analysis was made on mean values for each of two subplots per half-block for the parameters above. This was calculated for all species combined and for each of the 9 main species cut (*table II*) each year (1994–99). The analysis of variance was performed with the following general linear model (GLM):

$$Y_{ijk} = \mu + \beta_i + L_j + (\beta L)_{ij} + F_k + (LF)_{jk} + e_{ijk}$$

where Y_{ijk} was the response variable for a dendrological parameter, μ was the overall mean, β_i was the effect of block (replication) i, L_j was the effect of livestock (main-plot) j and F_k was the effect of fire (sub-plot) k. The parameters β_i, L_j, F_k and their interactions were regarded as fixed effects. The experimental error e_{ijk} (= $(\beta F)_{ik}$ + $(\beta FL)_{ijk}$) was used as error term for testing F_k and $(\beta L)_{ij}$ was used as error term for testing L_j. Multiple comparisons were made with Tukey's test to detect differences between F_k [38]. The level of significance was 5%.

3. RESULTS

3.1. Coppice growth and species specific responses

Stool mortality was largest the first year after cutting (1994) with an average of 15% and thereafter it increased by about one point per year to a total mortality of 20% during 1999 (*table III*). All 52 species that were cut sprouted, but sprouting ability varied among them. Six years after cutting there were on average, all species combined, 20% dead stools and it varied from 5% (*Combretum glutinosum*) to 54% (*Piliostigma thonningii*) (*table III*).

In 1994 there were about 9 stems per stool (including stems < 10 cm GBH) all species combined and by 1999 it had decreased by self-thinning to about 4 out of which 0.8 stems > 10 cm GBH per stool *(figure 3A)*. Thus, still after six years there was a recruitment of stems > 10 cm GBH for which the basal area was calculated. For the 9 species mostly cut, there were 4.9 stems per stool, of which 1.4 stems > 10 cm GBH the sixth year following cutting *(table III)*. However there were large differences among species with *Detarium microcarpum* having 7.2 stems per stool of which 1.1 stem > 10 cm GBH, whereas *Combretum glutinosum* having 4.7 stems per stool of which 2.6 stems > 10 cm GBH.

For the 9 most common species the stem height was 218 cm in 1999 (6 years) and for stems > 10 cm GBH the corresponding figure was 378 cm *(table III)*. Basal area per stool at stump (Ba20) and at breast height (Ba130) was 58 cm^2 and 29 cm^2, respectively. *Anogeissus leiocarpus* had the largest Ba20 (110 cm^2) and height (496 cm). *Detarium microcarpum* had the largest number of stems per stool with 7.2 and they had an average height of 161 cm. Per hectare Ba20 was 1.2 m^2 (201stumps × 58 cm^2, *table III*) and Ba130 was 0.6 m^2 (201stumps × 29 cm^2). Six years after the selective cutting the degree of recovery of Ba20 was 20% and of Ba130 was 10%, disregarding the growth of non-cut stems in 1993.

Table III. Mean values of 48 plots with a size of 0.25 ha each, for dendrological parameters of coppice growth per species, six years after selective cutting in a coppice system. Basal area is calculated for stems > 10 cm gbh (girth at breast height).

species	Stools ha^{-1}	Mortality	Stems Stool-1		Basal area (cm^2 ha^{-1})		Height of stems (cm)	
	nb	%	all stems	> 10 cm gbh	*Ba20*	*Ba130*	all stems	> 10 cm gbh
Anogeissus leiocarpus (DC) Guill. et Perr.	6	18	6.4	2.0	110	47	265	496
Acacia macrostachya Reichenb. ex Benth.	28	13	3.4	1.5	45	26	263	365
Combretum ghazalense Engl. et Diels	7	12	5.6	1.9	60	29	204	314
Combretum glutinosum Perr. ex DC.	8	5	4.7	2.6	86	45	313	376
Combretum nigricans Lepr. ex Guill. et Perr.	8	13	5.2	2.0	88	47	297	465
Detarium microcarpum Guill. et Perr.	15	10	7.2	1.1	66	30	161	366
Entada africana Guill. et Perr.	74	9	5.5	0.8	41	20	168	357
Piliostigma thonningii (Schum.) Miln-Red.	15	54	3.6	1.1	37	20	146	332
Ximenia americana L.	6	16	3.9	0.6	16	9	181	316
others	34	32	4.1	1.0	35	17	204	384
total	201	20	4.9	1.4	58	29	218	378

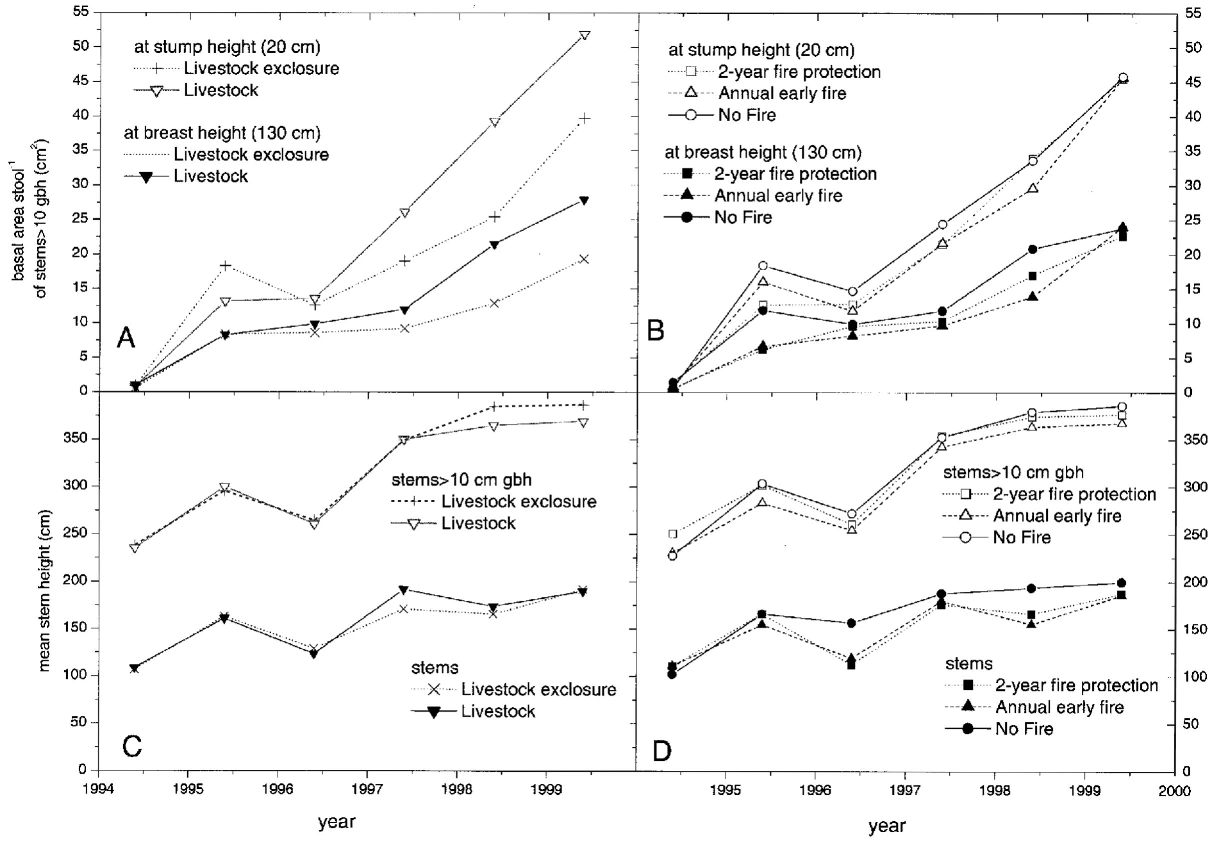

Figure 2. Effects of livestock (A and C) and fire regimes (B and D) on basal area and mean stem height during 6 years (1994–1999). A and B are basal area per stool (stems > 10 cm girth at breast) at stump and breast height. C and D are stem height for stems and stems > 10 cm GBH separated.

3.2 Livestock effects

The presence of livestock had several effects:

– Stool mortality was 7–8 points lower every year 1994–99 (p = 0.005, 0.006, 0.072 (not significant), 0.001, 0.003 and 0.007), i.e. mortality was 63% and 50% during 1994 and 1999, respectively.

– Basal area per stool was larger from the fourth year (1997–99) measured at stump (p = 0.01, 0.01, 0.00) or at breast height (p = 0.05, 0.00, 0.01) (*figure 2A*).

– Height of stems > 10 cm GBH were slightly shorter from fifth year, 1998–99 (p = 0.007, 0.053) (*figure 2C*).

– Number of stems > 10 cm GBH per stool was higher starting from the fourth year 1997–99 (p = 0.004, 0.001 and 0.005) (*figure 3A)*.

3.3 Fire regimes effects

– There was no statistically significant difference in the stool mortality between the 3 fire regimes. However, there was a trend to decreasing mortality for early fire 1997–99 than for 2-year initial protection.

– Basal area per stool was not affected by treatments (*figure 2B*).

– Stems were significantly higher for no fire than for fire regimes in 1996 and 1998–99 (*figure 2D*). Stems > 10 cm GBH were significantly higher for no fire than annual early fire in 1996 and 1999 (*figure 2D*).

– There was no difference between fire regime treatments but a tendency to more stems > 10 cm and less stems < 10 cm GBH per stool with no fire than for the prescribed fire treatments (*figure 3B*).

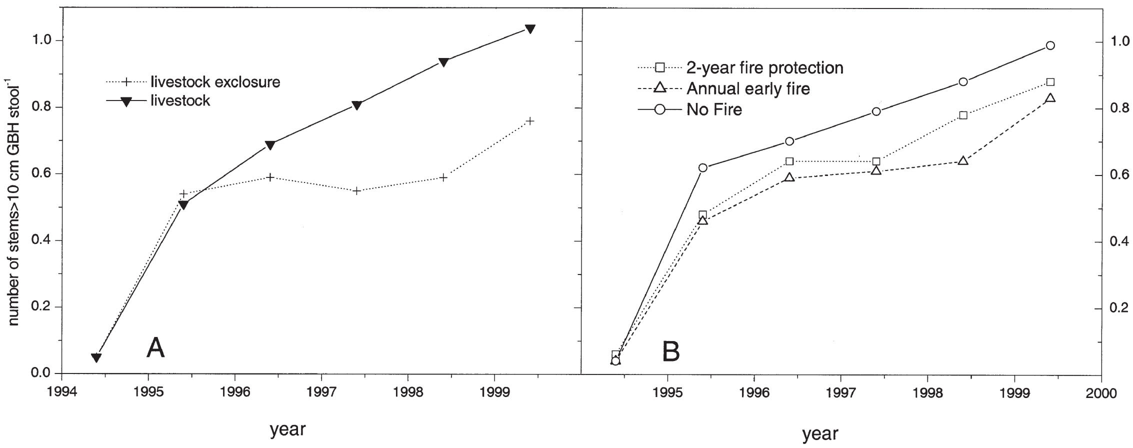

Figure 3. Effects of livestock (A) and fire regimes (B) on number of stems > 10 cm GBH per stool.

There were no interaction effects found between livestock and fire regimes, nor any significant block effects. Specific species analyses gave similar results as for all species combined.

4. DISCUSSIONS

4.1 Livestock effects

In many parts of West Africa, in particular in the transition between north Sudanian and south Sahel Zone, livestock browsing is considered harmful and sometimes devastating for forest reproduction [4, 5], whereas the effect of grazing on reproduction of woody vegetation is less discussed. This has often created conflicts among herders and foresters on how to manage tree and bush savannah areas. In this study which is situated in the transition from north to south Sudanian zone, livestock grazing reduced stool mortality, increased the basal area and number of stems > 10 cm GBH per stool, which indicates that livestock in the forest may actually be considered part of a silvicultural scheme. The livestock effect was unexpectedly highly significant considering that in a split plot design where grazing is applied on the main-plots this factor is "sacrificed". For instance stool mortality was significant (at the 0.01 level for every year, except 1997). There was no interaction between livestock and fire regimes and no block effect, which could have explained the effects of livestock. The results are in agreement with Peltier and Eyog-Matig [29] who found enhanced coppice recovery after cutting in the presence of livestock in Cameroon. In southern Africa encroachment by the woody layer on the grass layer due to overgrazing by cattle is perceived as a major problem for savannah management [32]. However, livestock influence on the balance between herbaceous and ligneous vegetation is complex and depends on the woody species, type of herbivore (cattle or goat), grazing and browsing intensity, rainfall patterns, soil type and human population density.

We assume the reduced mortality and increased coppice growth with livestock is due to a reduction of competing grass biomass. Grazing was about 50% of the theoretical capacity (1.4 TLU) of this ecosystem, but trampling must also be taken into consideration. In fact, Fournier [12] found that cattle intake reached 10 to 50% of the maximum epigeous herbaceous phytomass in the Sudanian Zone and Chidumayo [9] estimated the intake to 60% in the east and south African savannah. In Guinean savannahs, water stress was significantly higher for regenerating woody plants growing in the presence of grass competition [21]. According to Cesar [8] a short period of overgrazing could be an efficient management tool in the Sudanian-Guinean Zone to enhance woody vegetation growth. In this study we estimate the herbaceous biomass production to about 6 t ha^{-1} [35]. Some perennial grasses (i.e. *Andropogon sp.)* reached 3–4 m, and totally overcast sprouting, which had a mean height of only about one meter the first year (*figures 2C* and *D*). Until the height of the largest stems reached grass height, shading is a possible factor for reduced growth as well as for stool mortality [30]. At the end of the study period there was on average less than one stem per stool *(figure 3C)* reaching grass height.

Stool mortality was largest the first year following cutting (15%) and thereafter only increased marginally (1 percentage-point yr^{-1}). Livestock is considered most harmful the first year after logging because of browsing, but less attention has been paid to the reduced grass/sprout competition due to grazing. The probability of mortality is likely to be largest the first year after cutting and thereafter mortality of surviving stools could be expected to remain stable. In fact the effect of grazing on relative stool mortality was largest (63%) the first year and was thereafter reduced marginally (50% in 1999). Could more intensive grazing pressure the first year after cutting have reduced stool mortality even further? The risk for browsing is highest the first year after cutting, when stems are more palatable [5] and more accessible with a mean height of about one meter *(figure 2C)*. In this study we have not observed any damaging effects of browsing on stool sprouting. Not all woody species are considered palatable, although most species are browsed with higher stocking rates. However, grazing and trampling may have damaged seedlings and saplings, which have not been included in this study.

4.2. Fire regime effects

There was a tendency to higher stump mortality with 2-year fire protection than with early fire the last three years (1997–1999) for all species combined, which was contradictory to what could be expected. It looks like low intensity early fire, do not damage even young sprouts and therefore this study, does no support a management with initial fire suppression after cutting. In the case of *Detarium microcarpum*, the economically most important fuelwood, there were indications of a negative effect of 2-year fire protection on coppice growth, which could be due to accumulation of decaying grass (necromass) during this period, which increased the severity of fire the third year (1996). This trend of increased mortality the first year of burning (1996) with the 2-year fire protection treatment was not confirmed when all species were included. There was a tendency to faster recruitment of stems > 10 cm GBH per stool with no fire than for the prescribed fire treatments (*figure 3B*). The 2-year fire protection treatment had the lowest mean number of stems > 10 cm GBH per stool. The accumulation of necromass is an effect of the slow decomposition process due to the arid climate. It is possible that livestock trampling and manure could accelerate decomposition due to increased termite activity and thereby reduce fuel load, but there was no significant interaction between livestock and fire regimes to support this hypothesis.

The effects of livestock and fire regime treatments varied between years and subplots as well as within subplots. The latter variation is integrated in the design of the experiment as mean value per subplot (0.25 ha) was used in analysis. Squared experimental plots of 0.25 ha have been used in the Sudanian savannah ecosystems to encompass the spatial variation [29, 30]. Lack of consistency in time and uniformity in space, regarding treatments in tropical savannah areas have been reported from other studies [19, 33]. Wind velocity, air as well as vegetation humidity and in particular grass humidity were factors that were difficult to control when applying fire regimes. The quantity and composition of the herbaceous layer were important factors determining treatment effects on a particular location. For instance the mosaic of annual (*Loudetia togoensis*) and perennial (*Andropogon gayanus*) grasses with different life cycles affected the spatial variability of dry grass at the time of burning. Amount and distribution of annual rainfall over the season largely affected the species composition of the herbaceous layer [5, 35]. Another factor affecting the spatial heterogeneity was the occurrence of bush clumps [36]. Since they are very resistant to fire even under extreme burning conditions, fire generally skirts around the edges of them, leaving the center unburned. In order to include the heterogeneity of a fire treatment it would be necessary to record the impact on each stool and even on each stem on a qualitative scale.

Stools without any living stem were considered dead and in some cases stool mortality was reduced from year to another. Some stools had no living stem at the end of the dry season (May) when the inventory was made but were found sprouting the following season. Commonly new sprouts developed close to or under the ground in particular for species such as *Detarium microcarpum* and *Entada africana* and they could have been taken into account during the inventory. In fact, some of the more common species (e.g. *Entada africana*) exhibit different modes of vegetative propagation making it difficult to distinguish root suckers from basal sprouts that start below ground. Similar difficulties to identify the extent of a vegetative regenerating individual have been reported in other studies [2, 17, 25, 31].

4.3. Conclusions

Moderate livestock grazing does not have a negative effect on stool sprouting after wood harvesting and livestock grazing and could therefore be included in silviculture. In this study there was a highly significant positive effect on stool sprouting with moderate grazing, despite the low weight given to the factor in the split plot design. Livestock pressure (0.7 TLU ha^{-1}) was estimated to be about 50% of its theoretical capacity and this could be a reason for the harmless browsing. There was no significant interaction between livestock and the three fire regimes investigated. Total fire protection for two years following wood harvesting had no or negative influence on coppice growth performance compared with annual burning. In order to recommend a change in the current management practices, there is a need to collect further evidence from other sites. The effects of various livestock intensities and timing as well as procedures for prescribed early fire should also be further investigated.

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