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Influence of Fire on Floristic Diversity and Herbaceous Production in the Ollombo Savannahs in the Republic of Congo

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Abstract **Original Research Article**

The *Loudetia simplex* (Nees) C.E. Hubb. savanna and the *Hyparrhenia diplandra* (Hack.) Stapf savanna are the main savannas in the Ollombo area of the Republic of Congo. The functioning of these savannas is influenced by the different types of fire. The aim of this study is to assess the influence of fire on the floristic diversity and herbaceous production of the savannahs in the Ollombo area. The floristic inventory and phytomass measurements were carried out at the peak of vegetation before the fires and at 2 and 10 months after the fires. The floristic inventory was carried out using the aligned quadrat points method. The data from this inventory were used to calculate diversity indices, including the Shannon-Weaver index (H'). Above-ground herbaceous phytomass was assessed using the harvesting method. The results show that floristic diversity and herbaceous above-ground phytomass vary from one type of fire to another and from one type of savannah to another. In the *Loudetia simplex* (Nees) C.E. Hubb. savannah, seasonal fire (H'=2.69) and late fire (H'=2.43) appear to favour floristic diversity at 2 and 10 months after burning, respectively. In the *Hyparrhenia diplandra* (Hack.) Stapf savannah, on the other hand, only early fire seems to favour floristic diversity two months (H'=2.7) and 10 months (H'=2.4) after burning. In terms of herbaceous above-ground phytomass, seasonal fire (0.82 ±0.07 t DM/ha) and early fire (6.49 ±1.06 t DM/ha) appear to increase herbaceous production at 2 and 10 months after burning, respectively, in the *Loudetia simplex* Nees C.E. Hubb. savannah. On the other hand, late burning (0.88 ±0.07 t DM/ha) and early burning (6.98 ±1.01 t DM/ha) appear to increase herbaceous production at 2 and 10 months respectively in the savannah with *Hyparrhenia diplandra* (Hack.) Stapf. These results could serve as a scientific basis for the sustainable management of pastures by fire and as a benchmark for future studies.

Keywords: Savannas, fires, diversity indices, phytomass, Ollombo.

INTRODUCTION

The world's ecosystems are diverse and include savannas. Savannas are natural ecosystems in which a continuous herbaceous stratum and a more or less discontinuous woody stratum coexist, and are regularly found in tropical zones (Hetier and Lopez, 2005). These natural ecosystems are rich in fodder potential and provide the bulk of cattle feed (Sala *et al.*, 2017). The savannahs of tropical Africa have numerous agro-pastoral potentialities. They are large natural pastures that have always been used for livestock farming, providing almost all the dry matter consumed by cattle in Africa (Carriere, 1996). But savannahs are often exposed to the risk of degradation due to irrational exploitation, causing a reduction in the pasture's capacity to produce the fodder used by livestock. Similarly, Abadie (2000) has already pointed out that the use of savannahs for pastoral purposes poses the acute problem of over-exploitation of plant biodiversity and compromises the renewal of herbaceous species. Because of their great importance, savannas have already been the subject of numerous studies, including that by Sankaran *et al.*, (2005), which shows that the maintenance of savannas is generally determined by three main factors: rainfall, herbivory and fire.

Every year, the savannahs are traditionally set alight to renew the pastures. The burning of vegetation in tropical zones is a very common ancestral practice in agriculture and land management. Fire is a widespread seasonal phenomenon in savannah ecosystems that controls the structure, composition, succession and productivity of vegetation and the nutrient dynamics cycle (Badia-Villas *et al.*, 2014), and stimulates plant regrowth (Ghebrehiwot *et al.*, 2011). Ecologists, who have studied the highly effective adaptations of species to their environmental conditions, stress that fire maintains savannah vegetation rather than degrading it (César, 1992).

Numerous studies have been carried out around the world on fire and have provided knowledge for the proper management of savannah fires. Unfortunately, there are very few studies on savannah fires in Congo. The few studies undertaken by Yoka (2009) and Yoka *et al.*, (2007) did not take into account the types of fire (in relation to their ignition period) on floristic diversity and herbaceous above-ground phytomass. The lack of data on the effects of different types of fire on floristic diversity and herbaceous above-ground phytomass represents a knowledge gap with regard to the sustainable management of these savannahs for pastoral livestock farming. It is with the aim of filling this scientific void that the present study is being carried out.

The general objective of the study is to improve knowledge of the impact of different types of fire on floristic diversity and herbaceous above-ground production in the Ollombo savannahs. Specifically, the aim is to: (i) assess the impact of fire types on the floristic diversity of savannahs at 2 and 10 months after burning; (ii) estimate the herbaceous above-ground phytomass of savannahs at 2 and 10 months, in relation to fire types.

MATERIALS AND METHODS

Study environment

Ollombo is one of the districts of the Plateaux administrative department, located approximately 400 km north of Brazzaville, in the south-western part of the Congolese Cuvette, between 1º and 2º south latitude and between 15º and 16º east longitude (Yoka *et al.*, 2007). The climate in the Ollobmbo area is that of the south-western part of the Congolese Cuvette, and is sub-equatorial (Mengo *et al.*, 2001). The average annual temperature is over 26°C and the average annual rainfall is just over 1600 mm. Rainfall is almost permanent. Average relative humidity is always high (98%) (Yoka *et al.*, 2007). The soils in the Ollombo area fall into two main classes (ORSTOM, 1969):

Highly desaturated and impoverished ferrallitic soils: soils formed on sandy or sandy-low clay materials, poor in bases and very permeable;

Hydromorphic soils: soils characterised by hydromorphy that is either total, but not permanent, or partial. The texture of these soils is sandy.

The vegetation is characterised by the presence of forests and savannahs. The forests are of the mesophilic deciduous type, on dry land and in swamps (IUCN, 1990). In relation to the dominant species, the savannas in the Ollombo zone are : the *Hyparrhenia diplandra* (Hack.) Stapf savanna, the *Loudetia simplex* (Nees) C.E. Hubb savanna and the *Trachypogon spicatus* (L.f.) Kuntze savanna (Yoka *et al.*, 2007). In fact, the *Hyparrhenia diplandra* (Hack.) Stapf and *Loudetia simplex* (Nees) C.E. Hubb. savannas are subgroups of the *Trachypogon spicatus* (L.f.) Kuntze group (Yoka, 2009).

Methods

Surveys and botanical identification

Surveys were carried out in the savannahs in April 2021. They were used to select the sites for the experimental plots. One station was selected, at Akongo, about 5 km from the town of Ollombo. The plant species encountered were determined in the field, at the Laboratoire de Biodiversité, de Gestion des Ecosystèmes et de l'Environnement of the Faculté des Sciences et Techniques (Université Marien NGOUABI) and at the National Herbarium (Institut National de Recherche en Sciences Exactes et Naturelles, IRSEN) in Brazzaville, Republic of Congo. The scientific names and patrons were checked on the LEBRUN and STORK site of the conservatory of the botanical garden of the city of Geneva.

Study device

Two types of savannah were selected for the study: *Hyparrhenia diplandra* (Hack.) Stapf savannah and *Loudetia simplex* (Nees) C.E. Hubb savannah. The distance between the two types of savannah is 500 m. Four plots of 25 m x 25 m (i.e. 625 m^2) are delimited in each of the savannas, each corresponding to a type of fire: early fire, seasonal fire, late fire, off-season fire.

The fire periods were as follows: (i) early June: early fire; (ii) mid-July: seasonal fire; (iii) late August: late fire; (iv) early November: off-season fire.

Floristic inventory

The floristic inventory was carried out using the linear analysis method or the aligned quadrat points method (Daget *et al.*, 1974). This method makes it possible to study the botanical composition and to define the specific frequency (Fsi), which is the number of points where the species was recorded, and the specific contribution of the species (Csi), which represents the relative participation of each species in the stand. Four lines were laid out at random in each plot representing a homogeneous area. These lines were marked by two stakes between which a decametre was stretched over the grass cover. Observations were made along lines 10 m long, with readings taken every 10 cm. Readings were taken along the line using a metal rod with a tapered edge that was moved perpendicular to the ground. At each point observed, a species is contacted either by its leaves, its stem or its inflorescences. The species is counted only once per point. The main species are those with a specific contribution of more than 5% (Apani, 1990). A species is said to be a producer when its specific contribution reaches 1% (Diamouangana, 2000). For each study plot, the most representative line of 200 points was selected to characterise the floristic composition of the savannah.

Measurement of herbaceous above-ground phytomass

Herbaceous above-ground phytomass is measured using the harvesting method, which is considered to be particularly reliable (Fournier, 1994). In each study plot, measurements were taken in 1 m 2 plots chosen at random in the plot, with four repetitions, i.e. 4 times 1 m^2 (a total of 4 m^2 per plot). The above-ground parts of the plants were cut off flush with the ground using pruning shears. The samples obtained were weighed, wrapped in newspaper, air-dried and then oven-dried for 24 hours in the Biodiversity, Ecosystem Management and Environment laboratory of the Faculty of Science and Technology. After drying, the samples were weighed to obtain a dry weight. An average biomass was calculated for all the plots.

Processing of floristic inventory data

The floristic inventory data were processed to calculate specific contributions and floristic diversity indices. A line of 200 points, the most representative of the five plots, was selected to characterise the floristic composition of the savannah. Specific contributions are calculated according to the following formula (Diamouangana, 2002):

$$\mathbf{Csi} = \frac{\text{Fsi}}{\sum \text{Fsi}} = 100 \times \frac{\text{ni}}{\sum \text{ni}}$$

With: Csi: specific contribution of species i; ni: number of sampling units where species i is present; ∑ni: total number of specific observations made.

The rank of the species is calculated after ranking all the species in descending order of specific contribution. It is equal to the ratio of the number corresponding to the species' order number to the total number of species in the survey. The rank is expressed as a percentage (%) as follows (Yoka, 2009):

$$\text{Rank (\%)} = 100 \times \frac{\text{Number corresponding to the order number of species}}{\text{Total numer of species in the survey}}$$

Diversity and equitability indices are evaluated and defined as follows (Barbaut, 1997);

- Maximum diversity: Hmax = Log_2S; where S = total number of species
- Shannon-Weaver diversity index:

$$H' = - \sum pi \times log2pi \; ; \; O < Psi < 1;$$

With H': Shannon-Weaver diversity index; pi: proportional abundance or percentage abundance of species i and corresponds here to the specific contribution of species i (Csi);

Equitability index (regularity): Pielou's equitability (Frontier and Pichod-Viale, 1991) expresses the distribution of species within the association. It is calculated using the following formula:

$$E = \frac{H'}{Hmax}$$

With : E: equitability; H': Shannon-Weaver diversity index; Hmax: maximum diversity

The value of equitability varies between 0 and 1 (Legendre and Legendre, 1984). It is 1 when all the species have the same abundance and tends towards 0 when almost all the numbers are concentrated in a single species. According to Orth and Colette (1996), the Shannon-Weaver index has high values for species with the same degree of overlap and low values when a few species have a high degree of overlap, whereas equitability tends towards zero (0) when one species has a very high degree of overlap and tends towards one (1) when all species have the same degree of overlap.

Statistically, the biological diversity and phytomass index data collected were processed in R software, version i386 4.1.0, as suggested by Matoumouene (2022). Microsoft Excel version 2016 was used to calculate means and standard errors to express the standard deviation of the phytomass sampling distribution.

For the diversity indices, which were not repeated within the same plot, the T-test or Student's t-test and the Wilcoxon 1-factor test were used after the normality test, which is the Shapiro Wilk test with a threshold of 5% (0.05). This is used to verify normality within the modalities of a variable. The Student's t-test is used when the normality test (N) is above the 5% threshold (0.05) and the 1-factor Wilcoxon test is used when the normality test (N) is below the 5% threshold (0.05).

For phytomass results that were repeated within the same plot, the 1-factor ANOVA (analysis of variances) and Kruskal Wallis tests were used, after applying two other tests: the normality test and the test for equality of variances at the 5% threshold.

The test of homogeneity or equality of variances used is the Bartlett test, used to verify the equality of variances or to evaluate the null hypothesis H0, according to which the variances of k samples drawn are identical, against the alternative hypothesis H1, that at least two of them are different.

RESULTS

Floristic composition of the savannas before the fires

The *loudetia simplex* (Nees) C.E. Hubb. savannah and the *Hyparrhenia diplandra* (Hack.) Stapf savannah are the two types of savannah in the Ollombo zone sampled at the Akongo station. Tables 1 and 2 present the floristic composition of these savannas, with the specific frequencies, specific contributions, cumulative specific contributions and ranks of the species inventoried before the fires.

Table 1, which presents the floristic composition of the *Loudetia simplex* (Nees) C.E. Hubb. savannah, shows that the main species of this savannah are *Loudetia simplex* (Nees) C.E. Hubb., *Urochloa comata* (Hochst.ex A.Rich.) Sosef, *Elionorus hensii* K. Schum and *Cyperus* sp. These species rank first in the hierarchy of the 16 species recorded in this savannah. The 16 species recorded are divided into 16 genera and 5 families. The proportions of the 5 families inventoried are as follows: Poaceae, 37.50%; Cyperaceae, 31.25%, Commelinaceae, 12.25%, Fabaceae, 12.25% and Melastomataceae, 6.25%.

Table 2 presents the floristic composition of the *Hyparrhenia diplandra* (Hack.) Stapf savannah and shows that the main species of this savannah are *Hyparrhenia diplandra* (Hack.) Stapf, *Andropogon schirensis* Hochst. ex A. Rich. Rich, *Trachypogon spicatus* (L.f) Kuntze and *Urochloa comata* (Hochst.ex A.Rich.) Sosef. These species rank first in the hierarchy of 13 species recorded in this savannah. These 13 species are divided into 12 genera and 5 families. The proportions of the 5 botanical families inventoried are as follows: Poaceae, 53.84%; Cyperaceae, 15.38%, Fabaceae, 15.38%, Asteraceae, 7.69% and Rubiaceae, 7.69%.

Table 1: Specific frequencies, specific contributions, cumulative specific contributions and ranks of species in the most representative plot in the *Loudetia simplex* (Nees) C.E. Hubb savannah

Species	Families	Fsi (%)	Csi (%)	Csc (%)	Rank (%)
Loudetia simplex (Nees) C.E. Hubb.Susp.simplex	Poaceae	169	52.16	52.16	6.25
Urochloa comata (Hochst.ex A.Rich.) Sosef	Poaceae	39	12.03	64.19	12.25
Elionorus hensii K. Schum	Poaceae	25	7.71	71.9	18.75
Cyperus sp.	Cyperaceae	22	6.70	78.6	25.00
Setaria sphacelata (Schumach.) Stapf & C.E. Hubb.ex M.B. Moos var. sphacelate	Poaceae	14	4.39	82.99	31.25
Trachypogon spicatus (L.f) Kuntze	Poaceae	11	3.39	86.38	37.50
Cyanotis lanata Benth.	Commelinaceae	10	3.09	89.47	43.75
Monocymbuim ceresiiforme (Nees) Staapf	Poaceae	8	2.46	91.93	50.00
Eriosema erici-rosenii R.E. Fr. var.erici-rosenii	Fabaceae	4	1.23	93.16	56.25
Murdania simplex (Vahl) Brenan	Commelinaceae	4	1,23	94,39	62,50
Kyllinga erecta Schumach.	Cyperaceae	4	1,23	95,62	68,75
Scleria induta Turrill.	Cyperaceae	4	1,23	96,85	75,00
Bulbostylis laniceps (K.Schum.) C.B. Clarke ex T. Durand & Schinz	Cyperaceae	3	0.92	99.77	81.25
Undetermined	Cyperaceae	3	0,92	98,69	87,50
Heterotis sp.	Melastomataceae	3	0,92	99,61	93,75
Indigofera capitata kotschy	Fabaceae	1	0,30	**99,91**	**100**
		324	**99.91**		

Legend: Fsi: specific frequency of species i; Csi: specific contribution of species i; Csc: cumulative specific contribution.

Table 2: Specific frequencies, specific contributions, cumulative specific contributions and ranks of species in the most representative plot in the *Hyparrhenia diplandra* (Hack.) Stapf savannah

Species	Families	Fsi(%)	Csi (%)	Csc (%)	Rank (%)
Hyparrhenia diplandra (Hack.) Stapf var. diplandra	Poaceae	153	39.33	39.33	7.69
Andropogon schirensis Hochst. ex A. Rich.	Poaceae	79	20.30	59.63	15.38
Trachypogon spicatus (L.f) Kuntze	Poaceae	50	12.85	72.48	23.07
Urochloa comata (Hochst. ex A. Rich.) Sosef	Poaceae	32	8.22	80.7	30.76
Ctenium newtonii Hack. Var. newtonii	Poaceae	18	4.62	85.32	38.46
Urochloa maxima (Jacqq.) R.D. Webster	Poaceae	18	4.62	89.94	46.15
Cyperus sp.	Cyperaceae	14	3.60	93.54	53.84
Ageratum houstonianum Mill.	Asteraceae	10	2.58	96.12	61.53
Elionorus hensii K. Schum	Poaceae	4	1.02	97.14	69.23
***Bul**bostylis laniceps* (K.Schum.) C.B. Clarke ex T. Durand & Schinz	Cyperaceae	3	0.77	97.91	76.92
Indigofera capitata Kotschy	Fabaceae	3	0.77	98.68	84.61
Tephrosia nana Kotschy ex Schweinf.	Fabaceae	3	0.77	99.45	92.30
Spermacoce sp.	Rubiaceae	2	0.51	**99.96**	**100**
		389	**99.96**		

Legend: Fsi: specific frequency of species i; Csi: specific contribution of species i; Csc: cumulative specific contribution.

Floristic diversity before and after fires of the *Loudetia simplex* (Nees) C.E. Hubb. savannah

The values of the Shannon-Weaver, maximum diversity and Piélou equitability indices for the *Loudetia simplex* (Nees) C.E. Hubb. savannah, before and after the fires, are presented in Table 3. Analysis of this table shows that, before the fires, the Shanon-Weaver index, maximum diversity and Pielou equitability varied respectively from 1.97 to 2.54, from 3.58 to 4.09 and from 0.55 to 0.67 depending on the plots sampled. The differences between these values are statistically highly significant (P-value = 0.001). These values show that the *Loudetia simplex* (Nees) C.E. Hubb. savannah is less floristically diverse before the fires and the distribution of species seems less equitable.

Two months after the fires, the Shannon-Weaver index values appear to be higher than those recorded before the fires. It was the seasonal fire that seemed to increase the Shannon-Weaver index the most (H'=2.69), and consequently floral diversity, followed by the late fire (H'=2.66). The distribution of species appears to be more equitable after the seasonal fire and the late fire. The differences between the values of these diversity indices are statistically highly significant (P-value = 0.001).

Ten months after burning, the late fire seems to have increased floristic diversity (H'=2.43 compared with 1.97 before the fire) and allowed an equitable distribution of species. The differences between the values of these diversity indices ten months after the fire are statistically highly significant (P-value = 0.001), with the exception of maximum diversity, where the values are not statistically different (P >0.05). In the control plot (not burnt), the Shannon-Weaver diversity index was 1.78, the maximum diversity was 3.17 and the equitability was 0.56. These results are lower than those found ten months after the fires. Fire therefore favours floristic diversity and the equitable distribution of species in the *Loudetia simplex* (Nees) C.E. Hubb. savannah after ten months.

Table 3: Values of the Shannon-Weaver, maximum diversity and Piélou equitability indices of the *Loudetia simplex* (Nees) C.E. Hubb. savannah before and after fires

Type of fire	Before the fire			2 months after the fire			10 months after the fire		
	H'	Hmax	E	H'	Hmax	E	H'	Hmax	E
Early fire	2.23b	3.81a	0.58a	2.21a	4.00a	0.55a	2.02a	3.70a	0.54a
Seasonal fire	2.52a	4.09a	0.62b	2.69b	3.81a	0.71b	2.06a	3.58a	0.57a
Late fire	1.97c	3.58b	0.55a	2.66b	3.70b	0.72b	2.43b	3.70a	0.66b
Off-season fire	2.54a	3.81a	0.67b	2.60b	3.91a	0.66b	2.30b	3.70a	0.62b
P-value	***	***	***	***	***	***	***	0.08	***

Legend: ***: 0.001 (highly significant difference); >0.05: no difference; H': Shannon-Weaver index; Hmax: maximum diversity; E: Piélou equitability.

Floristic diversity before and after fires of the *Hyparrhenia diplandra* (Hack.) Stapf savannah

The values of the Shannon-Weaver, maximum diversity and Piélou equitability indices for the *Hyparrhenia diplandra* Hack.) Stapf savannah, before and after the fires, are presented in Table 4. Analysis of this table shows that before the fires, the Shanon-Weaver index, maximum diversity and Pielou equitability varied respectively from 1.76 to 2.67, from 3.17 to 3.70 and from 0.53 to 0.72 depending on the plots sampled. The differences between these values are statistically highly significant (P-value = 0.001). These values show that the *Hyparrhenia diplandra* (Hack.) Stapf savannah is less floristically diverse before the fires and the distribution of species seems less equitable.

Two months after the fires, the Shannon-Weaver index values appear to be higher than those recorded before the fires. It was the early fire that seemed to increase the Shannon-Weaver index the most (H'=2.70), and consequently floral diversity, followed by the off-season fire (H'=2.52). The distribution of species appears to be more equitable after the early and in-season fires. The differences between the values of these diversity indices are statistically highly significant (P-value = 0.001).

At ten months after burning, the early fire appears to maintain floristic diversity (H'=2.40 compared with 2.67 before the fire) and seems to maintain the equitable distribution of species. The differences between the values of these diversity indices ten months after the fire are statistically very significant (P-value = 0.001). In the control plot (not burnt), the Shannon-Weaver diversity index was 1.52, the maximum diversity was 3.00 and the equitability was 0.51. These results are lower than those found ten months after the fires. Fire therefore favours floristic diversity and the equitable distribution of species in the *Hyparrhenia diplandra* (Hack.) Staf savannah after ten months.

Table 4: Values of the Shannon-Weaver, maximum diversity and Piélou equitability indices for the *Hyparrhenia diplandra* (Hack.) Stapf savannah before and after fires

Type of fire	Before the fire			2 months after the fire			10 months after the fire		
	H'	Hmax	E	H'	Hmax	E	H'	Hmax	E
Early fire	2.67a	3.70a	0.72a	2.70a	3.58a	0.75a	2.40a	3.70a	0.65a
Seasonal fire	2.15a	3.58a	0.53b	2.33b	3.32a	0.70a	1.94b	3.70a	0.52b
Late fire	1.76b	3.52a	0.53b	2.27b	3.58a	0.63b	1.69b	2.81b	0.60a
Off-season fire	1.97b	3.17a	0.61a	2.52c	4.00b	0.63b	1.79b	3.17b	0.56b
P-value	***	***	***	***	***	***	***	***	***

Legend: ***: 0.001 (highly significant difference); H': Shannon-Weaver index; Hmax: maximum diversity; E: Piélou equitability

Average herbaceous above-ground phytomass of the *Loudetia simplex* (Nees) C.E. Hubb. savannah

Table 5 shows the average herbaceous above-ground phytomass values for the *Loudetia simplex* (Nees) C.E. Hubb. savannah. Analysis of this table shows that phytomass is reconstituted two months after burning and varies on average from 0.73 ±0.05 to 0.82 ±0.07. Seasonal fire seems to favour good phytomass reconstitution (0.82±0.07 t DM/ha) at this period compared with other types of fire. However, there was no difference in phytomass between fire types (P-value >0.05).

Ten months after the fires, mean phytomass values varied between 4.57 ±0.75 and 6.49 ±1.06 t DM/ha for all plots. The early fire (6.49 ±1.06 t DM/ha) seems to favour good phytomass reconstitution ten months after the savannah was burnt. The differences in phytomass were statistically highly significant between fire types (P-value = 0.001).

In the control plot (not burnt), the herbaceous above-ground phytomass was 6.27 ±1.12 t DM/ha. This result is almost the same as that found 10 months after the early fire. Fire therefore favours herbaceous above-ground production in the *Loudetia simplex* (Nees) C.E. Hubb. savannah after ten months.

Table 5: Phytomass of *Loudetia simplex* (Nees) C.E. Hubb. savannah plots before and after fires

Type of fire	Before the fire	2 months after the fire	10 months after the fire
	Ph (t DM/ha)	Ph (t DM/ha)	Ph (t DM/ha)
Early fire	10.18 ±1.55b	0.74 ±0.05a	6.49 ±1.06a
Seasonal fire	4.54 ±1.15a	0.82 ±0.07a	4.57 ±0.75b
Late fire	8.32 ±1.32ab	0.73 ±0.05a	4.58 ±0.63b
Off-season fire	6.27 ±1.05 ab	0.78 ±0.01a	4.91 ±0.05b
P-value	***	0.07	***

Legend: *** : 0.001 (highly significant difference); >0.05 (no difference); Ph = phytomass

Average above-ground herbaceous phytomass of the *Hyparrhenia diplandra* (Hack.) Staf savannah

The mean herbaceous above-ground phytomass values for the *Hyparrhenia diplandra* (Hack.) Stapf savannah are presented in Table 6. Analysis of this table shows that phytomass is reconstituted two months after burning and varies on average from 0.39 ±0.02 to 0.88 ±0.07. Late fire seems to favour good phytomass reconstitution (0.88 ±0.07t DM/ha) at this period compared with other types of fire. However, the differences in phytomass between fire types were statistically highly significant (P-value = 0.001).

Ten months after the fires, mean phytomass values varied between 5.34 ±1.55 and 6.98 ±1.01 t DM/ha for all plots. The early fire (6.98 ±1.01 t DM/ha) seems to favour good phytomass reconstitution ten months after the savannah was burnt. Statistically, there was no difference in phytomass between fire types (P-value >0.05).

In the control plot (not burnt), the herbaceous above-ground phytomass was 5.9 ±1.08 t DM/ha. This result is lower than that found 10 months after the early fire. Fire therefore favours an increase in herbaceous above-ground production in the *Hyparrhenia diplandra* (Hack.) Stapf savannah after ten months.

Table 6: Phytomass of *Hyparrhenia diplandra* (Hack.) Stapf savannah plots before and after fires

Type of fire	Before the fire	2 months after the fire	10 months after the fire
	Ph (t DM/ha)	Ph (t DM/ha)	Ph (t DM/ha)
Early fire	9.12 ±1.08ab	0.55 ±0.01c	6.98 ±1.01a
Seasonal fire	11.77 ±1.98a	0.68 ±0.09b	6.65 ±0.98a
Late fire	7.37 ±1.52b	0.88 ±0.07d	6.20 ±1.06a
Off-season fire	7.62 ±0.97b	0.39 ±0.02a	5.34 ±1.55a
P-value	***	***	0.27

Legend: ***: 0.001 (Very significant difference); ** :0.01 (Significant difference); * :0.05; >0.05 (No difference); Ph = phytomass.

DISCUSSION

The floristic composition of the savannahs sampled before the fires varied according to the dominant species in the savannah. In the *Loudetia simplex* (Nees) C.E. Hubb. savannah, 16 species in 16 genera and 5 families were recorded, and in the *Hyparrhenia diplandra* (Hack.) Stapf savannah, 13 species in 12 genera and 5 families were recorded. Stapf, 13 species in 12 genera and 5 families have been recorded. In both types of savannah, the most representative families in terms of number of species are Poaceae (37.50% to 53.84%) and Cyperaceae (15.38% to 31.25%). These two families are characteristic of savannahs. The high proportion of Poaceae in the study area can be justified by the fact that these taxa have a very high tillering capacity and a greater rate of regrowth after the passage of fire (Salette, 1970). These results are similar to those found by Akossoua *et al.*, (2010) in coastal areas of Côte d'Ivoire, where they showed the predominance of Poaceae and Cyperaceae. Pooaceae offer very high fodder potential, which would favour the use of savannahs for pastoral purposes (Yoka, 2009).

The diversity indices found in this study show that they vary from one type of savannah to another and, for one type of savannah, they vary according to the type of fire. In the *Loudetia simplex* (Nees) C.E. Hubb. savannah, the Shannon-Weaver index is high two months after seasonal fire (H' = 2.6) and ten months after late fire (H' = 2.43), and in the *Hyparrhenia diplandra* (Hack.) Stapf, it is high two months (H' = 2.70) and ten months (H' = 2.40) after the early fire. At two months after the fires, a favourable period for grazing (Yoka *et al.*, 2013), early and late fire appear to favour the diversification of the flora in the *Loudetia simplex* (Nees) C.E. Hubb. savannah and the *Hyparrhenia diplandra* (Hack.) Staf savannah, respectively. These two types of fire could then be encouraged in the regreening of these savannahs, which are potential pastures for feeding livestock. In their studies in Madagascar, Rakotoarimanana *et al.*, (2001) and Rakotoarimanana and Grouzis (2006) had already shown that early fire increases the floristic diversity of the savannah.

At the peak of vegetation, i.e. ten months after the savannah fires (Yoka, 2009), late fire seems to increase floristic diversity in the *Loudetia simplex* (Nees) C.E. Hubb. savannah and early fire acts in the same way in the *Hyparrhenia diplandra* (Hack.) Stapf savannah. These results show that the action of fire is not uniform in the vegetation; it depends on the type of vegetation and the burning period. This difference in fire action could also be explained by the moisture content of the plants and the soil, the behaviour of the plants in the face of fire and the wind speed at the time of burning. Sustainable management of savannahs by fire would recommend early and late fire to increase their floristic diversity, in relation to the type of grassy vegetation. These two types of fire would encourage the equitable distribution of species within the vegetation. Poilecot and Loua (2009) showed that fire favours floristic diversity in savannahs. The results of the present study, which show that after ten months, the floristic diversity of the unburnt savannah (set aside) is lower than that of the burnt savannah, confirm those of these two previously cited authors.

Fires allow the vegetation to recover. The herbaceous above-ground phytomass of the savannas sampled varies from one type of savanna to another and, for one type of savanna, from one type of fire to another. In the *Loudetia simplex (*Nees) C.E. Hubb. savannah, seasonal fire and early fire appear to increase herbaceous above-ground phytomass at two months and ten months respectively. In the Hyparrhenia diplandra (Hack.) Stapf savannah, late and early fire appear to increase herbaceous above-ground phytomass at two and ten months respectively. Overall, these results show that seasonal and late fire would be favourable for increasing herbaceous production at two months after burning, while early fire would be favourable for increasing this production at ten months after burning. In their study in Madagascar, Rakotoarimanana *et al*., (2001) had already shown that late fire increases savannah phytomass. Dembele (1996) states that the passage of fire stimulates herbaceous production. The results of the present study, which show that after ten months, the herbaceous above-ground phytomass of the unburnt savannah (set aside) is lower than that of the burnt savannah, confirm those of the above-mentioned author.

CONCLUSION

This study shows that fires have a positive influence on the floristic diversity and herbaceous production of savannahs, but their effect varies according to the vegetation and the time of ignition. More specifically, early fire and seasonal fire seem to favour flora diversification two months after burning; early fire and late fire seem to increase floristic diversity ten months after burning. In terms of herbaceous above-ground production, seasonal fire and late fire seem to increase it two months after burning, whereas early fire seems to increase it ten months after burning. The choice of fire type therefore depends on the objective set. These results provide basic information for the sustainable management of savannahs by fire and could serve as a benchmark for future scientific work.

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