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Impacts of early and repeated fires on microbial activities in the wooded savannahs of Burkina Faso

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Abstract

Bush fires which effects depend on their intensity as well as their season of occurrence are considered as a major disturbance of savanna ecosystems. The objectives of this research were to understand the changes induced on the properties of the soil by repeated early fires on microbial activities. The study was conducted on a factorial design installed on two (02) sites, namely the classified forest of Dindéresso located in the West (firsts fires were applied in 2010) and that of Tiogo located in the Center West (first fire were applied since 1992) of the country. Measurements have been carried out before, after the passage of the fire and during the rainy season on soils. The results obtained showed that the period during which the measurements were taken played a role in the microbial dynamics, thus showing the highest rates in the rainy season for the control (3.02 C $g.m^{-2}$) and the burnt plots (3.63 C $g.m^{-2}$) after fire. Microbial nitrogen is the element that varied considerably, going from 1.60 for the control to 1.74 N $g.m^{-2}$ for the burnt plots for the Dindéresso site. Concerning Tiogo, the microbial biomass is higher on the burned plots (6.04 C $g.m^{-2}$) and (6.01 C $g.m^{-2}$) for the control in rainy season sampling.

Keywords: Savannah; Early Fires; Repeated Fire; Microbial Biomass; Burnt Plots; Burkina Faso

1. Introduction

In African savannahs, fire is a key factor[1]; it causes major disturbances and changes in savannah ecosystems [2]. Between 25% and 50% of the Sudanian zone burns each year [3]. These fires are mainly caused by human activity [3]. The regular occurrence of fire, depending on its intensity and severity, can have varying degrees of impact on the biogeochemical, physical and microbial processes that govern nutrient storage [4]. Soil microorganisms play an important role in nutrient cycling, but they are extremely sensitive to environmental changes [5]. In general, fire helps to reduce microbial respiration, and the extent of this depends on the severity of the fire and the time elapsed after it [6]. Among the population of microorganisms, fungi are the most sensitive to heat [7] The work of [8] showed that high-intensity fires can significantly reduce soil microbial biomass. On the other hand, [9] reported an increase in microbial biomass after fire, which may be due to the deposition of nutrient-rich ash, stimulating microbial growth after fire [10]. Other studies suggest that the responses of the microbial community to fire are restricted to the first few centimetres of soil [11]. In the wooded Sudanian savannah, fire is widely used as a development and management tool [12]. Early or prescribed fire is recommended by managers as the only practical alternative to late fires, which are often unavoidable and harmful to biodiversity and to the maintenance of ecosystem structure and functioning. Fire can affect soil organisms directly or indirectly, and the quantity of nutrients in savannah soils and the consequences for the soil and its components seem to depend strongly on the intensity and timing of the fire [13]. However, despite the need to assess

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the impact of different management practices on sustainable carbon management, little information exists on the effect of fire on soil respiration [14]. In this study, we analyse the response of soil respiration to repeated fires and variations in fuel quantity in a wooded savannah in West Africa. We hypothesise that variation in fuel quantity will influence the respiratory activity of microorganisms. The specific objectives are as follows: (1) to evaluate the respiratory activity of soil microorganisms in response to variation in fuel quantity; (2) to identify the limiting nutrients in the soil by analysing the kinetics of microbial respiration after the addition of nutrients (glucose, nitrogen and inorganic phosphorus).

2. Material and methods

2.1. Site description

The long-term burning experiments were conducted at two Sudanian savanna woodland sites in western Burkina Faso. The first experimental site was located in the Dinderesso state forest (11. 225°N, 4.447°W; 359m above seas level, asl) (Figure 1). The geological parent material of castic sediments is composed of schists, sandstones and dolomite [15] and formed during the Neoproterozoic era. The second site was located in the Tiogo State Forest (12.223°N, 2.706°W; 257m asl). The soils at both sites are >75 cm deep, have relatively high silt fractions, slightly acidic pH, high base saturation and both are classified as lixisols (FAO classification system)[16]. The soil at the Tiogo site was slightly more fertile than the Dinderesso site, as evident from the higher effective cation exchange capacity, total nitrogen and organic carbon stocks in the topsoil (5 cm). Both sites have a unimodal precipitation, with a prolonged dry season from November till April which is followed by a short yet intense rainy season. The mean annual precipitation at the Tiogo site is 862±125mm (2006-2015) and at the Dinderesso site is 1010±145 mm (2009-2011). The Tiogo experimental site started in 1992, while the Dinderesso experiment was established in 2010. For our study, we selected three plots where fire had been permanently excluded, hereafter called fire-exclusion plots (24 years and 6 years of fire-exclusion in Tiogo and Dinderesso, respectively), and four plots that had been burnt annually, hereafter called “fire plots”. At the Tiogo site, the plots were 50 x 50 m with a 20-30 m firebreak; at the Dinderesso site, the plots were 80 x 30mwith a 5-10 m firebreak. The prescribed burning was conducted early in the dry season, in accordance with the local practices. A fire was set, which can be characterized as low intensity given the low amount of fuel load and a team of workers monitoring the fire to ensure it remained contained. Once burning, the fire was left undisturbed, which meant that unburnt patches were incidentally left within the plot.

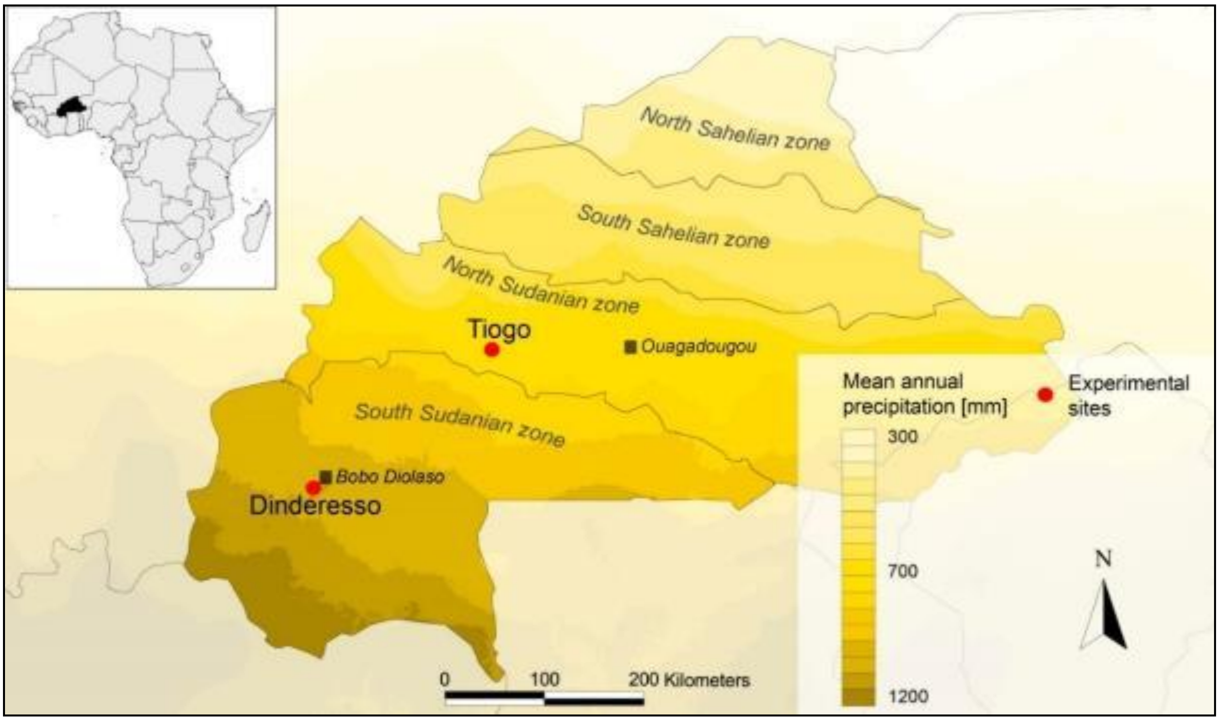

Figure 1 Location of the Dindéresso and Tiogo classified forests [17]

2.1.1. Soil physical characteristic

The results show that both sites have a sandy-clay texture (Table 1). Soil moisture varies from 0.6 to 0.7% in the control and burnt plots. At Tiogo, soil moisture is higher, at around 2% in both the burnt and control plots. Bulk density values were 1.45 and 1.36 at Dindéresso and Tiogo respectively.

Table 1 Soils characteristics (0-5cm)

Parameters measured	Dindéresso		Tiogo	
	Burnt plots (n=9)	Control plots (Unburnt plot) (n=3)	Burnt plots (n=9)	Control plots (Unburnt plot) (n=3)
Sand (%)	6±1	9±4	13±1	12±1
Silt (%)	52±3	57±3	30±2	32 ±1
Clay (%)	42±2	34±1	57±2	56 ± 0
Soil moisture (%)	0,7±0,0	0,6±0,0	2±0,3	2±0,1
Soil density ($g\ cm^{-3}$)	1,45±0,03	1,45±0,03	1,36±0,03	1,36±0,03

2.1.2. Analysis of soil

Soil samples were taken before and after the fire and composites were made for each individual plot. Monitoring continued during the rainy season in the burnt and control plots. The fumigation-extraction method [18] was used to determine microbial biomass. The technique for measuring microbial biomass involves measuring the alpha-amino nitrogen contained in the soil microorganisms, which is then measured using colorimetry. The microbial biomass values were calculated and converted into biomass stock $g\ C/m^2$ and $g\ N/m^2$.

2.2. Statistical analysis

The statistical treatment of all the data in this study was carried out using analysis of variance (ANOVA) and the generalised linear regression model with the aid of the SPSS 19.0 for Windows software (IBM Corporation, USA).

3. Results

3.1. Quantification of microbial biomass in burnt and control plots in Dinderesso's site

Table 2 Quantity of microbial biomass in burnt and control plotsin Dinderesso's site (Means followed by the same letter in the same column are not significantly different p<0.05)

Measured parameters	Season	Humidity %	Microbial Biomass C [$g\ C/m^2$soil]	Microbial Biomass N [$g\ N/m^2$ soil]
Control (without fire)	Dry season	9,75±0,63	1,71±0,5^{ab}	1,74±0,5^{a}
	Rainy season	8,91±0,7	3,02±0,91^{c}	1,36±0,3^{a}
Burnt plots (before fire)	Dry season	8,67±2,14	1,34±0,4^{a}	1,60±0,24^{a}
Burnt plots (after fire)	Dry season	8,92±0,2	3,63±0,80^{c}	0,76±0,5^{b}
Burnt plots (after fire)	Rainy season	8,67±0,92	2,86±0,6^{bc}	1,28±0,2^{a}
Probability		P=0,758	P<0,0001	P<0,0001

The results of the analysis of microbial biomass dynamics showed that the lowest microbial biomass was observed in the control ($1.71\ g\ C\ m^{-2}$) without fire and in the burnt plots ($1.34\ g\ C\ m^{-2}$) before the application of fire (Table 2). On the other hand, the highest microbial biomass was found in the control during the rainy season ($3.02\ g\ C\ m^{-2}$) and in the burnt plots ($3.63\ g\ C\ m^{-2}$) after fire. Statistical analysis showed significant variations between the different treatments (p<0.0001). For microbial nitrogen, the highest values were found in the control and in the plots burnt before the fire.

Values ranged from 1.60 to 1.74 g N m^{-2} in the pre-fire burnt plots and the control (no fire) respectively. Statistical analysis revealed significant variations in microbial biomass C [g C/m^2soil] and N [g N/m^2soil] ($p<0.0001$), although soil moisture did not vary significantly between the different treatments ($p=0.758$).

3.2. Quantification of microbial biomass in burnt and control plots in Tiogo's site

At the Tiogo site, the highest values for microbial biomass were observed in the burnt plots (6.04 g C m-2) and the control plots without fire in the rainy season (6.01 g C m^{-2}), and to a lesser extent in the control plots (5.01 g C m^{-2}) (Table 3). In terms of microbial nitrogen, the highest biomasses were also observed in these same plots: the plots burnt in the rainy season (1.66 g N m^{-2}) and the control in the rainy season (0.87 g N m^{-2}). In addition to these high values in the control and burnt plots where samples were taken in the rainy season, soil moisture levels measured in these plots were also high, suggesting a correlation between soil moisture levels and microbial biomass. Statistical analyses confirmed significant variations between the different treatments for soil moisture ($p<0.005$), microbial C ($p<0.004$) and microbial N ($p<0.0001$).

Table 3 Quantity of microbial biomass in burnt and control plots in Tiogo's site (Means followed by the same letter in the same column are not significantly different $p<0.05$)

Measured parameters	Sampling period	Humidity %	Microbial Biomass C [g C/m2]	Microbial Biomass N [g N/m2]
Control (without fire)	Dry season	12,06±2,6b	5,01±0,66ab	0,31±0,12a
	Rainy season	15,54±0,9a	6,01±0,24a	0,87±0,52a
Burnt plots (before fire)	Dry season	12,35±1,86b	4,7±0,96b	0,45±0,25a
Burnt plots (after fire)	Dry season	12,32±1,64b	4,9±0,60b	0,51±0,33a
Burnt plots (after fire)	Rainy season	14,61±1,27ab	6,04±0,74a	1,66±0,45b
Probability		P<0,005	P<0,004	P<0,0001

4. Discussion

The results of the study showed that for the Dindéresso site, the microbial biomass in g C/m^2 is almost twice that of Tiogo. However, the biomass in g N/m^2 was much lower at Dindéresso. Complete combustion (around 80% at Dindéresso compared with only 60% at Tiogo) makes more carbon available. This could explain the high level of microbial carbon. As for microbial nitrogen, when soil moisture is analysed at the time of sampling, it is much higher in Tiogo. This could explain the low mineralisation of nitrogen and therefore the low level of microbial nitrogen in the soil. However, by monitoring this activity over time and extending sampling during the rainy season, the results showed a strong increase in microbial activity in the burnt plots and in the control plots without fire.

This regrowth is also slightly noticeable in plots burnt just after the fire. This slight increase just after the fire may be due to the deposition of nutrient-rich ash, which stimulates post-fire microbial growth [10]. In addition, during the rainy season, microbial activity is also high, especially at the Tiogo site, where soil moisture reaches 15% in the plots burnt as a control. Soil moisture is a limiting factor in microbial activity [19]. This could explain why, in the rainy season and with the increase in soil moisture, microbial activity resumed and was much higher than in the dry season, even with the addition of nutrients through ash. Ash incorporated into the soil temporarily increases the soil's pH and nutrient reserves and modifies its physical properties. Ash deposition also stimulates soil microbial activity and vegetation growth [20]. However, it should also be noted that ash deposition is susceptible to huge losses throughout the year. The fire season can have a different impact on the magnitude and direction of these biogeochemical effects due to differences in fire intensity and differences in weather conditions immediately after the fire [21]. Post-fire weather conditions can also influence soil physico-chemical conditions and nutrient concentrations. Heavy rainfall immediately after a fire can lead to loss of the nutrient-rich ash layer through erosion and runoff [22]. In our context, after the fire, the ash deposit is much more subject to enormous losses due to wind and runoff at the start of the rainy season.

This could explain why the control plots may have similar and often higher microbial activity than the burnt plots, which have benefited from an additional supply of nutrients. We can therefore deduce that ecosystems under the influence of early and frequent fires make enormous gains in terms of nutrients (around 122 to 653 kg/ha in ash), but that this contribution is not stable over the year and actually represents a loss on two levels for the system (first level of loss: the combustion of the biomass removed, which is a loss of income for the system, and the second level of loss: the instability of the input or gain over the season, which in reality represents a loss because the system is unable to retain the gain within itself). As a result, over time, and given that tropical soils are already poor in nitrogen and carbon, these losses due to fires could contribute even more to the degradation of these tropical and savannah soils. However, much more in-depth studies of the mineral balance over a longer period, taking into account other savannah ecosystems (wet savannah) and using modelling, could help us to better channel and quantify the various losses and gains in savannah ecosystems subject to regular fire.

5. Conclusion

In terms of microbial activity, due to the deposition of ash, an increase in microbial biomass was observed after the fire and lasted until the rainy season. However, ash deposit remains unstable and variable on the burnt plots, leading to huge losses in the potential contribution that the fires could make to the soil by burning the epigenetic vegetation.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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