World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(Research Article)

Check for updates

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

Sabine W. M. F. Doamba [1, *], Abraham-Yannick O. Bamouni [2] and Patrice Savadogo [3]

[1] *Yembila Abdoulaye TOGUYENI University, High Institute for Sustainable Development, BP: 54. Fada N'Gourma, Burkina Faso.*
[2] *Nazi Boni University, Rural Development Institute, 01 BP 1091, Bobo Dioulasso, Burkina Faso.*
[3] *National Center for Scientific and Technological Research (CNRST), Institute for Environmental and Agricultural Research (INERA), Department of Environment and Forests,03 BP 7047, Ouagadougou 03, Burkina Faso.*

World Journal of Advanced Research and Reviews, 2024, 24(03), 1210–1216

Publication history: Received on 29 October 2024; revised on 11 December 2024; accepted on 12 December 2024

Article DOI: https://doi.org/10.30574/wjarr.2024.24.3.3768

Abstract

Bush fires, considered to be a major ecological disturbance in savannah ecosystems, are also rife in large parts of Burkina Faso. The objectives of this research were to understand nutrient dynamics by early and repeated fires. The study was conducted on a factorial set-up installed on two (02) sites, namely the Dindéresso classified forest located in the west (where the first fires started in 2010) and the Tiogo classified forest located in the centre-west of the country (since 1992, for the first fires). Measurements were taken before and after the fire and ashes were also evaluated. The results showed that the epigeous biomass was approximately the same on both sites (around 4 $t.ha^{-1}$). With regard to biomass dynamics and ash levels, analysis of the results showed that the control plots had the highest herbaceous biomass levels (320 and 350 $m.g^{-2}$), while ash levels were much higher at the Tiogo site (65.3 $g.m^{-2}$) than at Dindéresso (12.19 $g.m^{-2}$). Assessment of the nutrient pool showed that before the fire, the carbon present in the biomass was high at both sites (168±19 g m^{-2} at the Dindéresso site and 178±0.6 g m^{-2} at the Tiogo site). After the fire, nutrient losses at the different sites were observed for C (82% at Dindéresso compared with only 45% at Tiogo), N (91% at Dindéresso compared with only 69% at Tiogo) and P (79% at Dindéresso compared with only 63% at Tiogo). In general, nutrient losses are higher in Dindéresso than in Tiogo, with an estimated difference of more than 45% for C, 24% for N and 20% for P.

Keywords: Savannah; Early Fires; Repeated Fire; Ash; Nutrients; Burkina Faso

1. Introduction

The savannahs cover 20% of the earth's surface and represent important ecosystems and a unique habitat for many human and animal populations[1]. The main characteristic of savannahs is that they are composed of herbs and trees in varying proportions. They are highly dynamic environments. The structure and dynamics of these ecosystems, of inestimable importance for the human economy, are essentially regulated by the availability of water and nutrients, on the one hand, and by the occurrence of important disturbances, such as herbivores and feral animals, on the other. Savanna species, often referred to as shrub species, are generally produced at the landscape level. The biomass produced during the growing season is decomposed and transformed into fuel for fires. In wooded savannahs, around 25% to 50% of the land burns each year, mainly as a result of human activity[2]. The local population generally uses the wood for the production and renewal of pastures, as well as for their daily needs (firewood, medicinal plants, other products and services). These activities also have an impact on the environment. Recent studies in the Guinean savannah in Côte d'Ivoire have shown that perennial grass species differ in their sensitivity to fire treatments [3]. Late fires always cause a decline in the population of these species, whereas the absence of fire is unfavourable to grasses and even leads to the disappearance of certain species such as *Loudetia simplex* [3]. In addition to their destructive effect on vegetation,

* Corresponding author: Sabine W.M.F. Doamba

fires have repercussions on the soil, particularly on surface horizons, modifying their physical, chemical and biological properties [4-6]. Burnt vegetation returns to the soil surface in the form of ash, providing the soil with fine elements and nutrients [7, 8]. This addition of ash also raises the soil's pH value, thereby stimulating microbial activity and, at the same time, the mineralisation of nitrogen [9]. However, in an ecosystem that is also subject to climatic constraints, the fate of ash on the soil remains problematic, as it is often quickly blown away by the wind or washed away by rainwater [7]. The loss of soil cover not only increases soil erosion, but also alters the physical characteristics of the soil and causes nutrients to be lost through leaching or drainage [10, 11]. Fire is also known to have a negative impact on infiltrability [12]. All these disturbances inhibit the chances of regrowth and also slow down the activity of the soil fauna that plays a vital role in the processes of decomposition, nutrient recycling and modification of soil structure [13]. Similarly, the significant loss of organic matter directly and indirectly affects soil microorganisms [14, 15]. In the West African savannah, much research on bushfires has focused on vegetation dynamics [16-18], fire behaviour [19, 20] and soil fauna [21]. Recent work has also studied the impact of fire on greenhouse gas emissions [22] and on physico-chemical parameters [23, 24]. Little work has been done on the impact of fire on nutrient dynamics and soil microbiology. A study of these latter aspects will make it possible to supplement the work already underway in this field, and to formulate, at a later date and in a comprehensive manner, fairly substantial conclusions for a more participatory and environmentally friendly development and management system. This explains the choice of the theme “Impacts of early and repeated fires on nutrients in the wooded savannahs of Burkina Faso**”**. The overall aim of this study was to evaluate the dynamic of nutrient of Sudanian savannahs subjected to the action of early and repeated fires in Burkina Faso. Specifically, the aim was to: (1) Assessing the richness of the ash and (2) quantify the nutrient pools and losses on burnt plots.

2. Material and methods

2.1. Site description and soil characteristics

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 [25] 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)[22]. 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.

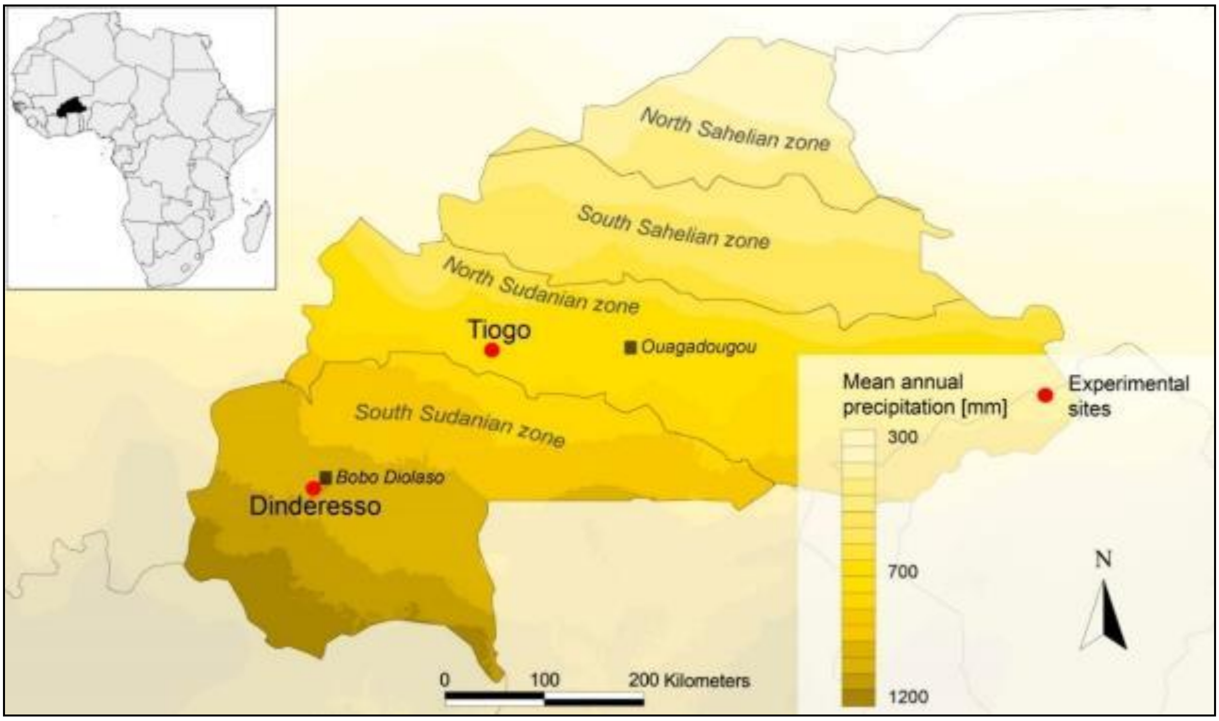

Figure 1 Location of the Dindéresso and Tiogo classified forests [24]

2.1.1. Carbon and nitrogen losses through burning

Total above-ground C and N losses from volatilization through burning were quantified by comparing the C and N stocks in leaf litter before and after burning as well as from ash deposits. Within each of the four fire plots we established 10 paired sampling locations. From one of the paired sampling locations, we collected the biomass before burning (using a 0.25 m^2 sampling frame), and from the other pair, we collected the left-over unburnt biomass and ash after burning. Ash was collected using a small brush, carefully excluding any soil particles. Plant biomass as well as the ash was oven dried at 40°C and weighed. A sub-sample was taken for C and N analysis and measured using a CN analyzer (Elementar Vario EL; Elementar Analysis Systems GmbH, Hanau, Germany). Volatization losses of C and N from biomass burning are the differences in C and N stocks before and after burning. In addition to nitrogen and carbon, total phosphorus was measured using the Bray 1 method [26]. Exchangeable bases (Ca^{2+}, Mg^{2+}, K^+, Al^+, Fe^{2+}, Mn^+, P, Na^+, S) were determined by atomic absorption [27].

2.1.2. Ash richness index

The nutrients (C, N, P, K, Ca, Mg, Mn, Na, S) contained in the ash and the soil were analysed and evaluated. The ash specific richness index was calculated as the ratio between the quantity of nutrients contained in the ash and that contained in the soil on the horizon (0-2cm). The ash specific richness index gives an indication of the likely gain in each nutrient for the system.

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. Biomass and ash quantities

These results showed that the total quantity of material likely to be consumed is roughly equal (4 $t.ha^{-1}$) at both sites (Table 1). However, analysis of the composition of the fuel shows that it consists mainly of grass (2.8 $t.ha^{-1}$) at Dindéresso and less of fallen broadleaves (0.7 $t.ha^{-1}$). At Tiogo, the fuel was composed mainly of 2.7 $t.ha^{-1}$ of leaves, compared with only 1.2 $t.ha^{-1}$ of grass. The results also showed that after the fire, the total percentage consumed was higher (80%) in Dindéresso than in Tiogo (60%). Statistical tests showed significant differences ($p<0.001$) in fuel composition between the two sites.

Table 1 Pre burning fuel loads and fuel consumption

Fuel category	Dinderesso	Tiogo
Grass (t. ha^{-1})	2,8±0,4[a]	1,2±0,3[b]
Leaves and others (t.ha^{-1})	0,7±0,1[b]	2,7±0,3[a]
Total fuel loading (t.ha^{-1})	4±0,4[a]	4±0,2[a]
Total consumption (%)	80	60

3.1.1. Nutrient pool and losses

The results show that before the fire, the nutrients contained in the biomass are very rich in C (168±19 g.m^{-2} for the Dindéresso site and 178±0.6 g.m^{-2} for the Tiogo site) (Table 2). The other most important nutrients contained in this biomass before the fire was as follows: N, K, Ca, Mg, S and P. In terms of the nutrients contained in the biomass before the fire, the levels remained more or less the same at the two sites. In terms of losses after the fire, the results showed that the greatest losses were in C (82% in Dindéresso compared with only 45% in Tiogo), N (91% in Dindéresso compared with only 69% in Tiogo) and P (79% in Dindéresso compared with only 63% in Tiogo). Comparing the two sites, the greatest losses in all elements combined (C, N, P, K, Ca, Mg, Mn, Na) were at Dindéresso, suggesting that combustion was much more complete at this site than at Tiogo.

Table 2 Quantification of nutrient pools and losses

	Dinderesso		Tiogo	
	Nutrient pool before fire (g m^{-2})	Losses (%)	Nutrient pool before fire (g m^{-2})	Losses (%)
C	168±19	82±5	178±0.6	45±5
N	2.4±0.3	91±3	3.1±0.1	69±13
P	0.2 ± 0.0	79±5	0.3 ± 0.0	63±5
K	5 ± 1	73±4	4 ± 0.7	27±8
Ca	2 ± 0.2	62±8	1.9 ± 0.3	17±5
Mg	1 ± 0.1	63±7	0.8 ± 0.1	29±6
Mn	0.1± 0.0	58±8	0.1 ± 0.0	16±6
Na	0.0 ± 0.0	65±5	0.0 ± 0.0	31±9
S	0.2± 0.0	85±3	0.2 ± 0.0	54±7

3.1.2. Ash nutrient index

The results indicate that the nutrients that remain in significant proportions in the soil after the fire are P, K, Na, Al and especially Fe (Table 3). Nutrients such as C, N, Ca, Mg and Mn are present in minute quantities in the soil after the fire.

Table 3 Ash nutrient richness index (C: Carbon; N: Nitrogen; P: Phosphorus; K: Potassium; Ca: Calcium; Mg: Magnesium; Mn: Manganese; Na: Sodium; Al: Aluminium; Fe: Iron

	Dinderesso	Tiogo
C	0.005	0.001
N	0.001	0.003
P	3,25	2,87

K	5.7	2.82
Ca	0.1	0.04
Mg	0.1	0.05
Mn	0.2	0.17
Na	0.2	0.28
Al	3.2	17.06
Fe	158.10	469.60

4. Discussion

The results of the study showed that the total quantity of material likely to be consumed (fuel) is roughly equal (4t.ha^{-1}) in the two sites (Tiogo and Dindéresso). Previous studies had found herbaceous biomasses of around 2.5 to 4 t.ha^{-1} in *Andropogon gayanus* and *Andropogon ascinodis/Loudetia togoensis* fallows [19]. However, it should also be noted that the herbaceous biomass recorded in the two sites compared with the values of work in the fallows at Bondoukuy (Burkina Faso) in previous years remains low [28]. Production in these fallows varied between 3.69 and 9.61 t/h/yr and maximum phytomass was between 2.79 and 7.02 t/ha [28]. In the wet savannahs of Lamto in Côte d'Ivoire, grass production is only weakly correlated with rainfall, but reaches 10 to 20 t/ha per year [29]. These low biomass levels, compared with previous research results, could be attributed to various human and animal removals [16, 28], as well as to climatic variations, which greatly reduce annual production. These various removals amount to 10-50% of the maximum epigeous phytomass, i.e. 4-40% of potential epigeous production [30]. Analysis of the composition of the fuel (biomass removed) shows that it is made up of grass at Dindéresso and less of tree leaves. In Tiogo, on the other hand, there are more leaves than grass. This may explain the high percentage of total fuel consumed (80%) in Dindéresso compared with only 60% in Tiogo. The grass cover is more continuous and dense than the leaves, which burn more easily than the leaves, which generally have a discontinuous cover. This could also explain why, despite an epigeous biomass composed essentially of leaves rather than grass at Tiogo, this site has a much higher quantity of ash (65.3 g.m^{-2}) compared with only 12.2 g.m^{-2} at Dindéresso. Consequently, biomass composition is a very important indicator of fire continuity and severity [8]. In addition, the type and quantity of fuel in savannahs play an important role in determining fire type and intensity [16]. Fires can also have effects on soil and nutrient dynamics.

Fire leaves ash on the ground, the colour of which varies according to the intensity of combustion [31]. The presence of ash is one of the main characteristics of burnt areas. It is the organic and inorganic residue that remains after the combustion of organic matter. In our study, the results showed that the nutrients contained in the biomass before the fire were very rich in C, but also in N, K, Ca, Mg, S and P. However, the greatest losses were in C, N and P. As a result, fires cause much greater loss of carbon, nitrogen and phosphorus in the combustion of epigenetic biomass. These results are supported by those of the ash specific richness index, which indicate that ash is much richer in P, K, Na, Al and Fe but poor in C, N, Ca, Mn and Mg. Previous studies have shown that nitrogen levels tend to decrease in areas subjected to fire. [32] in their study found a 50% loss of P, K, Ca, Mg and up to 99% loss of C and N in burnt sites. However, magnesium (Mg), calcium (Ca) and manganese (Mn) are relatively less sensitive than nitrogen due to the high temperature thresholds of 1107°C, 1484°C and 1962°C respectively [10]. Phosphorus (P) and potassium (K) are partially affected by high-intensity fires [88].

5. Conclusion

The current research was undertaken to evaluate the dynamics of nutrients with the practice of repeated fires. The results showed high losses of carbon and nitrogen. Ash deposits on the soil contain elements such as potassium, calcium and magnesium. However, given the climatic context of these areas (Tiogo, Dindéresso), which are subject to harmattan winds and torrential rains that degrade and wash away a great deal during their passage, this ash deposit remains unstable and variable on the burnt plots, resulting in huge losses of the potential contribution that the fires could make to the soil by burning the epigeous vegetation.

Compliance with ethical standards

Acknowledgements

Funding for this study was provided by VolkswagenStiftung (Grant Agreement No. VW/88083). We thank technicians Pascal T. Simporé; Kaboré Narcisse; for their help during surveys. Thanks, are also due to villagers from the two sites for their hospitality and franc collaboration.

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Laclau, J.P., et al., Biomass and nutrient dynamics in a littoral savanna subjected to annual fires in Congo. Acta Oecologica, 2002. 23: p. 41-50.

[2] Stocks, B.J., et al., Fuels and fire behavior dynamics on large-scale savanna fires in Kruger National Park, South Africa. Journal of Geophysical Research, 1996. 101: p. 23541-23550.

[3] Koffi, K.F., Impact du feu sur la démographie des Graminées de savane (Lamto, Côte d'Ivoire), in Biodiversité et Ecologie. Sorbonne Université; Université Nangui Abrogoua (Abidjan),. 2019, Sorbonne Université; Université Nangui Abrogoua (Abidjan),. p. 175.

[4] Mataix-Solera, J., et al., Fire effects on soil aggregation: a review. Earth Sci. Rev., 2011. 109: p. 44–60.

[5] Gongalskya, K.B., et al., Do burned areas recover from inside? An experiment with soil fauna in a heterogeneous landscape. Applied Soil Ecology 2012(59): p. 73– 86.

[6] Badía-Villas, D.C., et al., Changes in water repellency, aggregation and organic matter of a mollic horizon burned in laboratory: laboratory: Soil depth affected by fire. Geoderma, 2014. 213: p. 400 -407.

[7] Gillon, D., Les effets des feux sur la richesse en éléments minéraux et sur l'activité biologique du sol. Rev. For.fr., 1990. 42: p. 295-302.

[8] Certini, G., et al., Wildfire effects on soil organic matter quantity and quality in two fire-prone Mediterranean pine forests. Geoderma 2011: p. 167-168.

[9] Abbadie, L., et al., Environmental constraints on living organisms, in In Abbadie, L., Gignoux, J., Roux, X.L., & Lepage, M. (eds.)Lamto. 2006, Ecological Studies. Springer, New York. p. pp. 45–61.

[10] DeBano, L.F., The effect of fire on soil properties, in In: Harvey, A.E., Neuenschwander, L.F., (Eds). Proceedings-management and productivity of western-montane forest soils. 1991, Boise, ID. Gen. Tech. Rep. INT-280. Ogden, UT: USDA, Forest Service, Intermountain Research Station. p. p. 151-156.

[11] Certini, G., Effect of fire on properties of soil - A review. Oecologia, 2005. 143p. 1-10.

[12] Stoof, C.R., J.G. Wesseling, and C.J. Ritsema, . , Effects of fire and ash on soil water retention. Geoderma, 2010. 159: p. 276–285.

[13] Mando, A., The role of termites and mulch in the rehabilitation of crusted sahelian soil, tropical ressources management. 1997, Wageningen Agriculture University. p. 101p.

[14] Neary, D.G., et al., Fire effects on belowground sustainability: a review and synthesis. Forest Ecology and Management 1999(122): p. 51-71.

[15] Verma, S. and S. Jayakumar, Impact of forest fire on physical, chemical and biological properties of soil: A review, in Proceedings of the International Academy of Ecology and Environmental Sciences 2012. p. 168-176.

[16] Savadogo, P.D., et al., Herbaceous species responses to long-term effects of prescribed fire, grazing and selective tree cutting in the savanna-woodlands of West Africa. Plant Ecology, 2008. 10, 3: p. pp. 179-195.

[17] Savadogo, P., D.L.S. Tiveau, and M. Tigabu, Herbaceous species responses to long terme effects of prescribe fire, grazing and selective cutting tree in the savanna woodland of West Africa. Perspectives in Plant Ecology, Evolution and systematizes, 2009. 10: p. 179-195.

[18] N'Dri, A.B., et al., The dynamics of hollowing in annually burnt savanna trees and its effect on adult tree mortality. Plant Ecology, 2014. 215: p. 27–37.

[19] Sow, M., et al., Fuel and fire behavior analysis for early-season prescribed fire planning in Sudanian and Sahelian savannas. Journal of Arid Environments, 2013. 89 (13): p. pp. 84-93.

[20] N'Dri, A.B., et al., Principaux indices de l'intensité du feu dans une savane Guinéenne d'Afrique de l'Ouest. Int. J.Biol.Chem.Sci.,, 2018. 12 (1): p. 266-274.

[21] Doamba, S.W.M.F., Feux et propretés biogéochimiques des sols en savanes boisées. 2014, Institut du Développement Rural, Université Polytechnique de Bobo-Dioulasso. p. 122 p.

[22] Van Straaten, O., et al., Fire and soil greenhouse gas fluxes in West African savanna woodland (CO2, N2O, CH4, NO). Journal of Arid Environments 2019. 165: p. 132-140.

[23] Doamba, S.W.M.F., P. Savadogo, and B.H. Nacro, Modifications induced in soil physico-chemical properties by repeated fire at different seasons and fuel load treatment in a West African savanna-woodland. Journal of Soil Science and Environmental Management, 2020b(11(4)): p. 164-175

[24] Doamba, S.W.M.F., et al., Facteurs écologiques et intensité du feu en savane soudanienne au Burkina Faso. Afrique Science 2020 a. 17 (6): p. 236-246.

[25] Hottin, G. and O.F. Ouédraogo, Carte géologique de la République de Haute-Volta. 1976: Direction de la Géologie et des Mines.

[26] Bray, R.H. and L.T. Kurtz, Determination of total, organic, and available forms of phosphorus in soils. Soil Science 1945. 59: p. 39–45.

[27] König, N. and H. Fortmann, . Probenvorbereitungs-Untersuchungs und Elementbestimmungs-Methoden des Umweltanalytik-labors des Niedersächsischen Forstlichen versuchsanstalt, 1-4, Berichte des Forschungszentrums Waldökosysteme, Reihe B. 1996. 1996, University of Göttingen.

[28] Fournier, A., Cycle saisonnier et production nette soudaniennes pâturées de la matière végétale herbacée en savanes les jachères de la région de bondoukuy (Burkina Faso). Ecologie, 1994. 25 (3): p. 173-188.

[29] Gignoux, J. and P. Mordelet, Biomass cycle and primary production, in L. Abbadie, J. Gignoux, Z. Le Roux and M. LePageedited by, Lamto: Structure, functioning and dynamics of a savanna ecosystem.. 2006.

[30] Fournier, A., Phénologie, croissance et production végétales dans quelques savanes d'Afrique de l'Ouest : variation selon un gradient climatique. 1991: ORSTOM

[31] Pereira, P., et al., Effects of a low prescribed fire in ash water soluble elements in a Cork Oak (Quercus suber) forest located in Northeast of Iberian Peninsula. Environmental Research 111, 2011: p. 237-247.

[32] Kugbe, J., et al., Annual vegetation burns across the northern savanna region of Ghana. Nutrient Cycling in Agroecosystems, 2012. 93 (3): p. 265-284.