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RESEARCH ARTICLE

CUMULATIVE EFFECTS OF 20-YEARS OF LIVESTOCK GRAZING, PRESCRIBED EARLY FIRE AND SELECTIVE TREE CUTTING ON BELOW GROUND BIOMASS IN SUDANIAN SAVANNA WOODLAND, WEST AFRICA

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ABSTRACT

Belowground biomass is important components of terrestrial ecosystem carbon. Understanding its size and influence of disturbance on its level is essential for carbon evaluation in savanna ecosystems. We studied root biomass after twenty years (1992-2012) of application of early fire, grazing and selective tree cutting on two factorial experimental sites characterized by deep and shallow soils in Sudanian savanna-woodland ecosystems of Burkina Faso. Coring methods was used and at each sampling point, a block of soil 25×25×50 was taken and the roots (fine and coarse) were quantified used to measure root biomass. at two depths (0-20 and 20-50 cm). We found that *grazing*, *selective tree cutting* and *early fire* applied alone did not affect ($p > 0.05$) total root biomass. Nevertheless, signifcant cumulative effect was significant ($P=0.001$). Total dry weight of roots biomass ranged from 8.7 t.ha^{-1} on plots treated simultaneously with grazing, fire and wood cutting to 18.3 t.ha^{-1} on plots protected from grazing but subject to fire and wood cutting. Therefore, projects which aim to mitigate climate change by increasing carbon stocks in dry savanna ecosystems should pay more intention to roots biomass, taking care to avoid the co-occurence of the three disturbances factors in the same landscape.

INTRODUCTION

In the climate change context, there is increased interest in estimating the biomass of forest because of their role in regulating the cycling of carbon and nutrients (Cairns *et al.,* 1997). The above ground biomass had been for long term considered for carbon estimates (Bontemps *et al.,* 2012), whiles studies on belowground biomass and its distribution is still quite limited (McNaughton *et al.,* 1998). However plant roots are a major terrestrial sink for carbon (Waisel *et al.,* 1996), and influence in large part the development of the above ground biomass (Dipesh and Schuler, 2013). Therefore, reliable measurements of roots biomass are necessary to have estimate of carbon balance in savannah ecosystems.

Shrubs in arid and semi-arid regions generally invest more carbon for the development of their root system compared with species in tropical rainforests where trees are important (Gang *et al.,* 2012). However, savanna woodlands face disturbance such as fire, grazing and tree cutting. All disturbances affect plants to some extent, either directly or indirectly, depending on the timing, intensity, and frequency of the disturbance. Understanding their impact on the different carbon pools is basic need for balancing carbon in savanna ecosystems. Fire is a common disturbance in many shrubland ecosystems (Chambers *et al.,* 2013; Keane *et al.,* 2008; Keeley and Fotheringham, 2001; Moritz, 2003), and has profound impacts on nutrient cycling and availability. An increase in dead fine root biomass after fire was reported by Jose *et al.* (1982), Moya and Castro (1992) and Tufekcioglu *et al.* (1999). Recent studies also show an increase belowground biomass after fire (Limb *et al.,* 2011; Ohnson, 2001). Fire consumes plant biomass, litter, and soil organic matter, converting organic nutrients into

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inorganic forms (Certini, 2005). Nevertheless, its effects on ecosystems depend on the interaction between many factors, including severity, intensity, degree of combustion, vegetation type, climate, slope, topography, soil characteristics, time of occurrence and periodicity (Neary *et al.,* 1999).

Grazing which includes feeding, trampling and excreting, directly or indirectly influence plant root growth and development depending on many factors such as the type of environment, grazing intensity, type of animals considered and the management in place (McNaughton *et al.,* 1998). This fact make its effects on belowground biomass are various and contradictories. McNaughton *et al.* (1998) reported no inhibition of roots production by grazing in grassland while others studies from semi arid grasslands show that effect of grazing affects negatively below-ground (Chen *et al.,* 2006; Limb *et al.,* 2011; Liu *et al.,* 2005). These studies noted that this negative effect worsens with higher stocking rate, however a number of studies have found the opposite. The selective harvest removes most of the sparser patches of large trees and leaves denser patches of undersize trees. The canopy opening may even persist when condition of vegetation recovery are not favorable. Unfortunately relationships between above-ground canopy gaps and the availability of belowground growing space (the "root gaps" have been hypothesized but tested in only a few ecosystems (Wilczynski and Pickett, 1993; Sanford 1989; 1990).

Fire and grazing disturbances can act independently or additively (Drewa and Havstad, 2001; Valone *et al.,* 2002). Generally in savannah woodland, there is co-occurrence of fire and grazing and that produce a synergistic effect. Many grazers are attracted to recently burnt ground to feed on the post-fire regrowth of grasses. Grazers, in turn, reduce the fuel load by consumption and trampling and therefore lower the intensity, temperature (Savadogo *et al.,* 2007) and frequency of fire. Since fire and grazing regimes can be manipulated directly, they are potentially important management tools for savannah ecosystems management (Frost *et al.,* 1986; Liedloff, *et al.,* 2001). In recent decade, in most protected Sudanian savanna-woodlands, prescribed early fire has been adopted as an ecosystem management tool to minimize the risk of severe late fire, to improve pasture production for wildlife and domestic animals, and to maintain species composition and richness (Bellefontaine *et al.,* 2000; Sawadogo *et al.,* 2005). Moreover, grazing intensity is being evaluated to support a sustainable inclusion of pastoral activities in the forest management policy. Selective tree cutting has been recommended on a rotational basis to sustain fuelwood production. Extensive data on early burning and grazing and its effects on vegetation dynamics are becoming available (Sawadogo *et al.,* 2002; Savadogo *et al.,* 2007a; Zida e*t al.,* 2007; Savadogo *et al.,* 2008; Dayamba *et al.,* 2010; Savadogo *et al*., 2012; Doamba *et al.,* 2014; Yé *et al*., 2015). However, the knowledge on belowground biomass and its distribution are still quite limited. Increasingly reliable estimates of belowground biomass are required for the prediction of the emissions from land use change and of biomass stock in ecosystems (Alves *et al.,* 2010; Ribeiro *et al.,* 2011). This study aim to respond to the following question: Do disturbances such as grazing, fire and selective tree influence in long term roots (fine and coarse) biomass in a given ecosystem? The objectives were (1) to determine how coarse and fine roots spread in the soil profile and to determine how much fine and coarse roots contribute to the total biomass, (2) analyse how the fine and coarse roots fluctuate and relate to disturbance.

MATERIAL AND METHODS

Site

The study was conducted in Tiogo (12°13' N, 2°42' W) and Laba, (11°40' N, 2° 50' W) both State Forest at an altitude of 300 m above sea level in Burkina Faso, West Africa (Figure 1). Phyto-geographically the study sites are situated in the transition from the north to south Sudanian zone with an aridity index of 0.32 and 0.29 for Laba and Tiogo, respectively. The rainfall is unimodal and lasts for about 6 months, from May to October. Based on data collected from insitu mini weather station at each site, the mean annual rainfall for the period 1992–2012 was 916±158 mm at Laba and 837±158 mm at Tiogo. The number of rainy days per annum during the study period was 64±16 and 62±12 at Laba and Tiogo, respectively. Rainfall and number of rainy days per annum showed large inter-annual variability. Mean daily minimum and maximum temperatures are 16° and 32° C in January (the coldest month) and 26° and 40° C in April (the hottest month).

Soils are generally are shallow (<45 cm depth) and the texture is 17,5±8,8% Clay, 8,7±2,4% Fine silt, 16,4±6,2% coarse silt, 16,7±4,3% Fine sand and 40±11,6% Coarse sand at Laba and mainly deep (>75 cm) with texture 24,8±7,7% clay; 15±4,3% Fine silt; 25,4±3% coarse silt; 21,7±6,7% Fine sand; 13,1±4,2% coarse sand at Tiogo (Sawadogo *et al.,* 2005a). The vegetation is woodland and bushland savannah with a grass layer dominated by the annual grasses *Andropogon pseudapricus* and *Loudetia togoensis* as well as the perennial grasses *Andropogon gayanus*. The main forbs species are *Cochlospermum planchonii*, *Borreria* spp *and Wissadula amplissima*. In terms of basal area, the main species are *Entada africana*, *Lannea acida*, *Anogeissus leicarpus*, *Vitellaria paradoxa*, *Detarium microcarpum*, *Combretum micrantum* and *Acacia macrostachya*.

The livestock carrying capacity in Laba State Forest was 1.0 tropical livestock unit ha−1 (T.L.U. ha−1) compared to 1.4 T.L.U. ha−1 in Tiogo State Forest (Sawadogo, 1996) and the grazing pressure at both experimental sites was about half of this capacity.

Experimental design

This study is part of a larger split-plot experiment with four replicates of 4.5 ha established for long-term studies of the ecological effects of grazing, prescribed fire and selective tree cutting (Figure 2). The experimental site (18 ha) was split into two contiguous main plots of which one was fenced off at the beginning of the dry season in December 1992 to exclude livestock. Each main plot was further divided into 4 blocks of 2.25 ha, each containing 9 subplots of 0.25 ha (50 m x 50 m). The subplots were separated from each other by 20–30 m firebreaks.

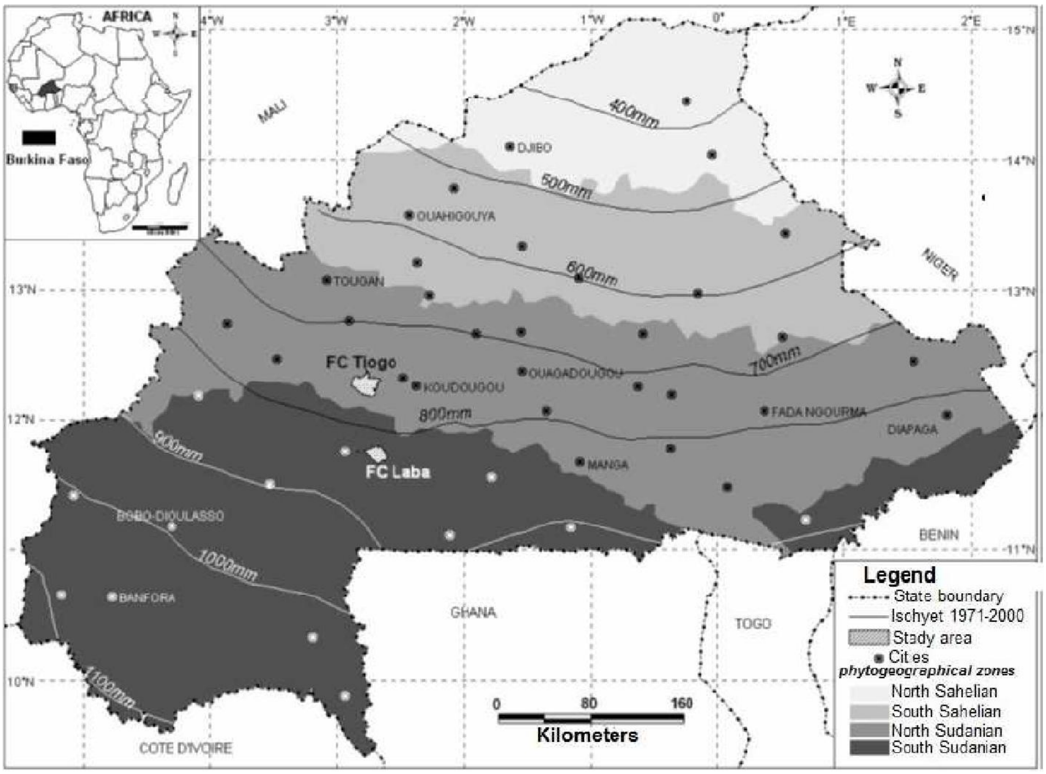


Figure 1. Location of Laba and Tiogo forests in vegetation and isohyets map of Burkina Faso
(Readapted April 2007 by CTIG/INERA, Burkina Faso after Fontes & Guinko 1995 and Direction of the National Meteorology)

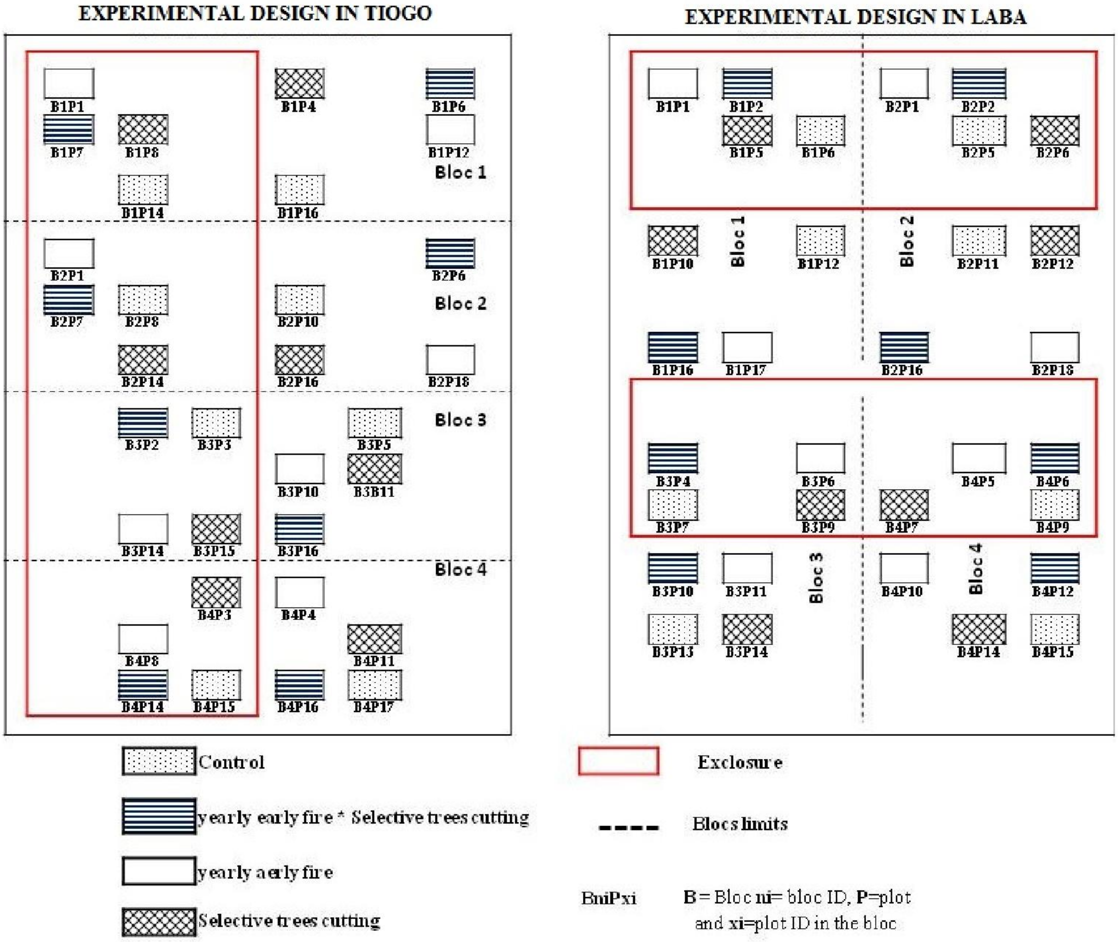


Figure 2. Experimental design in Tiogo and Laba

To the nine subplots within each block, three treatments were randomly assigned as no cutting, selective cutting of 50% of the basal area at stump level and selective cutting of 50% of the basal area followed by direct seeding of tree species. Three fire treatments were also applied: ‘‘fire protection’’, ‘‘2-year fire protection followed by early annual fire’’ and ‘‘early annual fire since the establishment of the trials’’. The prescribed early fire was applied at the end of the rainy season (October–November) each year beginning 1992, when the grass layer humidity was approximately 40%. In this study, the “2-year fire protection followed by early annual fire” and “selective cutting of 50% of the basal area followed by direct seeding of tree species” was not considered because the first one was applied only 4 years after the beginning of the experimental site and the second has felt at the beginning. The designs then of the two experiment sites without these two treatments are shown in Figure 2.

Roots biomass assessment

Method used was direct and monoliths sampling. Procedures to extract monoliths are widely described in the literature (Groot *et al.,* 1998; Krishnamuthy *et al.,* 2012; Ping *et al.,* 2010; Rau *et al.,* 2009; Taylor *et al.,* 2013a; Vogt *et al.,* 1998). Briefly, samples were taken in each plot (see Figure 4). Taking into account heterogeneity of the vegetation in the plots, sample points were placed according to vegetation type. The following type of vegetation were found in the two types of experimental plots: Type 1: mainly composed of annual herbaceous (*Loudetia togoensis*, *Cetaria pallidefusca*, *Aspilia bussei*, *Microchloa indica* etc.), Type 2: Perennial herbaceous (*Andropogon gayanus*, *Diheteropogon amplectens*, *Andropogon fastigiatis* etc.), Type 3: forbs (*Cochlospermum planchoni*, *Chasmopodium caudatum*), Type 4: Mainly combretaceae + annual herbaceous and Type 5: combretaceae + perennial herbaceous, and Type 6: Termite mount area.

Figure 3. Vegetation physiognomies in the different study plots. A=Type 1: mainly composed of annual herbaceous, B=Type 2: Perennial herbaceous, C=Type 3: forbs, D=Type 4 : Mainly combretaceae + annual herbaceous, E=Type 5: combretaceae + perennial herbaceous and F=Type 6 :Termite mount area

Two sample points (2) was installed in each type of vegetation found in the plot. Thus, 4 to 10 monoliths (25 × 25 cm) were carefully excavated to a depth of 50cm (0-20 and 20-50 cm layers) at each sample point. Because of the difficulties in separating live from dead roots and the ambiguous definitions of root death (Ping *et al.,* 2010), we considered the overall biomass of coarse and fine roots in each layer. The roots was sorted manually in fine roots (d≤2mm) and coarse roots (d>2mm) and put in plastic bags and fresh weight measured immediately. To avoid carrying all the soil to the lab, in each layer, before disturbing the soil, sample were taken with a metallic box (10x10x5cm) for washing process. For this sample, visible and easy to remove roots are sorted first manually in the field. Then, sample is transported to the lab for washing. For the present study, we developed a device similar to that used by (Klumpp *et al.,* 2007; Pucheta *et al.,* 2004a) to wash and separate roots from the soil more efficiently. It consisted of three vertically connected recipients (50 cm in diameter), each of them separated by 5, 4 and 2 mm meshes. The fine roots extracted after washing is weighted and extrapolation were made for the volume of the monolith of each step and the weight founded was added to the one of fine roots biomass sorted in the field. Dry weight was measured after the sample had put in oven at 105° until constant weight. In order to characterize the vegetation in more detail a forest inventory was conducted. In all the 64 study plots of 0.25 ha (50m x 50m), exhaustive inventory of all the trees (diameter at breast height (DBH) > 3 cm) was undertaken. In this study, only the number of stump in each plot was considered.

Figure 4. Roots sampling devices. A= box (25x25x50) used for monolith sampling. B= box (10x10x5 cm) used to in each layer to take soils sample for washing in lab

Data analysis

Fine roots and coarse roots dry weight were pooled to estimate the total roots biomass in each layer. In order to compare with existing studies, weight of fine and coarse roots previously in $g/0.0625\ m^2$ was converted in $t.ha^{-1}$. All the statistical analyses were carried out using XLSTAT Version 2014.2.07 and IBM SPSS Statistics 22. Grubb test was performed to check outliers and existing ones were removed or correct. Shapiro-Wilk normality test was then undertaked. Noting that datas were not normally distributed, they were log transformed before analysis. General Linear Model (GLM) was used and Multivariate Analysis of Variance (ANOVA) and Tuckey Multiple comparisons were used to compare effects of factors (grazing, fire, tree sellective cutting, site, vegetation type) on roots biomass dry weight. For each factor effects of size were calculated using Eta square (η2) and a statistical power related estimated. In all cases, a level of P less than 0.05 was accepted as statistically significant. General Linear Model (GLM) used had formula as follow :

$$Y_{ijkl}=\mu+\beta_i+G_j+F_k+C_l+S_m+L_n+\beta G_{ij}+\beta F_{ik}+\beta C_{il}+\beta S_{im}+\beta L_{in}+GFCSL_{jklmn}+\varepsilon_{ijkl\,mn}$$

Where

G= Grazing, F= Early fire, C= Selective tree cutting, S=Site and L=Layer. μ the overall mean, βi the block effect (replication) i and $\varepsilon_{ijkl\,mn}$ *is the error term with k replicates.*

Spatial variability of vegetation: vegetation type and plot were considered as random effects.

RESULTS

Distribution of roots following sites and layer

Coarse roots and total roots biomass were not significantly different between the two sites. Nevertheless, they varied significantly in the layers ($F_{(1.728)}$ = 5.709, P=0.017, η^2= 0,7% and $F_{(1.728)}$ = 9.290, P=0.002, η^2= 1.2%), respectively for coarse roots and total roots). The top layer of soil (0-20 cm) contained more biomass than the bottom layer (20-50 cm) and the coarse roots and total roots ranged from 1.6 to 1.8 $t.ha^{-1}$, 7.1 to 9.4 $t.ha^{-1}$ and from 9.4 to 11.9 $t.ha^{-1}$, respectivly. In 20-50 cm the ranges were from 5.5 to 7.9 $t.ha^{-1}$ and from 7.2 to 9.9 $t.ha^{-1}$ respectively for coarse roots and total roots biomass. For fine roots, *site* x *layer* was significant $F_{(1.728)}$ = 10.286, P=0.001, η^2= 1.1%). In the two sites, the top layer of soil (0-20 cm) contained more biomass than the bottom layer (20-50 cm, refer to Table 1)

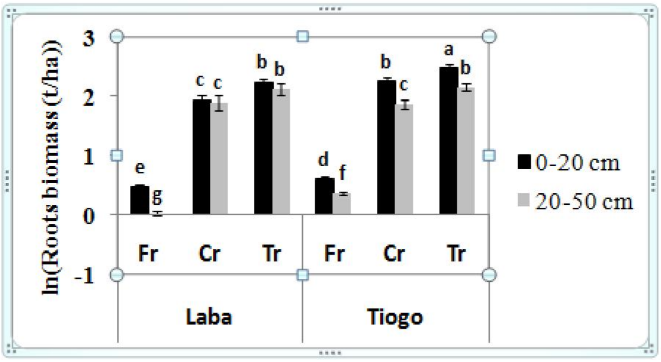


Figure 5. site difference of fine roots (Fr), coarse roots (Cr) and total roots (Tr) distribution between the two layers (0-20 cm and 20-50 cm) in sandy (Laba) and clay (Tiogo) soils

Effects of disturbance on roots biomass

Fine roots

The fine roots biomass at the site level varied significantly ($F_{1.728}$ = 48.647, P<0.001, η^2=5.4%). The deepest and clay soils in Tiogo had more fine roots both in the top soil (0-20 cm) and in the bottom (20-50 cm). *Grazing* and *early fire* varied significantly between the two sites. Indeed, *grazing* x *site* and *early fire* x *site* were significant ($F_{1.728}$ = 8.157, P=0.004, η^2= 0.9% and $F_{1.728}$ = 9.363, P=0.002, η^2= 1.0%), respectively. In Tiogo, their effects were not significant on fine roots biomass. However, in Laba, plots in which grazing and or early fire were applied had significantly lower fine roots biomass than ungrazed or unburnt plots (Table 1). Selective tree cutting did not affect significantly the fine roots ($F_{1.728}$ = 1.804, P=0.180) (Figure 6).

Cumulative effect, *Grazing* x *early fire* ($F_{1.728}$ = 7.757, P=0.005, η^2=0.9%) (Table 1) *Grazing* x *early fire* x *selective tree cutting* also affected significantly fine roots but was site specific ($F_{1.728}$ = 4.091, P=0.043, η^2=0.5%) (Figure 7). In Tiogo, cumulative effect did not affect significantly the root biomass compare to the control, while in Laba it reduced significantly the fine roots biomass. The other interactions were not significant (P > 0.05). The magnitude of the effect measured by the eta squared and power coeficient show that the main effect of *grazing* and *early fire* (respectively 1.1% and 1.2%) that accounted more than their interactions on the fine roots variation.

Coarse roots

The main effect of the treatment, only *selective tree cutting* affected significantly coarse roots biomas ($F_{1.728}$ = 5.377, P=0.021) and showed site specificity. *Selective tree cutting* x *site* was significant ($F_{1.728}$ = 4.885, P=0.027). In Tiogo, coarse root did not vary when selective tree cutting was applied but in Laba, plots submitted to this treatment decreased coarse roots biomass compare to uncut plots. Coarse roots biomass did no vary following grazing ($F_{1.728}$ = 3.201, P=0.074) and early fire ($F_{1.728}$ = 0.058, P=0.810). Cummulative effect of grazing and early fire (*grazing* x *early fire*) and cumulative effect of all the three treatments (*grazing* x *early fire* x *selective tree cutting*) had significant effect on roots biomass.

Table 1. Results of statistics analysis of the effects of different factors (Site, Layer, Grazing, Early fire and Selective tree cutting) and their interaction on biomass of coarse, fine and total roots biomass

	Ln_Coarse roots Biomass					Ln_Fine roots Biomass					Ln_Total roots Biomass				
	DL	F	P-value	η^2	Power	DL	F	P-value	η^2	Power	DL	F	P-value	η^2	Power
S	1	2,928	0,087	0,004	0,40	1	48,647	0,000	0,054	1,00	1	3,377	0,067	0,004	0,45
G	1	3,201	0,074	0,004	0,43	1	10,115	0,002	0,011	0,89	1	4,190	0,041	0,005	0,53
F	1	0,058	0,810	0,000	0,06	1	10,534	0,001	0,012	0,90	1	0,006	0,940	0,000	0,05
C	1	5,377	0,021	0,007	0,64	1	1,804	0,180	0,002	0,27	1	4,664	0,031	0,006	0,58
L	1	5,709	0,017	0,007	0,67	1	103,889	0,000	0,116	1,00	1	9,290	0,002	0,012	0,86
G x F	1	4,599	0,032	0,006	0,57	1	7,757	0,005	0,009	0,79	1	5,408	0,020	0,007	0,64
G x C	1	1,614	0,204	0,002	0,25	1	0,028	0,868	0,000	0,05	1	1,740	0,188	0,002	0,26
G x L	1	0,332	0,565	0,000	0,09	1	0,368	0,544	0,000	0,09	1	0,246	0,620	0,000	0,08
F x C	1	2,015	0,156	0,003	0,29	1	1,979	0,160	0,002	0,29	1	2,460	0,117	0,003	0,35
F x L	1	0,722	0,396	0,001	0,14	1	0,706	0,401	0,001	0,13	1	0,533	0,466	0,001	0,11
C x L	1	0,163	0,686	0,000	0,07	1	0,416	0,519	0,000	0,10	1	0,033	0,855	0,000	0,05
S x G	1	3,623	0,057	0,005	0,48	1	8,157	0,004	0,009	0,81	1	4,514	0,034	0,006	0,56
S x F	1	0,183	0,669	0,000	0,07	1	9,363	0,002	0,010	0,86	1	0,391	0,532	0,000	0,10
S x C	1	4,885	0,027	0,006	0,60	1	0,176	0,675	0,000	0,07	1	4,678	0,031	0,006	0,58
S x L	1	3,537	0,060	0,004	0,47	1	10,286	0,001	0,011	0,89	1	2,188	0,139	0,003	0,31
G x F x C	1	9,284	0,002	0,012	0,86	1	1,986	0,159	0,002	0,29	1	10,576	0,001	0,013	0,90
S x G x F	1	0,384	0,536	0,000	0,09	1	0,069	0,793	0,000	0,06	1	0,474	0,491	0,001	0,11
S x G x C	1	0,206	0,650	0,000	0,07	1	2,748	0,098	0,003	0,38	1	0,073	0,787	0,000	0,06
S x F x C	1	0,009	0,926	0,000	0,05	1	1,722	0,190	0,002	0,26	1	0,006	0,938	0,000	0,05
SxGxFxC	1	0,008	0,930	0,000	0,05	1	4,091	0,043	0,005	0,52	1	0,037	0,847	0,000	0,05

(respectively $F_{1.728}$ = 4.599, P=0.032 and $F_{1,728}$ = 9.284, P=0.002). They reduced coarses roots biomass compare to the control (Figure 9). The magnitude of the effect size of *grazing* x *early fire* x *selective tree cutting* was 1.3% and was the one that mostly affected coarse roots biomass (Table 1).

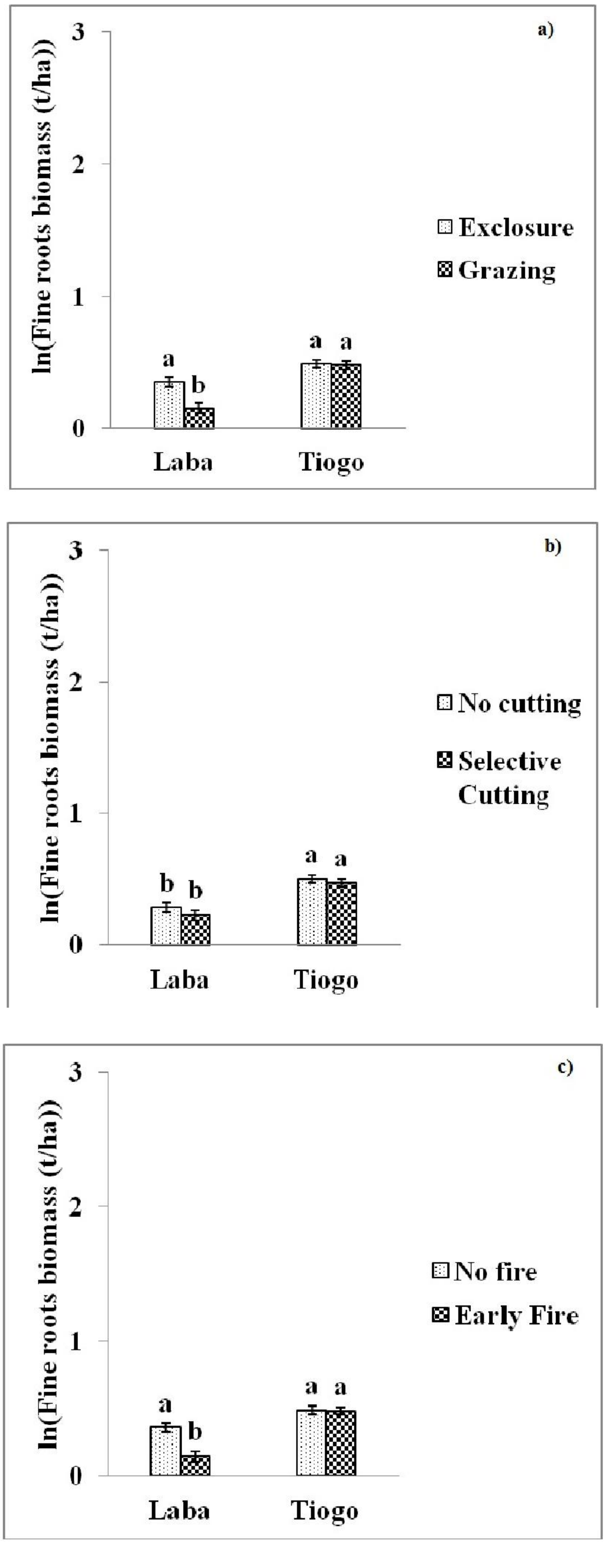


Figure 6. Grazing and grazing enclosure (a) selective tree cutting and no cutting (b) and early fire no burning (c) effect on fine roots biomass after 20-year of treatment application in sandy (Laba) and clay (Tiogo) soils. In each sub-figure (a, b and c) biomass values with the same letter are not significant different *(P<0.05)*

Total roots

For total roots (fine + coarse roots) also, site specificity occured. *Grazing* x *site* and *selective tree cutting* x *site* were significant (respectively $F_{1.728}$ = 4.514, P=0.034 and

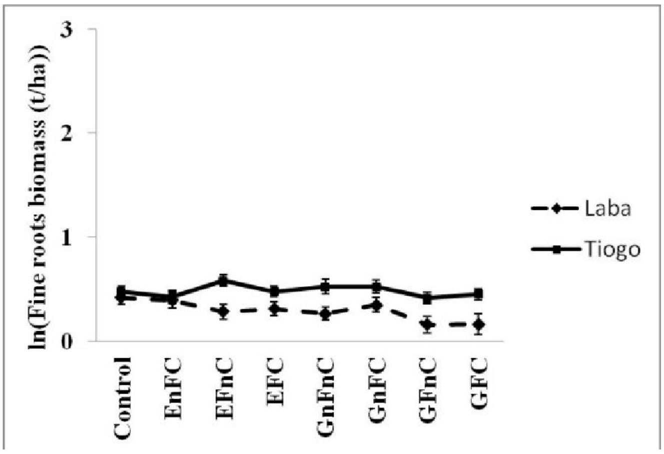
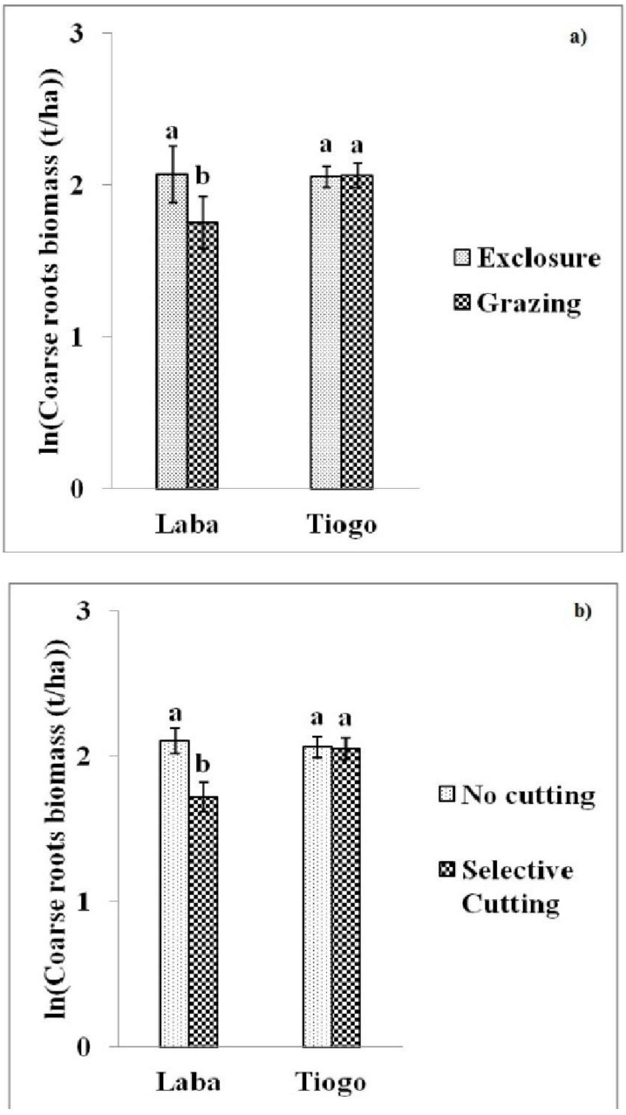


Figure 7. Combined effect of grazing, selective tree cutting and fire on fine roots biomass in sandy (Laba) and clay (Tiogo) soils in savannah woodland. E= Exclosure, G= Open grazing, C=selective trees cutting, nC= No cutting, F= Yearly early fire and nF= No fire



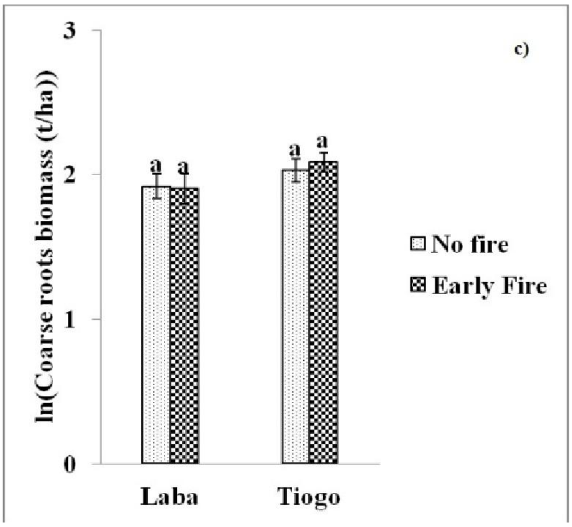


Figure 8. Grazing and grazing enclosure (a) selective tree cutting and no cutting (b) and early fire no burning (c) effect on coarse roots biomass after 20-year of treatment application in sandy (Laba) and clay (Tiogo) soils. In each sub-figure (a, b and c), biomass values with the same letter are not significant different *(P<0.05)*

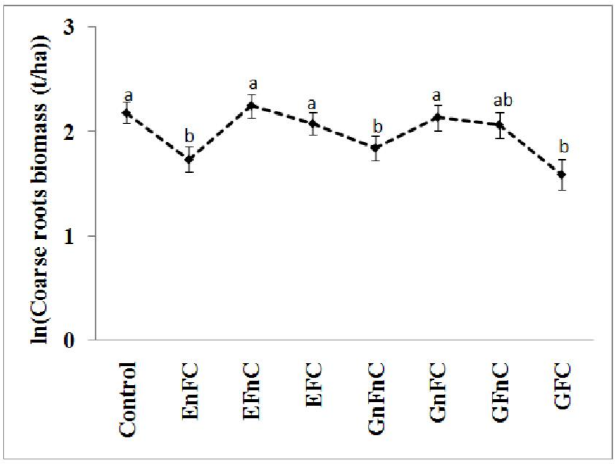
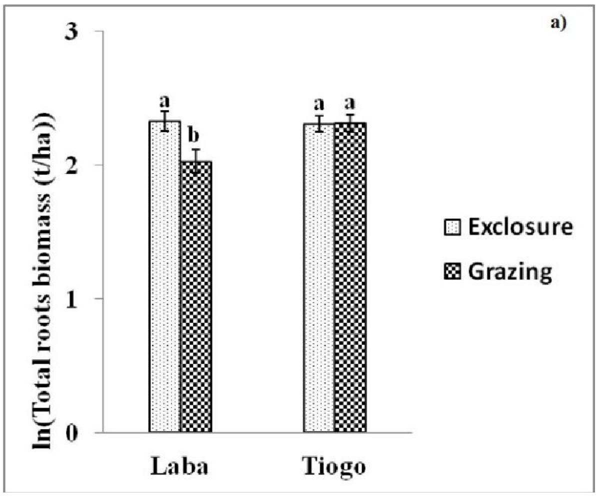
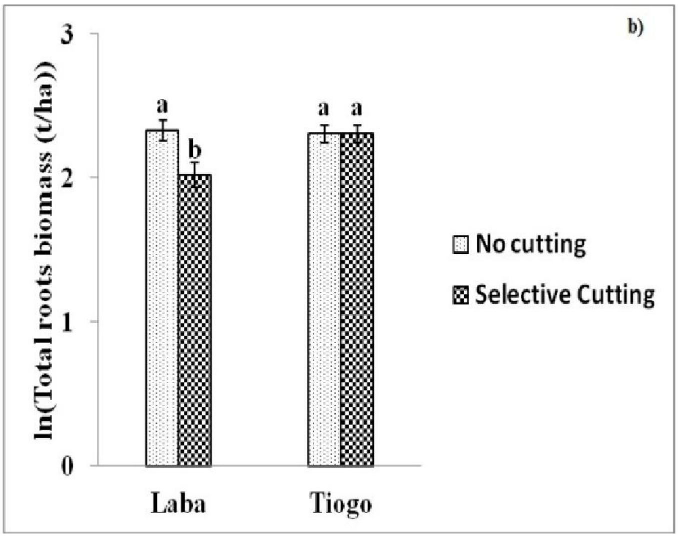


Figure 9. Combined effect of grazing, selective tree cutting and fire on coarse roots biomass in savannah woodland. E= Exclosure, G= Open grazing, C=selective trees cutting, nC= No cutting, F= Yearly early fire and nF= No fire. Biomass values with the same letter are not significant different *(P<0.05)*





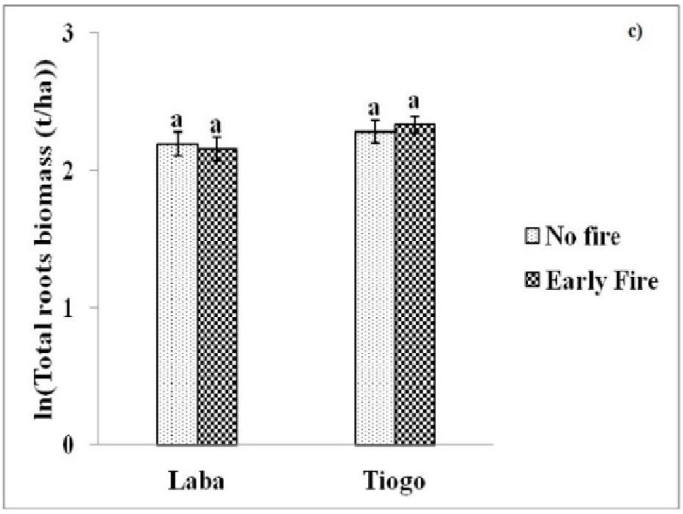


Figure 10. Grazing and grazing enclosure (a) selective tree cutting and no cutting (b) and early fire no burning (c) effect on total roots biomass after 20-year of treatment application in sandy (Laba) and clay (Tiogo) soils. In each sub-figure (a, b and c), biomass values with the same letter are not significant different *(P<0.05)*

$F_{1.728}$ = 4.678, P=0.031) (Table 1). In Tiogo (deep soil), the effect of *grazing* and *selective tree cutting* were not significant on total roots biomass. However in Laba, grazing and selective tree cutting reduced total roots biomass. Early fire in the two sites did not affect significantly total roots biomass (P=0.532) (Figure 10). For cumulative effects of the treatments, only *grazing* x *early fire* and *grazing* x *early fire* x *selective trees cutting* had significantly affected on total roots biomass ($F_{1.728}$ = 5.408, P=0.020) and ($F_{1.728}$ = 10.576, P=0.001). in the two site respectively. These combinations with total roots biomass ranged fron 7.62 to 14.1 $t.ha^{-1}$ had significant lower total roots biomass compare to the control (ranged from 12,85 to 18,78 $t.ha^{-1}$) (Table 2). As for coarse roots, interaction of the three prescribed treatment (*grazing* x *early fire* x *selective tree cutting*) explained 1.3% of total roots biomass that could explain strongly total roots variation (Table 1).

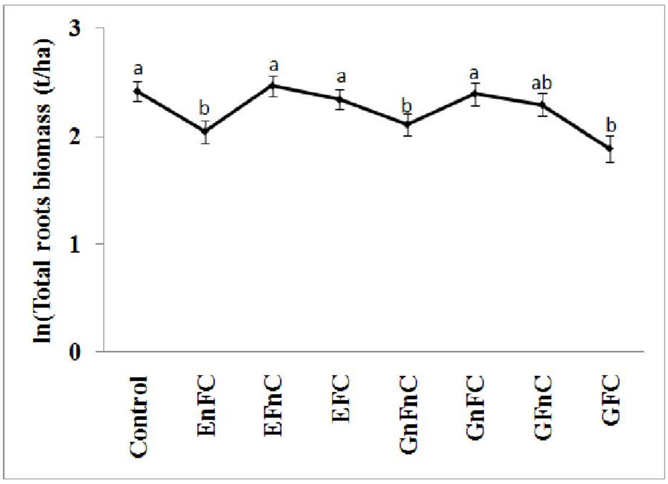


Figure 11.Combined effect of grazing, selective tree cutting and fire on total roots biomass in in savannah woodland. E= Exclosure, G= Open grazing, C=selective trees cutting, nC= No cutting, F= Yearly early fire and nF= No fire. Biomass values with the same letter are not significant different *(P<0.05)*

Table 2. Estimated marginal mean and confident intervals (CI) of Coarse roots, Fine roots and Total roots in the savanna-woodland subject to main effects and cumulative effect of grazing, selective tree cutting, and early fire in Burkina Faso (West Africa

	Coarse roots weight (t/ha)			Fine roots weight (t/ha)			Total dry weight (t/ha)		
	Mean (t/ha)	CI (95 %) LL	UL	Mean (t/ha)	CI (95 %) LL	UL	Mean (t/ha)	CI (95 %) LL	UL
Grazing	12,31	10,65	13,97	1,57	1,49	1,65	13,88	12,21	15,55
Fire	13,58	12,01	15,14	1,64	1,56	1,71	15,21	13,64	16,79
Cutting	12,52	10,87	14,17	1,62	1,54	1,70	14,14	12,47	15,81
Grazing*Fire	12,03	9,76	14,29	1,51	1,40	1,61	13,54	11,25	15,82
Grazing*Cutting	12,51	10,13	14,89	1,60	1,48	1,71	14,11	11,71	16,50
Fire*Cutting	12,28	10,09	14,46	1,59	1,49	1,70	13,87	11,67	16,07
Grazing*Fire*Cutting	9,35	6,13	12,57	1,51	1,36	1,66	10,86	7,62	14,10
Control	14,09	11,15	17,04	1,72	1,58	1,86	15,82	12,85	18,78

Trees density (Number per hectare)

Result of inventory show that there was difference of density between the sites. Density in Laba was higher than Tiogo. However, only fire affected trees density within the sites. In Tiogo, fire did not influenced tree density, while in Laba, it influenced significantly. Regression performed between tree density and roots biomass show that there is significant correlation between tree density and coarse and total roots. Tree density explained 9 and 10% respectively for total roots and coarse root. For fine roots, correlation with tree density was not significant.

DISCUSSION

With this method, approximate proportion of 55.70% of the root biomass was allocated to the 0–20 cm and 44.30% to 20–50 cm soil layer. That is in contrast results found in meadow ecosystems where 91,1 % was found in top soil (0-20 cm) and only 8.9% in the bottom (20-50) (Wu *et al.,* 2011) and temperate grassland where 83% of roots was find in the layer 0-30 cm (Jackson *et al.,* 1996). Total roots biomass and fine roots (respectively ranged from 7.62 to 18.8 t.ha^{-1} and 1.4 to 1.9 t.ha^{-1}) can be compare to the result (Wu *et al.,* 2011) that find in the layer 0-20 cm biomass of 15, and 19.95 t.ha^{-1} for total biomass and 1.19 to 1.96 t.ha^{-1} for fine roots. However, was lower than others results for total roots ranged from 14 to 26 t.ha-1 reported by (Gao *et al.,* 2008) and fine roots ranged approximately from 0.5 to 11 t.ha^{-1} (Pucheta *et al.,* 2004) and 3.1 to 6.4 t.ha^{-1} (Peichl *et al.,* 2011) were higher than fine and total roots biomass find in this study.

Roots spreading

Coarse roots in shallow soils were uniformly distributed between the two studied layers (0-20 cm and 20-50 cm) while in the deep soil, roots were mostly accumulated in the top soils (0-20 cm). Roots are characteristically concentrated in the more nutrient-rich surface organic horizons (Vogt *et al.,* 1993). Roots also proliferate most in the layers with greatest moisture if the other factors are conducive, for example, temperature (Dipesh and Schuler, 2013). That could suggest that there are good water condition in Laba compared to Tiogo. Indeed, infiltration measurment made in these two site (Koala *et al.,* 2014) shown high significant infiltration rate in Laba compare to Tiogo. Accumulation of roots in the top layer could suggest that water resources and others nutient are mostly located in this layer.

Effects of disturbances on roots biomass

Fine roots are important because they are directly responsible for water and nutrient uptake, carbon, and nutrient cycling, and are associated with above ground biomass productivity (Dipesh and Schuler, 2013). *Grazing* and *early fire* affected significantly fine roots. That could be explain by the more moisture condition in unburnt and ungrazed plot because in theses plots it was reported accumulation of significant quantities of surface detritus, which has considerable influence soils moisture (Lal, 2002; Wu *et al.,* 2011) Also root growth depends upon several environmental factors, particularly on soil temperature (Dipesh and Schuler, 2013). *Fire* by heating soil in term increase soils temperature (Sawadogo *et al.,* 2010). Also fire as grazing have negative effects on Carbon assimilating organs developing aboveground mostly for herbaceous stratas (Savadogo *et al.,* 2008; Sawadogo *et al.,* 2005) that reduced root carbohydrates however necessary for their growth because intensively re-translocated to shoot system (Gao *et al.,* 2008). That in term may be responsible of decreasing of fine roots biomass. However Different effect between the two site could be explained by the difference of the disturbance intensity due to the difference of combustible. Indeed, the herbaceous strata that constitute the combustible for fire were reported to be more dense in Laba than the one of Tiogo (Savadogo *et al.,* 2009). That could explain why this treatment affected differently firstly tree (Ø>10 cm) density observed in this study and fine roots in the sites. In addition fine root investment is strongly affected by soil penetration resistance (Wu *et al.,* 2011), in the deep soils in Tiogo, fine roots in the the bottom layer was 44% of the total fine roots. That suggest that vegetation in this site, had idleness to extend their roots in bottom layer where temperature due to fire is lower than the top. While in shallow soils as for Laba, fine because of the restriction accumulate in the top soil exposing them the high temperature caused by fire. Negative effect of fire on fine roots in Laba is in agreement with the results reported by (Kitchen *et al.,* 2009) but disagree with those reported increasing of belowground biomass after fire (Limb *et al.,* 2011; Ohnson, 2001).

Coarse roots were affecting by selective tree cutting and presented site specificity. That could due to shoot mortality of some species after cutting mostly the first year (Sawadogo *et al.,* 2002). However, Dayamba *et al.* (2011) show that the mortality differed following the species considered. So the site specificity observed in this study could be explained by the different distribution of the vulnerable species between the two site.

Management implication

Fine roots are the most biologically active roots and are responsible for water and nutrient uptake (Taylor *et al.,* 2013b). Fine roots have shorter life span than coarser roots and are in a constant flux of production and mortality.When dead, fine roots are large carbon and nutrient sources and important components of forest ecosystems (Taylor *et al.,* 2013b) Fine roots are major sources of carbon inputs into the soil (Gang *et al.,* 2012) with their annual contribution being up to 50% of the carbon cycled in forested ecosystems (Taylor *et al.,* 2013b) Hence, improvements in understanding fine-root production and mortality would provide insight to the recycling of carbon and other nutrients to the soil after their death and decomposition and will be helpful in soil nutrient and water management. A part of carbon production, rotation for fuelwood production devoted to many of managed forest require relatively intensive management practices to maintain high productivity that include sustainable production system by preserving soil quality and water resources. Grazing and Early fire as applied in the two sites (Laba and Tiogo) notwithstanding they affect above ground biomass through negative effect of herbaceous biomass (Savadogo *et al.,* 2008; Sawadogo *et al.,* 2005) and tree density had no effect on total roots biomass when tey are not applied simultaneously. they could remain a good alternative tool for ecosystem management, particularly given the fact that in savannah ecosystems, practices of grazing and fire is not avoidable.

Conclusion

Belowground biomass is important components of terrestrial ecosystem carbon stock. Understanding its size and the influence of disturbance is essential for carbon evaluation in savanna ecosystems. Reliable measurements of roots biomass are necessary to have a real view on carbon balance and sustainability of the savannah ecosystems. Results show that the effects of grazing, early fire and selective tree cutting on root biomass differed based on the site suggesting need to take into account biophysical aspects of the sites when they are to be used.

Grazing and early fire notwithstanding they affect above ground biomass through negative effect of herbaceous biomass and tree density had no effect on total root biomass when they are not applied simultaneously. They could remain a good alternative tool for ecosystem management, particularly given the fact that in savannah ecosystems, practices of grazing and fire are not avoidable. Nevertheless, we recommend further to understand roots turnover rate in each disturbed environnement that will allow to measure the suitability for root biomass production.

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