Available online at http://www.ifg-dg.org

Int. J. Biol. Chem. Sci. 10(3): 1048-1058, June 2016

ISSN 1997-342X (Online), ISSN 1991-8631 (Print)

International Journal of Biological and Chemical Sciences

Original Paper http://ajol.info/index.php/ijbcs http://indexmedicus.afro.who.int

Vegetation improvement and soil biological quality in the Sahel of Burkina Faso

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ACKNOWLEDGEMENTS

This study was funded by the Re-greening project with the partnership of the University of Stockholm. Our thanks go to WAAPP / WAAPP (West Africa Agricultural Productivity program) Burkina Faso for the financial assistance.

ABSTRACT

Soil living environment contains macro-fauna that play important role in the soil structure and chemical composition, the degradation process of organic matter and in the resilience of ecosystems. Few studies evaluated the impact of the "re-greening" trend observed in the Sahel on soil biological quality. The objective of this study is to assess the impact of the "re-greening" of the Sahel on soil macro-fauna population and diversity. The method of Tropical Soil Biology and Fertility (TSBF) was used to assess macro-fauna abundance and diversity in different land use types (cropland, shallow land, degraded land and forest). Four sites were selected, in the Sahelian zone of Burkina Faso, with contrasted Normalized Difference Vegetation Index (NDVI). In each site, four repetitions were taken for each land use type. In total, 64 plots samples were used to assess the abundance of macro-fauna. Results showed that there were more individuals (64.92%) and higher macro-fauna density in re-greening zones compared to the degrading zones. There was dominance of *Arthropoda* phylum (60.85%), *Insecta* class (59.03%) and *Isoptera* order (46.97%) in macro-fauna population. There were more species in the shallow land and cropland in re-greening zones and all trophic groups are represented in all sites. Despite this abundance, composition and diversity, it was observed that the re-greening processes have not significantly improved soil biological quality. It is concluded that vegetation improvement might be at the beginning stage in the Sahel, especially in croplands, and clear change of soil biological quality is not perceptible but may be tangible in the future.

Keywords: Macro-fauna, ecosystem, soil quality, re-greening, degradation.

2640-IJBCS
DOI : http://dx.doi.org/10.4314/ijbcs.v10i3.12

INTRODUCTION

Soil, water, climate, flora and fauna constitute the basic natural resources on which human depend for his well-being and survival. Soil is the most important natural resource (Gajbhiye and Mandal, 2000); therefore, it is necessary to know its potential and limitations to support the activities and production systems.

The soil living organisms of different shapes and sizes contribute to soil fertility which is important for a sustainable agriculture (Ouedraogo et al., 2014). In the living environment, this system contributes to the vital function as regulating the dynamics of soil organic matter, soil carbon sequestration, modification of the physical structure of soil and it increases the amount and effectiveness of nutrients acquisition by plants (Lavelle et al., 2001; Lavelle, 2002). However, the abundance and distribution of their populations are influenced by vegetation, soil conditions, cultural practices, crop type and also the effect of fire (Hallaire et al., 2004; Tondoh, 2008; Traore et al., 2012). Soil macro-fauna improves soil productivity and contributes to the sustainability of all ecosystems (Milau et al., 2015).

During the three last decades, there has been a controversy on the state of the Sahel ecosystems. Although many studies supported that the Sahel is continuously degrading (Hountondji et al., 2006; Ozer et al., 2007; Ozer, 2009), some others argued that there is a sign of re-greening in some specific zones in the Sahel (Anyamba and Tucker, 2005; Hickler et al., 2005; Fensholt et al., 2012; Dardel et al., 2014; Savadogo et al., 2015; Savadogo et al., 2016). The studies of Eklundh and Olsson (2003), Anyamba and Tucker (2005), Olsson et al. (2005), Hickler et al. (2005) and Turcker et al. (2005) on the NDVI values in the Sahel have shown that in Burkina Faso, the areas around Ouahigouya are in re-greening state while in Kaya, the degradation process is persisting. The re-greening is caused by, but not limited to, the return of rainfall, human activities (Botoni et Reij, 2009; Sendzimir et al., 2011) contributing to improve environment. This environmental change may contribute to the improvement of the communities of the pedo-fauna. Studies of re-greening are most interested in rainfall, vegetation, human activity and soil conditions (Eklundh and Olsson, 2003; Herrmann et al., 2005; Olsson et al., 2005; Botoni et Reij, 2009; Sendzimir et al., 2011; Ouedraogo et al., 2014). Yet, there is no study that has focused on soil macro-fauna to find out what could happen to soil biological quality in the context of re-greening and/or continuous degradation processes in the Sahel.

This study was focused on the assessment of the abundance, composition, diversity and trophic functions that belong to soil macro-fauna in two contrasted ecosystems in the Sahel of Burkina Faso. More specifically, the research explored the contribution of the re-greening to the soil macro-fauna quality in the Sahel.

MATERIALS AND METHODS

Description of the study sites

The study sites were located in the North and Central-North Regions of Burkina Faso. Oula and Boursouma are located in Ouahigouya district and fall within the re-greening zone while Lebda and Koalma in Kaya district belong to the degrading zones according to previous studies (Anyamba and Tucker, 2005; Hickler et al., 2005; Fensholt et al., 2012; Dardel et al., 2014) (Figure 1). All the sites belong to the semi-arid climate zone that has been severely damaged by the different droughts episodes of 1972-73 and 1983-84. The vegetation type encountered is shrub savannah, and the mean annual rainfall varies between 500 and 600 mm. Monthly mean maximum and minimum temperatures range from 32 to 42 ^{o}C and from 16 to 29 ^{o}C, respectively. The main soils are: (i) tropical ferruginous types, poorly to fully leached (ii) degraded holomorphic soils comprising solonetz (iii) tropical eutrophic brown soils overlying high clay parent material and poorly evolved erosional soil overlying gravelly material (CILSS et OMM, 2001).

Site selection

Sites were selected based on thetrends in NDVI and residual NDVI from 1982 to 2008 from Herrmann et al. (2005). The sites have roughly the same population density (Ouedraogo, 2010) and are located in the same agro-ecological zone where soil water conservations technologies are used intensively (Figure 1). According to Eklundh and Olsson (2003), Anyamba and Tucker (2005), Olsson et al. (2005), Hickler et al. (2005), and Turcker et al. (2005), the areas surrounding Ouahigouya are experiencing a vegetation re-greening trend while areas around Kaya are in continuous degradation.

Sampling

Soil macro-fauna was assessed using the Tropical Soil Biology and Fertility (TSBF) method (Anderson et Ingram, 1993) and the sampling procedure was done during the rainy season (September 2013) in each plot. TSBF method consists of isolating a monolith of soil after randomly selecting a small square in the different types of land uses (Shallow land, cropland, forest and degraded land) in each site. The monoliths measured 25 cm x 25 cm sizes and 30 cm soil depth.

The monolith was shared into four strata: 0-5 cm, 5-10 cm, 10-20 cm and 20-30 cm. Each stratum was spread on a tray and macro invertebrate picked up by hand. The macro-invertebrates visible to eye were removed, fixed in alcohol of 90° and brought to the laboratory for identification. The identification was achieved through a binocular microscope and an identification key. They were then grouped according to the taxonomic group (earthworms, ants, termites, beetles, millipedes, spiders, cockroaches and snails). Individuals not belonging to these groups are classified in a separate group called others.

Four repetitions were taken for each land use type in each site. In all, sixty four soil samples were used for the assessment.

Data analysis

The raw data from the treatment of monoliths gave the number of soil macro-fauna per sample, per land use type, per zone and per taxon. They allowed the determination of parameters for the appreciation of soil fauna, such as the abundance and diversity. The macro-fauna abundance, a quantitative factor, was expressed by the average number of individuals collected per plot and densities (mean number of individuals per unit area). Macro-fauna species diversity was assessed using the Shannon-Weaver index (H') and the equitability (E) for each plot. The H' value takes into account the number of taxa encountered (s). Its value is given by the following equation:

$$H' = -\sum_{i=1}^{s} Pi\ ln\ (Pi)$$

where P_i is the proportion of species i with respect to the total number of species in the study plot, which is calculated as follows:

$$P_i = \frac{n_i}{N}$$

where n_i is the number of individuals for species i and N is the total effective; s = total number of taxa encountered on the plot. H' is zero when only one group is represented and its value is maximal when all groups have the same abundance. The equitability (E) or regularity measures the fair distribution of taxa and allows the comparison of populations with different numbers of taxa. The objective was to observe the balance of the populations. Its value is given by the following formula:

$$E = \frac{H'}{\ln(s)}$$

The equitability tends to 0 when a taxon dominates widely, and is equal to 1 when all groups are evenly represented.

Data were prepared for analysis of variance using *Genstat (Edition 4*) to determine the influence of re-greening on the abundance, composition and diversity of macro-fauna and trophic functions of the different groups of macro-fauna extracts in each zone. The means comparison was made using Newman-Keuls test with the significance probability of 5%.

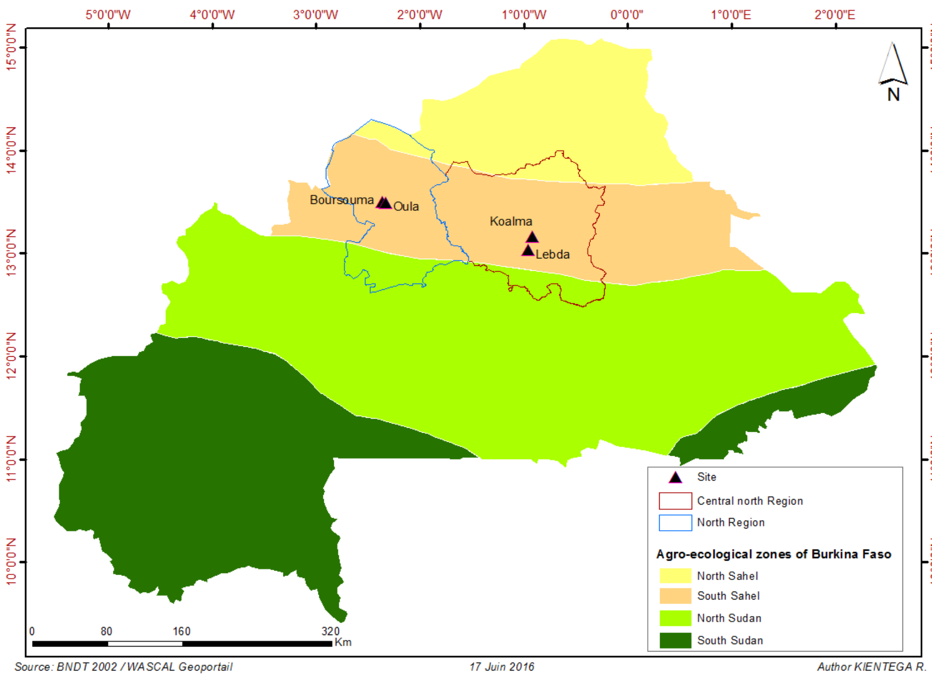

Figure 1: Burkina Faso Agro-ecological zones and Site location map.

RESULTS

Abundance and composition of macro-fauna in contrasted ecosystem

A total of 1599 macro-invertebrates were collected in both zone and in all land use types of which 64.92% individuals belong to the re-greening zone. The average density is important in the degraded land (305.92 ind/m²) and shallow land (80.42 ind/m²) at Oula. In croplands and forest, the average densities of macro-invertebrates were 46.05 ind/m² and 84.50 ind/m² respectively in Boursouma and Koalma (Table 1).

The inventory showed a clear dominance of *Arthropoda* phylum which represented 92.37% from which 60.85% of individuals were found in the re-greening zone and 31.52% in the degrading zone. The class of *Insecta* dominated with 87.76% of individuals with 59.03% in the re-greening zone and 28.64% in degrading zone. In both zones, the order of *Isoptera* prevailed among *insecta* with 46.97% and 15.82% of individuals, respectively in the re-greening and degrading zones, followed by *Hymenoptera* with 8.88% in the degradation zone and 6.57% in the re-greening zone.

There was a large dominance of individuals in land use types classified as degraded land (31.21%) and shallow land (20.33%) in the re-greening zone. However, in the degrading zone, the dominance of individuals was found in cropland and shallow land with 11.63% and 11.01% respectively. With regards to order, *Isoptera*, *Hymenoptera* and *Coleoptera* were the three dominant orders in all sites. *Isoptera* order was dominant at Boursouma (Shallow land 4.38%, cropland 4.88%), Oula (Shallow land 5.13%, degraded land 29.14%) and Koalma (Forest 4.69%), while, *Hymenoptera* order was dominant at Oula (shallow land 5.19%) (Table 2). The re-greening zone sheltered twice the number of macro-fauna found in degrading zone irrespective to soil depth (Table 3).

Diversity of soil macro-fauna

Species richness varied from 19 to 33 species per site. The shallow land and cropland in the re-greening zone had the highest number of species (18) and the degraded land of Boursouma and forest of Lebda were the poorest with respectively 8 and 2 species. The differences were significant for species number, family number and order number with high values in shallow land at Boursouma and Oula (Table 4). For Weaver Shannon diversity index and equitability, the differences were not significant between zones and sites. But there was a trend of land use effect (p=0.08) with E and H' highest values in shallow and cropland (Table 5).

Contribution to macro-fauna to soil function

All the sites had different trophic groups necessary to soil function and soil improvement capacity to support disturbance. Predators include *Arachnida*, *Chilopoda* and *Coleoptera* (adult and larva), decomposers comprising Earthworms (epigeic), *Diplopoda* (millipede), *Coleoptera* and *Isopoda*, the Ecosystem engineers such as Ants and Earthworms, and phytophage comprising *Coleoptera* (adult and larva) and *Hemiptera*. *Coleoptera* and Earthworm are represented respectively in 3 and 2 trophic groups (Table 6).

Table 1: Macro-fauna density according to land use (ind/m²).

	Boursouma	Oula	Lebda	Koalma
Shallow land	52.40	80.42	74.67	25.04
Cropland	46.05	18.00	44.36	45.47
Degraded land	16.00	305.92	17.23	37.14
Forest	16.67	30.61	24.00	84.50

Table 2: Percentage of individual (%) in the three dominates order per land use.

	Orders	Shallow land	Cropland	Forest	Degraded land
Boursouma	*Coleoptera*	0.19	1.06	0.44	0.38
	Isoptera	4.38	4.88	0.69	0.75
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Oula	*Coleoptera*	0.69	0.69	0.75	0.19
	Isoptera	5.13	0.50	1.56	29.14
	Hymenoptera	5.19	0.31	0.06	0.06
Koalma	*Coleoptera*	0.56	0.50	0.56	0.38
	Isoptera	0.88	3.56	4.69	0.38
	Hymenoptera	0.06	3.19	0.19	1.25
Lebda	*Coleoptera*	0.81	0.19	0.13	0.56
	Isoptera	3.00	2.44	0.13	0.19
	Hymenoptera	3.75	0.63	0.13	0.25

Table 3: Percentage of individuals according to the soil depth.

Depth	Degrading zone (%)	Re-greening zone (%)
0_5 cm	34.39	25.49
5_10 cm	22.35	20.86
10_20 cm	29.09	25.85
20_30 cm	14.16	27.81

Table 4: Species, family and order number according to land use.

	Sites	Shallow land	Cropland	Forest	Degraded land	Probability
Species number	Boursouma	7.00	8.50	4.25	2.25	0.05
	Oula	8.00	4.50	4.75	3.75	
	Koalma	3.75	5.00	5.00	5.00	
	Lebda	5.50	3.50	1.00	4.50	
Family number	Boursouma	6.25	6.50	3.75	2.25	0.05
	Oula	6.25	3.25	4.25	3.50	
	Koalma	3.50	4.25	4.50	4.75	
	Lebda	5.00	3.25	1.00	4.00	
Order number	Boursouma	5.00	5.50	2.75	1.75	0.02
	Oula	4.75	2.75	2.50	3.25	
	Koalma	2.75	3.75	4.00	4.00	
	Lebda	3.75	3.00	1.00	3.50	

Table 5: Diversity index and equitability of macro-fauna.

	Sites	Shallow land	Cropland	Forest	Degraded land	Probability
Diversity	Koalma	1.00	1.22	1.44	1.38	NS
	Lebda	1.61	1.18	0.38	1.15	
	Boursouma	1.89	1.94	1.15	0.68	
	Oula	1.88	1.19	1.37	0.86	
Means		1.60	1.38	1.09	1.01	0.08
Equitability	Koalma	0.83	0.88	1.04	0.96	NS
	Lebda	1.07	0.86	0.54	0.77	
	Boursouma	1.02	1.06	0.77	0.75	
	Oula	1.03	0.85	0.94	0.61	
Means		0.99	0.91	0.82	0.77	0.59

NS: not significant

Table 6: Collected macro-fauna trophic group.

		Boursouma	Oula	Koalma	Lebda
Predators	*Arachnida*	+		+	+
	Chilopoda	+	+	+	
	Coleoptera (adult and larva)	+	+	+	+
Decomposer	Earthworms (epigeic)	+	+	+	+
	Diplopoda (millipede)	+	+	+	+
	Coleoptera	+	+	+	+
	Isopoda	+	+	+	+
Ecosystem engineer	Ants	+	+	+	+
	Earthworms (aneciques and endoge)	+	+	+	+
Phytophage	*Coleoptera* (adult and larva)	+	+		+
	Hemiptera	+	+		+

+: presence of species

DISCUSSION

Importance and contribution of soil macro fauna to ecosystem functions

Environment conditions the presence and species types of macro-fauna (Doamba et al., 2011). Cropland and shallow land are environment where trees and a low sunlight facilitate macro-fauna proliferation. Hence, this explains the high densities of macro-fauna in the cropland and shallow land. The presence of macro-fauna in the soil contributes to the increase in soil available phosphorus content by 68% (Ouedraogo et al., 2014) and to enhance nutrient use efficiency and crop water uptake (Ouedraogo et al., 2006). Moreover, macro-fauna build up soils structure that gives them a specific architecture (Lavelle, 2002). Soil organisms also have the ability to regenerate compact structures (Hallaire et al., 2004) which allows degraded land to recover its vegetation and become a green zone.

The density and diversity of macro-fauna decreased in degraded land, compacted and acidified land due to the hostility of the environment that reduces their number. But, at Oula in the re-greening zone, the degraded land regenerated with a high density of macro-fauna. *Isoptera* order, ecosystems engineers are dominants in the re-greening zone. According to Lavelle et al. (1994), these are species that are more resistant to disruption. These species colonize degraded land allowing their rehabilitation. Generally, ants are the most abundant species in the forest and, for Tondoh (2008), ants, *Diplopoda*, earthworms and the beetles have proven to be the most sensitive macro-invertebrates to forest degradation and thus can be used as "bio-indicators" of forest conservation status. Indeed, soil biodiversity give to soil, resistance and resilience to disturbance and stress (Brussaard et al., 2007).

Macro-fauna and ecosystems stability

Ecosystem health involves the provision of ecosystem services that can improve livelihood. Activity of soil fauna creates soil mixing, which allows significant soil volume traffic by surfacing rich mineral horizons and burying organic upper horizons. We found a significant proportion of macro-fauna in soil upper layer (0 – 10 cm) in the re-greening zone due to better soil conditions.

The presence of healthy macro-fauna population is important for water infiltration (Sarr et al., 2001), the sustainability of soil functions and suitable agricultural ecosystem is dependent on soil organisms (Barrios, 2007). It is evident that ecosystem engineers increase porosity by gallery formations that are very important for soil aeration (Ilboudo-Tapsoba et al., 2011). In addition, macro-fauna offers preferential pathways to the roots, stability of the ecosystem and contributes to water retention (earthworms, ants, termites) and, soil restoration (Milau et al., 2015). The effects of macro-fauna on the dynamics of soil organic matter improve soil fertility and increases yields (Lavelle et al., 2001).

In re-greening zones, macro-fauna is more diverse, contributing to soil quality improvement. The presence of a microclimate facilitates their migration to the soil surface layers. For ecosystem regulation, predators participate in biological control and balance population, while decomposers recycle the organic matter, and the ecosystems engineer control the structuration and bioturbation of the soils. Their complementary functions allow the ecosystem to resist to disturbances.

Conclusion

The improvement of trees densities in some land use types was not accompanied by more macro-fauna abundance and diversity. In the re-greening zones, macro-fauna was more diverse and abundant than in the degrading zones. Soil macro-fauna contributed to improve soil quality and functions.

The results showed that the improvement in some landscape units did not give a positive impact on the abundance and diversity of soil macro-fauna, but macro-fauna was composed of many species, families and orders in each land use type and each site. These results provide a basis for monitoring soil quality in the Sahel of Burkina Faso. Further studies are needed to find out how macro-fauna will evolve with the evolution of re-greening. Actually, the improvement of the vegetation cover was not accompanied with a very strong macro-fauna community, but the existence of different trophic groups will boost the functioning of ecosystems and may improve soil quality and yield in the coming years.

COMPETING INTERESTS

All authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

OMS collected the data, run the statistical analysis and wrote the manuscript (20%). KO contributed to design the methodology (all authors agreed on the method to use for sampling, sampling period and site choice). He also contributed to the statistical analysis and provided comments to the manuscript (15%). IO participated in the writing and improvement of the manuscript. He also contributed to the language checking (15%). SS/K, JB and LG read and improved the discussion section. They also provided logistical and financial assistances during the field work (10% each). MT was helpful in the laboratory works (10%). SP and NPZ contributed to write the methodology (5% to each person).

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