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Effects of charcoal production on soil biodiversity and soil physical and chemical properties in Togo, West Africa

Jérémie Kokou FONTODJI [1*], Gbénonchi MAWUSSI [2], Yaovi NUTO [3] and Kouami KOKOU [1]

[1] *Laboratoire de Botanique et Ecologie Végétale, Faculté des Sciences, Université de Lomé, Togo, BP 1515, Lomé, Togo.*

[2] *Unité de Recherche sur les Agroressources et la Santé Environnementale, Ecole Supérieure d'Agronomie, Université de Lomé, BP 1515, Lomé, Togo.*

[3] *Département de Zoologie, Faculté des Sciences, Université de Lomé, BP 1515, Lomé, Togo.*

[*] *Corresponding author, E-mail: fontodjijeremie@yahoo.fr, Tél: (228) 988 65 04*

ABSTRACT

In Togo, traditional energy sources including charcoal represent 80% out of total household energy requirements. The techniques of charcoal production in earth kiln are quite common. During carbonization, the temperature rises from 20 to over 500°C. This study focuses on the impact of this high temperature on the soil properties and soil fauna in three biogeographical zones of Togo. The methodology used consists in comparison of soil sampling in surface layer (0-20 cm depth) inside burnt plot i.e. inside the kiln to an unburnt plot in charcoal production area. The results revealed that the soil physical, chemical and microbial properties were altered. The organic matter was destroyed; it is higher at the unburnt plot level than inside the kiln. The soil pH increased at the kiln level by the provision of rich ash bases during the carbonization. Fire increased the permeability at the kiln level by raising the bulk density and the total porosity of soil. The variation in microbial biomass induced by the heat around the kilns is different according to the ecosystem; it is of 15 m radius around the kilns in Sudanian or Guinean savanna areas while this radius is 5 m in Semi-deciduous forest. The soil fauna assessment permitted to record 81 micro-organisms belonging essentially to the Beetles, Hymenoptera, Heteroptera, Diptera, Orthoptera, Myriapods, Homoptera, Acarians, Nematodes, Isoptera, etc. The hypogeal biodiversity index calculation (average species richness, Shannon average indexes and average evenness) revealed that farther moving away from the kiln, greater the fauna species diversity was.

Key words: Charcoal production, kiln, soil physical and chemical properties, soil biodiversity, Togo.

INTRODUCTION

Biomass is the most heavily used energy source in developing countries (Okello et al., 2001; Parikka, 2004; Dovie et al., 2004; Naughton-Treves et al., 2007). This reliance is more obvious in sub-Saharan Africa where fuel wood and charcoal are the main energy, as well in terms of energy source as in terms of the users' number (Amous, 1999; Ballis et al., 2005).

In Togo, traditional energy sources are the most commonly used for domestic and craftsmanship needs (cooking, water heating, forging, etc.). Fuel woods represent 80% out of the national household energy consumption, while modern energy sources account for 16%, as far as the petroleum products are concerned and 4% for electricity (MEMEPT, 2002). Charcoal consumption is estimated at 62 kg/year per capita (Fontodji, 2007).

To satisfy this important demand, the techniques used to produce charcoal in Togo are mostly traditional as in many African countries. It is done by burning logs in oxygen-restricted pyrolytic conditions inside earth kilns (Naughton-Treves et al., 2007). These kilns are inappropriate and the expected incomes are generally not found due to many shortcomings and the lowest level of producers'organization. According to Thiam (1991), the output of the carbonization was ~ 10 to 18%. In addition, wood carbonization induces negative effects on the environment (Kersten et al. 1998). The temperature that rises from 20 to over 500°C, (Mezerette et al., 1991), impacts the soil and the fauna surrounding the earth kilns. These effects are more important because of the large distribution of earth kilns in the areas of charcoal production. Fontodji (2007) reported that the kilns' average area is about 13 m^2 and the number of kilns per hectare is 72 in some areas with intense charcoal production. He also mentioned that the areas burned by charcoal production represent 10% of farmland in Togo.

Several studies were carried out on the production, the marketing and the consumption of charcoal in Togo (Thiam, 1991; Ouro Djeri, 1994; Porosi, 1997; Ministère des Mines, de l'Energie et des Postes et Télécommunication (MMEPT), 2002; Akpamou, 2003; Agbéré, 2006). However, a little attention had been given to the impacts of charcoal production on biodiversity (Kokou et al., 2009), especially on the soil and the ground fauna. The aims of this study were to assess the impact of the charcoal production on the soil physical and chemical properties and on the ground fauna.

MATERIALS AND METHODS

Study areas and samples collection

Togo extends over an area of approximately 56,600 km^2 and five biogeographical zones (Ern, 1979). The study was focused on three ecological zones which are the Sudanian savanna in the northern plains of Togo, the Guinean savanna in the central plain and the Semi-deciduous forest and anthropogenic savanna in the southern part of the Togolese Mountains. In each zone, a charcoal production area was randomly selected (Figure 1).

Charchoal production fire effects were investigated by analysing four factors: fire, climate (guinean, sudanian and subequatorial), vegetation types (semi deciduous forest, Guinean savanna and Sudanian savanna) and the distance between the kiln and the control (witness). This distance is of 15 m for the determination of the physical and chemical properties of soil (figure 2), of 5, 10, and 15 m for the determination of the microbiological biomass (Figure 3), of 2, 10, and 26 m for the specific inventory of the soil fauna. One charcoal kiln of one week of age was selected for sampling purposes in each zone.

Samples were achieved according to AFNOR-Norm NF X 31-100 (1999). Soil of the surface layer (0-20 cm depth) was taken randomly from 10 different sites in each experimental kiln to make a composite sample. Control samples were collected in an unburnt area (witness) in the similar conditions according to the distance sus-mentionned.

Soil physical and chemical analysis

Soil bulk density, total porosity and soil permeability were determined as described by Soltner (1982). The bulk density is a measure of the weight of the soil per unit volume (g/cc), usually given on an oven-dry (105°C) basis, while the total porosity was calculated from values of soil bulk density. For instance, organic carbon was evaluated by wet-oxidation using the Walkley method (Walkley, 1947). The organic matter content was computed from the organic carbon content through a conversion factor of 1.72. Soil pH was determined by conventional standard procedures (AFNOR, 1999) in soil-water (1:2) medium using digital electronic pH meter.

Assessment of hypogeal soil fauna

Fauna assessment was carried out by microbial biomass quantification and fauna species inventory. The microbial biomass was quantified using the technique of soil respiration measurements i.e with regard to the amount of CO_2 produced (Schinner et al., 1996). First of all, the soil samples were tested with a hand magnifier and the macro organisms were collected. Then, samples were put through a "Berlèse" devise to collect

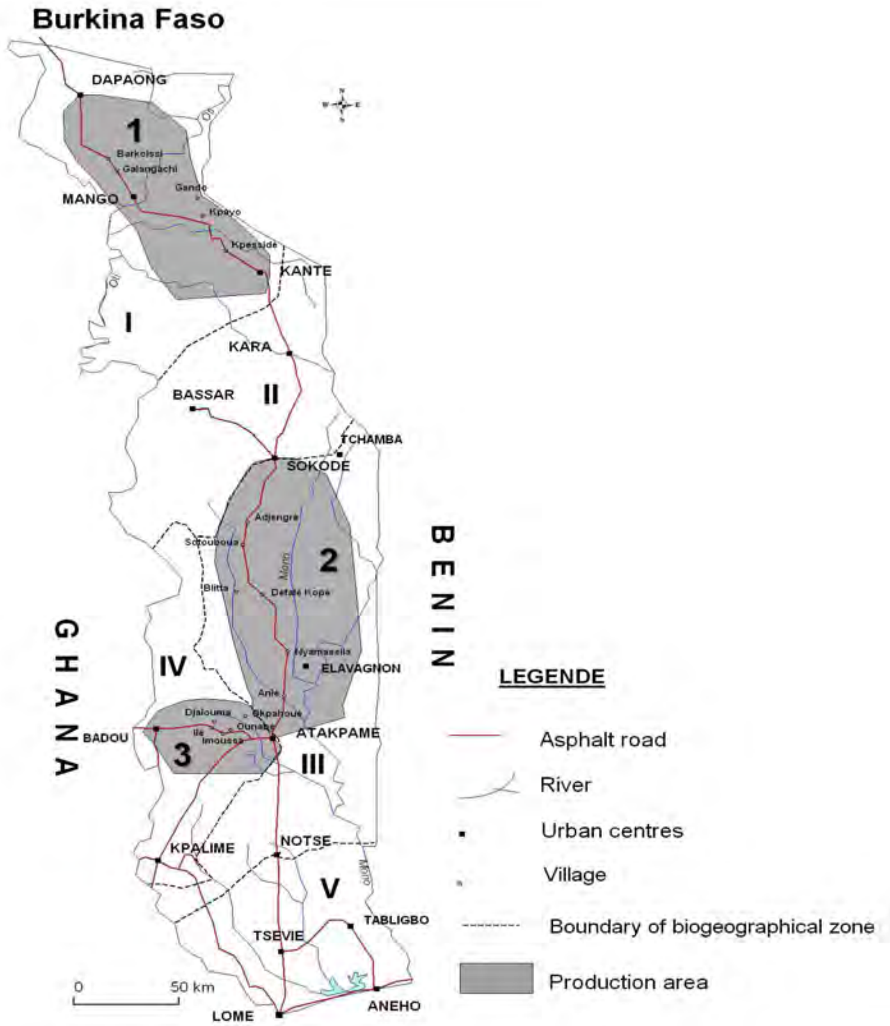


Figure 1: Location of the production areas in the biogeographical zones of Togo.

Zone I. Refers to the plains in the north with a sudanian climate characterized by a rainy season running from June to October and a dry season from November to May, with an average of 6–7 dry months. Total rainfall is between 800 and 1000 mm. The predominant vegetation is Sudanian savanna. Zone II. Concerns the hilly dry forest and savannah mosaic zones in the north with a soudano-guinean climate including cool nights at elevated regions, and with a rainy season from April to October and a dry season from October to March, characterized by the harmattan. Yearly rainfall is 1200–1300 mm, but is very irregular within the year and between years. Zone III. Concerns Guinean savanna in the plains in the centre of the country having a tropical climate characterized by a rainy season from May till October and a dry season of at least 4 months. Total rainfall is between 1200 and 1500 mm per year. The savanna of Central Togo is interspersed with islands of semi-deciduous forest in the southern part and with dry forest in the northern parts. Zone IV. Corresponds to the southern part of Togo Mountains with a transitional subequatorial climate characterized by a long rainy season occurring from March to October and disrupted by a slight decrease in rainfall in August or September. The rainfall amounts range from 1300 to 1600 mm per year. Here, semi-deciduous moist forest are the major vegetation type. Zone V. Refers to the coastal plain in the south under a subequatorial climate characterized by a shortage of rainfall in the coastal part (800 mm/year in Lome, the capital). The landscape offers a mosaic of savanna, agricultural land and prereserved forest. Islands of dry semi-deciduous forest are found mainly as sacred forest or as classified forest.

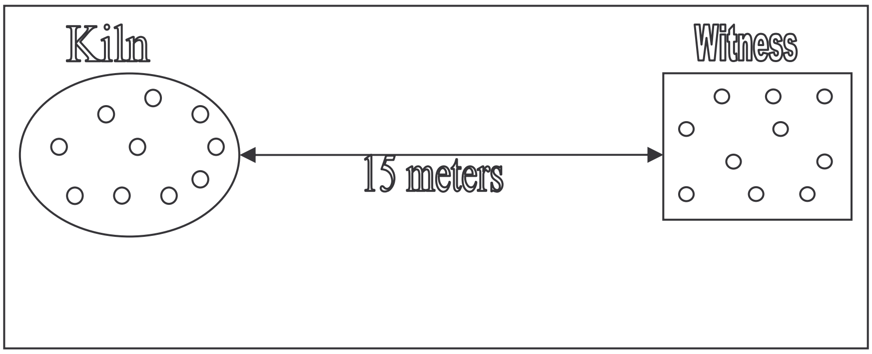
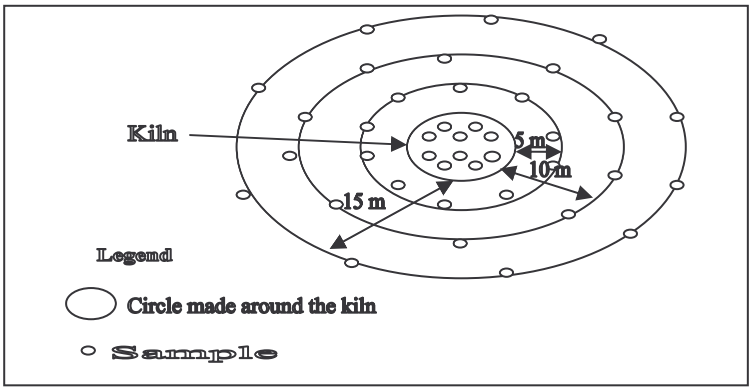


Figure 2: Site sampling to determine the soil physical and chemical properties.



m = meter

Figure 3: Site sampling to determine the soil microbial biomass.

smaller arthropods. The experience consisted in placing the soil samples in a funnel fitted with a mesh sieve from 1 to 5 mm and to expose them to a light source.

The insects fleeing the heat, the dryness, and especially the light fall into a becker containing a fixer alcohol 70° under the funnel (Figure 4). Species were identified using a determination key (Coineau, 1974) and a reference of samples of the Applied Entomology Laboratory (L.E.A) of the University of Lomé (Togo).

Data analysis

The organic matter (OM) rate was calculated considering that one mole of organic carbon (C) corresponds to 12 g. The rate of oxidization is 77%. V_1 in ml is the volume indicated by the burette of the sample's dosage and V_2 (ml) the volume of the witness (without water) measured to title the salt of Mohr. Organic carbon quantity is obtained using the following formula: $C_{(mg)} = \frac{12}{4} x (10 + V_1 - V_2) x \frac{77}{100} = 3.896 x (10 + V_1 - V_2)$. If A is the quantity of carbon in mg of the dry mass of the sample: $C_{\%} = 389.6/A \, x(10 + V_1 - V_2)$. The organic matter (OM) rate is given by the relation: percentage of the organic C x100/55 (Walkley, 1947).

Diversity indexes of the soil fauna were calculated inside each area of charcoal production, using species richness, Shannon index and evenness index (Daget, 1980; Shannon et Weaver, 1949; Pielou, 1977):

- Species richness (N_o), which represents the total number of fauna species inside an area of charcoal production;

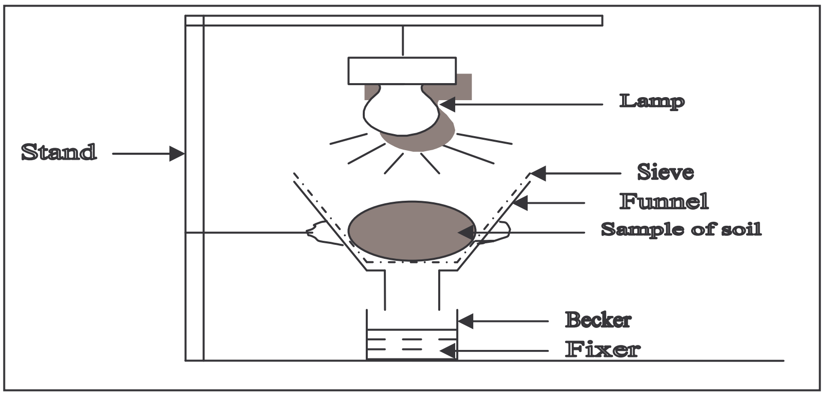


Figure 4: Berlèse device to identify soil fauna.

- Shannon index

$$I_{sh} = -\sum_{i=1}^{n} pi \log(pi) \text{ or } pi = \frac{qi}{Q},$$

qi being the population of *i* species and *Q* the total population. $Q = \sum_{i=1}^{n} qi$. Its value is high when the number of species in the collection is important or shows slightly different frequencies between species encountered;

- Evenness ($Q = \sum_{i=1}^{n} qi$) corresponding to the relationship between the diversity encountered and the possible maximum diversity.

RESULTS

Soil physical and chemical properties

Soil texture ranged from sand to sandy loam (Soil Survey Division Staff, 1993) in Sudanian and Guinean savanna areas and comprised between sandy clay loam and sandy clay in Semi-deciduous forest zone. The soil structure was massive inside the burnt plots and gritty inside the unburnt plots. Similarly, the colour in top layers is modified. By contrast, the texture before and after the fire remains unchanged.

The organic carbon contents (1.05–3.15%) are approximately comparable among the study areas (Table 1). The percentage of organic matter is higher inside the witness than inside the kilns indicating the fire impact on the soil. The organic matter is higher in Semi-deciduous forest area than in Sudanian and Guinean savannas.

The pH values ranged between 4.61 and 8.00. The values are more important in Guinean area (Guinean savanna and Semi-deciduous forest) than in Sudanian savanna (Table 2).

Bulk density was from 1.12 to 1.57, while the total porosity calculated was between 0.39 and 0.56 and permeability between 0.015 and 0.711 (Table 3).. Bulk density of soil under charcoal kiln decreased as compared to the witness then increasing total porosity. The fire increased the permeability at the kilns level by raising the total porosity of soil. Comparing different Charcoal production areas, soil total porosity is higher in Guinean savanna area than in Semi-deciduous forest. The total porosity of the soil is more important in Sudanian savanna than in Guinean savanna (Table 3).

Impacts of charcoal production on hypogeal soil fauna

The change in microbial mass was measured with regard to the amount of CO_2 produced. As CO_2 evolution in the soil results from the decay of organic matter, the results of this survey showed that the reduction of CO_2 caused by fire is different according to the ecosystem. It is the most important in Sudanian savanna (figure 5). In savannas (Sudanian or Guinean) the variation in microbial biomass reaches a radius of 15 m around the kilns while this radius is 5 m in Semi-deciduous forest.

Table 1: Soil organic matter content (%).

Soil characteristic / Charcoal production area	Kiln		Witness	
	% C organic	O.M. (%)	% C organic	O.M. (%)
Sudanian savanna	1.0519	1.912	1.4025	2.550
Guinean savanna	1.1688	2.125	2.1817	3.966
Semi-deciduous forest	2.3376	4.250	3.1557	5.737

O.M.= Organic Matter, C= carbon

Table 2: Soil pH variability.

Charcoal production area	Kiln	Witness
Sudanian savanna	5.58	5.48
Guinean savanna	6.11	5.23
Semi-deciduous forest	8.00	4.61

Real Density D=2.6

Table 3: oil bulk density, total porosity and permeability.

Soil characteristic / Charcoal production area	Kiln			Witness		
	Permeability (cm/mn)	Bulk density D'	Total Porosity (1-D'/D)	Permeability (cm/mn)	Bulk density D'	Total Porosity (1-D'/D)
Sudanian savanna	0.022	1.46	0.438	0.015	1.575	0.394
Guinean savanna	0.675	1.257	0.516	0.056	1.486	0.428
Semi-deciduous forest	0.711	1.120	0.569	0.284	1.171	0.549

Real Density D=2.6

In addition, the inventory of soil fauna allowed to record 81 micro-organisms belonging essentially to the Beetles, Hymenoptera, Heteroptera, Diptera, Orthoptera, Myriapods, Homoptera, Acarians, Nematodes, Isoptera, etc. The hypogeal biodiversity indexes (average species richness, Shannon average index and average evenness) were more important in Semi-deciduous forest areas than in Sudanian or Guinean savannas (Table 4). Farther moving away from the kilns, greater the species diversity was. The curve representing specific richness (N_0) and Shannon Index tend to stabilise beyond a radius of 10 m from the kiln (Figure 5). Semi-deciduous forests provided the most micro-organisms and Sudanian savannas provided less micro-organisms than Guinean savannas.

The soil fauna is more diversified in surface than in depth. But in Guinean savanna, the results of this study revealed more diversified fauna in depth than in surface (Figure 6).

DISCUSSION

Soil physical and chemical properties

The organic matter was decreased by fire. Similarly, Bird et al. (2000) observed that annually, the burnt plots in a sub-humid savanna in Zimbabwe had the lowest soil organic carbon stocks compared to plots in which fire had been excluded.

The soil pH is higher inside the burnt plots than inside unburnt plots (Table 2). The soil pH was slightly acidic originally but became alkaline after charcoal burning mainly because of the increase in the levels of basic cations (Oguntunde et al., 2004) as a result of organic acids denaturation (Arocena and Opio, 2003). Similar results were obtained in studies related to charcoal production in Ghana (Oguntunde et al., 2004), to slash-and-

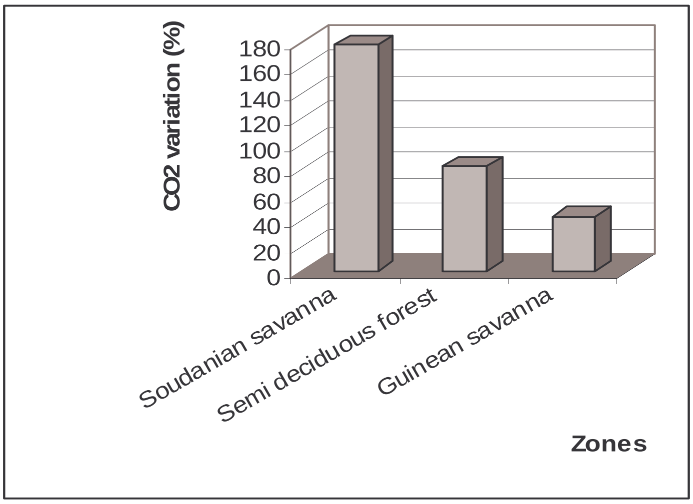
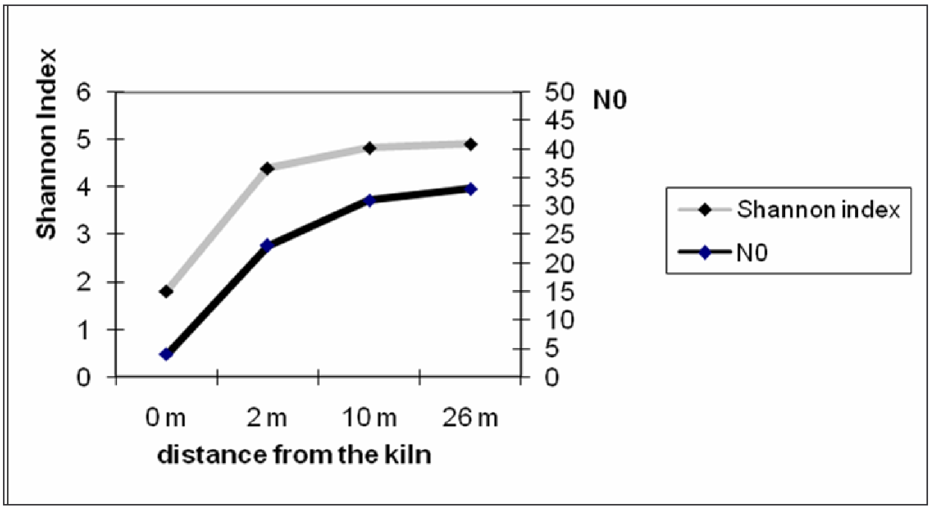


Figure 5: CO_2 variation per zone



m= meter

Figure 6: Variability of Diversity index in Semi-deciduous forest area.

Table 4: Variability of species diversity.

Charcoal production area / **Diversity indices**	Semi-deciduous forest	Guinean savanna	Sudanian savanna
Specific richeness	46.0	10.0	21.0
Shannon index	5.15	2.64	3.83
Evenness	0.93	0.80	0.87

burn and soil amended by addition of charcoal (Glaser et al., 2002).

Bulk density of soil under charcoal kiln decreased as compared to the witness increasing then total porosity and permeability. The total porosity and the permeability increased due to the heat of the fire that broke the colloidal connections. Those results are similar to previous studies reported on charcoal production in Ghana (Oguntunde et al., 2008). They found significant decrease by 9% of bulk density of soil under charcoal kiln and significant increase of total porosity. In contrast, Giovannini et al. (1988) assessed that bulk density increased as a result of the collapse of the organo-mineral aggregates.

Impacts of charcoal production on hypogeal soil fauna

The soil respiration rate, as assessed by carbon dioxide (CO_2) evolution, is an indicator of soil biological activity. Microbial biomass was reduced by fire. Fire effect was broader in savannas than in forest DeBano et al. (1998) assessed that immediate effect of fire on soil microorganisms is a reduction of their biomass. They argued that the peak temperatures often considerably exceed those required for killing most living beings. In a soil under *Pinus spp*., Prieto-Fernandez et al. (1998) also assessed that immediately after the occurrence of a wildfire, microbial biomass had almost disappeared in the surface layer (0-5 cm) and reduced by 50% in the immediate subsurface zone (5-10 cm). Semi-deciduous forests provided the most micro-organisms and Sudanian savannas provided less micro-organisms than Guinean savannas. This is due to the humidity gradient and the availability of plant waste (more OM) in the forests than in the savanna areas.

The local climate has a large influence on fauna distribution. In Guinean savanna, the results of this study reveal more diversified fauna in depth than in surface. This could be explained by the fact that in savannas the surface of soil is completely dried by the effect of the dry season (6 to 8 months of dryness). In the Semi-deciduous forests, whatever the season, there is always favourable moisture for the soil fauna because of the abundant waste, which not only keeps this preferential moisture, but serves as nutrients. In savanna, animals of the soil, in search of preferential moisture run off to the depth because of the heat of the dry season. Certini (2005) assessed that invertebrates have higher mobility that enable them a potential to escape heating by burrowing deep into the soil. The species are already facing survival difficulties before the event of fire which destroys them completely. In the dry season, the effect of fire only worsens temperature variations that have very serious effects on soil fauna. It is therefore reasonable that the effect of fire be broader in savannas than in forest. Species diversity and microbial biomass increase up to a radius of 10 m in forests and 15 m in savannas. Furthermore, the destruction of the microbial biomass is more disastrous in Sudanian savannas than in any other plant communities considered in this study. The savannas species are more delicate than those of the forests especially in the dry season because of the precarious ecological conditions. The destruction of some species by fire may be permanent. The carbonization constitutes then a real threat to the diversity of the soil fauna. Meanwhile, the role of these organisms is essential in the restoration of the soil. Their action is very complex. They are the ones that are imposing the plant waste degradation into simple elements, and then synthesise them into more complex sets like humic acids, for example. In fact, 80% of soil animals are ground scavengers (Coineau, 1974). As Organic matter provides the food or substrate on which heterotrophic soil microbes feed, it is obvious that the soil micro-organisms, relying on plant waste for survival and unable to bear high temperatures, be more abundant and more diversified in the forest than in the savanna.

Conclusion

Charcoal production activity impacts soil physical and chemical properties, biodiversity, which are altered. The organic matter is destroyed; the pH rises as well as the permeability and porosity of the soil from the kilns. The effect of charcoal production on the microbial mass is more important at 5 m in average around the kiln in semi-deciduous forest ecosystems and 15 cm in savanna. The hypogeal biodiversity indexes (species richness, Shannon index and equitability) are also more important in Semi-deciduous forest areas than in savannas.

In the light of these findings, the growth, the rationalization and the modernization of the woody biomass uses are vital for a sustainable management of forest resources and their restoration. Considering the extent and the distribution of kilns in the charcoal production areas (~72 per hectare i.e. an average of 950 m^2/ha), the surface of natural or farmland affected by this activity is important. Then, considering that the effect of a single kiln may extend over a radius of 10 in forest area and 15 m in savanna areas, soil properties and hypogeal fauna are regularly destroyed by fire in more important area than above-mentioned. Therefore, it is an urgent need to review the overall policy in terms of wood energy pricing to take into account, the rising degradation of forest resources, fauna and soil and make better use of wood energy. The definition of production areas, periods and types of logging as well as the introduction of new more environmental production techniques are necessary than ever.

Beyond these interesting findings, the main limit of this survey is the length and the cost necessary for the observations and the analyses that didn't permit to achieve several repetitions in the time and in the space. Some devices are currently monitored to bring complementary results to this survey, important for decision making.

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