International Journal of Biosciences | IJB |
ISSN: 2220-6655 (Print), 2222-5234 (Online)
http://www.innspub.net
Vol. 15, No. 4, p. 278-288, 2019

INNSPUB

RESEARCH PAPER OPEN ACCESS

Evaluation of soil fertility indicators under planted trees fallows in northern Côte d'Ivoire

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Key words: Fallows, Restoration, Soil Fertility, Agroforestry, Côte d'Ivoire.

http://dx.doi.org/10.12692/ijb/15.4.278-288 Article published on October 27, 2019

Abstract

In impoverished soils in northern Côte d'Ivoire, the use of mineral fertilizers alone does not maintain soil fertility. Planted trees fallows is certainly one of the best alternatives for a biological restoration of the fertility of degraded soils. The present work aims to study the effects of 3 planted trees fallows on soil fertility indicators. Three fallows of *Acacia auriculaeformis*, *Eucalyptus camaldulensis* and *Gmelina arborea* and a control fallow were sampled from July to November 2017 to evaluate successively the density of termites and earthworms, soil granulometry, organic matter and mineral elements of soils, as well as litter produced. The Tukey-HSD test showed similar termite densities on *Acacia auriculaeformis* and *Eucalyptus camaldulensis* fallows with the highest density on the first fallow. Similarly, similarities of the earthworm densities were observed on *Acacia auriculaeformis* and *Gmelina arborea* fallows (Tukey-HSD test). The litter was more abundant under improved fallows than the control plot with a maximum reached under *Acacia auriculaeformis*; the leaf component represented at 93%. Granulometry of *Acacia auriculaeformis* fallow soil showed a percentage of clay (17.33%) and silt (13.08%) slightly greater than their percentages under *Eucalyptus camaldulensis*, *Gmelina arborea*fallows.Soils of the 4 plots were rich in organic matter and had a low content of exchangeable cations. The C/N ratio was low enough for the biomass of all fallows to allow early mineralization of N. *Acacia auriculaeformis* appeared as the species capable of restoring soil fertility.

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Introduction

The sustainable management and recovery of highly degraded soils is a challenge for agriculture in tropical countries. Optimizing production requires the use of chemical fertilizers, which remain very expensive for farmers (Mokossesse *et al.*, 2009). In addition, the misuse of these products is problematic because of their harmful effects on the environment.

In such a context, fallow is certainly one of the best alternatives for a biological restoration of soil fertility. Unfortunately, the strong increase of the population in developing countries and the increasing shortage of land in many parts of the tropics have resulted in a decreasing bush fallow period for natural regeneration of the soils and a continuing reduction in agricultural productivity on these sites (Drechsel *et al.*, 1991). Planted tree fallow seems to be a solution to overcome the problems of the traditional land use system and increase crop production and income. Indeed, improved fallow has several advantages as improving soil chemical, physical conditions and biological activity, accumulating nutrient stocks in fallow vegetation, and reducing weed, insect and pathogen populations (Nair and Latt, 1997).

Otherwise, soil macroinvertebrates play a major role in restoring and maintaining soil fertility. Indeed, if the termites are recognized as "ecosystem engineers" because of their ability to modify the availability of resources for other organisms (Konaté, 1998) and to encourage soil transformation (Dangerfield *et al.*, 1998, Rajeev *et al.*, 2011), earthworms are "true architects" of fertile soils (Lukas, 2013). According to Nair and Latt (1997), accumulation of litter on soil surface and microclimatic changes might lead to increase activity and abundance of soil macrofauna under trees planted fallows, particularly in the subhumid and humid environments. The diversity and abundance of these macroinvertebrates are also correlated with the vegetation of the soil. Also, the use of ecosystem services of these organisms is a way in exploration (Lukas, 2013; Kifukieto *et al.*, 2016; Dosso *et al.*, 2017b) for fertilization at lower cost of soils. However, in Côte d'Ivoire, only a few studies had been done on of soil macroinvertebrates and focused on the analysis of their community in natural or transformed habitats (Dosso *et al.*, 2012; 2013, 2017a and b, Tra-Bi *et al.*, 2012; Coulibaly *et al.*, 2013) and their harmful action in agriculture (Akpesse *et al.*, 2008, Coulibaly *et al.*, 2014). Little is known about the impact of planted trees fallow types on macroinvertebrates densities and soil fertility. The purposes of this study were: (1) to compare the density of the soil macroinvertebrates under different fallows, (2) to compare the litter production on different fallows, (3) to evaluate the granulometry, the organic matter and the mineral elements in soil.

Material and methods

Study area

The experimental device was installed on the Kamonon Diabaté Forest Research Station, with geographical coordinates 5-32' W longitude and 9-34'N latitude, about 20 kilometers from Korhogo (Figure 1). The climate is of the dry Sudanese tropical type with two contrasted seasons: the rainy season (monthly rains >50 mm) extends from April to October and the dry season from November to March. The annual average rainfall varies between 1000 and 1600 mm. Rainfall constitutes the most influential climatic factor. The average humidity is 65–70% and the annual average temperature varies between 24 and 36 °C. The natural vegetation is a savanna, with an almost complete cover of high grass dominated by *Panicum* sp. The general pattern of the region is a tabular set of ferruginous cuirasses with gentle breaks caused by garlands of hills and hillocks with rounded reliefs set on plateaus of medium height (Avenard *et al.*, 1971). According to Beaudou and Sayol (1980), the geological substratum consists of calc-alkaline granites of the Precambrian. The soil cover of this region is characterized by the very large predominance of ferrallitic soils (Avenard *et al.*, 1971).

Field methods

The present work was conducted under three six-year-old fallows, *Acacia auriculaeformis* A. Cunn ex Benth, *Eucalyptus camaldulensis* Dehnh. And

Gmelina arborea Roxb. With an initial density of 5000 trees per hectare. A natural fallow, contiguous to the three planted fallows was the control plot. Sampling took place over 5 months with one sampling per month 2017. The soil samples were taken according to T.S.B.F. (Tropical Soil Biology and Fertility) method. The monolith of soil taken was 25 x 25 x 30 cm. Four monoliths of soil were collected by fallow per month. In the laboratory, the soil is loosened and the macroinvertebrates harvested with forceps and kept in 90° alcohol until sorted and weighed.

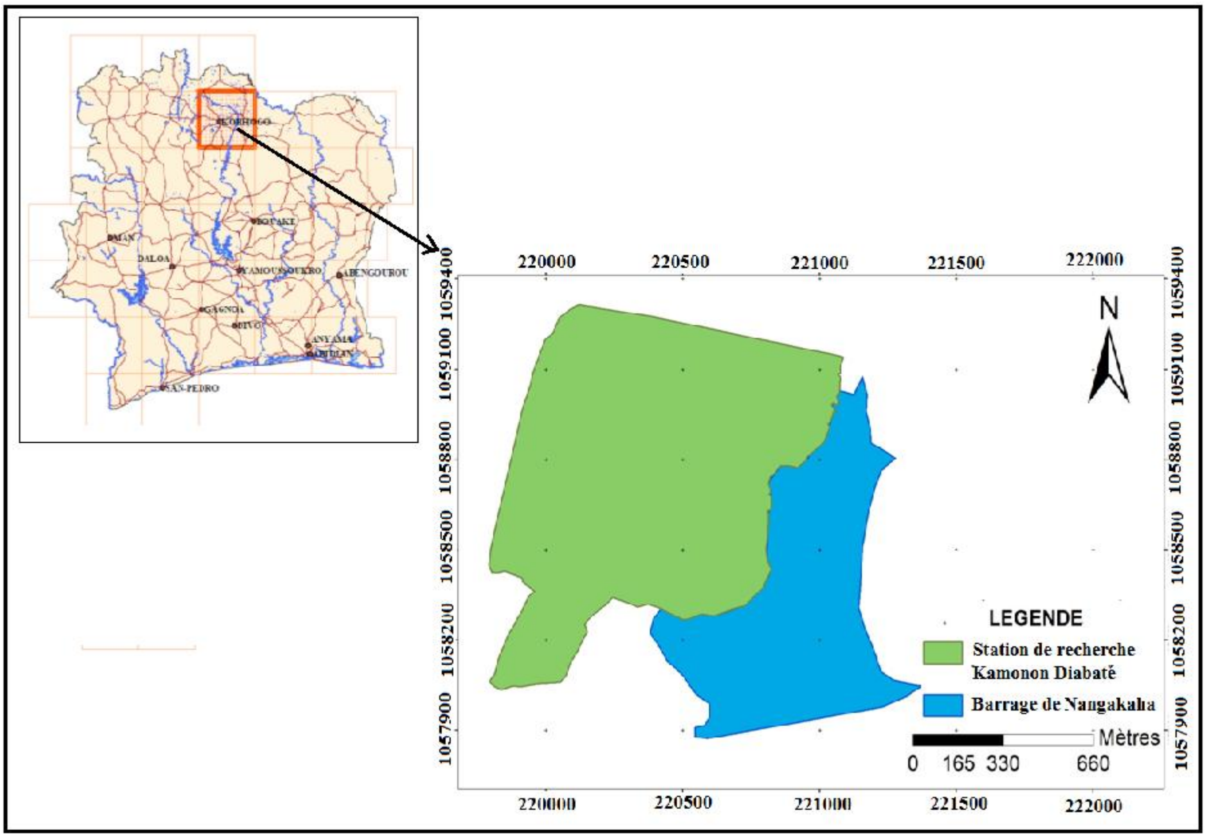


Fig. 1. Geographical location of the study area.

The litter productions in different fallows were measured using traps of 1 m^2 size at 4 random points at each site. Sampling was done monthly from July to November. Litter samples were dried at 80°C and weighed.

The sixteen composite soil samples were physically and chemically analyzed in the soil and plant laboratory of Félix Houphouet-Boigny National Polytechnic Institute of Yamoussoukro. On these fine earth samples, the granulometric analysis was performed using the densimetric method using Robinson's pipette (Gee and Bauder, 1986). The water pH measurement was performed by electrometry, in a soil suspension in the water in a ratio of 1/2.5. Organic carbon (C) was dosed using the Walkley and Black method (1934), the result was converted to organic matter (MO) using factor 1.72 (MO= C x 1.72). Total nitrogen was determined by the Kjeldahl method (Bremner, 1996).

The exchangeable cations and cationic exchange capacity were combined in an ammonium acetate extraction solution (CH_3COOH, 1N) stamped at pH 7 (Thomas, 1982). Total phosphorus was determined by colorimetry, after extraction with perchloric acid (Olsen and Sommers, 1982).

Data analyses

An ANOVA model was used to compare termite and earthworm densities, litter production and soil granulometry among the fallows. Before analyses, values were square root-transformed using power transformations (Clarke and Warwick, 1994) to the normality and homogeneity of variance assumptions. If the results of ANOVA indicated significant main effects at the 0.05 probability level, then Tukey-HSD test was used to determine which means significantly differed. These tests were performed using Xlsat2014 Software.

Results

Soil macrofauna

Termite densities (Fig. 2) were significantly greater at *Acacia auriculaeformis* and *Eucalyptus camaldulensis* fallows and lower at *Gmelina arborea* fallow and natural fallow (Anova. $p < 0.05$, Tukey-HSD test). However, the highest densities of termites were generally observed in the 3 shrubby fallows.The highest densities of earthworms (4.84 million/Ha) were observed at *Acacia auriculaeformis* fallow in September. Then came *Gmelina arborea* fallow with a density of 4.04 million/Ha. *Eucalyptus camaldulensis* fallow had the lowest density of earthworms among shrubby fallows (Fig. 3).

Earthworm densities were highest on shrubby fallows than natural fallow. A significant difference ($p < 0.05$) was recorded between earthworm densities. The Tukey-HSD test combined the natural and *Eucalyptus camaldulensis* fallows with low densities that differed from *Acacia auriculaeformis* and *Gmelina arborea* fallows with high earthworm densities.

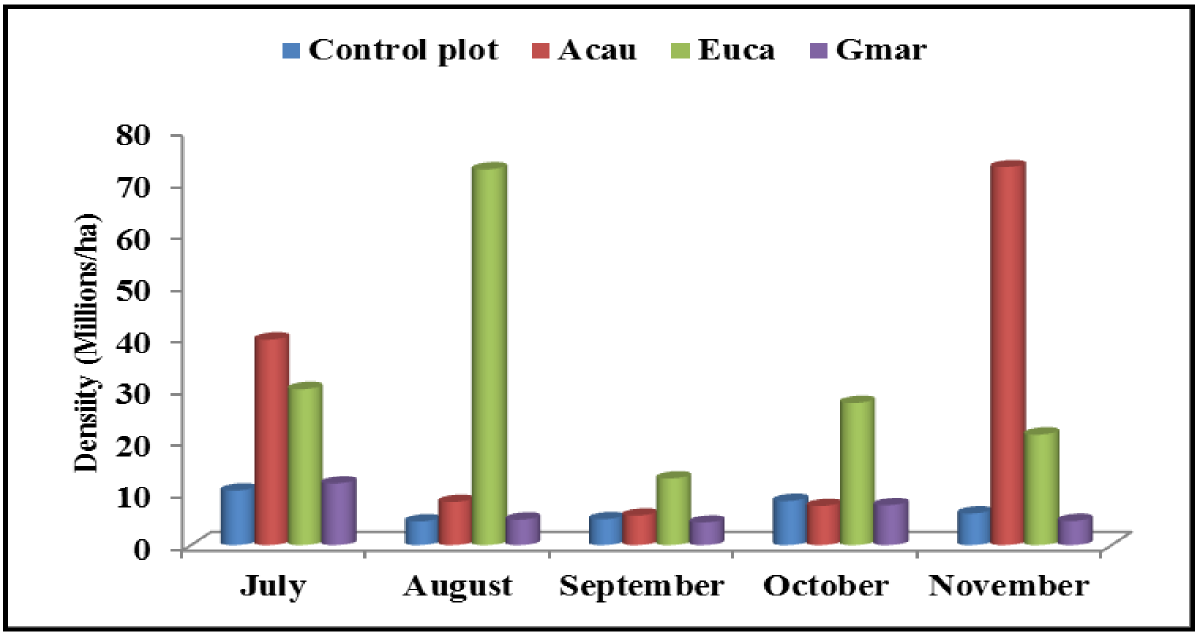
Table 1. Physico-chemical analysis results of the soils of the 4 plots.

	reference values	Control plot	*Acacia auriculaeformis*	*Eucalyptus camaldulensis*	*Gmelina arborea*
Granulometry (%)					
Clays		15.8	17.33	16.1	15.73
Silts		4.01	5.4	4.18	4.4
Coarse silts		7.1	7.68	6.28	7.43
Fine sands		25.2	23.3	24	29.93
Coarse sands		47.88	46.3	49.48	42.48
Organic matter					
Organic matter (g/kg)	>1.30	1.45	1.99	1.69	1.85
Organic Carbon (g/kg)		0.84	1.16	0.98	1.07
Total Nitrogen (g/kg)		0.081	0.094	0.075	0.087
C/N Ratio	9 à 12	10.3	12.4	13.1	12.3
Phosphorus (mg/kg)	> 26	9.8	8.55	10.9	10.54
Exchangeable cations					
Ca (cmol/kg)	>3.83	2.51	2.94	2.89	2.6
Mg (cmol/kg)	>1.84	0.82	1.03	0.86	0.9
K (cmol/kg)	>0.31	0.16	0.28	0.2	0.13
Na (cmol/kg)		0.03	0.03	0.03	0.02
S (Ca, Mg, K, Na) (cmol/kg)	>5,50	3,52	4,22	3,75	3,64
C.E.C. (cmol/kg)	>5,80	3,8	4,37	3,95	3,8
S/CEC (%)	90 à 100	96,44	96,42	94,94	95,79
pH					
pH eau		6,45	6,31	6,71	6,39

Litter production

No significant differences in Litter abundance was observed among the fallows (Fig. 4, p >0.05). Therefore, litter was more abundant under the 3 shrubby fallows (*Acacia auriculaeformis* (8.3 T), *Eucalyptus camaldulensis* (7 T) and *Gmelina arborea* (6.6 T).

The leaf component was higher under the 4 fallows (Fig. 5). It was maximal (93%) with *Gmelina arborea* fallow and minimal (64%) with *Eucalyptus camaldulensis* fallow. The wood component of litter was high (34.75%) with *Eucalyptus camaldulensis* fallow and low (1.88%) with *Gmelina arborea*.



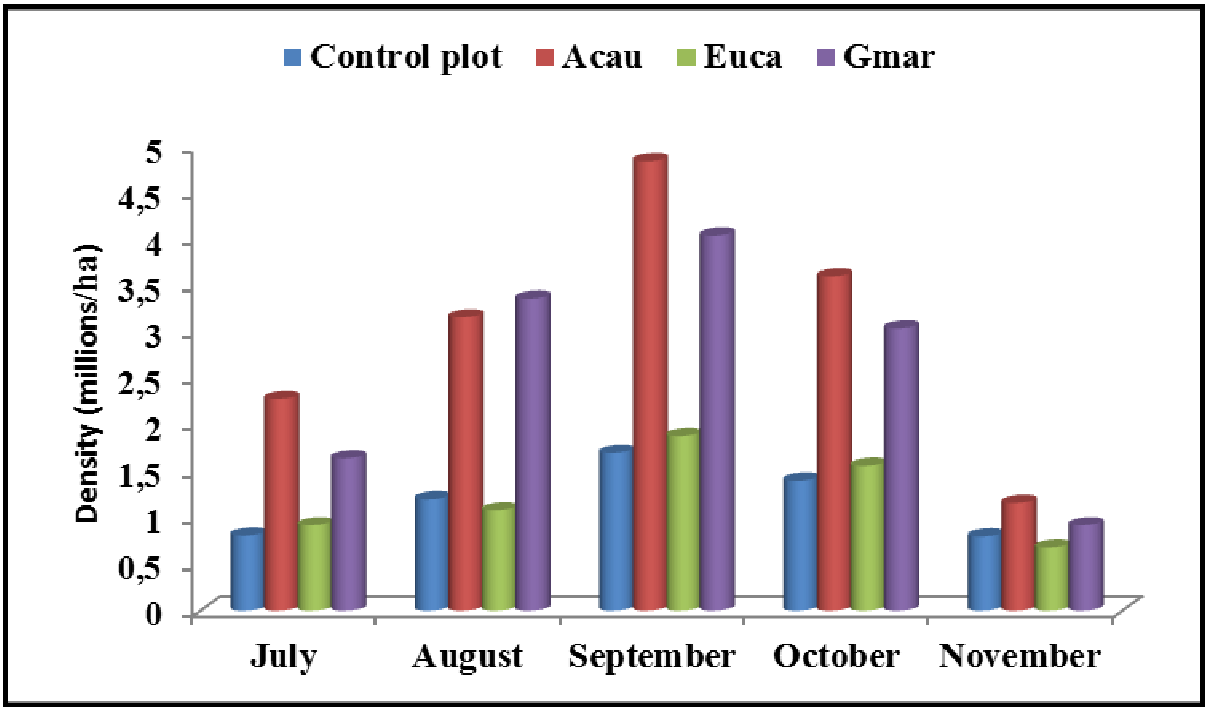
(Acau : *Acacia auriculaeformis,* Euca : *Eucalyptus camaldulensis*, Gmar : *Gmelina arborea*)

Fig. 2. Density of termites on the 4 plots during the rainy season.

Physical and chemical characteristics of agrosystem soils

Table I showed the results of physical and chemical analyzes of the soil of each agrosystem after six years. At the textural level, the data revealed that improving fallow with these trees did not have a significant effect (p >0.05) on the soil content of clay, silt and sand. Overall, under *Acacia auriculaeformis* fallow, clay and silt percentage, respectively (17.33% and 13.08%) were slightly higher than their percentages under other fallows. The data showed that the average values of organic matter and nitrogen content were relatively higher under *Acacia auriculaeformis* fallow soil (OM: 1.99 g/kg, N: 0.94 g/kg) than under *Eucalyptus camaldulensis* and *Gmelina arborea* fallow soils. The lowest organic matter content (OM: 1.45 g/kg) was recorded on the control plot. The fallowing of the plots did not influence pH of the soil which remained weakly acidic (6.31 < pH> 6.71) on all the agrosystems. According to Phosphorus, soils generally showed low levels (> 26 mg/kg). Fallow planted with *Acacia auriculaeformis* recorded the lowest value (8.55 mg/kg). The other two improved fallows and the control plot had values between 9.8 mg/kg and 10.54 mg/kg. For exchangeable cations, soils were deficient in exchangeable cations generally.

There was no significant fallow effect (p>0.05) on the soil content in Calcium, Magnesium, Potassium and Sodium. Nevertheless, the soil calcium content of *Acacia auriculaeformis*, *Eucalyptus camaldulensis* and *Gmelina arborea* were up 17.13%, 15.14% and 3.59%, respectively. Planted tree fallows also increased the Magnesium content from 4.88% to 25.61% in the soil of these agrosystems. For Potassium, the upward trends were 75% under *Acacia auriculaeformis* and 25% under *Eucalyptus camaldulensis*.



(Acau : *Acacia auriculaeformis,* Euca : *Eucalyptus camaldulensis*, Gmar : *Gmelina arborea*)

Fig. 3. Density of earthworms on the 4 plots during the rainy season.

There was a drop of 18.75% in the Potassium content under *Gmelina arborea*. The Sodium content remained invariable on all agrosystems. Like the exchangeable cations, the cationic exchange capacity (CEC) also showed a trend improvement of 3.95% and 15% respectively under *Eucalyptus camaldulensis* and *Acacia auriculaeformis*.

Discussion

Macrofauna of the soil under the four plots

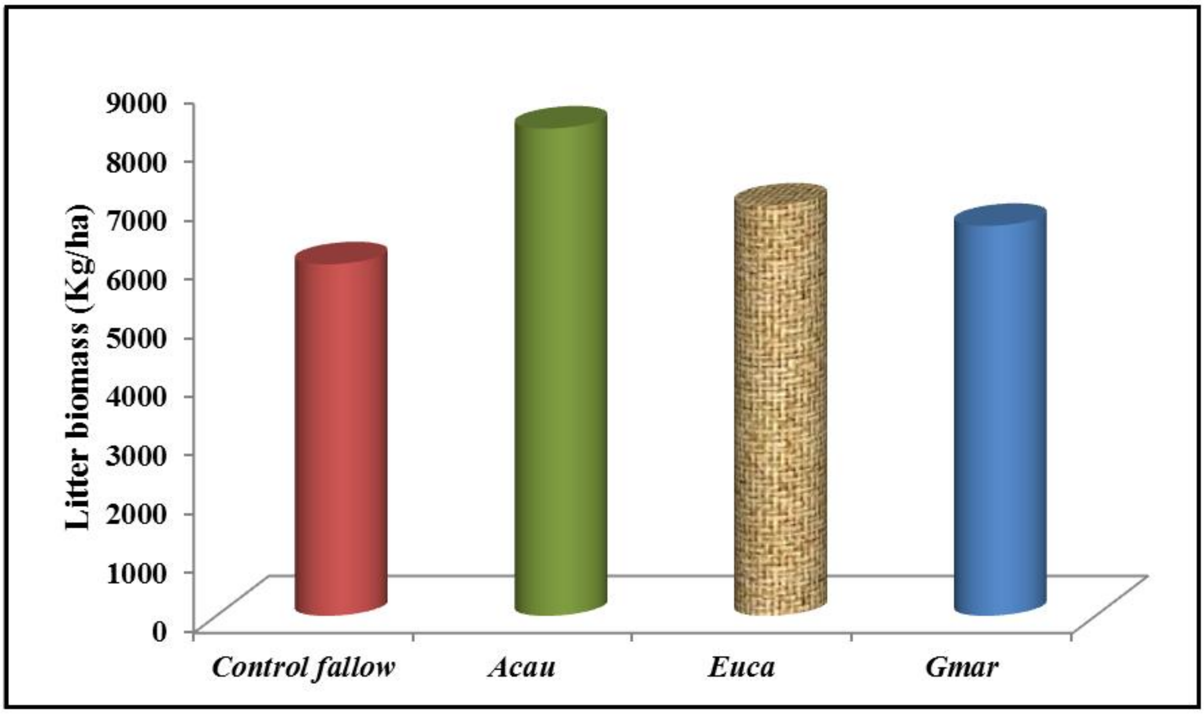
The density of these two groups of macroinvertebrates was highest for the termites under *Acacia auriculaeformis* and *Eucalyptus camaldulensis* fallows, whereas for the earthworms it was highest under *Acacia auriculaeformis* and *Gmelina arborea* fallows. The abundance of macrofauna under the 3 tree fallows could be explained by the lack of agricultural activities on them. Indeed, according to Eggleton *et al.* (2002), the soil macrofauna is affected by the exploitation of the soil and the use of chemical inputs. This lack of activities would induce an important plant succession during the fallow period (Serpantié and Ouattara, 2001). This would increase soil macrofauna. In addition, the high stock of organic matter could attract termites and earthworms that would find abundant nutrients under these fallows.In the case of earthworms, litter of *Acacia auriculaeformis* and *Gmelina arborea* would mineralize relatively more rapidly than those of *Eucalyptus camaldulensis*. Moreover, they could be relatively more digestible. Their higher density under the 3 fallows in September could be explained by the peak of rainfall observed this month which would contribute to more humidify the litter to promote its digestibility and thus create best conditions to the proliferation of earthworms.

Litter production

Planted fallows improved with *Acacia auriculaeformis* produce a lot of litter, especially for older individuals. This high production has already been highlighted in several works, among others, those of Sente (2011) and Wang *et al.* (2010). These authors had found that this species produced much more than the other species studied, even compared to other Nitrogen-fixing species. The litter plays a major role in the return of nutrients to the soil but also a role in the increase of nitrogen in the soil, via the symbiotic nitrogen fixation by *Acacia auriculaeformis* which supplies large amounts of nitrogen to the system. Aerial trees, and more particularly to leaves.

Soil Granulometry, Organic matter and Soil Minerals

Granulometry: Under *Acacia auriculaeformis* fallow, percentage of clay and silt was slightly higher above their percentages under *Eucalyptus camaldulensis* and *Gmelina arborea* fallows. This result could be related to the action of termites and earthworms, which are very abundant in the soil. Indeed, these organisms affect the infiltration of water and the aggregation of the soil, therefore the porosity and its organization. According to Lavelle *et al.* (1991), in savannah soils, the physical protection and maintenance of the physical structure of the soil is very largely determined by the activity of the macrofauna. Termites affect the physical organization of the soil by building nests, aggregating the soil and digging underground galleries and chambers (termitospheric effects) according to Léonard and Rajot (2001). As for earthworms, they have a drilospheric action on the physical structure of the soil.

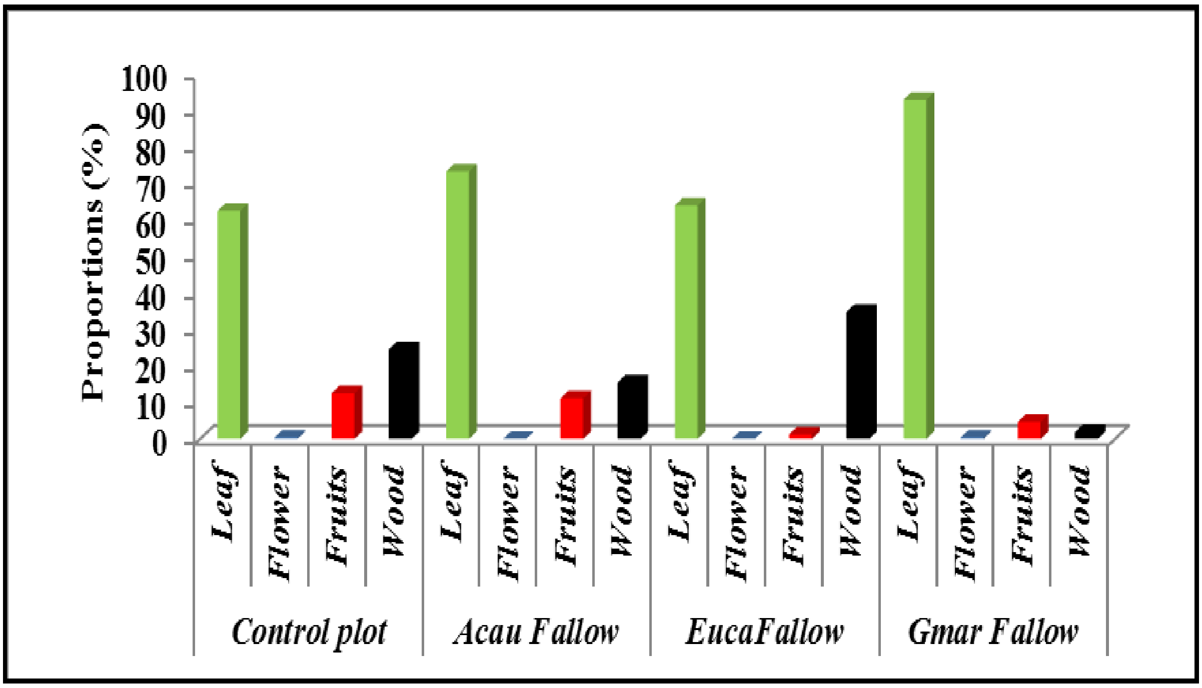


(Acau : *Acacia auriculaeformis,* Euca : *Eucalyptus camaldulensis*, Gmar : *Gmelina arborea*)

Fig. 4. Litter biomass produced on the plots.

This activity is manifested by their incredible architectural skills that contribute to modify the soil structure. This is done at different levels in a soil profile (Piron, 2008), and modifies the porosity and aggregation of the soil (Freyssinel, 2007), thus the aeration of the soil (Feller *et al.*, 2003) and even the drainage (Karaca, 2011). Girard *et al.* (2005) and Lorranger-Merciris *et al.* (2012) demonstrated that earthworm activities increase micro and macroporosity. Organic matter: Improved fallow and control plot soils can be considered rich in organic matter (> 1.30 g / kg). This richness is more marked for *Acacia auriculaeformis* fallow. This would be due to the faster decomposition of the abundant litter resulting from *Acacia auriculaeformis*. It could also be related to the activity of soil macroorganisms. Indeed it has been demonstrated by Jouquet *et al.* (2002) and Roose-Amsaleg *et al.* (2004) that the activity of termites increases the organic matter content in the soils they use for the construction of their nests. The low values of the C/N ratio could be due to the richness of this vegetation in Nitrogen. It could also mean that the organic matter is rich in decomposed substances, proof of a strong microbial activity.

Exchangeable cations: The lowest values of Exchangeable cations and CEC would show the low chemical fertility of soils. Latham *et al.* (1985) mentioned that soil acidity is evidence of a very high desaturation state of CEC and that this desaturation state becomes critical below pH-water of 5. All pH values above this threshold value measured in this study would indicate that the desaturation state of the CEC would not be very advanced. It should be noted according to Senté (2011) that the cation content of the exchange complex depends on many other factors, such as particle size, mineralogy and carbon contents.



(Acau : *Acacia auriculaeformis,* Euca : *Eucalyptus camaldulensis*, Gmar : *Gmelina arborea*)

Fig. 5. Component of litter produced on plots.

The lower values of exchangeable cations would partly be due to the mineralogical composition of these soils. In fact, these soils consist mainly of quartz and kaolinite (Maymard, 1964), minerals that are not very weatherable thus providing very little nutrients to plants.

Acacia auriculaeformis appears here as the species with the best influence on the soil properties. Compared to other plants, it "increases" total nitrogen, organic matter, exchangeable magnesium, calcium and potassium. Many authors have already investigated the impact of fallow planted with *Acacia auriculaeformis* on soils fertility. According to them, the restoration of soil fertility by using*Acacia auriculaeformis* is mitigate and depends very much from one region to another, as well as the type of soil on which the plantation isinstalled. Kasongo *et al.* (2009), as well as Wang *et al.* (2010) conclude that *Acacia auriculaeformis* can be used torestore the fertility of degraded soils. Other authors like Partey *et al.* (2011) found no increase in soil fertility, following the planting of *Acacia auriculaeformis* for a short time (7 to 9 years) but nevertheless they state that after a longer period of time, *Acacia auriculaeformis* is likely to improve the physico-chemical properties of soils, mainly by the significant accumulation of litter produced by *Acacia auriculaeformis*, which in the long term could allow the return of nutrients to the soil.

This return to soil nutrients is not observed after 7 to 9 years because the decomposition rate of *Acacia auriculaeformis* litter is very slow and the release of nutrients is not very slow. Kang *et al.* (1997) state that *Acacia auriculaeformis* does not allow a significant improvement in soil fertility.

Conclusion

Acacia auriculaeformis appears here as having the best influence on the soil. This species can therefore, be used for the restoration of soil fertility through the promotion of improved tree fallow as a replacement for natural fallow that gradually disappears from crop rotations leaving land exhausted by long years of cultivation. Planted fallows improved with *Acacia auriculaeformis* have also considerable potential to contribute to soil fertility maintenance and increased food production.

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