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Organic carbon and nutrients dynamics along a chronosequence of slash and burn agriculture in southern Cameroon

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Abstract
Six chronosequences of shifting cultivation land uses were studied in three blocks of forest land differentiated by increasing land use intensity (Ebolowa, Mbalmayo and Yaoundé) in southern Cameroon, in order to evaluate the effects of slash and burn agriculture on the organic carbon and nutrients dynamics. Each chronosequence consisted of different types of land uses comprising original forest, old fallow, mid fallow, young fallow, crop land and old cocoa plantation. In each land use types, biomass measurements were done on trees, understory, litter and roots. Soil samples were taken for chemical and physical analyses for routine determinations. The total system carbon ($t.ha^{-1}$) along the chronosequence was as follows: original forest (305), old fallow (251), old cocoa plantation (184), mid fallow (180), young fallow (101), and cropland (67). Soil organic carbon represented 26% of the total system carbon stocks in original forest, 31% in old fallow, 43% in old cocoa plantation, 39% in mid fallow, 78% in young fallow, and 93% in cropland. Above ground carbon accounted for more than 97% of loss from forest converted to croplands but the soil organic carbon was also reduced by 17%. Carbon sequestration rates were calculated for land uses patterns. Natural fallows re-accumulated 3.9 $t.C.ha^{-1}.year^{-1}$ following land abandonment (r=0.91, p=0.001). When comparing the original forest to the other types of land uses, there was also a net increase of soil pH, exchangeable bases, effective cation exchange capacity, base saturation percentage, available phosphorus and a net decrease of soil organic matter, exchangeable aluminium, and the C/N ratio. These variations of the chemical status of the soil mainly attributed to the facts that these soils have in general, low inherent fertility and most of their nutrients are tied up in the forest biomass.

Keywords: Organic Carbon, Nutrients dynamics, Chronosequence of land uses, Slash and burn agriculture, humid forest zone, southern Cameroon.

1- Introduction
Slash and burn agriculture, characterized by shifting cultivation and perennial plantations (cocoa, oil palm) is the main land use system practised by small-scale farmers to ensure subsistence food crop production and a small income in the tropical evergreen forest zone of Southern Cameroon. The resulting pattern of this agricultural land use in space is a landscape mosaic system (Forman, 1995), which leads to a spatial aggregation of various fallow types of different duration, various food crop fields, various perennial plantation types, and undisturbed forest.

The shifting cultivation system, which was in the past qualified as sustainable in the tropics (Nye and Greenland, 1960; Sanchez, 1977) is nowadays considered one of the main causes of deforestation, soil degradation and spatial expansion of agriculture at the expense of forest (Allen and Barnes, 1985; Mertens and Lambin, 2000; Oldeman et al., 1990). According to Brown et al. (1997), deforestation due to this slash and burn agriculture has led to an important quantity of carbon loss to the atmosphere. Many soil characteristics have also been shown to vary over time from forest land clearing to the end of food cropping phase and during the fallow period or subsequent perennial plantations (Bewket and Stroosnijder, 2003; Tulaphitak et al., 1985).

Research on environmentally and economically sound alternatives to this slash-and-burn agriculture in the tropics is ongoing (Alegre and Cassel, 1996; Brady, 1996) to limit or halt its presumed destructive effects on the tropical forest. There is a common agreement that for a better quantification of the attributes of the most promising alternatives, there is a need for a better characterization of factors of shifting cultivation such as vegetation dynamics and soil properties in natural ecosystem for monitoring changes in transforming agricultural systems. This research was therefore motivated by such requirements.

The purpose of this study was to evaluate the effects of slash and burn agriculture on the organic carbon and nutrients dynamics in the shifting agricultural landscape mosaic system (SALMS). The fundamental questions we sought to answer in this study are: what is the average carbon stock in the SALMS as compared to the primary forest, and what are changes occurring in carbon stocks and nutrient elements as related to land use/land cover (LULC) chronosequence of shifting cultivation in the SALMS?

2- Materials and Methods

The research site and research design

The study took place in the Forest Margins Benchmark area of the humid forest zone of Cameroon located between 2º20’ - 4º30’ N and 11º00’ - 11º15’ E. The climate is characterized by four seasons: two rainy seasons (March-June and September-November) and two dry seasons. The average annual rainfall is between 1600 to 2000 mm, with annual average temperature between 24°C and 25°C.

The area has been subdivided in three North-South blocks based on land use intensity and population pressure. The sparsely populated block is Ebolowa located south; the more populated block is Yaoundé, located north; with Mbalmayo block in between. The whole area is undulating, with some incised rivers and widely distributed swampy drainage ways. Most of the upland soils (about 95%) found in the three blocks are Ferralsols and Acrisols according to the World Reference Base (WRB) for Soil Resources (FAO-ISRIC, 1998). These soils groups differ primarily by the presence of a strong textural contrast between topsoil and subsoil horizons in Acrisols and the dominance by sesquioxide clays in Ferralsols. Less developed poorly drained soils (about 5%) occupy the swampy drainage ways. Extensive shifting agriculture is the most important land use activity.

Two agricultural villages were chosen in each block and a land use chronosequence was used for the experiment in each village (a total of six chronosequences). LULC treatments in each chronosequence (6 in total) were chosen based on actual agricultural production cycles at smallholder scale described in Yemefack (2005, Chapter 2) and samples were taken with three or four different fields as replications in each village. These comprised three fallow types with increasing duration (Young fallow, 2-3 year-old; Mid-fallow, 7-9 year-old; Old fallow, more than 20 year-old), one one-year cropped land, one Jungle cocoa plantation of more than 25 year-old, and the primary forest used as control. No fertilizers were applied on any plot.

Data collection and analyses

Aboveground sampling: Aboveground data were collected on each patch in a quadrate of 25 * 4 m (100 m^2) according to the sampling strategy described by Kotto-Same et al. (1997). For estimating aboveground trees biomass, a diameter tape was used to measure tree diameter at breast height (Dbh) for all the trees with Dbh>2.5 cm in each quadrate. Quadrate bordering trees with at least 50% of their diameter falling within the quadrate were included in the quadrate.

Understorey vegetation and surface litter were measured within two sub-quadrates of 1*1 m located at random within each quadrate. Understorey vegetation included tress with Dbh<2.5 cm and all the herbaceous vegetation. Surface litters were collected on a quarter (50*50 cm) of each of the 1*1 m sub-quadrates.

Live trees biomass was estimated from the allometric equation of Brown et al.(1989) for moist tropical forest:

$$Kg.tree^{-1} = 39.4908 - 11.7883*Dbh + 1.1926*Dbh^2$$

For organic carbon, live vegetation was assumed to contain 45% of organic carbon in a dry biomass weight (Anderson and Ingram, 1993). For litter biomass and organic carbon estimates, litter samples were weighed and sub-samples were oven-dried at 65°C to a constant weight, ground and analyzed for organic carbon.

Belowground sampling: All the plant roots in a soil volume of 25*25*25 cm from each sub-quadrate were collected, washed, weighed and sub-samples were oven-dried for biomass estimate and organic carbon analysis. No effort was made to separate live and dead roots. Soil samples were collected at two depths (0-20 and 20-50 cm) and analyzed in the IRAD soil and plant laboratory at Nkolbisson (Yaoundé) for organic carbon, pH, exchangeable bases, exchangeable acidity, available phosphorus and particle size distribution using routine methods described in Van Reeuwijk (1993).

Statistical analyses: Analysis of variance (ANOVA) and means separations (Turkey’ HSD methods) were used to describe the data and compare changes in plant biomass, carbon stocks, and soil

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characteristics under various LULC types within the SALMS. These analyses were performed using the SAS statistical program (SAS Institute Inc., 1997).

3- Results and discussion

Comparability of the six chronosequences

To evaluate the homogeneity and the comparability of the six chronosequences from two different soil orders and three land-use blocks, ANOVA and means separations were applied to above and belowground data from the primary forest (PF) considered as the reference state. The results of these analyses are shown in Table 1. No significant difference (at $p<0.05$) was found in aboveground carbon stock between the six chronosequences. However, the Mengomo chronosequence produced significantly ($p=0.033$) lower total carbon stocks as compared to the highest value obtained from Awae II. Based on this result, we considered that the six choronosequences are comparables. Therefore, further analyses were made only on average values from the six chronosequences.

Table 1: Comparison of carbon stocks (T.C/ha) for the primary forest between the six chronosequences (n=26). Note: R^2 = coefficient ANOVA determination and p=probability. Figures following with different letters are significantly different at $p<0.05$.

Block	Soil type (WRB)	Village	Above ground (R^2 =59, p=0.118)	Below ground (R^2 =67, p=0.036)	Sum (R^2 =67, p=0.033)
Yaoundé	Ferric Acrisol	Nkometou	224 a	77 a	301 ab
	Rhodic Ferralsol	Nkolfoulou	234 a	81 a	315 ab
Mbalmayo	Acric Ferralsol	Awae II	246 a	85 a	331 a
	Haplic Acrisol	Mvoutessi	214 a	71 a	285 ab
Ebolowa	Xanthic Ferralsol	Mengomo	204 a	71 a	275 b
	Xanthic Ferralsol	Mekoe	236 a	88 a	324 ab
		Average	226	79	305

Carbon stocks dynamics within the SALMS

Figure 1 shows the results of total system carbon stocks estimated in trees, understorey, surface litter roots and 0-50 cm-soil slice for each LULC from the six combined chronosequences. The total system carbon stock of the PF averaged 305 $tC.ha^{-1}$, with about 65% contained in the tree biomass. While, the total carbon stock in the SALMS averaged 157 tC/ha^{-1}, representing only half of the PF. However, this mean-value in the SALMS remains slightly higher than the value of 140 tC.ha-1 reported by Brown (1997) for other tropical forests. This is justified by the current practice of shifting cultivation in the area in which some big trees are always left in the SALMS (crop field, fallow lands and cocoa plantations).

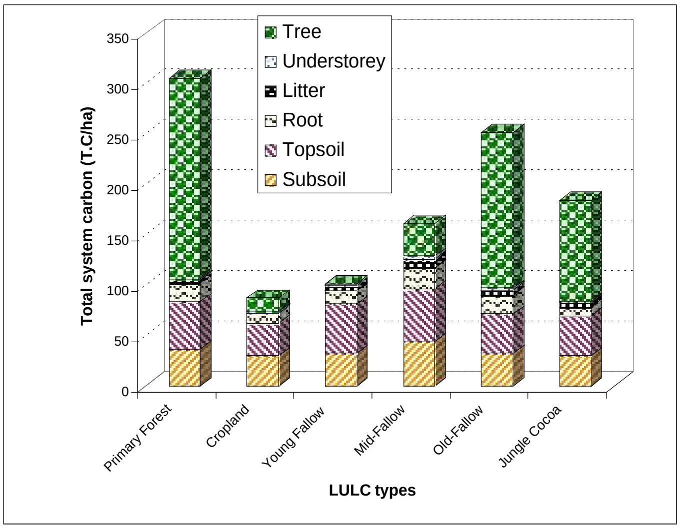

Figure 1: Carbon stocks distribution in various pools by LULC types

Cropland gave the lowest total carbon stock (67 $tC.ha^{-1}$), corresponding to about 80% loss of carbon stock due to cultivation as compared to PF. The most vulnerable carbon pool in this process is the

aboveground biomass. Kauffmann et al. (1995) reported similar findings in the Amazonian forest converted into pasture. The total soil carbon stock represented about 26% in the PF and varied less throughout the shifting cultivation cycle. Although the loss of soil carbon by cultivation is small as compared to the aboveground biomass, Nye and Greenland (1960) considered it however, to be not negligible. Though this soil carbon stability is reassuring for carbon sequestration, soil organic matter failed to act as indicator of soil fertility in this area (Kotto-Same et al., 1997; Meijboom et al., 1995).
During the fallow period, C accumulation proceeds at a rapid rate. Based upon the estimated duration of LULC types, a mathematical model of C accumulation during the fallow period was developed through the correlation between fallow duration and total system carbon. This regression (Figure 2) showed that 77% of total carbon stocks variation could be explained by the duration of fallow regrowth. In the old fallow (OF) almost 85% of total carbon stock is recovered. The jungle cocoa plantation (JC), considered by Kotto-Same et al. (1997) as the best bet alternative to slash and burn agriculture produced 60% of the total system carbon as compared to PF.

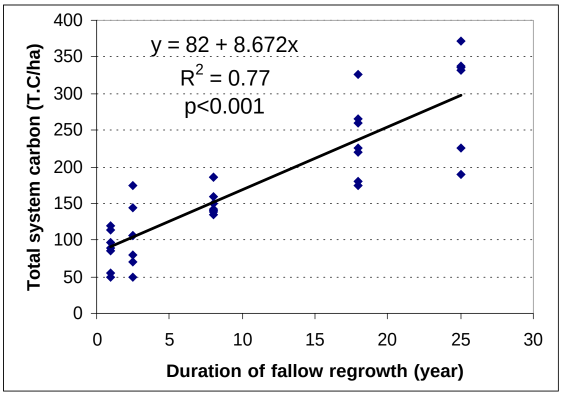

Figure 2: Total system carbon re-accumulation with fallow duration within the SALMS of Cameroon (adapted from Kotto-Same et al. (1997)).

Soil properties dynamics within the SALMS

Mean values of soil physico-chemical properties from each LULC types in the two soil types are shown in Table 2. Despite the fundamental difference between Ferralsols and Acrisols, all the variables in both soil types showed significant (at $p<0.05$) variation by LULC types within the SALMS, with a similar trend. Exchangeable Aluminum (Exch. Al), organic carbon and clay content decreased from PF to cropping and increased during the fallow phase; while, pH and available phosphorus showed the reverse trend. These trends of soil properties dynamics within the SALMS were also reported in other parts the humid forest zone of Cameroon and elsewhere in the tropics (Tulaphitak et al., 1985; Yemefack et al., 2004; Yemefack et al., In press).

Table 2: Top soil properties (0-20 cm) changes with LULC types within the SALMS. Note: Figures following with different letters are significantly different at $p<0.05$.

Soil types and LULC types	pH water	Organic carbon (%)	ECEC ($cmol.kg^{-1}$)	Exch. Al ($cmol.kg^{-1}$)	P available (ppm)	Clay (%)
***Ferralsols** (n=16)*						
Primary Forest (PF)	3.8 a	2.6 a	9.8 a	8.2 a	7 a	39 a
Crop land (CL)	4.9 b	1.6 b	5.7 b	0.5 b	17 b	28 b
Young Fallow (YF)	4.5 b	2.1 ab	5.2 b	1.3 c	8 a	33 a
Mid Fallow (MF)	3.9 a	2.3 b	4.4 c	2.4 c	7 a	37 a
Old Fallow (OF)	3.8 a	2.6 b	5.1 bc	3.5 d	7 a	39 a
Jungle Cocoa (JC)	4.5 b	1.8 ab	4.2 c	1.8 c	5 a	29 b
***Acrisols** (n=9)*						
Primary Forest (PF)	5.7 a	2.0 a	8.1 a	0.2	6 a	22 a
Crop land (CL)	7.2 b	1.8 a	14.4 b	0	16 b	15 b
Young Fallow (YF)	6.8 b	2.6 b	11.4 b	0	7 a	15 b
Mid Fallow (MF)	5.4 a	2.3 ab	6.6 c	0	4 a	18 ab
Old Fallow (OF)	5.7 a	2.1 a	7.9 ac	0	6 a	19 ab

Jungle Cocoa (JC)	6.4 b	2.4 ab	8.6 a	0	3 a	23 a

In general, there is an imbalance nutrient distribution between biomass and soil, which implies that a substantial amount of mineral nutrients released during slash and burn operations may be lost through leaching and runoff if the soil system is unable to retain them. In soils containing limited reserves of nutrients such as the two soil types of our study area, slash and burn agriculture contributes to the release of the nutrients stored in the forest trees biomass and this results in an increase of soil pH, available P and exchangeable bases (Stromgaard, 1984; Tulaphitak et al., 1985).

4- Conclusion

The shifting agricultural landscape mosaic system (SALMS) of the humid forest zone of Cameroon stores in average half the total system carbon found in the primary forest of the area. However, because of the common practice of shifting cultivation that always leaves some big trees the SALMS, this value remains comparable to other tropical forest. Within the SALMS, organic carbon and nutrient stocks are quite dynamic; changing significantly from forest to cropping and inversely during the fallow period. Seventy seven percent of the total carbon stock production during the fallow phase is a linear function of the fallow age (p=0.001). During the conversion of land to agriculture, a huge amount of nutrients stored in the aboveground biomass is released through slashing and burning. The stock of aboveground biomass is rapidly reconstituted during the fallow period and after about 15-20 years, 80% of the total system carbon stock is recovered from fallow as compared to the primary forest. This potential of organic matter dynamics offers to the SALMS an important potential for carbon sequestration.

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