Dynamics of Shifting Agricultural Systems and Organic Carbon Sequestration in Southern Cameroon

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Summary

A conceptual model of the spatio-temporal dynamics of Shifting Agricultural Systems (SAS) in the rainforest region of Southern Cameroon made it possible to identify five different cultivation cycles, which enabled the quantification of soil dynamics and carbon stocks. Carbon stocks in each pool were evaluated using all chronosequences for land use types, including Virgin forest (PF), Secondary forest (SF), Forest fallow (FF), Chromolaena fallow (CF), Mixed crop field (MC) and Old cocoa plantations (OCP). Under each treatment, biomass measures were conducted on trees, undergrowth, litter and plant roots. Soil samples were analysed for physicochemical determinations. The total carbon (in TC/ha^{-1}) varies in the following decreasing order: VF (305), SF (251), OCP (184), FF (180), CF (101), and MC (67). Although the average soil carbon stock represents 93% and 78% under the MC and CF systems, respectively, it represents only 26% of total carbon for the VF system. When a PF system is converted into MC, there is a total carbon loss of 97% from aerial biomass and 17% from soil. Fallowing and reconversion to SF lead to a carbon re-accumulation of 3.9 TC/ha^{-1}.year^{-1} (r^2= 0.83, p= 0.001).

Several soil parameters have shown major variability within the system. This study has produced quantified data, which can be used to evaluate soil quality according to land use and the cost of the carbon sequestered by these agricultural systems.

Résumé

Dynamique des agro-systèmes itinérants et séquestration du carbone organique au Sud Cameroun

Un modèle conceptuel de la dynamique spatiale et temporelle des Agro-systèmes Itinérants (ASI) en zone de forêt humide du Sud Cameroun a permis d'identifier cinq cycles d'exploitation agricole des terres sur la base desquels la dynamique des sols et le stock du carbone ont été quantifiés. Les stocks de carbone dans chaque pool du système ont été évalués le long des chronoséquences d'utilisation de terres composés de Forêt primaire (PF), Forêt secondaire (FS), Jachère forestière (JF), Jachère à Chromolaena (JC), Champs de cultures mixtes (CM) et Vieille cacaoyère (PPv). Sur ces traitements, les mesures de biomasse ont été faites sur les arbres, le sous-bois, la litière et les racines. Les échantillons de sols ont été analysés pour les déterminations physico-chimiques. Le carbone total (TC/ha^{-1}) varie selon l'ordre décroissant suivant: PF (305), FS (251), PPv (184), JF (180), JC (101), et CM (67). Le stock du carbone du sol représente en moyenne 26% du carbone total du système PF, mais 93 et 78% sous CM et JC respectivement. A la conversion de la PF en CM, il y a perte de 97% du carbone total de la biomasse aérienne, contre une perte de 17% dans le sol. Après la mise en jachère des parcelles et leur reconversion en FS, la ré-accumulation du carbone est de 3,9 TC/ha^{-1}. an^{-1} (r^2= 0,83, p= 0,001). Plusieurs paramètres du sol ont montré une très grande variabilité à l'intérieur du système, en fonction du temps. Cette étude a produit un ensemble de données quantifiées qui peuvent être utilisées pour évaluer la qualité du sol en fonction de leur utilisation, et le coût du carbone séquestré par ces agro-systèmes.

Introduction

Slash-and-burn agriculture, which is practised for the production of annual food and perennial crops (cocoa, oil palm) is the main land use method adopted by small growers in Southern Cameroon, in order to make a living and generate a small income. In spatial terms, this agricultural practice results in the creation of a mosaic landscape (5), characterised by a spatial aggregation of land used as fallow for variable durations, fields used for food crops, various perennial crop plantations and virgin forest. This agricultural system, which was previously seen as sustainable for under-populated tropical regions (11), is now considered one of the main causes of deforestation, soil degradation and spatial expansion to the detriment of the tropical rainforest (9, 10). According to Brown (2), this leads to a significant loss of carbon in the form of CO_2 and a

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major temporal variation in soil characteristics.
Many research studies continue to focus on environmentally and economically viable alternatives to slash-and-burn agriculture in the tropics (1). The aim of these studies is to develop strategies with the aim of limiting or halting its destructive effects on the forest. However, it will only be possible to assess the impact of these alternative and promising strategies based on an effective assessment of factors associated with the vegetation dynamics and soil properties during the transition from a natural eco-system to other types of land use and vegetation cover.
This study therefore aims to evaluate the effects of slash-and-burn agriculture on the dynamics of Shifting Agricultural Systems (SAS), implications for nutrient cycling and organic carbon sequestration. The following questions prompted this research: What are the dynamics of SAS? How much carbon is sequestered in SAS compared to primary forests? How do soil parameters vary throughout the chronosequence of Land Use and Vegetation Cover Types (LUVC)?

Materials and methods

1- Location of study
The study focused on a site located between 2°20' - 4°30' N and 10°20' - 11°15' E in the humid forest zone of the Cameroon. The climate is characterised by two rainy seasons (March-June and September-November) and two dry seasons. The annual rainfall ranges from 1600 - 2000 mm, with an average temperature of 24 °C-25 °C. According to the World Reference Base for Soil Classification (4), approximately 95% of the soils are ferralsols and acrisols. Less-developed and badly drained soils (approx. 5%) can be found in marsh zones (14). Slash-and-burn agriculture represents the main agricultural practice, without any additional fertiliser applications.

2. Descriptive approach to agricultural systems
At the study site, 200 households were interviewed using a questionnaire covering three priorities for the farmers (crop production, small animal farming and other socio-economic activities). Group surveys and direct observations in the field complemented the information obtained during interviews. The dimensions of cultivated and fallow fields were determined for the 35 farmers surveyed. Two hundred ninety-three fields farmed for three consecutive years were therefore measured in order to evaluate the spatial dynamics of these SAS. A synchronic approach to data collection was therefore combined with diachronic monitoring of 33 fields, which were observed for 7 years in order to identify any change in the use or development of the fallow land. Based on the description of LUVC types produced by Yemefack (18, Chapter 2), the treatments concentrated on three categories of fallow land of increasing ages (CF, FF and SF), a forest field (FF), a mixed crop field (MC), in which the soil was sampled at the beginning and end of cultivation (sub-treatments MC1 and MC2), two types of cocoa tree plantation (*Theobroma cacao* L.) of different ages, including a tree of aged 7-9 years (YCP) and an old tree aged over 30 years (OCP) and primary forest (PF), which is seen as a control sample and starting part for all the changes. A total of 158 fields were studied during repeated treatments: CF [12], MC1 [27], MC2 [27], CF [12], FF [12], SF [12], PF [34], YCP [10], OCP [12] (the figures between brackets [ ] indicate the number of fields per treatment).

3. Study of biomass and organic carbon
In order to study organic carbon dynamics, six LUVC types (PF, SF, FF, CF, MC and OCP) were selected in the localities of Nkometou, Nkolfoulou, Awae II, Mvoutessi, Mengomo and Mekoe, distributed to the north and south of the study site. Data on above-ground biomass, understory vegetation, litter and roots were collected from each treated area within the blocks, according to the method described by Kotto-Same *et al.* (8). The amount of organic carbon produced by living vegetation has been estimated at 45% of dry biomass, while that produced by litter and roots has been determined as 60 °C in the IRAD laboratory in Nkolbisson, based on a sub-sample, which was ground after being dried in the heat chamber.

4. Soil samples and laboratory analyses
Composite soil samples were taken from each treatment at three depths (0-10, 10-20 and 30-50 cm) at the beginning of the study, based on a synchronous sequence and seven years later using a diachronic series. These soil samples were analysed in the IRAD soil laboratory in Nkolbisson (Yaoundé) in order to determine the following: pH, organic matter, assimilable phosphorus, exchangeable bases, exchangeable acidity and grain size, using the methods described by Van Reeuwijk (16).

5. Statistical analyses
In terms of statistics, the data obtained from the laboratory analyses was processed using SAS/STAT (12) and Ihaka *et al*. (6) software. A conceptual model for shifting agricultural system dynamics developed by Yemefack (18, Chapter 2) served as a reference for the evaluation of changes occurring within SAS over a period of time. Variance analyses (ANOVA) and average separation (method developed by Turkey'HSD) were used to describe the data and evaluate the changes occurring in the various LUVC types found in SAS, in terms of biomass, carbon stocks and soil characteristics.

Results and discussion

1. Dynamics of shifting agricultural systems
In shifting slash-and-burn agriculture systems, different fields are used for food crops (CF and MC)

Table 1
Comparison of carbon stock (T.C/ha) of primary forests between the six sites (n= 26)

Soil type	Village	Above-ground parts (R^2= 59, p= 0.118)	Under-ground parts (R^2= 67, p= 0.056)	Total (R^2= 67, p= 0.053)
Ferric Acrisol	Nkometou	224 a	77 a	301 a
Rhodic Ferralsol	Nkolfoulou	234 a	81 a	315 a
Acric Ferralsol	Awae II	246 a	85 a	331 a
Haplic Acrisol	Mvoutessi	214 a	71 a	285 a
Xanthic Ferralsol	Mengomo	204 a	71 a	275 a
Xanthic Ferralsol	Mekoe	236 a	88 a	324 a
Mean		226	79	305

N.B.: R^2= coefficient of determination (ANOVA) and p= probability. The figures followed by various letters are significantly different level of $p< 0.05$

each season. New fields are created by clearing fallow land (SF, FF or CF) or a portion of primary forest (PF). The spatial distribution arising from the arrangement of these fields corresponds to what Forman (5) calls a "landscape mosaic system", which consists of units of primary forest, fallow land of all ages, fields used for crops, perennial plantations and dwellings with their own gardens. Based on the conceptual model developed by Yemefack (18, Chapter 2), the following five cycles characterise the SAS:

1- The short-term fallow rotation system (SFR), based on the CF-MC-CF-MC-CF pattern;
2- The long-term fallow rotation system (LFR), based on the CF-MC-CF-FF-MC-CF-FF pattern;
3- Very long-term fallow rotation system (VLFR), based on the CF-MC-CF-FF-SF-CF-MC-CF-FF-SF-CF pattern;
4- The expansive agriculture system in the primary forest (EAS), based on the FV-CF-MC-PP pattern;
5- The system of definitively returning land to fallow (CF/MC-CF-FF-SF-FV and CF-MC-PP-FV).

Land use proportions (in terms of surface area and households) based on these various cycles are defined as follows: an average of 12% of food crop fields (MC) were originally EAS, but this applies to only 5% of households and does not include the portion of perennial fields. Over half the land and half of households are occupied by LFR systems. Seventeen and 11%, respectively, are used for VLFR, while a good proportion of land (19%) and households (32%) are used for SFR systems.

2. Organic carbon sequestration

Comparability of the six chronosequences: In order to evaluate the homogeneity and comparability of the six chronosequences in terms of carbon sequestration, variance analysis (ANOVA) and mean separation were applied to data collected exclusively from primary forest (PF), which was used as a base reference for the six sites. The results of these analyses are shown in table 1. No significant difference could be observed at a probability level of $p< 0,05$ in terms of carbon variations in the above-ground and under-ground primary forest at the six sites. Based on these results, we considered that the six sites were very much comparable and the other analyses focused directly on averages from the six chronosequences.

Carbon stock dynamics in SAS: Figure 1 shows the results for carbon stocks in various systems, as distributed between the trees, undergrowth, litter, roots and soil (in the 0-50 cm layer). Total carbon from the PF system amounts to an average of 305 T.C/ha^{-1} at the six sites, with almost 65% contained in tree biomass. However, the average total carbon produced by the shifting agricultural landscape is only 157 T.C/ha^{-1}, which is half that stored in PF. This value obtained from agricultural systems in Southern Cameroon remains slightly higher than that (140 T.C/ha^{-1}) reported by Brown (2) for other tropical forests. This is justified by the fact that, based on the agricultural practices encountered in Southern Cameroon, many

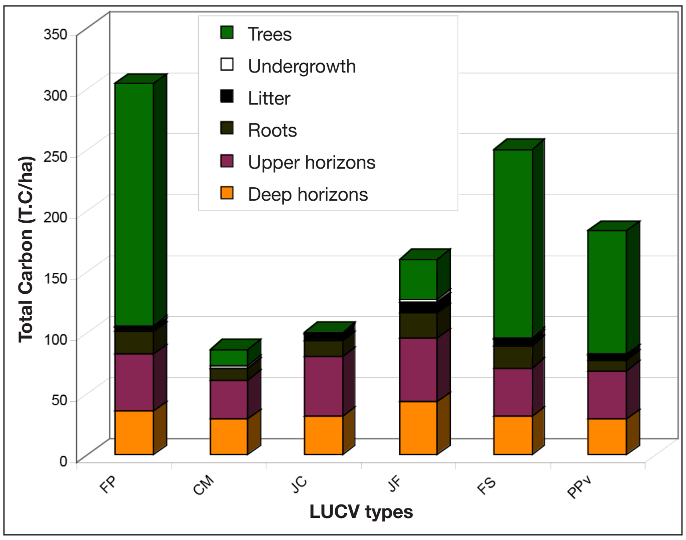

Figure 1: Distribution of carbon stock in various pools for each LUCV type.

Table 2
Statistical summary of properties within the SAS (sample population n= 155)

	Water pH	Organic C	Ca	Total acidity	Total bases	Saturation in Bases	Available P	Clay	Apparent density
		(%)	------- cmol+/kg -----			(%)	(ppm)	(%)	(g/cm²)
0-10 cm									
Minimum	3.2	1.04	0.16	0.04	0.6	4	2	14	0.63
Mean	4.9	2.98	2.31	2.35	5.3	53	10.5	29	1.12
Difference	5.0	2.70	1.38	2.11	22.1	148	84.6	63	0.88
Maximum	8.2	10.90	10.7	9.15	22.7	152	86.6	67	1.51
Standard deviation	1.08	1.50	2.39	2.31	4.1	34	11.6	13	0.19
Standard error	0.09	0.12	0.19	0.19	0.33	2.7	0.93	1.04	0.02
Bias (skewness)	1.06	1.92	1.75	1.11	1.2	0.36	4.37	0.45	-0.34
Flattening (Kurtosis)	0.43	6.51	2.41	0.62	1.3	-0.83	22.26	-0.10	-0.28
Coef. Variation (CV%)	22.2	50.2	104	98.5	77.9	64.5	110	45	17.1
10-20 cm									
Minimum	3.3	0.30	0.01	0.04	0.33	2	1	16	0.91
Mean	4.8	1.40	0.76	3.18	2.25	36	3.4	35	1.29
Difference	4.5	1.30	0.52	14.14	12.65	103	11.3	64	0.77
Maximum	7.8	3.70	3.55	14.18	12.98	105	12.3	70	1.68
Standard deviation	0.92	0.72	0.69	2.4	2.05	32	1.74	14.3	0.17
Standard error	0.07	0.06	0.06	0.19	0.17	2.5	0.14	1.15	0.014
Bias (skewness)	1.22	0.95	1.76	1.03	2.59	0.95	1.94	0.08	-0.09
Flattening (Kurtosis)	0.78	1.02	2.79	2.54	8.92	-0.69	5.97	-0.56	-0.40
Coef. Variation (CV%)	19.4	50.2	90.6	75.3	91.2	87.1	51	41.3	13.1
30-50 cm									
Minimum	37	0.20	0.01	0.08	0.33	4	1	20	nd
Mean	4.9	0.81	0.57	2.9	1.4	27	1.6	43	nd
Difference	3.9	0.84	0.36	6.8	5.1	127	6.2	71	nd
Maximum	7.6	1.70	2.81	6.9	5.4	131	7.2	77	nd
Standard deviation	0.73	0.32	0.60	1.62	1.16	27	1.04	14	nd
Standard error	0.06	0.03	0.05	0.14	0.10	2.3	0.09	1.23	nd
Bias (skewness)	1.35	0.08	2.13	-0.35	1.82	1.7	2.48	-0.29	nd
Flattening (Kurtosis)	1.68	-0.44	4.00	-0.70	2.60	2.1	7.74	0.15	nd
Coef. Variation (CV%)	14.9	39.5	105	56	83.4	98.7	64.8	33.1	nd

Key: nd= not determined.

large trees are generally allowed to continue growing in agricultural fields.

Crop fields produce the lowest total quantity of carbon from the system (67 $TC.ha^{-1}$), which is equivalent to a carbon stock loss of almost 80% due to the cultivation of forest land. The most vulnerable carbon pool in this conversion is the above-ground biomass. Kauffmann *et al.* (7) reported a similar situation in parts of the Amazon rainforest that have been converted to pasture.

The total amount of soil carbon represents 26% of the total stock in the primary forest and is subject to very little variation within the shifting agricultural landscape. Other authors believe, however, that this variation in soil carbon, though insignificant compared to that for above-ground biomass, must not be neglected. This relative stability of soil carbon during forest conversion cannot, however, be used as an effective indicator for soil fertility in this region (8).

During the fallow period, carbon accumulation is very rapid. Based on the estimate produced according to the age of various LUVC types, a mathematical regression model has been developed by correlating the fallow period and total system carbon. This regression shows that 77% of the total carbon stock variation could be explained by the fallow period duration. In these secondary forests, 85% of the total carbon stock is recovered. The old cocoa plantation, considered by Kotto-Same *et al.* (8) to be the best alternative to slash-and-burn agriculture, produces 60% of total system carbon compared to primary forest.

3. Temporal variability of soil property dynamics

Property variability in SAS: Table 2 summarises the statistics for several soil variables studied in SAS. With a few exceptions, all the variables showed a positive bias with very low coefficients, ranging from 0.08 - 2.5. This means that the average for each variable is slightly greater than the median. But this original data has not be converted in any way, as variance analyses are fairly insensitive to slight deviations from the norm (17).

The variation coefficients (CV%) are fairly high (between 50 - 110%) for most of these properties. This shows that these variables are very sensitive to the effects of the different LUVC types in SAS. Most of these variables show major variations on upper soil horizons (0-20 cm). This effectively supports the hypothesis, according to which the effects of shifting agricultural practices are more effective on the surface (19). The available P is the most variable and worst structured element on upper horizons. Only soil properties that are greatly influenced by the cinders produced by burning vegetation (pH, total bases, calcium, etc.) show fairly high variation coefficients at lower depths. This could provide us with information concerning the cinder disintegration process, which leads to rapid leaching and vertical cation movement. The works of Cattle *et al.* (3) in Australia have also shown that pH, electrical conductivity, soil acidity and organic matter were most affected by the cultivation of a Rhodoxeralf. These changes, though short-term, have the advantage of improving several chemical aspects of soil fertility, if only during the cultivation period.

Variance analyses and average separation confirmed the sensitivity of most soil variables to the effects of LUVC types. The variables that showed greater sensitivity are shown in table 3 for the two soil types found at the study site. The mixed crop fields showed significant differences for all variables. Agricultural practices thus have a significant influence ($p< 0.05$) on variations in upper soil layers (0-20 cm). Their effects explain almost 30-35% of the total variance affecting soil property variations in the region (20). This suggests that research focusing on appropriate management practices for these resources must concentrate on the factors and processes, which arise on the agricultural land where the soil variation is mainly due to dynamic factors, such as slash-and-burn agriculture.

Dynamic trend analysis: Several properties of the two soil types (ferralsols and acrisols) are significantly sensitive to the effect of LUVC types on the first 20 centimetres of soil. These properties showed the same variation trends, but with variable rates of change for some soil parameters. Despite the fundamental difference between the two soil types, all the variables change with the same tendency and significantly (at $p< 0,05$) between the LUVC types (Table 3 and Figure 2). Exchangeable aluminium, organic carbon and granulometric clay content decrease in the primary forest (PF) at the end of cultivation (MC2) and increase during the fallow period; pH, calcium, assimilable phosphorus and apparent density vary in the opposite direction. The analogous tendencies affecting soil property dynamics in SAS had been observed and reported at other sites in Cameroon's humid forest zone and even elsewhere (13, 19). Figure 2 shows these variations affecting some ferralsol properties during the various cultivation-fallow phases and on perennial plantations.

The soil's short and long-term response to LUVC types throughout a chronosequence has shown two

Table 3
Soil property variation (0-20 cm) according to LUVC type within the shifting agricultural landscape

Soil and LUVC types	Water pH	Organic carbon (%)	Ca	CECE	Exchangeable Al	Assimilable P (ppm)	Clay (%)	Apparent density (g/cm^3)
			-------------- ($cmol.kg^{-1}$)	--------------				
Ferralsols (n=16)								
Primary forest (PF)	3.8 a	2.6 a	0.52 a	9.8 a	8.2 a	7 a	39 a	1.08 ab
Crop fields (CF)	4.9 b	1.6 b	2.19 c	5.7 b	0.5 b	17 b	28 b	1.23 de
Chromolaena fallo (CF)	4.5 b	2.1 ab	1.42 b	5.2 b	1.3 c	8 a	33 a	1.17 cd
Forest fallow (FF)	3.9 a	2.3 b	0.69 a	4.4 c	2.4 c	7 a	37 a	1.12 bc
Secondary forest (SF)	3.8 a	2.6 b	0.40 a	5.1 bc	3.5 d	7 a	39 a	1.01 a
Old Cocoa Plantation (OCP)	4.5 b	1.8 ab	0.51 a	4.2 c	1.8 c	5 a	29 b	1.29 e
Acrisols (n=9)								
Primary forest (PF)	5.7 a	2.1 b	3.21 bc	8.1 a	0.2	6 a	22 a	1.22 bc
Crop fields (CF)	7.2 b	1.6 c	5.54 a	14.4 b	0	16 b	15 b	1.42 a
Chromolaena fallow (CF)	6.8 b	2.6 a	4.50 ab	11.4 b	0	7 a	15 b	1.28 bc
Forest fallow (FF)	5.4 a	2.3 a	2.67 c	6.6 c	0	4 a	18 ab	1.40 a
Secondary forest (SF)	5.7 a	2.1 b	3.60 bc	7.9 ac	0	6 a	19 ab	1.20 c
Old cocoa plantation (OCP)	6.4 b	2.4 a	5.49 a	8.6 a	0	3 a	23 a	1.31 b

These values are based on least square averages. Values followed by the same letter in the same colum are not significantly different from over 95% confidence according to the Tukey's HSD test.

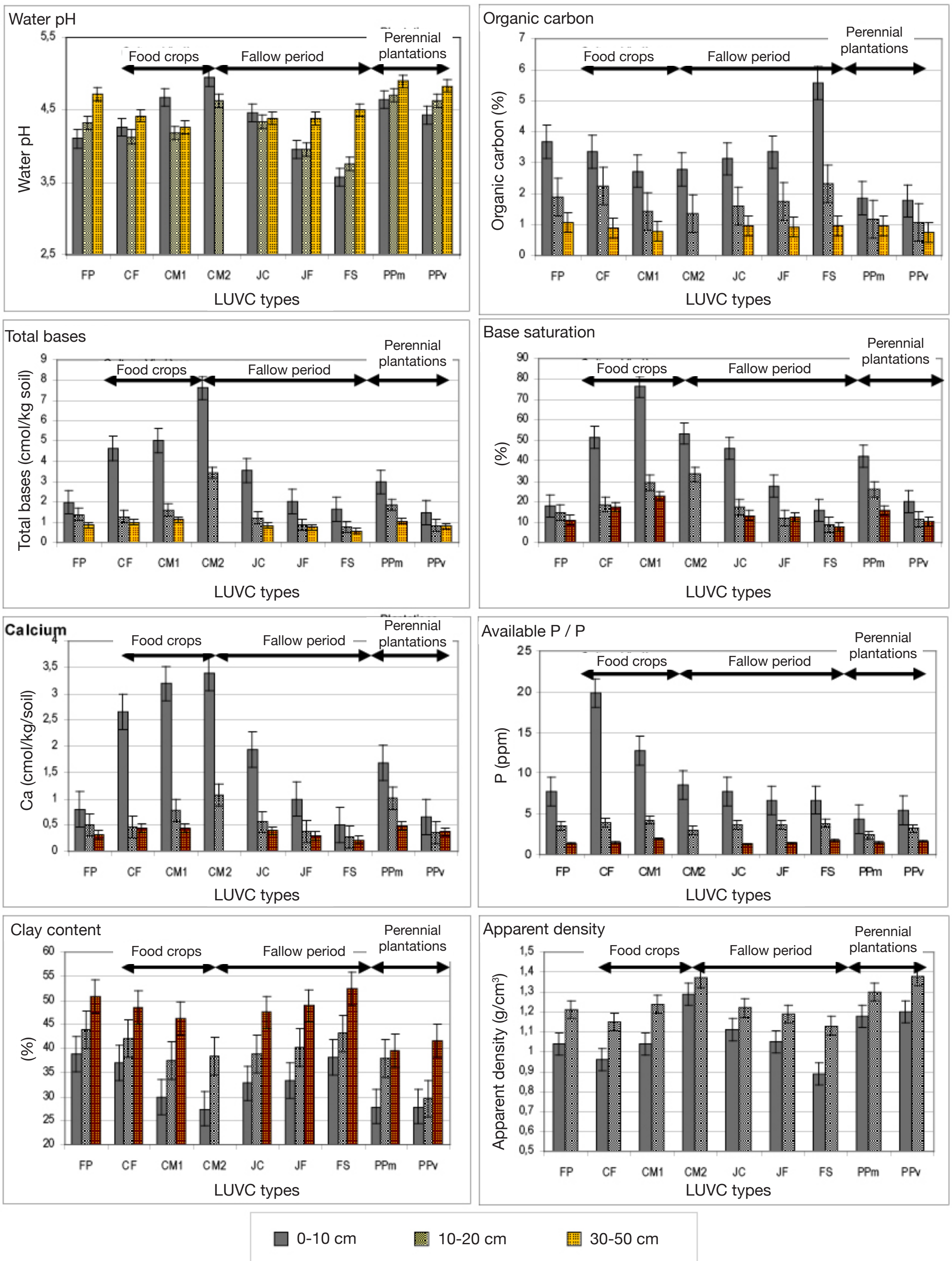

Figure 2: Effects of LUVC types on physico-chemical properties of the Ferralsols studied.

Key: FF= Start of forest field; MC1= Start mixed crop field; MC2= End of mixed crop field; CF= Chromolaena fallow =3-5 years; FF= Forest fallow =7-9 years; SF= Secondary forest>15 years; PF= Primary forest; c= young cocoa plantation (YCP) =5-7 years; OCP= old cocoa plantation >30 years.

phases (Figure 2): an initial change with clearance and biomass burning, which continues into the initial cultivation phase; and a change in the opposite direction, frequently following the final cultivation stage, but regularly during the fallow or PP period. The first change corresponds to the effects of burning and cinders, which act in the same way as lime and increase the pH, calcium, assimilable phosphorus and apparent density. The organic carbon behaves in the opposite way, with an initial decrease, probably due to the rapid mineralisation of organic matter due to the effects of burning and tillage. The opposite trend in the dynamics of all these properties confirms the value of fallowing in terms of rehabilitating degraded soils.

These variations also indicated a very early reaction to the conversion of the PF, in terms of calcium, assimilable P and organic carbon, which peaked at the end of the first year of cultivation. However, the reaction of the soil and apparent density change slightly later. The overall tendency of the organic carbon dynamics indicates that a significant reduction during the short cultivation period confirms the results obtained by Van Noordwijk *et al.* (15) using soils from a similar environment in Sumatra.

In general, an imbalance emerges between the biomass and soil property distribution. This may indicate that a good proportion of nutrients supplied by the cinders produced by burning are lost due to leaching and erosion processes. Therefore, in poor soils like those found at our site, slash-and-burn agriculture substantially helps increase the soil nutrient stock based on forest biomass reserves; this results in an increased soil pH, assimilable phosphorus and exchangeable bases.

Conclusion

On average, the shifting agricultural systems (SAS) found in Cameroon's humid forest region sequestrate half the total carbon produced by the primary forest. However, this value remains comparable to the quantity produced by some types of forest due to the presence in this agricultural system of large trees, which the farmers allow to continue growing in cultivated fields. Within the SAS, the organic carbon and nutrient stock are highly dynamic; it involves the highly significant changeover from forest to cultivated fields and vice-versa during the fallow period. Seventy-seven percent of the total carbon stock sequestered during the fallow period is a linear indication of the fallow age ($p= 0.001$). When forests are converted into agricultural land, an enormous quantity of nutrients stored in the above-ground biomass is lost due to clearance and burning. The above-ground biomass is then rapidly rehabilitated during the fallow period and after 15-20 years, eighty percent of the total carbon stock is recovered from the fallow land compared to primary forest. This potential for carbon dynamics provides SAS with a major source of sequestered carbon.

Soil properties are significantly affected by this agricultural practice in the upper layers. The region's empirical method of soil management can be seen in two consecutive phases: an organic matter destruction phase linked to substrate cultivation and an organic matter rehabilitation phase linked to fallowing. Effective management of the soil property behaviour during these phases may be useful when it comes to making decisions aimed at improving agricultural strategies.

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