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Monitoring Soil Dynamics within Shifting Agriculture in Southern Cameroon

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Résumé
La présente recherche fournit une série d'informations quantitatives sur les effets à court et à long terme des systèmes d'agriculture itinérants sur les sols ainsi que leur dynamique dans le temps. Une robuste méthode quantitative et multicritères a permit de quantifier et de sélectionner les propriétés du sol qui sont les plus sensibles à l'effet de ces pratiques agricoles. Il s'agit de : pH, calcium, phosphore, densité apparente, et carbone organique, considérés comme un ensemble minimum de données (MDS) pédologiques nécessaires pour la caractérisation de la productivité actuelle et potentielle des sols de la région. Les modèles empiriques reposant sur les fonctions rationnelles linéaires/quadratiques ont été judicieusement ajustés aux données chronoséquentielles des variables du MDS afin d'en déduire des mesures quantitatives des changements temporelles qui surviennent dans le sol suite à leur exploitation agricole. Cette étude a ainsi produit un ensemble de données quantifiées qui peuvent être utilisées pour (i) évaluer la qualité du sol en fonction de leur utilisation, (ii) supporter la prise de décisions sur l'amélioration de cette agriculture et l'orientation de nouvelles recherches.

1- Introduction
The imbalance between the luxurious forest stands and the low agricultural production of soils of the tropical rain forest region calls for the development of methods and strategies for conserving and maintaining soil fertility, based on a good understanding of soil behaviour under each land use practice, with quantified rates of changes in soil properties (Tulaphitak et al., 1985; Sanchez et al., 2003).Under shifting cultivation land use systems in the region, many soil characteristics have 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 (Tulaphitak et al., 1985; Bewket and Stroosnijder, 2003). These changes can be codified in models which can then be used to quantify soil behaviour under various scenarios (Hoosbeek et al., 2000). Models are simplified representations of a system, in this case the soil and nutrient cycle, designed to facilitate the understanding of processes and to predict the behaviour of the system, and which can be expressed in symbolic or mathematical form.
The objective of this study was to provide quantitative information, developed through modelling processes, on short and long-term effects of shifting agriculture on soil. Various scientific techniques have been applied to simplify and model information extracted from a comprehensive dataset collected under various land use/land cove (LULC) types, in order to provide answers to the following questions: What are the most affected soil parameters within the system, and what are the extent and rates of changes in time?

2- The research site
The study area is located between 2º47' - 3º14' N and 10º24' - 10º51' E in the humid forest zone of southern Cameroon. 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 (Waterloo et al., 2000). The area is undulating, with some incised rivers and widely distributed swampy drainage ways. Most of the upland soils (about 95%) are Ferralsols and Acrisols according to the World Reference Base (WRB)

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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 (Van Gemerden and Hazeu, 1999). The area is sparsely populated, with seven to ten inhabitants per km² in general, but about 20 inhabitants per km^2 within agricultural villages because most inhabitants live along the roads. Extensive shifting agriculture is the most important land use activity.

3- Research design and methods

3.1-Data collection

Four representative villages were selected to represent the distinct agro-ecological and physiographic zones of the study area based on the landscape ecological survey by Van Gemerden and Hazeu (1999). The Synchronic approach for data collection was combined with diachronic monitoring of plots during seven years. LULC treatments (9 in total) were chosen based on actual agricultural production cycles (Fig. 1) 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 treatments as defined in Fig. 1, comprised three fallow types with increasing duration (CF, BF and FF), one CL monitored from the beginning to the end of the cropping phase (coded: CL1=at the beginning and CL2=at the end of cropping), one FCF, two PP types (PPm=less than 7 year-old and PPo=more than 30 year-old), and one PF as control. No fertilizers were applied on any plot. A total of 158 patches were surveyed (FCF (12), CL1 (27), CL2 (27), CF (12), BF (12), FF (12), PF (34), PPm (10), PPo (12)).

(insert Fig. 1)

In each selected LULC patches, composite soil samples were bulked from five augerings along diagonals across each agricultural plot and along a 100-200 m transect in forests, at three depths (0-10, 10-20, and 30-50 cm). CL plots were sampled two times (CL1 and CL2). These soil samples were analysed in the IRAD soil laboratory at Nkolbisson (Yaoundé) for pH, organic matter, available phosphorus, exchangeable bases, exchange acidity and particle size distribution, using procedures described in Van Reeuwijk (1993).

Thirty-three plots, which were in the first year of cropping in 1996 (after the preceding fallow in 1995), were subjectively selected for monitoring of land use conversion from 1995 to 2002.

3.2- Statistical data analysis and modelling

Various statistical techniques (descriptive statistics, analysis of variance and means separations (Tukey's method), and principal component analysis) were applied to different datasets designed purposely for each specific objective. Detailed descriptions of these analyses are giving in Yemefack (2005). The analyses were carried out using R environment (Ihaka and Gentleman, 1996).

4- Results and discussion

Many properties of the two soil types (Ferralsols and Acrisols) were significantly sensitive to land use effect within the first 20 cm of soil depth (but not for deeper layers); with the same trend but different rates of changes for some soil characteristics. Soil behaviour under shifting cultivation was here quantified by the most sensitive soil properties to shifting agricultural practices (or minimum data set) and their mathematical model as a function of time.

4.1- Minimum Data Set (MDS)

Under shifting agriculture, some soil characteristics are more sensitive to change in management than others. These may serve as early signals of soil change. In addition, some soil properties may be highly corrected that a few may substitute for many. This coupled to the expense of comprehensive data collection motivated the development of a minimum data set (MDS) for characterizing soil productivity status and potential. A multi-criteria quantitative procedure for MDS selection was developed (Yemefack et al.,*In press*) and applied to a set of 13 soil variables collected within a chronosequence of shifting cultivation system. Five soil properties (pH, exchangeable calcium, available phosphorus, bulk density and organic carbon) came out as the most affected by the shifting agricultural practices. These can be used individually or in combination to assess the effect of this practice on soil condition. The five MDS indicators could be easily interpreted in terms of their relation to land management practices and land use changes (Yemefack et al.,*In press*).

The five selected soil properties all contribute to one or more soil functions proposed by Doran and Parkin (1996) as indicators of soil quality. Soil pH stands for soil reaction and contributes to the definition of soil biological and chemical thresholds essential to process modelling. Calcium represents the status of soil exchangeable bases and contributes to the ability of soil to supply nutrients. Available phosphorus is important in supplying N and P to plants. Bulk density influences soil porosity and water infiltration, and contributes to the potential for leaching and erodibility. Finally, organic carbon affects the ability of soil to accept, hold, and release nutrients, water and other chemical constituents as well as to the physical soil structure. These are only a few of the soil quality functions that are related to these MDS variables.

4.2- Change in soil properties with time

The five soil properties making up the MDS were used individually to model the behaviour of soil over time, the time being represented by a land use chronosequence (Yemefack et al., *In press*). Within the longest cycles of shifting cultivation (SC) and agroforest cocoa plantations (PP), each soil property changes as a function of time *t*, with

$$P(t) = P_0 + f(t) \qquad (1)$$

where $P(t)$ is the value of the soil property P at time t, P_0 is the value of soil property P at time $t=0$ (under the PF cover), and $f(t)$ is the change function of time. Since our interest for this study was to model the changes, not the absolute values, we converted each variable to a proportional deviation (*Pd*) from the reference sites PF as follows: If P_i is the value of a soil property from treatment *i* and P_0 the non-zero value of the same property from the corresponding PF on the same soil type, the Proportional deviation Pd_i is computed as:

$$Pd_i = \frac{P_i \quad P_0}{P_0} \cdot \qquad (2)$$

Pd values were plotted against time to determine the form of $f(t)$ and attempts were made to fit suitable functional forms, of which low-order fractional rational functions proved to be most appropriate. In this case, proper linear/quadratic fractional rational functions,

$$f(t) = \frac{a + bt}{1 + ct + dt^2} \qquad (3)$$

showed a reasonable shape to model changing soil properties in response to events such as land clearing, burning, cropping, fallowing and PP. The fitted functions were used to evaluate metrics describing soil behaviour over time: maximum proportional deviation from the base state (y_m), time to reach this maximum (t_m), and relaxation time towards the original value (t_p = time after t_m at which the curve reaches some predefined proportion of recovery).

Based on these functions, the long-term response of the soils to LULC types along the chronosequence was found to have two phases in both SC and PP (Fig. 2): an initial change with land clearing by burning, which continues into the initial cropping phase, and a reversal of this change, sometimes during the late cropping phase but always during the fallow period or PP. The first phase responds to the effects of heat and liming ashes from burning and corresponds to an increase of pH, Calcium, Available P and bulk density. For organic carbon, there was an initial decrease, probably due to the rapid mineralisation of organic matter caused by heat and tillage. The reversal trends confirmed the effect of fallow; tending toward the initial values of soil properties.

(insert Fig. 2)

The fitted function explained 50 to 80% of soil dynamics for the first four variables in the 0-20 cm layer on both Ferralsols and Acrisols but only 25% for organic carbon. These functions showed a very quick reaction to forest conversion for calcium, available P and organic carbon which maxima are reached at the end of the first year. Soil reaction and bulk density showed significant changes a bit later (2.5 to 3.5 years). The general trend of organic carbon dynamics showing a significant decrease during the short cultivation period and an increase during the period of fallow or PP corroborated with the results of Van Noordwijk et al. (1997) on soils in a similar eco-zone of Sumatra. The low contribution (only 25%) of organic carbon to the models could be explained by the strong fluctuations of data during the years.

5- Conclusion

Five soil properties (pH, exchangeable calcium, available phosphorus, bulk density and organic carbon) are the most affected (MDS) by the shifting agricultural practices in topsoil. They can be used individually or in combination to assess the effect of this practice on soil condition. This MDS is expected to help researchers, agronomists and others users of soil information to minimize the cost of data collection while improving the quality of the information. The empirical trend of soil behaviour under shifting agriculture is well described by linear/quadratic fractional rational functions of time. Interpretation metrics derived from these functions are useful figures for supporting decision in defining and timing any intervention action. These set of quantitative information are useful for (i) soil quality assessment in relation to land-use practices, (ii) developing improved agricultural strategies and new research orientation.

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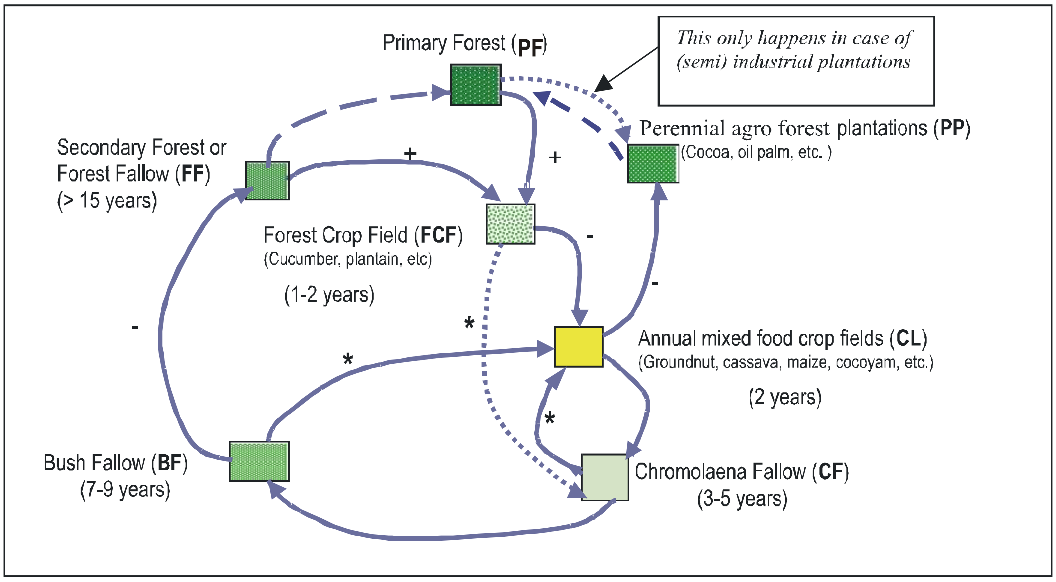
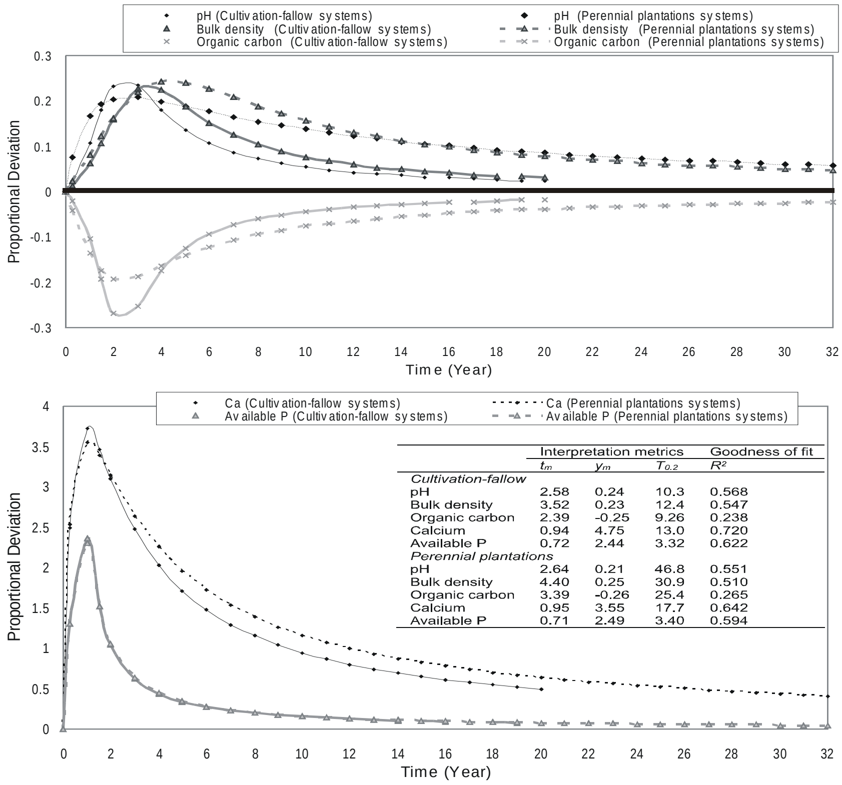


Figure 1: Observed transitions between land uses. Adapted from Yemefack (2005, Chapter 2)
Key: (⟶) Common transitions; (⋯⋯▸) Infrequent transitions; (– – ▸) PF recovery after definite abandonment; (+)patches can split (fragmentation); (-)patches can merge with others of the same type (consolidation); (*)patches can merge with those of other types.



	Interpretation metrics			Goodness of fit
	t_m	y_m	$T_{0.2}$	R^2
Cultivation-fallow				
pH	2.58	0.24	10.3	0.568
Bulk density	3.52	0.23	12.4	0.547
Organic carbon	2.39	-0.25	9.26	0.238
Calcium	0.94	4.75	13.0	0.720
Available P	0.72	2.44	3.32	0.622
Perennial plantations				
pH	2.64	0.21	46.8	0.551
Bulk density	4.40	0.25	30.9	0.510
Organic carbon	3.39	-0.26	25.4	0.265
Calcium	0.95	3.55	17.7	0.642
Available P	0.71	2.49	3.40	0.594

Figure 2: Linear/quadratic fractional rational functions fitted to soil properties (0-10 cm) dynamics under two land use chronosequences (food cropping-fallow system and perennial plantation) as shown by proportional deviations from the reference under primary forest over time.