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Assessment of some important fertility parameters related to different land use systems in the humid forest zone of southern Cameroon

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ABSTRACT

A field study was carried out in 1999 and 2000 in the village of Akok 180 km south of Yaoundé in the humid forest zone of southern Cameroon to assess changes in particle size distribution and soil chemical properties related to five different land-use systems namely: a secondary forest, a young forest, a cocoa farm, a *Chromolaena* fallow and a mixed food crop field. The results showed that land-use systems significantly affect the soil particle distribution and the highest proportions of sand and silt fractions were found in soils of young forests, the highest clay content was found under cocoa farms (P<0.0001). Soil pH_{H2O}, exchangeable Ca and Mg, Al saturation and ECEC in the first, second and third 10 cm layers varied significantly with land-use systems (P<0.0001); organic carbon in the first and the second 10 cm layers significantly differ with the land-use systems (P=0.0115); and available P in the second and third 10 cm layers varied significantly with land-use systems (P<0.0007). Moreover cocoa farms had the highest pH, the lowest Al saturation, the highest soil Ca, Mg, ECEC and P contents compared to the other land-use systems. Based on their pH level and their high base saturation levels, soils of cocoa farms seem to present a higher fertility status than those of the rest of land-use systems. It is assumed that permanent vegetation coverage and/or exposure to heavy rains of the soils, disturbances due to land preparation, organic matter supplied by the vegetation, nutrient cycling, nutrient restitution and nutrient uptake could be differentiation factors.

Key words: Saturation, ECEC, particle size distribution, nutrient cycling, requirement.

INTRODUCTION

In the rain forest zone of southern Cameroon, shifting cultivation (mixed food fields) and perennial plantations (cocoa plantation) are the main land use systems practiced by small-scale farmers to meet food needs and provide small incomes. The traditional shifting cultivation system involves the manual clearing of a small area of natural vegetation (forest, bush, woody savanna or grassland) and leaving the land under fallow for a long period after a few cropping years to allow soil fertility restoration (ASB, 2000). According to Yemefack (2005), the analysis of soil characteristic changes with the cropping systems may follow two phases: (i) clearing and burning of the vegetation biomass during which derived ash causes rapid changes in soil properties and (ii) the slower changes in soil properties during the cropping period and subsequent fallowing or perennial plantations. Lal (1996) and Shepherd et al. (2000) reported that land-use in tropical ecosystems could significantly affect soil properties. Shipper and Sparling (2000), Birang et al. (2003) indicated that those modifications were biologically and chemically more rapid than physically. Tchienkoua et al. (2004) found that land use conversion from semi-permanent mixed food crop system to Eucalyptus and tea plantation in the highlands of West Cameroon led to significant organic matter build up in the soil system; the *Eucalyptus* system induced an enhanced cycling of macronutrients (Ca and Mg) and immobilization of large amount of P and K.

Research on soil characteristics changes is important to design soil fertility options for better land-use. This study, evaluates the effects of land-use systems on the following soil properties: particle size distribution (sand, clay, silt), pH, organic carbon, total nitrogen, C/N ratio , available P, exchangeable bases (Ca, Mg, K), exchangeable Al, ECEC, base saturation and Al saturation under the following land use system: soils cropped under food crops, perennial crops, fallow, young and secondary forests of Akok village in Cameroon in order to propose management options that could maintain or improve their fertility status.

MATERIALS AND METHODS

Site location and land-use systems selected

The geographical coordinates of Akok village are: 11^{o} 14$'$ E longitude, 2^{o} 44$'$ N latitude and 585 m altitude (Figure 1). The climate is humid tropical, with annual rainfall range of 1350-1900 mm and air temperature of 22-26 ^{o}C. The natural vegetation in the village is a dense humid semi-deciduous tropical forest. Most of the upland soils belong to the group of Kandiudox (USDA, 1986). The area is characterized by low level of deforestation and low level of land-use intensity. The 5 most common land-use systems (LUS) of the region, are: a groundnut/maize/cassava annual inter-crop field (**crop**), *Chromolaena odorata* dominated fallow (4-5 years old, **Chro**), a young forest fallow (12-15 years, **Yfor**), a shaded (35 years old) cocoa plantation (**Coco**) and a secondary forest (> 30 years, **Sfor**). The experiment was laid out in a randomized complete block design including 5 land-use systems as treatments, 3 soil depths (0 – 10 cm, 10 – 20 cm and 20 – 30cm) and 5 replicates.

Soil sampling and analyses for physical properties assessment

Soils Samples were taken for physical properties determination in each land use from each of the five mini pits (50x50x30cm (LxWxD) along a 100 m transect. From each mini pit, bulk soil samples were horizontally collected at the walls of the mini-pit at 0-10 and 10-20 and 20-30 cm from three 100 cm^3 soil cores and used, air-dried, ground to pass a 2-mm mesh sieve for determining soil textural classes. Soils particle sizes were determined by the pipette method (Gee and Bauder, 1986).

Soil sampling and analyses for chemical determinations

Between May and August of each year, prior to establishing the cropped plots, five mini-pits of 50x50x30 cm (L x W x D) were dug out along a 100 m transect in each fallow. Soil samples were taken from these mini-pits at three different depths (0-10 cm, 10-20 cm and 20-30 cm) for chemical analysis. All the samples were oven dried at 65 ^{o}C for 48 hours, then ground to pass through a 0.5 mm mesh size sieve and analysed for pH, total N, organic C, available P and exchangeable Ca, Mg, K and Al.

Soil pH was determined in a water suspension at a 2:5 soil/ water ratio. Exchangeable Ca^{2+}, Mg^{2+}, K^{+}, Al^{3+} and available P were extracted by the Mehlich-3 procedure (Mehlich, 1984). Exchangeable cations were determined by atomic absorption spectrophotometry and available P by the Malachite green colorimetric procedure (Motomizu et al., 1983). Organic C was determined by chromic acid digestion and spectrophotometry (Hearnes, 1984). Total N was determined using the Kjeldahl method for digestion and ammonium electrode determination (Bremmer and Tabatabai, 1972; Bremmer, 1982).

Statistical and numerical analyses

Analyses of variance were conducted using the General Linear Model (GLM) procedure of the Statistical Analysis System (SAS, 1999). Statistical comparisons of land-use systems were performed by analysis of variance. The means were separated using the Student-Newman-Keuls Test.

RESULTS

Soil characteristics

The results on soil properties of Akok village are presented in Table 1. In overall average from the three layers, this soil fell in the sandy clay soil class according to the triangle methods of soil classification (sand 41%, clay 51% and silt 8%). The topsoil (0-10 cm) features as a sandy clay and the subsoil

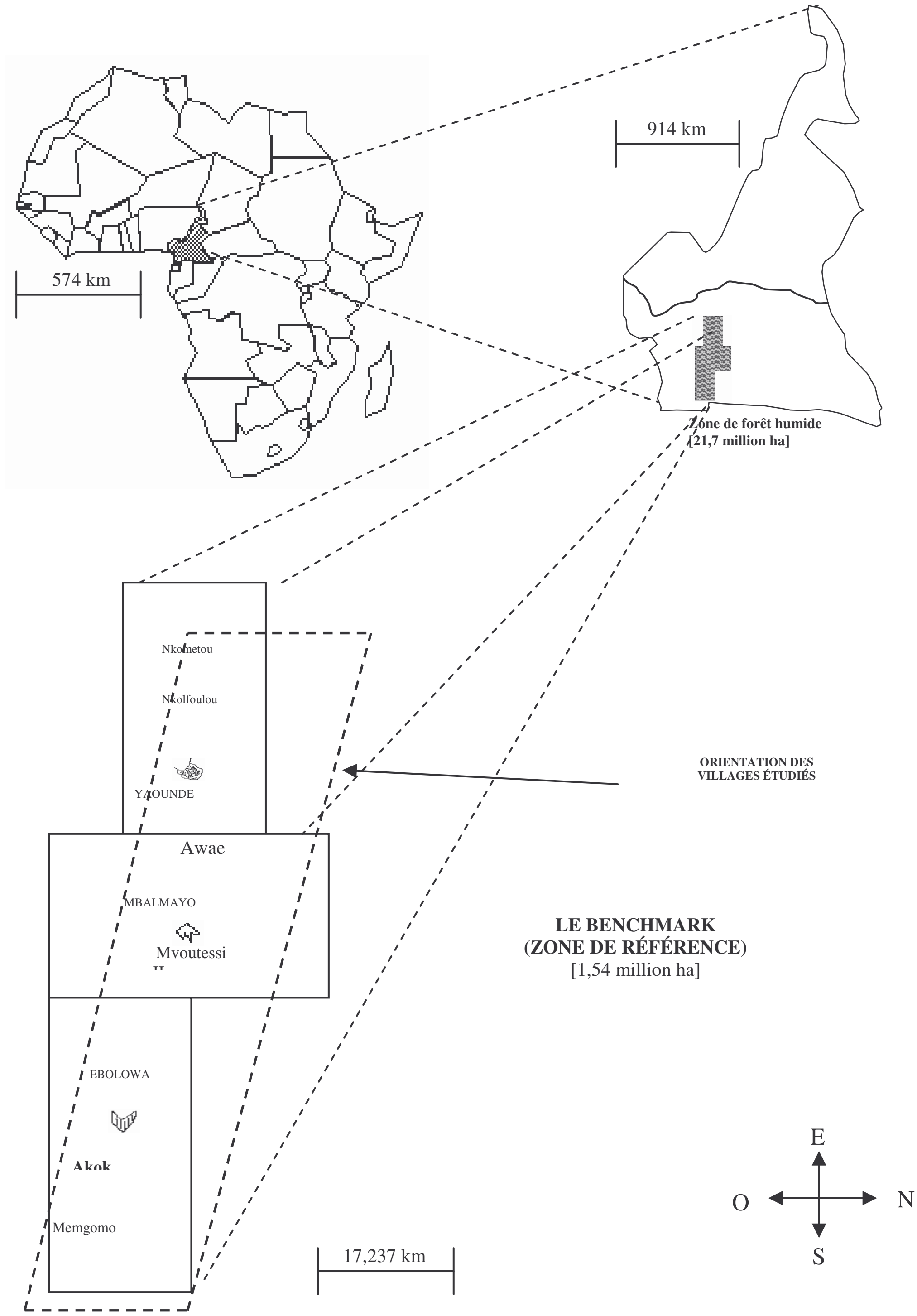

Figure 1: Study area: the forest margins Benchmark area in Southern Cameroon.
(Source: Thesis Birang Madong, Wageningen University, 2004).

Table 1: Means and probabilities of soil characteristics of Akok village in Southern Cameroon.

Characteristics	Soil depth				
	0 – 10 cm	10-20 cm	20-30 cm	P [$]	$LSD_{0.05}$
Sand (%)	47.45	39.27	36.18	<0.0001	2.22
Clay (%)	43.27	53.63	56.07	<0.0001	2.61
Silt (%)	9.28	7.10	7.75	0.0003	1.05
pH_{H2O} (2 : 5)	4.54	4.53	4.60	0.5072	
OC (%)	2.18	1.11	0.91	<0.0001	0.20
Total N (%)	0.17	0.09	0.07	<0.0001	0.02
C/N	13.01	12.50	12.71	0.6040	
Available P (ppm)	6.21	2.07	1.52	<0.0001	1.27
Exchangeable Ca (me/100g)	1.26	0.36	0.32	<0.0001	0.41
Exchangeable Mg (me/100g)	0.52	0.16	0.09	<0.0001	0.13
Exchangeable K(me/100g)	0.11	0.05	0.04	<0.0001	0.01
Exchangeable Al (me/100g)	1.69	2.09	2.17	0.0014	0.34
ECEC (me/100g)	3.57	2.65	2.62	0.0007	0.55
Base saturation (%)	49.42	27.06	24.03	<0.0001	7.78
Al saturation (%)	50.58	72.94	75.97	<0.0001	7.78

P [$] = probability

(10-30 cm) as a clay. Overall soil pH_{H2O} was below 5, with no significant difference between layers. Organic carbon and total N decreased significantly with soil depth but the C/N ratio did not follow that trend. Available P and exchangeable cations decreased significantly with depth while Al in the opposite increased significantly. ECEC decreased significantly with depth.

Effect of land-use systems on soil particle size distribution

Land-use systems significantly affected the sand and the clay fractions of the soils (Figure 2.). In the top layer (0-10 cm), the proportion of sand was greater in soils of Yfor than in soils of the other land-use systems and the clay percentage followed the reverse sequence. In the medium layer (10-20 cm), the sand fraction was in soils as Yfor=Sfor= Chro= Crop and Sfor=Chro=Crop=Coco and Yfor>Coco, and the clay fraction was as follows: Coco=Crop=Chro=Sfor and Crop= Chro=Sfor=Yfor and Coco>Yfor. In the third layer (20-30 cm), the sand fraction was greater in soils as Yfor>Chro=Crop= Sfor>Coco and the clay fraction followed the reverse sequence. The silt fraction differred only for the second and third soil layer as respectively follows: Sfor=Yfor and Yfor=Crop=Chro=Coco and Sfor>Crop= Chro=Coco in the 10-20 cm, Yfor>Sfor> Crop=Chro=Coco in the 20-30 cm.

Effect of land-use systems on soil chemical properties

All the measured soil chemical properties varied with land-use systems (Table 2, Figure 3).

Coco plantation contained significantly more exchangeable bases and presented a significantly greatest pH (Figure 3) than all the other land-use systems while in the opposite, secondary forest exhibited more available Al (Al saturation) and lowest pH values in all three layers. Sfor contained significantly more Org C and Tot N than Chro in first two layers. Coco plantation significantly contained more available P than all the other land use systems and in the three layers.

DISCUSSION

The soils of Akok were mostly sandy clay with a high fraction of clay. This could derive from the dissolution and leaching of silica due to high rainfall in the site whose pattern is bi modal with pics in May and October (Tchienkoua, 2005). The particle

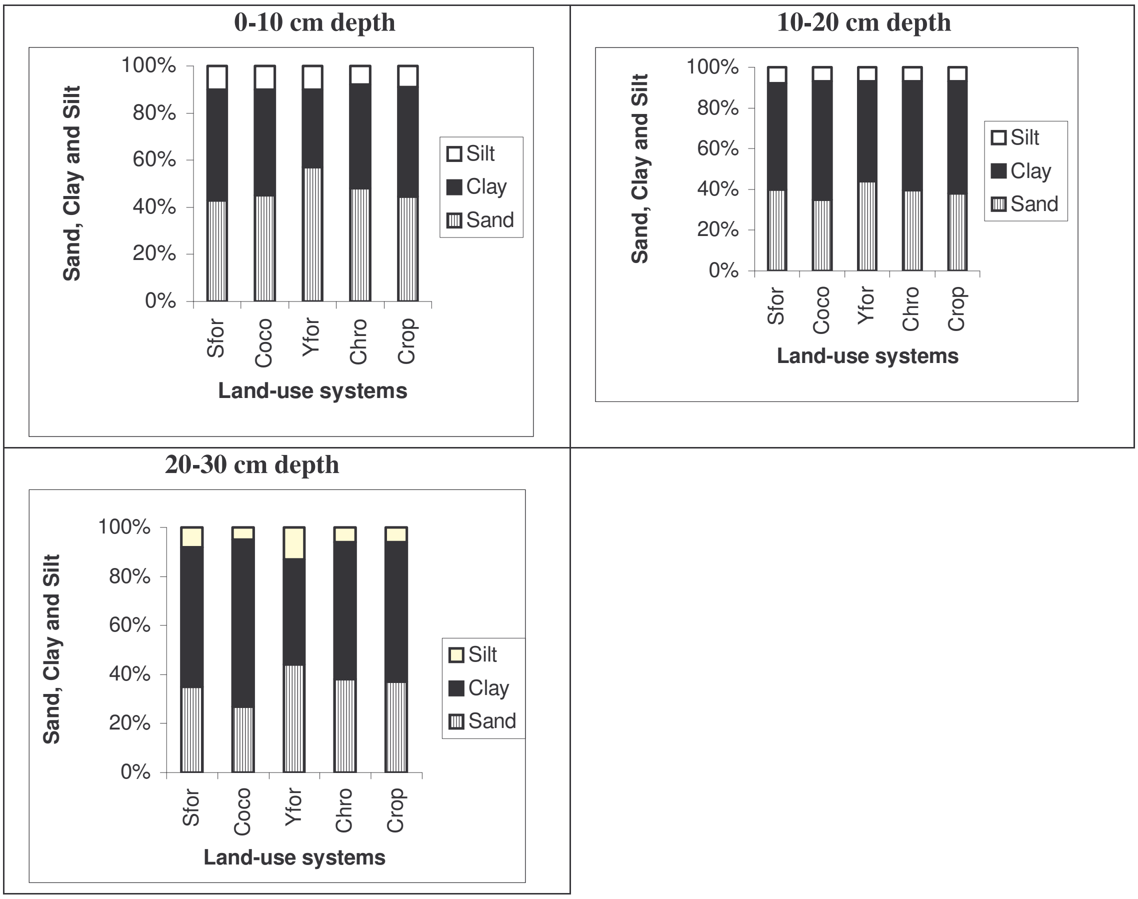

Figure 2: Effect of land-use systems on soil particles size distribution.

size distribution might also reflect the texture of the area parent material which is granite (Tchienkoua, 2005). The sand and silt percentages decreased with the depth whereas the opposite situation was found for the clay. This hints the possibility of clay translocation in soil profile. Clay accumulation in the subsoil could result in reduced porosity, increased water retention and reduced drainage.

Our result showed a significant difference between layers for the silt fraction. But Voundi Nkana and Tonye (2002) did not find any changes in silt fraction distribution, may be because they dealt with 0-20 cm soil layer while this study dealt with 0-10 cm soil layer.

Lal (1996) and Voundi Nkana and Tonye (2002) found similarly that continuous cropping and intensive land-use both affect the particle size distribution and these changes depend on cultivation duration. Shepherd et al. (2000) indicated no effect of land-use systems on soil particle size distribution. The similarity or differences between results can be attributed to differences between experiments conditions. Cocoa farms had the highest clay percentage (58%). But as the overall soil texture must take into account both soil organic carbon and Ca contents (Duchaufour, 1960), soils under cocoa farms might have the highest fertility status since they keep the first ranking for organic carbon and calcium contents.

According to the guidelines elaborated by Landon (1991) for tropical soils, high, medium and low Org C content correspond to: > 10, 4 – 10 and <4%; for Org N to: >0.5, 0.2 -0.5 and <0.2% and for P to:0 – 5, 5 – 10 and 10 – 15 respectively. Therefore in our study, organic carbon and total nitrogen contents

Table 2: Effect of land-use systems on soil chemical properties in Akok in southern Cameroon.

Land-use System	pH_{H2O} (1:2.5)	Org. C	Tot. N	C/N	Available P	Ca	Mg	K	ECEC
		(%)	(%)		(ppm)	(me/100g)	(me/100g)	(me/100g)	(me/100g)
				0-10 cm depth					
Sfor	3.80c	2.65a	0.13a	12.68ba	3.43b	0.14b	0.17c	0.11ba	4.22b
Coco	5.50a	2.33ba	0.11b	12.32ba	5.76a	3.97a	1.22a	0.07b	5.35a
Yfor	4.51b	2.32ba	0.11b	14.88a	4.31b	1.13b	0.63b	0.13a	2.89c
Chro	4.56b	1.68b	0.10b	11.85b	1.84c	0.63b	0.33b	0.13a	2.51c
Crop	4.51b	1.89ba	0.10	13.18ba	1.61c	0.97b	0.39b	0.10ba	3.26cb
P	**<0.0001**	**0.0161**	**0.0071**	**0.0403**	**<0.0001**	**<0.0001**	**0.0001**	**0.0066**	**0.0011**
				10-20 cm depth					
Sfor	4.21c	1.40a	0.10a	13.37a	1.40b	0.06b	0.07b	0.06a	3.26a
Coco	4.98a	0.92b	0.08b	11.47a	5.52a	1.00a	0.26a	0.04a	0.31d
Yfor	4.46b	1.00b	0.08b	11.85a	1.89b	0.34b	0.27a	0.05a	2.18c
Chro	4.55b	1.05b	0.08b	12.70a	0.74b	0.11b	0.06b	0.06a	2.18c
Crop	4.39b	1.21ba	0.09ba	13.29a	0.65b	0.21b	0.11b	0.07a	2.75b
P	**<0.0001**	**0.0115**	**0.0322**	**0.2232**	**0.0007**	**<0.0001**	**0.0051**	**0.2105**	**<0.0001**
				20-30 cm depth					
Sfor	4.35c	1.01a	0.07a	0.08a	0.48b	0.03c	0.05c	0.04ba	3.10a
Coco	5.07a	0.82a	0.07a	0.08a	5.75a	0.95a	0.15b	0.01b	0.34c
Yfor	4.58b	0.85a	0.07a	0.07a	0.50b	0.46b	0.24a	0.04ba	2.99a
Chro	4.55b	0.82a	0.07a	0.07a	0.01b	0.08c	0.05c	0.05ba	2.33b
Crop	4.42cb	1.02a	0.08a	0.06a	0.24b	0.17c	0.08cb	0.06a	2.57ba
P	**<0.0001**	**0.0662**	**0.3370**	**0.3370**	**<0.0001**	**<0.0001**	**0.0010**	**0.0485**	**<0.0001**

Note: Figures with the same letter within a column are not significantly different at 5% level of significance.

were low. The low content of available P (<5 ppm) indicated its deficiency in the soils. Exchangeable Ca, Mg and K were low (<4 me/100g for Ca, <0.5 me/100g for Mg and <0.2 me/100g for K), showing that these soils are impoverished with respect to basic cations. Due to the strong acidity (pH < 5), these soils contained Al in the exchangeable form. The very low ECEC derived from the low pH and reminded that the adsorption capacity of these soils was pH-dependent regulated by the sesquioxides. There is creation of negative sites on the adsorption complex by increasing the pH via the deprotonation processes. Menzies and Gillman (1997), and Voundi Nkana et al. (1997) justified this low and variable character of the CEC or ECEC within the cameroonian humid forest zone by the domination of low –activity components such as kaolinite, Fe and Al (hydr-) oxides in these soils. According to these authors the latest are due to higher degree of weathering of rock's constituent minerals. The parent material (granite) is no longer weatherable, that means that it is full of minerals of low activity and its contribution to the CEC is very low. Thus the charge of these soils is highly organic matter dependent. In such soils, a large part of the plant nutrients and about 90% of the capacity of the soil nutrient retention depends on soil organic matter (Kauffmann et al., 1998). Buol et al. (1975) noted that soils with ECEC of 4 me/100g or less had limited ability to retain nutrient cations. The base saturation was less than 35% while the Al saturation was greater than 65%. Sanchez et al. (1982) defined two important thresholds values : soils with more than 10% Al saturation present acidity problems while soils with more than 60% Al saturation exhibit Al toxicity. Base on this findings we can state that acidity problems will occur in the topsoil and Al toxicity problems in the subsoil.

Statistically, the three depths significantly differed for most of soil properties except for pH and C/N ratio. The organic carbon, total nitrogen, available P,

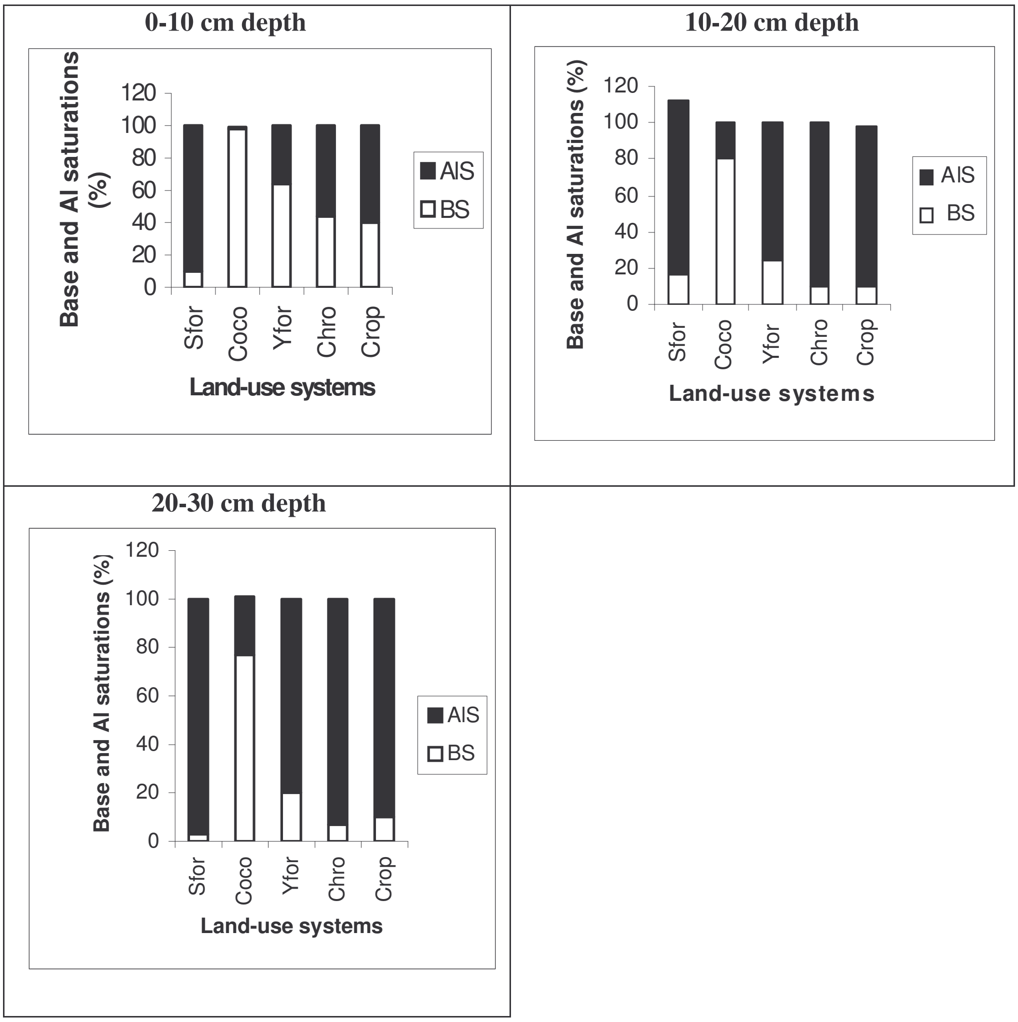

Figure 3: Effect of land-use systems on base saturation (BS) and Al saturation (Als).

exchangeable Ca, Mg and K were higher in the 0-10 cm layer than in the two subsequent 10 cm layers. The relative richness of the top 10 cm layer could be attributed to the regular restitution of N, P and basic nutrients at the soil surface via decomposition or burning of plant residues or biomass (Dabin, 1984) . The limited amount of exchangeable Al in the topsoil might be due to its complexation by a good cement formed by the complex organic matter-clay-calcium in this layer, providing thus the soil with a stable structure (Duchauffour, 1960) .

Thus, soils under cocoa farms presented the highest fertility level compared to those of secondary forests because of their higher clay percentage, pH, Ca, Mg, available P and lowest Al saturation .

Although in another soil type (Typic Kandiudult) with similar land-use systems, Voundi Nkana et al. (2002) obtained different results in the chemical status among land-use systems. But in another study, Kanmegne et al. (2004) found that cocoa farms were the only land-use to have a positive nutrients balance among the studied land-use systems. The highest soil fertility status (higher soil pH, higher available P, higher Ca content, lower exchangeable Al and Al saturation, higher clay percentage) in cocoa farms might be due to the fact that the cycles of N and S nutrients issued from the mineralization of organic matter were not washed out of the system.

Differentiation Factors

Under secondary forests as under cocoa farms, soil erosion was low and there was no difference in particle size distribution which were entirely dominated by the clay fraction as clay class in all the three 10 cm layers (Figure 2). Soil fertility depends on the quantity of organic matter supplied by the natural vegetation and the nutrient cycling (Juo and Manu, 1996). Important changes could therefore occur in base and Al saturation, and in soil nutrient levels (Table 2, Figure 3). For food crop fields, a significant benefit of slash and burn is the rapid release of nutrients from the ash to the soil (Jordan, 1985 ; Tulaphitak et al., 1985). Burning and cultivation lead to the destruction and rapid decomposition of soil organic matter and reduce the contribution of organic and microbial processes to nutrient cycling (Juo and Manu, 1996). In addition, cocoa farms are established on relatively more fertile soils (Leplaideur, 1985). *Chromolaena* fallows and food crop fields had similar particle size distribution (Figure 2). However, the fertility status depends on the inevitable loss of soil nutrients in crop (plant material) harvest and additional losses by leaching and runoff.

Consequences for Agricultural Development

Secondary forest conversion to other land-use systems resulted in less Al saturation and more nutrients in cocoa farms, and in less acidity and more nutrients in young forests, *chromolaena* fallows and food crop fields. There was a decrease in organic carbon, exchangeable Al and an increase in soil pH (Table 2). Constraints for agricultural development remain the low level of plant nutrients, a low adsorption capacity, the soil acidity and the toxicity caused by high exchangeable Al levels. These conditions are related to the nature of the soils of the rainforest zone. The combination of these nutrient constraints with a very high leaching due to heavy rains, nutrients removal with harvested crops (or plant material) and other losses from the system could result in serious soil degradation. Severely degraded soils do not support any vegetation and hence the land has to be abandoned or taken out of production. This affects the long-term sustainability of intensive production ; even the potential benefits of genetically improved varieties cannot be realized (Voundi Nkana and Tonye, 2002).

Management options

Improving and maintaining soil productivity include erosion control, liming and fertilizer application. Residues from harvests must be used to cover the soil surface in order to minimize the evaporation and the effects of erosion specially in food crop fields. For nutrients that persist in the soil such as P, Mg and K, commercial fertilizers can compensate for nutrients taken up or lost by runoff and leaching. For mobile nutrients like N, because uptake and runoff and/or leaching can be immediate, adding commercial fertilizers is not an option.

Between 0.43 t and 5.60 t $CaCO_3$ ha^{-1} (or 0.24 t to 3.14 t CaO ha^{-1}) must be applied to increase the soil pH and eliminate Al toxicity (Kamprath, 1970). Phosphorus additions must take into accounts both the adsorption capacity and P requirements of the soil (Menzies and Gillman, 1997). Phosphorus requirements were calculated by using the relationship established by Menzies and Gillman (1997) for various humid forest zone of Cameroon.

Basic cations must be applied in proportion to achieve an ideal soil complex. According to Liebbhardt (1981), the ideal is to have the exchange complex saturated with 65% Ca, 10% Mg and 5 per cent K, But fluctuations between 65 and 85% Ca, 6 and 12% Mg and 2 and 5% K do not affect the production capacity of the soil. Except for secondary forests for Mg and K, and cocoa farms for K (2% K, 3% Mg, and 2% K saturation), calculations showed that the Mg and K saturation are almost within the acceptable range (8-21% Mg and 3-4% K). However, Ca saturation (3-71%) was lower than those required. Therefore, Ca must be added to the soil through liming; and K should be added to the soil as well as K soil content situated at the extreme lower limit.

Primary forests on strongly acid and leached soils, depend on internal cycling to meet their mineral requirements (Juo and Manu, 1996) and do not need nutrient management. Liming and P fertilization appeared therefore as the first and the most important operations required for productivity improvement in crop land-use systems of Akok area. N fertilization could be added according to crop requirements (Table 3.)

Recommendation

A cheap alternative for the farmers of Akok is the use of wood ash, which is widely available and considered as waste by the wood industries established in the forest zone of Cameroon. Since the government stopped subsidizing the use of commercial fertilizers and amendments, the use of wood ash, is a justified option, as no farmers have no access to financial credit. Ash is a good source of Ca, K, P and Mg (Etiegni and Campbell, 1991). Its application in tropical acid soils can help increasing soil pH and neutralizing Al toxicity and at the same time it could supply P and K (Voundi Nkana et al., 1998).

Conclusion

The acid soils of Akok are mainly composed of sand and clay. They are poor in organic carbon, total nitrogen and ECEC. The soil nutrients are mainly stored in the topsoil, together with organic matter (normal). Land use significantly affects the sand, the clay and the silt fractions. For agricultural development, utilization of residues from harvests to cover the soil surface, liming and P fertilization appeared as the first and the most efficient management options. N and K fertilizations could be added according to crop requirements. Since farmers cannot afford chemical fertilizers, the use of cheap and locally available wood ash as a liming material and P and K supplier can be seen as a promising option that requires further investigations concerning their quality and application doses.

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Table 3: Lime, P and K requirements in different land use systems in southern Cameroon.

Land-use system	Lime requirement ($t\ ha^{-1}$)		P requirement ($kg\ ha^{-1}$)	K requirement ($kg\ ha^{-1}$)
	$CaCO_3$	CaO		
Sfor	5.60a	3.14a	-2a	13ba
Cocoa	0.43d	0.24d	77a	16a
Yfor	3.01c	1.69c	14a	10bc
Chro	3.27cb	1.83cb	78a	9c
Crop	3.92b	2.19b	69a	12bc
P	<0.0001	<0.0001	0.2406	0.0028

Note: Figures with the same letter within a column are not significantly different at 5% level of significance.

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