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Impacts of land use on soil microbial biomass and soil organic status in Western Cameroon

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Abstract

Living organisms and their enzymes are responsible of most of the soil biotic interactions in agro-ecosystems. This study was to evaluate the impact of land use (cropping systems and farming practices) on the physical, chemical and biological properties of soil in Western Cameroon. We sampled soil (0-20 cm) in four different land use systems (extensive, intermediate, intensive and an undisturbed natural habitat). We also measured soil health indicators in each land use type. We observed that the total organic carbon (C_{org}) and P availability was significantly higher in agro-ecosystems as compared to undisturbed natural habitat. Similar trends were recorded for pH, electrical conductivity, and β-glucosidase, dehydrogenases and acid phosphatase activities. We also recorded a significant variation in microbial biomass C (C_{mic}: 312.0 to 544.5 mg kg^{-1} dry soil) and microbial biomass N (N_{mic}: 5.40 to 25.31 mg kg^{-1} dry soil) with land use intensity. The C_{mic}/C_{org} ratios of soils were two-fold lower in agricultural lands with vegetables than the undisturbed control plot indicating a decrease in soil microorganisms. Regression analysis revealed a negative correlation ($r = - 0.806$, $P < 0.01$) between soil clay content and microbial biomass C, and a high C_{org}/N ratio suggesting a heterogeneous distribution of the population of microorganisms between soils and the immobilization of P, respectively. Our results suggest that the selected soil health indicators were sensitive to farming practices and cropping systems.

Keywords: Farming practices, cropping systems, microbial biomass, enzymes activities, field conditions, tropical soil quality, Western Cameroon.

1. Introduction

Soil is the most important factor for crop production and is at the same time the factor most influenced by the farmer. For a given type of soil, high values of microbial biomass means that the soil biological fertility is high and therefore the agronomic properties of soil have the best chance to be insured.

In Cameroon, the Urban and Peri-Urban Agriculture (UPA) has grown in recent decades due to the proximity of the centers of commercialization of products derived therefrom and the availability of labor corollary of the urbanization. Thus, agriculture is shifted from subsistence agriculture to commercial agriculture and currencies. It was practiced by more than 70% of the labor force and contributed to more than 41% of the Gross Domestic Product (GDP) in 2008.

However, this agriculture is facing a number of difficulties: lack of knowledge on good agricultural practices by farmers, not mastery of technical information, uncontrolled and inappropriate use of agrochemicals (insecticides, fungicides, herbicides and fertilizers) (Fotio and Monkiedje, 2005; Mathews, 2003), and soil acidity mainly due to

aluminum and manganese (75% of soils) that favor the persistence of agrochemicals in the environment (Yemefack et al., 2004; Moukam and Ngakanou, 1997).

Despite these constraints, the new policy of development of crop and animal productions of the Cameroonian government aims to develop sustainable agriculture, to double production and exports, and to increase farmers' incomes by 4.5% per year in order to halve poverty in rural areas by 2015. To achieve this, incentives measures such as increasing of agrochemicals products, and more specifically the increasing of the level of fertilization current from 8 kg/ha to 50 kg/ha were taken. In the mean-time, environmentally datasheets supporting this policy exist but they are very little disseminated among farmers.

Agrochemicals are toxic to plant pathogens and pests (pests and auxiliaries) as well as for humans, animals and microorganisms responsible for soil fertility (Fotio et al., 2006). Chemical fertilizers in particular are sometimes responsible for soil acidity (Barak et al., 1998) and a decrease of microbiological activities in fertilized soils compared to those in natural habitat (Monkiedje et al., 2006). Enzyme activities are often used to determine the effects of pollutants on the microbiological status of soil (Ascoli et al., 2006). Thus, interactions between pollutants and soil microorganisms may lead to inhibition of enzyme activities or their stimulation depending on both the nature of pollutants, the pollutant contents and the type of enzyme (Dick and Tabatabai, 1983).
Therefore, a healthy and balanced soil for a profitable growing program appears to be an important agricultural factor to protect. Other consequences of human activities involving agrochemicals poorly controlled in Cameroon concern the contamination of crops with pesticide residues (Fotio and Monkiedje, 2005) and the pollution of groundwater (Tabue et al., 2007; Tita and al., 2007). The soils assessment contributes to strengthening the integrated approach and to anticipate interactions between soils and an intervention (policy, program, and project) in order to predict and assess its potential impacts on the environment. This assessment consists of identifying soil health indicators including, microbial biomass (Monkiedje et al., 2006; Carter et al., 1999), available nitrogen and the activities of soil enzymes (Casida, 1977), plant nutrients (O'Neil et al., 1977).

Foumbot basin west of Cameroon is characterized by an extensive use of agrochemicals and significant production of vegetable crops supplying both the major cities of Cameroon (Bafoussam, Douala and Yaounde) and neighboring countries (Gabon, Equatorial Guinea and Congo-Brazzaville). However, knowledge about farming practices, the exposure level of soils to agrochemicals in this region is rare. Therefore, it was our objective to assess the impact of different farming practices of farmers of Foumbot Basin on physical and biological indicators of their soils to better understand and manage these soils in agronomic perspective.

2. Material and Methods

The study was carried out in 2008 in Foumbot basin. Its principle was based on the observation of peasant farming practices and assessing their impacts on indicators of soil health (physical, chemical and biological soil).

2.1 Presentation of the Study Sites

Foumbot basin (5° 32' 49" N, 10° 40' 52" E) is located at 24 km from Bafoussam city in the humid forest zone of West Cameroon. It is characterized by an equatorial climate and a shrubland vegetation type. The mean temperature is around 23°C while the annual average rainfall is about 1900 mm (March to November). Three sites of the basin that were Njognom, Koupara and Baïgom (Figure 1) were selected on the basis of intense gardening practices and family farming status. The basin is drained by small streams flowing into the river Nkoup. Otherwise, sources of drinking water were both groundwater (mainly water well) and surface water distributed through about twenty private taps of the Cameroonian society of Waters (CAMWATER) network. Although the basin is drained, many agricultural areas are not. Plots therein are forced fallow for about six months during the flood. The soils of four of those areas were subjected to different land uses involving contrasting cropping systems and agrochemical usage mentioned in Table 1: native shrubs savannah not cropped in the locality of Koupara (soil 1); cropped land in basil (*Ocimum basilicum* L.) in combination with African nightshade (*Solanum africanum*) and with fertilizers, fungicides and insecticides in the locality of Njognom (soil 2); cropped land in tomato (*Lycopersicon esculentum*) in combination with African nightshade and with fertilizers, fungicides and herbicides in the locality of Koupara (soil 3); cropped land in tomato in combination with African nightshade and green beans (*Phaseolus vulgaris*) and with

fertilizers and fungicides in the locality of Baïgom (soil 4). Those cropped lands were occupied the previous year at the time of sampling by the same crops. Crop rotation occurs at intervals of three to four years on average consisting of the permutation of crops, tomato and African nightshade grown in pure or in combination constituting the first choice. Phytosanitary practices are retained from one crop cycle to another and may change depending on the availability of inputs and purchasing power. In this case, farming practices have remained unchanged for three years, the year this study preceding the next round of crop rotation.

Sampled plots had an area of 100 x 100 m² and consisted of ridges 10 x 1.5 m² distant from each other by a 1.0 m path which serves as runoff crossing. These plots were initially weeded and then plowed deep (25-30 cm) to facilitate the burial of weeds and organic matter in the ridges. In addition, a natural savannah characterized by a soil that has not yet undergone anthropogenic activities, herbs close to 2 m in height and shrubs was identified in Koupara (soil 1) as the natural control soil to soils from cropped lands.

Values of different parameters of soils sampled showed a predominance of clay in the soil resulting in two textural classes (clay and clay loam), a variation of pH (5.0 - 5.5) and organic carbon (21.7 to 39 g/kg dry soil) (Table 2).

2.2 Soil Sampling and Preparation

A series of spot sampling of soils was carried out at interval of 7 days starting from the first application of agrochemicals that was 37 days after sowing. At each site, ten individual soil samples were collected from the 0-20 cm depth following a scheme W, using an auger. Those soil samples were subsequently bulked then homogeneously mixed. After the mixture was obtained, a composite subsample of 0.5 kg was collected, air-dried, ground, and sieved (<0.25 mm) to serve as substrate for the determination of the texture and soil organic carbon. A second composite subsample of 0.5 kg was also sieved (<0.5 mm) and then stored at 4°C until analysis to serve as substrate for the evaluation of the available nitrogen content (NH_4^+-N and NO_3^--N), phosphorus content (P), pH, electrical conductivity (EC) and enzyme activities. Finally, a third composite sample was sieved finer (<2 mm) and water capacity adjusted to 60% prior to its conservation at 4°C to serve as a substrate for the determination of microbial biomass. Following the above described methodology, soil sampling was made twice and analyzed separately, each with 3 replications.

2.3 Soil Physicochemical Properties

Particle size and soil pH were respectively determined using a hydrometer method and a pH-meter in a ratio of soil:water 1:2.5. Available nitrogen (N) was extracted with 2M KCl solution before being colorimetrically analyzed respectively according to the method of Soil and Plant Analysis Council (2000) and Tan (1996); available P was extracted using $NaHCO_3$, pH 8.5, before its colorimetrically quantification at 880 nm (Olsen and Sommers, 1982). Organic carbon (C_{org}) was determined according to the method of Heanes (1984).

2.4 Soil Microbial Biomass Carbon, Nitrogen and Phophorus

Soil microbial biomass C (C_{mic}), N (N_{mic}), and P (P_{mic}) were determined according to the methods described respectively by Voroney et al. (1993) and Brookes et al. (1982, 1985). The soluble soil organic carbon (TOC) content in the supernatants was determined by infrared spectroscopy after combustion at 850°C. The available nitrogen was quantified as indicated above. Values of soil microbial biomass obtained were determined from the following equations:

C_{mic} (mg C/kg soil) = tC_{org}/K_{EC}; N_{mic} (mg N/kg soil) = E_N/K_{EN}; P_{mic} (mg N/kg soil) = E_P/K_{EP};

where t_{Corg} = C fumigated extract - C non fumigated extract; E_N = (NH_4^+-N and NO_3^--N) in fumigated sample - (NH_4^+-N and NO_3^--N) in non fumigated extract; E_P = P in fumigated extract - P in non fumigated extract; K_{EC} = 0.45 (Martens, 1995); K_{EN} = 0.54 (Brookes et al., 1985); K_{EP} = 0.40 (Brookes et al., 1982).

2.5 Soil Enzymes Assays

Soil dehydrogenase (DHase) activity was determined according to the method of described by Casida et al. (1964). This method is based on the estimation of the concentration of 2, 3, 5-triphenyl formazan (TPF) released by dehydrogenases when soil is incubated with a buffer solution of chloride of 2,3,5-tetrazolium tryphenyl (TTC). The optical density of TPF was then determined colorimetrically at 485 nm using a spectrophotometer.

In addition, the activities of β-glucosidase, acid and alkaline phosphatase were evaluated respectively by the methods developed by Eivazi and Tabatabai (1988), Tabatabai and Bremner (1969) and Eivazi and Tabatabai (1977). Their enzyme activities were determined by spectrophotometric quantification of para-nitrophenol (PNP) at 410 nm. All enzyme activities were determined in soil dried at 105°C.

All determinations were the average of three analyzes. The data were analyzed using SPSS 13.0 (Statistical Package Social Science).

3. Results and Discussion

The data generated from the two soil samplings at 7 day intervals were very closed and therefore considered as those of a single soil sampling.

3.1 Impacts of Soil Management Mode on their Physicochemical Properties

Carbon, nitrogen and phosphorus are the fundamental constituents of organic matter. Assessing the availability of these compounds in the field in relation to soil texture provides a basic knowledge in the management of soils and crops. In this study, the results indicated that the physical and chemical properties of cultivated soils differ from those of uncultured soil (Table 2). The cultivation of the soil has led to a substantial increase in the pH and P compared to uncultivated soil, and significantly stimulated EC and C_{org} (Figure 2a, Table 2). PH and EC were higher in the soil where tomatoes and African nightshade were grown (soil 3). This was due to a continual burial of large quantities of weeds previously treated or not with agrochemicals and also to adsorption of organic degrading enzymes on the clay (Scott, 1962). Organic matter might act as absorbent of nutrients brought to soils or nutrient exchanger and therefore contributing to increase pH (Pieri, 1989). In contrast, the production of N in soil 2 and soil 3, and soil 4 were positively and negatively stimulated, respectively (Figure 2b). Higher values of electrical conductivity in cultivated soils could be due to salts that make up the various products of fertilization and crop protection as well as the water evaporation at the soil surface (Murtaza et al. , 2008), while the increase of C_{org} was due to burial of weeds. Moreover, it appeared that the C_{org} increase was higher in soil 3 and soil 4 which have yet received high doses of herbicide and fungicide, and fungicide, respectively. Bohn et al. (1985) and Giusquiani et al. (1994) reported that the rate of decomposition of organic matter in soils is high and proportional to the amount added. The increase in C_{org} may therefore also be a consequence of disruption of the decomposition of the organic matter. The conversion of land to cropland has led to changes in soil fertility parameters. This observation is characterized by two phenomena. First, this conversion reduces the amount of organic waste and plant resistance to microbial mineralization in soils. Indeed, the land is mostly covered with tall grasses before cropping. Second, it accelerates the decomposition of soil organic matter providing better aeration in the cultivated layer of soil (Ondo, 2011; Khresat et al., 2008). This disturbance of turnover of soil microorganisms has been more severe for bacteria involved in the process of nitrogen mineralization (Figure 2b). It is through the soil N mineralization that organic matter releases nitrogen (NO_3^--N + NH_4^+-N) used by plants. In addition, the substantial increase in the available P content in agricultural soils was due to their management and to the formation of clay organic complexes, particularly in the presence of elements such as aluminum and iron. The C_{org}/N ratio (206) in soil 3 was very high (C_{org}/N> 100-500), indicating immobilization of P (Upadhyay and Singh 1989; Janssen et al. 1990). Significant correlations between pH and C_{org} ($r = 0.961$, $P < 0.05$), clay and available N ($r = - 0.971$, $P < 0.05$), sand and available N ($r = 0.985$, $P < 0.05$) were found indicating that soil texture plays an important role in the availability of plant nutrients and the heterogeneity of soils.

3.2 Impacts of farming practices on soil microbial biomass

The soil microbiological status is an essential fertility parameter which is most often appreciated globally by microbial biomass C, N and P, complemented by microbial yield (C_{mic}/C_{org}) and soil enzymes' activities. The microbial biomass is a global measure representing an amount of living carbon in the soil. In this study, values of microbial biomass in cultivated soils were significantly high compared to those of uncultivated soil, except for soil biomass C and soil biomass N in soil 3 (Figures 3a and 3b, Table 3). In addition, farming practices stimulated the growth of microorganisms in soils 2 and 4 while they simultaneously stimulated and inhibited this phenomenon in soil 3, where high agrochemical loads were recorded. The change in the value of microbial biomass C (312.0 to 5 44.5 mg/kg soil) in the Foumbot basin appeared low compared to 458.0 to 739.0 mg/kg soil identified in the savannah zone (Some et al., 2007).

Living microscopic fraction of a soil has a high turnover rate. However, the C_{mic}/C_{org} ratio represents only a small percentage (1-3%) of the total organic matter (Feller, 1993). Microbial yield values obtained in this study varied differently according to farming practices. Only Soil 2 had a microbial yield (1.65%) higher than control soil (1.60%). In contrast, soils 3 and 4 provided lower microbial yields (1.35%) and (0.80%), respectively. These low microbial yields would signal an unfavorable physical environment for microbial life (poor drainage, compaction, excessive tillage and depth) or an unfavorable chemical environment for microbial life (acidity, toxic agrochemicals, particularly herbicides).

The analysis of our results showed that correlations between soil physicochemical properties and soil microbial biomass varied (Table 4). The correlation between clay and C_{mic} was significant and negative ($r = - 0.806$, $P < 0.01$) suggesting that farming practices and soil textures have been more harmful to bacterial than fungal. Indeed, there is a negative correlation between clay content and fungal biomass, whereas this correlation is positive with bacterial biomass (Kaczmarek and Pedziwilk, 1988). In addition, fungi predominate in the decomposition of materials of low quality (Swift et al., 1981). The results of the soil microbial biomass obtained in this study thus indicate that the Foumbot basin resembles a mosaic of heterogeneous sites with populations of different micro-organisms whose metabolism reflects the physicochemical conditions prevailing in their respective habitats.

3.3 Impacts of agricultural practices on soil enzyme activities

Soil enzymes play a crucial role in organic matter decomposition, nutrient cycling and soil health (Johansson et al., 2000). A multitude of these enzymes exist in soils, but only a few of them are sensitive to farming practices and can therefore serve as biological indicators of environmental stress induced by anthropogenic activities (Margesin et al., 2000). Most organic substrates are present in the soil as macromolecular, particulate or poorly soluble. Only enzymes produced by microorganisms in the extracellular medium and especially dehydrogenases (DHase) are able to initiate their degradation (Ross, 1971). However, these enzymes are subjected to adsorption, immobilization, entrapment, inactivation and degradation in the same extracellular medium. We found a negative correlation between clay and soil biomass C ($r = - 0.806$, $P < 0.01$) indicating that the activities measured in this study correspond to both extracellular (enzymes of soil solutions, adsorbed on the clay or humic substances) and intracellular (subcellular enzymes) enzymes.

Moreover, the results showed that Dhase activities varied little (58-75 mg TPF /kg dry soil /24 h), the highest and the lowest values corresponding to soil 2 and soil 3, respectively (Figure 4a). Only DHase activities in soil with tomato and African nightshade that received agrichemicals including Roundup (herbicide) were relatively low (58 mg TPF /kg dry soil /24 h) compared to the value (60 mg TPF /kg dry soil /24 h) of these activities in uncultivated soil. A positive and significant correlation between DHase activities and C_{mic} was recorded ($r = 0.999$, $P < 0.01$). However, no significant correlation between DHase activities and physicochemical parameters contents was found (Table 4) despite the use of green manures, particularly important in the site where these activities are low (Soil 3). These results might indicate inhibition of DHase activities consequently to the farming practices used (Engelen et al., 1998; Eivazi and Bayan, 1996) or to the predominance of microorganisms whose substrates are intermediate metabolites (soil 2 and soil 3).

Soil phosphatase activities are the most limiting factor to P cycling in soils. Phosphatases catalyze the hydrolysis of phosphoric esters and anhydrides of organic matter (Schmidt et Lawoski, 1961) and therefore the release of inorganic nutrients including P, allowing the assessment of phosphorus mineralization and the determination of correlations

between those enzymes, P deficiency and soil fertility. The results obtained in this study showed that the activities of acid phosphatase (Acid-P: 530-923 mg PNP /kg dry soil /h) and alkaline phosphatase (Alka-P: 488 - 555 mg PNP/kg dry soil /h) activities were relatively higher than in control soil (508 and 480 mg PNP /kg dry soil /h respectively). In addition, these phosphatase activities varied little depending on the cropping system, the farming practices and the class of enzymes. Acid-P values obtained were relatively high except Acid-P results in soil 3 where tomatoes and African nightshade were grown (soil 3) (Figure 4b). In this last case, the Acid-P activity (923 mg PNP /kg dry soil /h) was high compared to that of uncultivated soil and Alka-P in the same soil (488 mg PNP /kg dry soil /h). In addition, strongly positive correlation ($r = 0.992$, $P \leq 0.05$), and strongly negative correlation ($r = -0.995$, $P < 0.01$) were found between Acid-P and C_{org}/N, and between Acid-P and C_{mic}/C_{org} (Table 4), respectively. Phosphatase activities were therefore increased in cultivated soils with increasing C_{org}. Similar results were reported by Aon and Colaneri (2001). This increase in enzyme activity might be the consequence of a soil P deficiency, particularly in soil 3, resulting then to increased Acid-P synthesis in the roots of crops in order to overcome this stress (Versaw and Harrison, 2002). In addition, increasing Acid-P concentrations differed with cropping system and farming practices, the maximum value being produced in soil where tomatoes and African nightshade were grown. In all cultivated sites, the crops grown were vegetables. The mode of land management and the use of agricultural chemicals were responsible for the increase in enzyme activity.

β-glucosidase (β-Glu) is an important soil enzyme catalyzing the hydrolysis and the biological decomposition of various β-glucosides substrates of organic matter (Martinez and Tabatabai, 1997). Its sensitivity to soil management (tillage, cropping system, use of fertilizer and pesticides, rotation, etc.), as well as to pH changes have led to use this enzyme as an excellent soil health indicator (Acosta-Martinez and Tabatabai, 2000). The activity of this enzyme is sometime harmful to the soil, especially when the released aglycone is toxic or is a precursor of toxic substrates (Melouk and Horner, 1973; Sherrod and Domsch, 1970). The β-Glu activity in this study was stimulated in all cultivated soils compared to uncultivated land, and varied from one site to another (Figure 4b). The most important activity was recorded in the soil with tomato and Africa nightshade. In addition, significant and positive correlations between β-Glu and C_{org}/P ratio ($r = 0.962$, $P \leq 0.05$), β-Glu and EC ($r = 0.956$, $P \leq 0.05$), β-Glu and pH ($r = 0.976$, $P \leq 0.05$) were recorded (Table 4). These results were similar to those reported by Ajwa and Tabatabai (1994). They indicate that β-Glu was very sensitive to soil chemical properties.

4. Conclusion

Most of the soil physicochemical and enzymatic soil properties varied depending on the cropping system and farming practices. Positive and significant correlations between the soil physicochemical and enzymatic properties were observed indicating a beneficial effect of farming practices on the activation of soil enzymes and the increase in the population of soil microorganisms. However, the stimulation of the acid phosphatase activity and the high C_{org}/N ratio suggest a soil P deficiency. The clay content and the microbial biomass C were negatively correlated ($r = -0.806$, $P < 0.01$) to microbial biomass C suggesting a decrease in fungal biomass and the existence of different populations of microorganisms whose metabolism reflects physicochemical conditions prevailing in their respective habitats. Results from this study demonstrate that management practices and different vegetation types affect soil microbial processes.

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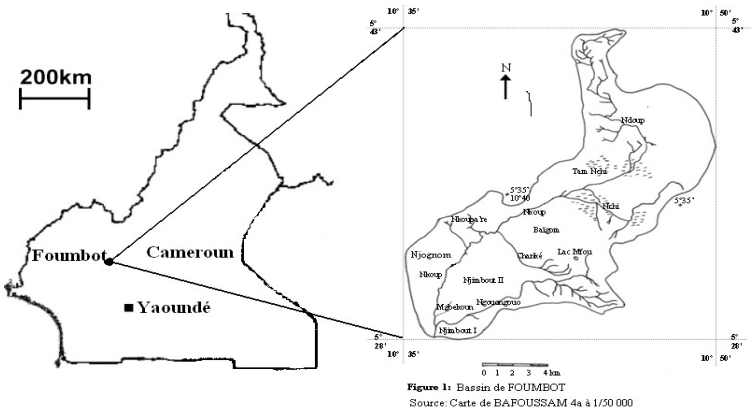


Figure 1: Map showing the study sites

Table 1: List of agrochemicals used on selected cropped land sites with rates as being applied

Location	Cropping systems	Trade name	Active ingredients	Class$^{\gamma}$	Application rate§
Njognom	Basil associated to African nightshade	Ammonium Sulfate	Ammonium (NH_4^+) and Sulfate (SO_4^{2-})	If	2 x 150 kg ha^{-1}
		Urea	Urea [$CO(NH_2)_2$]	If	150 kg ha^{-1}
		Penncozeb 75 DG Callidim 200 EC	Mixture of Mancozeb [manganese-zinc double salt of N, N'-ethylenebis dithiocarbamate] and Dimethoate [O,O-dimethyl-S-(2-methylamino-2-oxoethyl) dithiophosphate]	F and I resp.	3 x [(5 g + 2 mL) 15 L^{-1} w Wk-1 200 m^{-2})]
Koupara	Tomato associated to African nightshade	Roundup	Glyphosate [N-(phosphonomethyl) glicine]	H	300 mL 15 L^{-1} w 500 m^{-2}
		N-P-K (20-10-10)	Nitrate (NO_3-N), Phosphate (P2O2) and Potash (K_2O)	If	2 x 250 kg ha^{-1}
		Trimangol 80 WP	Maneb [manganese salt of N, N'-ethylenebis dithiocarbamate]	F	40 g 15 L^{-1} w 100 m^{-2}
Baïgom	Tomato associated to African nightshade and Green beans	N-P-K (20-10-10)	Nitrate (NO_3-N), Phosphate (P_2O_2) and Potash (K_2O)	If	2 x 250 kg ha^{-1}
		Trimaneb®	Maneb [manganese salt of N,N'-ethylenebis dithiocarbamate]	F	60 g 15 L^{-1} w 200 m^{-2}

γ If, inorganic fertilizer ; F, fungicide ; I, insecticide; H, herbicide: §w, water; Wk, week.

Table 2: Main characteristics of the soils at the study sites

Soil parameters		Shrubs savannah (natural control soil)	Basil, African nightshade	Tomato, African nightshade	Tomato, African nightshade, Green beans
Textural class		Clay	Clay loam	Clay	Clay
Texture (%)	Clay	47.6	40.0	51.5	48.4
	Sand	36.0	44.0	30.9	33.7
	Silt	16.4	16.0	17.6	17.9
pH(H_2O)		5.0	5.2	5.5	5.4
Conductivity (dS m^{-1})		0.07	0.07	0.18	0.12
Total C_{org} (g Kg^{-1} soil)		21.7	33.0	39.0	36.0
Origin		Koupara, Cameroon	Njognom, Cameroon	Koupara, Cameroon	Baïgom, Cameroon

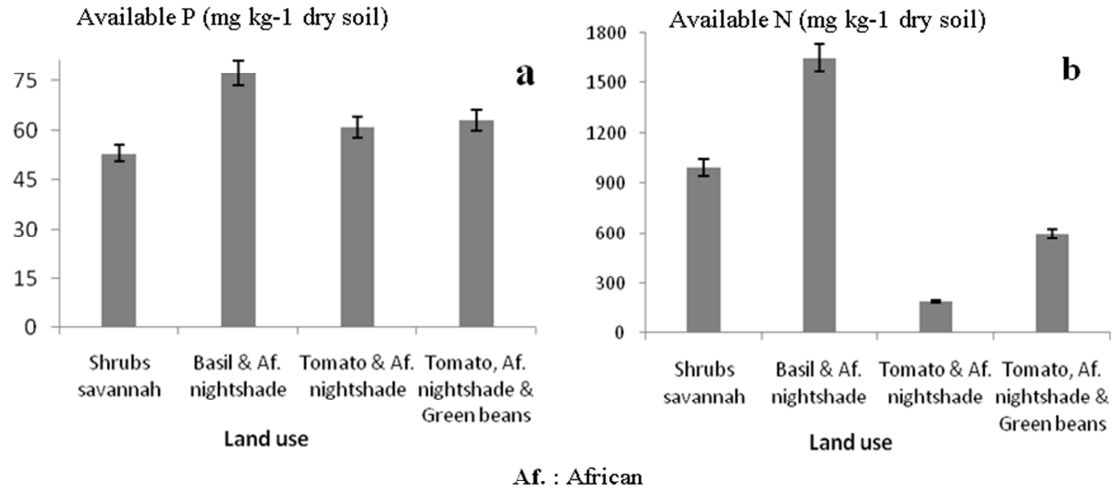


Figure 2: Impact of land use on the available phosphorus (**a**) and nitrogen (**b**) contents (Average ± SD)

Table 3: Soil microbial biomass and yields

Parameters	C_{mic} (mg/kg)	C_{mic}/C_{org} (%)	N_{mic} (mg/kg)	N_{mic}/N (%)	C_{mic}/N_{mic}	P_{mic} (mg/kg)	P_{mic}/P (%)	C_{mic}/P_{mic}
Shrubs savannah (natural control soil)	347.2	1.60	16.30	1.64	21.30	1.22	2.30	284.59
Basil + African nightshade	544.5	1.65	22.69	1.37	23.99	2.64	3.40	206.25
Tomato+ African nightshade	312.0	0.80	5.40	2.84	57.77	1.71	2.81	181.60
Tomato + African nightshade + Green beans	486.0	1.35	25.31	4.21	19.20	1.20	1.90	405.00

C_{org}: total organic carbon; N: available nitrogen, P: phosphorus; C_{mic}: microbial biomass C; N_{mic}: microbial biomass N.

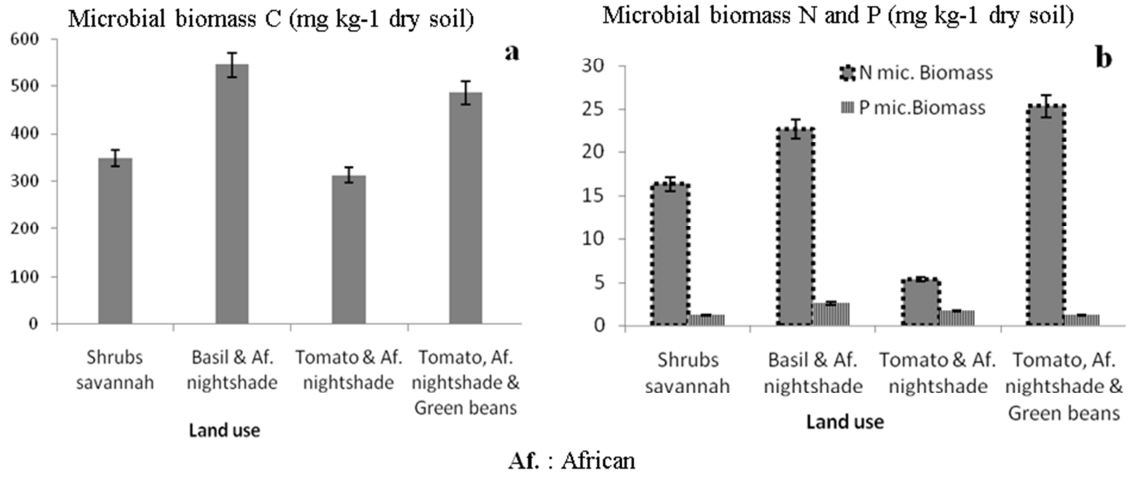
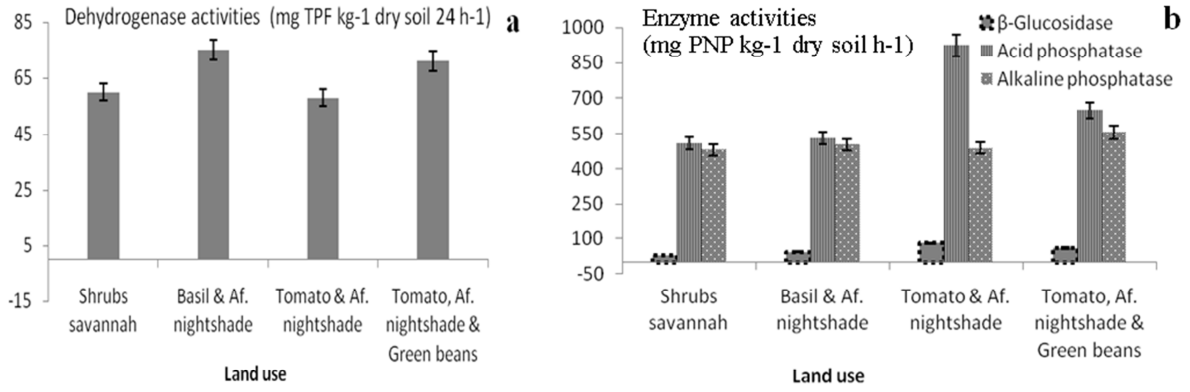


Figure 3: Impact of land use on microbial biomass C (**a**), N and P (**b**) (Average ± SD)



Af. : African

Figure 4: Impact of land use on dehydrogenases (TPF mg/kg dry soil /24 h) (**a**), β-glucosidase, acid and alkaline phosphatases (**b**) activities (Average ± SD)

Table 4: Coefficients of correlations and significance levels between microbial biomass and enzyme activities and physicochemical properties of soil

	C_{org}	N	C_{org}/N	P	C_{org}/P	EC	pH(H_2O)	% Clay	% Sand	% Silt
C_{mic}	0.151	0.698	-0.621	0.809	-0.351	-0.516	-0.073	-0.806	0.745	-0.282
C_{mic}/C_{org}	-0.694	0.879	-0.991**	0.247	-0.928	-0.990**	-0.830	-0.776	0.791	-0.727
N_{mic}	-0.178	0.607	-0.822	0.411	-0.470	-0.668	-0.306	-0.621	0.569	-0.193
N_{mic}/N	0.573	-0.691	0.366	-0.213	0.755	0.589	0.706	0.594	-0.669	0.947
C_{mic}/N_{mic}	0.565	-0.637	0.953*	-0.102	0.702	0.847	0.638	0.550	-0.536	0.363
P_{mic}	0.264	0.634	-0.090	0.891	-0.260	-0.208	0.008	-0.757	0.752	-0.587
P_{mic}/P	0.180	0.522	0.061	0.717	-0.238	-0.117	-0.035	-0.611	0.631	-0.624
C_{mic}/P_{mic}	-0.128	-0.130	-0.410	-0.290	0.023	-0.182	-0.034	0.167	-0.217	0.446
β-Glu	0.917	-0.736	0.903	0.085	0.962*	0.956*	0.976*	0.559	-0.608	0.756
Acid-P	0.751	-0.833	0.992**	-0.149	0.930	0.989*	0.862	0.710	-0.730	0.702
Alka-P	0.436	-0.115	-0.168	0.230	0.320	0.081	0.424	0.000	-0.093	0.570
DHase	0.185	0.673	-0.595	0.814	-0.316	-0.485	-0.036	-0.788	0.723	-0.250

*P ≤ 0,05 ; **P < 0,01.

C_{org}: total organic carbon, **N**: available nitrogen, **P**: phosphorus, **EC**: electrical conductivity, **C_{mic}**: microbial biomass C, **N_{mic}**: microbial biomass N; **β-Glu**: β-Glucosidase; **Acid-P**: acid phosphatase; **Alka-P**: alkaline phosphatase; **DHase**: dehydrogenases.

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