

## The Effect of Land Use on Soil Health Indicators in Peri-Urban Agriculture in the Humid Forest Zone of Southern Cameroon

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### ABSTRACT

The objective of this study was to identify the effect of different land uses in peri-urban agriculture on the soil properties. Soil health indicators were evaluated in the top 10 cm at five tilled agricultural sites involving different cropping systems and use of agrochemicals within the peri-urban agricultural areas of Yaounde, Cameroon, and compared with a native forest land. The experimental data showed that the selected indicators were sensitive to cropping practice. Most cropped land had significantly higher total C, available N and P concentrations, soil pH, electrical conductivity, salinity, biomass C and P, dehydrogenase,  $\beta$ -glucosidase, and acid phosphatase activities. Land producing corn (*Zea mays* L.) and sugarcane (*Saccharum officinarum* L.) differed from that producing tomatoes (*Lycopersicon esculentum* Mill.), but cultivation of these crops has significantly impacted native soil quality. However, phenol oxidase, microbial biomass C/organic C ( $C_{mic}/C_{org}$ ), and microbial biomass C/microbial biomass P ( $C_{mic}/P_{mic}$ ) were negatively affected. These appeared to be more consistent indicators of negative management causing changes to soil health and may be suitable for an early appraisal of soil health.

URBAN AND PERI-URBAN AGRICULTURE could alternatively serve to satisfy other requirements of the urban population (Smit et al., 1996). Nevertheless, the role that urban and peri-urban agriculture can play in improving livelihoods has been well documented and such intensive cultivation may indeed be the panacea for the urban food supply deficit found in many burgeoning Third World cities (Binns and Lynch, 1998). The use of agrochemicals has been the main option for increasing agricultural production in Africa. Fertilizers and pesticides are widely used by farmers in the forested zone of Cameroon, particularly in urban and peri-urban areas where the population density fuels the demand for food. The risks to soil health due to high input levels of fertilizers and pesticides in peri-urban agriculture must be recognized. The intensive use of agrochemicals may lead to soil degradation, residues of agrochemicals in crops or groundwater, and to negative effects on the health of agricultural workers, especially in intensive commercial horticulture, particularly in vegetable production (Fotio et al., 2004). Chemical fertilizers may gradually increase the acidity of the soil (Barak et al., 1998). Chemically

fertilized plots also exhibit less biological activity in the soil than do plots fertilized organically with manure or other biological sources (Raupp, 1997). Healthy soils are essential if the integrity of terrestrial ecosystems is to remain intact or to recover from disturbances such as drought, climate change, pest infestation, pollution, and human exploitation, including agriculture (Ellert et al., 1997). Protection of the soil is therefore a high priority and a thorough understanding of ecosystem processes is a critical factor in assuring that the soil remains healthy.

Since fertilizers and pesticides are being widely used by farmers in peri-urban agriculture in Yaounde, Cameroon, it is important to consider their possible impact on soil health. A unique balance of chemical, physical, and biological (including microbial) components contribute toward maintaining soil health. Hence, the evaluation of soil health requires indicators for all these components. Many indicators of soil health have been suggested, including microbial biomass (Smith and Paul, 1990; Larson and Pierce, 1994; Carter et al., 1999), potentially mineralizable N and soil enzymes (Doran and Parkin, 1994; Dick et al., 1996), and plant nutrients (O'Neil et al., 1977).

In our study we examine the effect of land use on soil health indicators in humid tropical forest zone peri-urban agriculture under contrasting management regime including cropping systems and agrochemical use practice, and determine the relationships between these indicators. For this a combination of physical, chemical, and biological soil properties were studied.

### MATERIALS AND METHODS

#### Soil

Soil subjected to six different land uses involving contrasting cropping systems and agricultural usage in four peri-urban agricultural sites of Yaounde in the humid forest zone of southern Cameroon were used in this study (Table 1): native forested land not cropped; cropped land in lettuce (*Lactuca sativa* L.) with fungicides and insecticides; cropped land in corn (*Zea mays* L.) with herbicides; cropped land in cocoa (*Theobroma cacao*) with fungicides and insecticides; cropped land in tomatoes (*Lycopersicon esculentum* Mill.) with fungicides, and cropped land in sugarcane (*Saccharum officinarum* L.) with herbicides. The sites are illustrated in Fig. 1. Minkoameyos, Nkolbisson, and Mvog Dzigui are the extension of Yaounde, and Mbandjock is a village about 122 km north from Yaounde, Cameroon. The climate in this region is of the equatorial type with two rainy seasons (March through June

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Published in J. Environ. Qual. 35:2402–2409 (2006).  
Technical Reports: Plant and Environment Interactions  
doi:10.2134/jeq2005.0447  
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**Abbreviations:** acid-PA, acid phosphatase; alk-PA, alkaline phosphatase;  $\beta$ -glu,  $\beta$ -glucosidase;  $C_{mic}$ , microbial biomass carbon;  $C_{org}$ , organic carbon; DHA, dehydrogenase; EC, electrical conductivity;  $N_{mic}$ , microbial biomass nitrogen; phenox, phenyl oxidase;  $P_{mic}$ , microbial biomass phosphorus; TDS, total dissolved salts.

**Table 1. Characteristics of the soils of the experimental sites.**

Parameter	Forested land	Lettuce	Sugar cane	Cocoa	Tomato	Corn
Textural class	sandy clay	clay	clay	sandy clay	clay loam	clay
Texture (%)						
Clay	39.4	52.6	46.3	36.6	38.5	41.6
Silt	13.1	17.4	14.2	16.0	17.1	14.4
Sand	47.5	30.0	39.5	47.5	44.5	44.0
pH						
Water	4.8	5.5	4.5	5.1	8.7	5.2
CaCl <sub>2</sub>	4.4	5.1	3.8	4.7	7.9	4.5
Conductivity (dS m <sup>-1</sup> )	0.05	0.10	0.05	0.07	0.16	0.04
Total dissolved salt (mg l <sup>-1</sup> )	29.0	52.3	24.1	36.0	81.0	19.0
Total C <sub>org</sub> (g kg <sup>-1</sup> soil)	14.0	28.6	19.3	26.4	21.1	16.3
Maximum water holding capacity (%)	36.3	33.5	39.3	38.5	40.8	33.4
Field capacity (m <sup>3</sup> water m <sup>-3</sup> soil)	0.3	0.4	0.4	0.3	0.3	0.3
Available water (m <sup>3</sup> water m <sup>-3</sup> soil)	0.1	0.1	0.1	0.1	0.1	0.1
Bulk density (kg m <sup>-3</sup> )	1300	1300	1300	1300	1300	1300
Origin	Minkoameyos, Cameroon	Nkolbisson, Cameroon	Mbandjock, Cameroon	Mvog Dzigui, Cameroon	Mvog Dzigui, Cameroon	Minkoameyos, Cameroon

and September through November) and two dry seasons (December through February and July through August). The mean annual rainfall amounts to 1800 mm and the mean temperature is 25°C. The soils which were collected at depths of 0 to 10 cm varied in soil pH (4.8 to 8.7), soil organic C (14.0 to 28.6 g C kg<sup>-1</sup> soil), clay content (36.6 to 52.6%), sand content (30.0 to 47.5%), and silt content (13.1 to 17.4%) (Table 1). Land management of these soils ranged from row vegetable production to permanent cocoa with varied agrochemical uses (Table 2). Sugarcane-, corn-, and cocoa-cropped land were selected from small- and large-scale industrial enterprises receiving fertilizer of N-P-K (20-10-10, 2 × 50 kg ha<sup>-1</sup>) and urea (4 × 50 kg ha<sup>-1</sup>) at split doses; whereas lettuce- and tomato-cropped lands were from family enterprises without any application of fertilizer, but they received compost manure. The size of each cropped land was 100 × 100 m<sup>2</sup>. The same crop was planted in adjacent lands. The distance between experimental plot and adjacent land was 2 m. The chosen plots had been cultivated with the same crops and the same agrochemical practices for more than 5 yr. A natural forested land, noncropped and without a history of any kind of agrochemical usage, was included to serve as control natural soil. Therefore, its comparison with cropped lands would measure the positive

or negative influences of land use on soil health attributes for each soil.

### Soil Sampling and Preparation

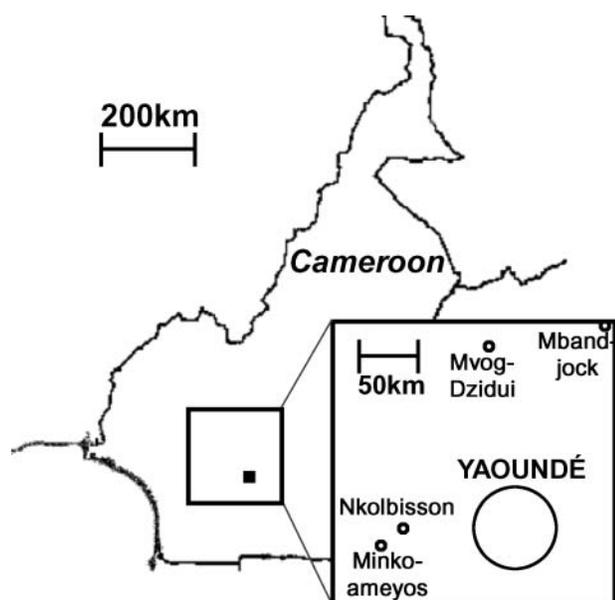
Ten separate soil cores for each of the three independent sets were taken at random from each site from the 0- to 10-cm depth using a soil tube. Each set of soil cores were subsequently bulked and homogeneously mixed. Subsamples for the determination of texture and organic C were air-dried, ground, and sieved (<0.25 mm). Subsamples for available N (NH<sub>4</sub><sup>+</sup>-N and NO<sub>3</sub><sup>-</sup>-N), available P, pH, electrical conductivity (EC), total dissolved salts or salinity (TDS), and enzymatic activities were kept field-moist, sieved (<0.5 mm), and stored at 4°C until needed. Subsamples for microbial biomass determinations were sieved (<2 mm), adjusted to 60% of the water holding capacity, and stored at 4°C before analysis. Each measurement was performed in triplicate. Following the above-mentioned methods, soil sampling was made twice within a 15-d interval and analyzed separately, each with 3 replications.

### Physical and Chemical Analyses

Particle-size analyses were done using the hydrometer method. The NH<sub>4</sub><sup>+</sup>-N and NO<sub>3</sub><sup>-</sup>-N were extracted in 2 M KCl (Soil and Plant Analysis Council, 2000) and quantified colorimetrically (Tan, 1996). Soil samples for available P were extracted with NaHCO<sub>3</sub> at pH 8.5 and analyzed spectrophotometrically at 880 nm (Olsen and Sommers, 1982). Soil pH and EC were measured with a glass electrode. Organic C was determined following the chromic acid method of Heanes (1984).

### Soil Microbial Biomass Carbon, Phosphorus, and Nitrogen Analyses

Soil microbial biomass C ( $C_{mic}$ ), N ( $N_{mic}$ ), and P ( $P_{mic}$ ) were measured following the fumigation-extraction methods described by Voroney et al. (1993) and Brookes et al. (1982, 1985), respectively. Total organic carbon (TOC) in soil extracts was determined by infrared spectrometry after combustion at 850°C (DIMA-TOC 100, Dimatec, Essen), and exchangeable NH<sub>4</sub><sup>+</sup>-N and NO<sub>3</sub><sup>-</sup>-N dissolved in the K<sub>2</sub>SO<sub>4</sub> extract were determined colorimetrically as described above. For  $P_{mic}$ , fumigated soil was analyzed as above with P-spiked control soil included in the procedure. Soil microbial biomass values were calculated according to the following formulae

**Fig. 1. A map of experimental sites.**

**Table 2. List of pesticides used on selected cropped land sites with rates as being applied.**

Location	Cropping systems†	Trade name	Active ingredients	Class‡	Application rates§
Mbandjock	sugarcane	Roundup	glyphosate [ <i>N</i> -(phosphonomethyl) glycine]	H	8 L 150 L <sup>-1</sup> w ha <sup>-1</sup>
		Certrol DS	ioxynil [4-hydroxy-3,5-diiodobenzonitrile] and 2, 4-D[2,4-dichloro phenoxyacetic acid]	H	1.5 L 150 L <sup>-1</sup> w ha <sup>-1</sup>
		Primextra Gold	atrazine[6-chloro-2-ethyl,4-isopropylamino, 1,3,5 s-triazine] and S-metolachlor[mixture of 80–100% (αRS, 1S) 2-chloro-6-ethyl-N-(2-methoxy-1-methylethyl)acet-O-toluidide]	H	3 L 150 L <sup>-1</sup> w ha <sup>-1</sup>
		Weed Hoe	MSMA[monosodium methyl arsonate]	H	3 L 150 L <sup>-1</sup> w ha <sup>-1</sup>
		Lasso Gold	alachlor[2-chloro-2, 6-diethyl-N-methoxy methyl acetanilide] and Atrazine[6-chloro-2-ethyl, 4-isopropylamino, 1,3,5 s-triazine]	H	6 L 150 L <sup>-1</sup> w ha <sup>-1</sup>
		Tazastomp 300	pendimethaline [ <i>N</i> -(1-ethylpropyl)-3,4-dimethyl-2, 6-dinitroaniline] and Atrazine[6-chloro-2-ethyl, 4-isopropylamino, 1,3,5 s-triazine]	H	6 L 150 L <sup>-1</sup> w ha <sup>-1</sup>
Nkolbisson	lettuce	Karmex	diuron[3-(3,4-dichlorophenyl)-1,1-dimethylurea]	H	0.64 kg 150 L <sup>-1</sup> w ha <sup>-1</sup>
		Velpar L	hexazinone[3-cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4(1H,3H)-dione]	H	0.64 kg 150 L <sup>-1</sup> w ha <sup>-1</sup>
		Decis 80 EC	deltamethrin [(S)- α-cyano-3-phenoxybenzyl (1R,3R)-3-(2,2-dibromovinyl)-2,2-dimethyl cyclopropane carboxylate]	I	40 mL 15 L <sup>-1</sup> w 126 m <sup>-2</sup>
Minkoameyos	corn	Ivory 80	mancozeb[manganese-zinc double salt of <i>N</i> , <i>N'</i> -ethylenebis dithiocarbamate]	F	40 mL 15 L <sup>-1</sup> w 126 m <sup>-2</sup>
		Plantineb 80 WP	maneb[manganese salt of <i>N</i> , <i>N'</i> -ethylenebis dithiocarbamate]	F	40 mL 15 L <sup>-1</sup> w 126 m <sup>-2</sup>
		Roundup	glyphosate[ <i>N</i> -(phosphonomethyl) glycine]	H	200 ml 15 L <sup>-1</sup> w 500 m <sup>-2</sup>
Mvog Dzigui	cocoa	Gramoxone Super	paraquat dichloride[1,1'-dimethyl-4, 4'-bipyridylum dichloride]	H	150 ml 15 L <sup>-1</sup> w 500 m <sup>-2</sup>
		Ridomil plus 72	metalaxyl[methyl <i>N</i> -(2-methoxyacetyl)- <i>N</i> -(2,6-xylyl)-DL-alaninate] and copper oxide	F	80 g 15 L <sup>-1</sup> w
		Nordox Super 75	cuprous oxide	F	40 ml 15 L <sup>-1</sup> w
Mvog Dzigui	tomato	Cyperdim 220 EC	cypermethrin[(RS)- α-cyano-3-phenoxybenzyl (1RS, 3RS; 1RS,3SR)-3-(2,2-dichlorovinyl)-2, 2-dimethylcyclopropanecarboxylate] and dimethoate[O,O-dimethyl-S-(2-methylamino-2-oxoethyl)dithiophosphate]	I	80 g 15 L <sup>-1</sup> w
		Penncozeb 80 WP	mancozeb[manganese-zinc double salt of <i>N</i> , <i>N'</i> -ethylenebis dithiocarbamate]	F	60 g 15 L <sup>-1</sup> w
		Plantineb	maneb[manganese salt of <i>N</i> , <i>N'</i> -ethylenebis dithiocarbamate]	F	60 g 15 L <sup>-1</sup> w
		Funguran	cupric hydroxide	F	60 g 15 L <sup>-1</sup> w

† Forested land used as natural control soil without any history of agricultural practices including pesticide application.

‡ H, herbicide; F, fungicide; I, insecticide; w, water.

§ Irrespective of recommended rate or frequency.

and converted to mg microbial biomass kg<sup>-1</sup> soil on an oven-dried basis:

$$C_{mic} = E_C/k_{EC} \quad [1]$$

$$N_{mic} = E_N/k_{EN} \quad [2]$$

$$P_{mic} = E_P/k_{EP} \quad [3]$$

where  $E_C$  = (TOC in fumigated samples- TOC in control samples),  $E_N$  = (NH<sub>4</sub><sup>+</sup> + NO<sub>3</sub><sup>-</sup>) in fumigated samples – (NH<sub>4</sub><sup>+</sup> + NO<sub>3</sub><sup>-</sup>) in control samples,  $E_P$  = P in fumigated samples – P in control samples,  $k_{EC}$  = 0.45 (Martens, 1995),  $k_{EN}$  = 0.54 (Brookes et al., 1985), and  $k_{EP}$  = 0.40 (Brookes et al., 1982).

### Enzyme Activity Analyses

Soil dehydrogenase (DHA) activity was estimated by reducing 2,3,5-triphenyl tetrazolium chloride(TTC) (Casida et al., 1964). Dehydrogenase enzymes convert TTC to 2,3,5-triphenylformazan (TPF). The absorbance of TPF was measured spectrophotometrically at 485 nm.

Following the method of Tabatabai and Bremmer (1969), Eivazi and Tabatabai (1977), and Eivazi and Tabatabai (1988), acid and alkaline phosphatases (acid-PA and alk-PA) and β-glucosidase (β-glu) were analyzed, respectively. The base substrate used was *P*-nitrophenol bound with phosphate or glucose

(Sigma-Aldrich Chemie GmbH, Munich, Germany). The artificial substrate (1 mL, 0.05 M), a pH buffer (pH = 6.5 for acid-PA, 11 for alk-PA, and 6.0 for β-glu), and 1-g moist samples were incubated in closed polypropylene centrifuge tubes at 37°C for 1 h. At the end of incubation, enzyme activity was stopped by addition of 4 mL of 0.5 M NaOH (PA) or 4 mL of 0.5 M THAM (β-glu) with 1 mL of 0.5 M CaCl<sub>2</sub>. The mixture was centrifuged and produced *P*-nitrophenol (PNP) in the filtrate which was determined spectrophotometrically at 410 nm.

Phenol oxidase (phenox) activity was measured following the method of Pind et al. (1994). The 1-g moist samples was mixed with 4.5 mL 10 mM L-DOPA (dihydroxyphenylalanine) aqueous solution. After incubation (1 h at 27°C), the mixture was filtered and released dihydroindole quinone carboxylate (diqc) which was measured spectrophotometrically at 400 nm.

All enzymatic activities were expressed on an oven-dried weight basis (drying the soil for 24 h at 105°C).

All statistical analysis were performed using the Statistical Graphics program, SYSTAT 11 for Windows of Systat Software. Simple correlation analysis was used to assess the relationships between biological parameters and various soil physicochemical properties.

## RESULTS AND DISCUSSION

For each measurement, data were generated for two soil samplings at 15-d intervals. Since the data generated

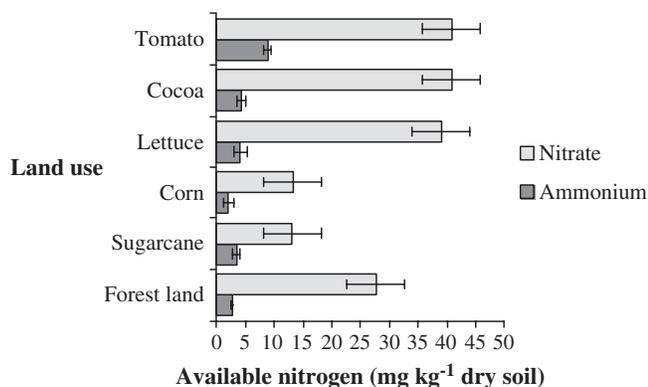


Fig. 2. Effect of land use on the available nitrogen content. Average  $\pm$  standard deviation (three independent samples); where absent, bars fall within symbols.

for the two samplings were of no or negligible difference, we consider the data of one sampling.

### Effect of Land Use on Soil Chemical and Physical Properties

All chemical and physical analyses revealed differences between the forested and cropped lands (Table 1). Land use significantly stimulated  $C_{org}$ , available N, available P, pH, EC, and TDS, as these parameters were significantly higher in all cropped lands than in the forested land (Table 1, Fig. 2 and 3), with the exception of cropped lands in sugarcane and in corn where values of available N, EC, and TDS were lower than those observed in the forested land. These cropped lands were large- and small-scale industrial enterprises, respectively, with higher and more frequent inputs of pesticides (Table 2). Their low values relative to other cropped lands may be due to the adverse effects of herbicides on soil microorganisms as shown in many research works (Fantroussi et al., 1999; Haney et al., 2002). The decline in EC and TDS could also be attributed to a reduction in biochemical cycling of nutrients due to herbicide applications (Naidu et al., 1996), as it has been evidenced in the present study with a low value of available N. Other cropped lands were family enterprises using composted domestic waste, crop

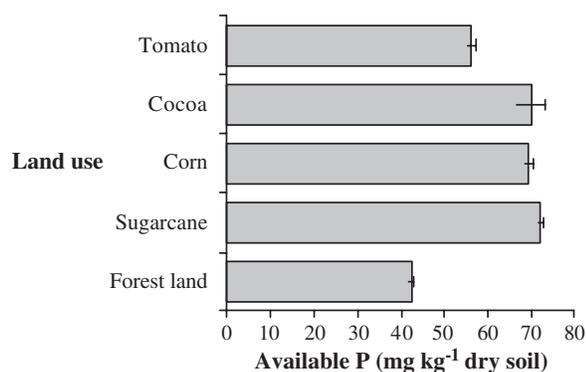


Fig. 3. Effect of land use on available P content. Value for cropped land in lettuce ( $1239.0 \pm 2.5 \text{ mg kg}^{-1} \text{ dry soil}$ ) is not plotted. Average  $\pm$  standard deviation (three independent samples); where absent, bars fall within symbols.

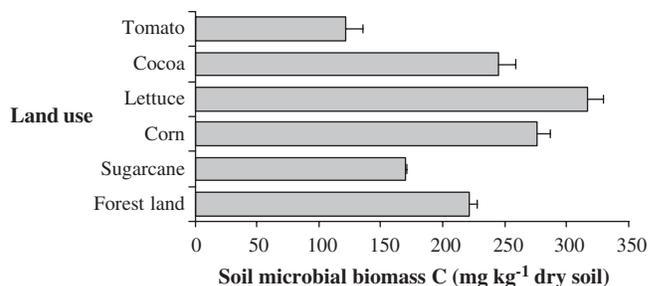


Fig. 4. Effect of land use on microbial biomass C. Average  $\pm$  standard deviation (three independent samples); where absent, bars fall within symbols.

residues, and animal dung in addition to pesticides (occasionally). These agricultural practices altered organic matter inputs and decomposition causing a net increase of carbon in soils (Table 1). Many other microbially mediated soil processes were stimulated as well. This was particularly evidenced in cropped land in lettuce which had the highest content of  $C_{org}$ , available P,  $C_{mic}$ ,  $P_{mic}$ , and acid phosphatase activity (Fig. 3 through 6), probably due to composted domestic waste, crop residues, and animal dung used in this site; which might cause a stimulation in microbial growth and in turn, nutrient enrichment in soil. Soil pH was significantly correlated with available N ( $r = 0.937$ ,  $p = 0.006$ ) and EC ( $r = 0.941$ ,  $p = 0.005$ ).

### Effect of Land Use on Soil Microbial Biomass

Although soil microorganisms constituting the microbial biomass do not represent a major fraction of the organic and inorganic nutrient pools in most ecosystems (Paul and Voroney, 1980), they are now recognized for their ability to carry out biochemical transformations of nutrients as well as for their importance as a source-sink for the major nutrient elements N, P, and S, as well as C (Paul and van Veen, 1978; Anderson and Domsch, 1980; Paul and Voroney, 1980). Positive and negative effects of pesticides on the growth and activities of microorganisms in soils have already been reported (Tu and Miles, 1976; El-Sahaat et al., 1987; Gianfreda et al., 1995; Sukul and Spitteller, 2001; Sukul, 2006). In the present investigation, different land uses represented in the peri-

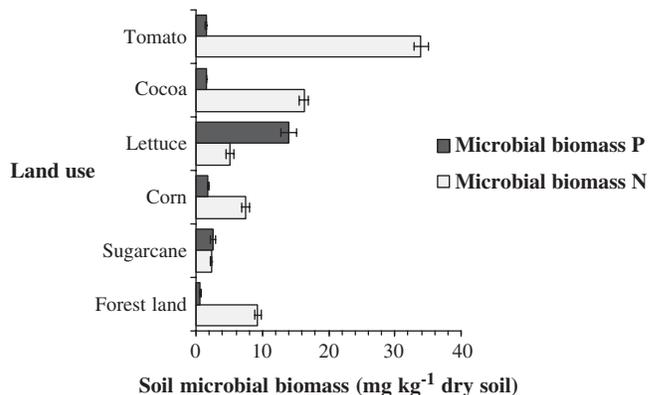
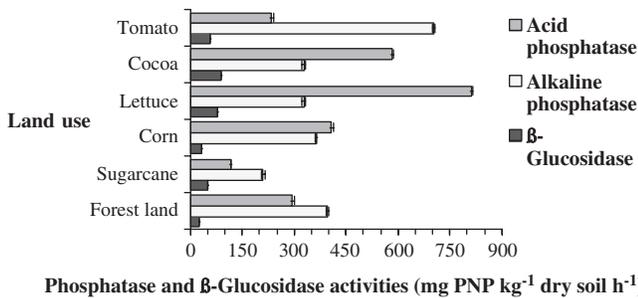


Fig. 5. Effect of land use on microbial biomass N and microbial biomass P. Average  $\pm$  standard deviation (three independent samples); where absent, bars fall within symbols.



**Fig. 6.** Effect of land use on soil phosphatases and  $\beta$ -glucosidase activities. Average  $\pm$  standard deviation (three independent samples); where absent, bars fall within symbols.

urban agricultural sites selected, which mainly differed in cropping systems and agrochemical use practices, also resulted in marked differences in  $C_{mic}$ ,  $N_{mic}$ , and  $P_{mic}$  among the forested and cropped lands. For these parameters, the precise relationships between cropped lands varied. The  $C_{mic}$  ranged from 125.5 to 317.5 mg kg<sup>-1</sup> (Fig. 4), which are values generally lower than those reported from other humid forest soil types (Arunachalam and Arunachalam, 2000), as the soils had lower levels of  $C_{org}$ , ranging from 14.02 to 28.61 mg kg<sup>-1</sup>. Relative to the forested land, cropped lands in tomato and sugarcane had lower  $C_{mic}$  (Fig. 4), and those in lettuce, corn, and sugarcane also had lower  $N_{mic}$  (Fig. 4). Cropped land in sugarcane had the lowest value of  $N_{mic}$  whereas cropped land in lettuce had the highest  $P_{mic}$  content. Land use could cause changes in soil C and N cycling rates and accumulation of organic matter (Chen and Stark, 2000). Significant correlation between  $C_{mic}$  and  $C_{org}$  has been reported (Chen and He, 2003). However, our findings revealed no such correlation. The  $C_{mic}/C_{org}$  ratio was lower, with the exception of cropped land in corn, in cropped lands than in the forested land (Table 3). Since this ratio is indicative of organic matter quality and availability, it suggests that the cultivation of these cropped lands resulted in a lower chemical diversity of organic matter input, and the microorganisms which are endowed with a more economic metabolism are disfavored with time (Anderson and Domsch, 1989). The ratio  $C_{mic}/C_{org}$  was significantly negatively correlated to  $NH_4^+-N$  ( $r = -0.826$ ,  $p = 0.043$ ) (Table 4). The  $N_{mic}$  and  $P_{mic}$  were also significantly affected by land use. Their values ranged from 2.3 to 33.9 mg kg<sup>-1</sup> and 0.6 to 14 mg kg<sup>-1</sup> (Fig. 5). Available N was also significantly influenced by land use (Fig. 2). The trend in the changes of available N was similar to that of  $N_{mic}$ . The correlation analysis showed significant relationships

between  $N_{mic}$  and  $NH_4^+-N$  ( $r = 0.887$ ,  $p = 0.018$ ), and between the ratio  $C_{mic}/N_{mic}$  and clay content and bulk density ( $r = 0.587$ ,  $p = 0.029$ , and  $r = -0.854$ ,  $p = 0.030$ , respectively) (Table 4). This might be due to exertion of a positive effect of clays on the formation and persistence of biomass (van Veen and Kuikman, 1990; Ladd et al., 1996). Significant correlation between  $N_{mic}$  and  $NH_4^+-N$  ( $r = 0.887$ ,  $p = 0.018$ ) could be explained by an essential contribution of N from microbial cell walls and cell contents to the organic N in soil. A similar phenomenon of a close relationship between  $N_{mic}$  and available N in soil was also demonstrated (Jenkinson and Ladd, 1981; Azam et al., 1989; Witt et al., 2000).

The  $P_{mic}$  was less affected by land use than  $C_{mic}$  and  $N_{mic}$  (Fig. 5). The  $P_{mic}$  ranged from 0.6 to 14 mg kg<sup>-1</sup>. Higher available P content in cropped land in lettuce led to the highest concentration of  $P_{mic}$  in this soil (Fig. 3 and 5). There was a wider range in  $C_{mic}/P_{mic}$  ratio than  $C_{mic}/N_{mic}$  (Table 3) mainly because there were lower contents of P inside soil microorganisms. The  $P_{mic}$  was significantly positively correlated with available P ( $r = 0.995$ ,  $p = 0.006$ ) and clay content ( $r = 0.867$ ,  $p = 0.025$ ) and negatively correlated with the sand content ( $r = -0.935$ ,  $p = 0.006$ ). The strong adsorption of P by variable-charged minerals has been reported (Chen et al., 2000).

### Effect of Land Use on Soil Enzyme Activities

Knowledge of the spectrum of enzymatic activities of a soil is important since it will indicate the potential of the soil to support the basic biochemical processes necessary for maintaining soil fertility. All enzyme activities measured were sensitive to changes in cropping management. This is consistent with reports that soil enzyme activities are very sensitive to both natural and anthropogenic disturbances and show a quick response to the induced changes (Dick, 1997). Relative to the forested land, DHA and  $\beta$ -glu activities were higher in all cropped lands (Fig. 6 and 7) whereas phenox activity was lower (Fig. 8). Cropped lands in lettuce and tomato had the highest acid-PA and alk-PA activities, respectively (Fig. 6).

Dehydrogenases are considered to play an essential role in the initial stages of the oxidation of soil organic matter by transferring hydrogen and electrons from substrates to acceptors (Ross, 1971). The highest DHA activity of agricultural soils was found in cropped land in tomatoes containing the highest amount of available N and high silt content. Differences in soil DHA activity

**Table 3.** Soil microbial biomass and its ratio to soil organic C, available N, and available P.

Land use	$C_{mic}^\dagger$ mg kg <sup>-1</sup>	$C_{mic}/C_{org}$ %	$N_{mic}$ mg kg <sup>-1</sup>	$N_{mic}/N_{available}$ %	$P_{mic}$ mg kg <sup>-1</sup>	$P_{mic}/P_{available}$ %	$C_{mic}/N_{mic}$	$C_{mic}/P_{mic}$
Forested land	222	1.58	9.3	30.7	0.6	1.42	23.8	367.2
Corn	276	1.69	7.5	49.3	1.8	2.56	36.8	155.3
Sugar cane	169	0.88	2.3	14.0	2.5	3.42	73.7	68.5
Lettuce	318	1.11	5.1	11.8	14.0	1.13	62.3	22.7
Cocoa	245	0.93	16.3	36.2	1.6	2.29	15.0	153.3
Tomato	122	0.57	33.9	68.3	1.5	2.63	3.6	82.1

$^\dagger C_{mic}$ , microbial biomass C;  $C_{org}$ , organic C;  $N_{mic}$ , microbial biomass N;  $N_{available}$ , available N;  $P_{mic}$ , microbial biomass P;  $P_{available}$ , available P.

**Table 4. Coefficients of correlation and *p* values between microbial biomass and enzyme activities and soil physical and chemical properties.†**

Parameter	$C_{mic}$	$N_{mic}$	$P_{mic}$	$C_{mic}/N_{mic}$	$C_{mic}/P_{mic}$	$C_{mic}/C_{org}$	$N_{mic}/N$	$P_{mic}/P$	DHA	Acid-PA	Alk-PA	$\beta$ -Glu	Phenox
$C_{org}$	0.492	0.141	0.674	-0.014	-0.609	-0.346	-0.100	-0.356	0.795	0.856*	0.019	0.888*	-0.756
C/N	0.306	-0.580	-0.027	0.546	-0.237	0.442	-0.152	0.466	-0.373	-0.110	-0.528	-0.320	-0.423
Ammonium	-0.634	0.887*	-0.017	-0.502	-0.395	-0.826*	0.569	0.144	0.779	-0.132	0.818*	0.385	0.208
Nitrate	0.007	0.610	0.312	-0.529	-0.137	-0.509	0.202	-0.512	0.733	0.528	0.507	0.695	-0.087
Available P	0.638	-0.316	0.995**	0.482	-0.493	-0.024	-0.533	-0.632	0.422	0.782	-0.188	0.457	-0.390
% Clay	0.463	-0.604	0.867*	0.857*	-0.554	0.032	-0.709	-0.252	0.131	0.393	-0.443	0.154	-0.284
% Sand	-0.437	0.420	-0.935**	-0.738	0.690	0.137	0.596	0.277	-0.370	-0.500	0.292	-0.341	0.370
% Silt	0.079	0.476	0.600	-0.129	-0.740	-0.639	0.163	-0.193	0.974**	0.565	0.410	0.785	-0.443
Bulk density	-0.416	0.568	-0.870*	-0.854*	0.602	0.052	0.711	0.217	-0.190	-0.382	0.430	-0.213	0.299
pH	-0.496	0.915*	-0.008	-0.612	-0.279	-0.585	0.727	-0.010	0.695	-0.056	0.947**	0.207	0.269
Conductivity	-0.403	0.804	0.239	-0.439	-0.405	-0.710	0.463	-0.143	0.816*	0.110	0.812*	0.419	0.179

\*  $P \leq 0.05$ ; \*\*  $P < 0.01$ .

† DHA, dehydrogenase; acid-PA, acid phosphatase; alk-PA, alkaline phosphatase;  $\beta$ -glu,  $\beta$ -glucosidase; phenox, phenol oxidase;  $C_{mic}$ , microbial biomass C;  $C_{org}$ , organic C;  $N_{mic}$ , microbial biomass N;  $P_{mic}$ , microbial biomass P.

between cropped lands could also be due to differences in soil textures (Table 1). The cropped land in tomatoes showed both high silt content and the highest DHA activity. The DHA activity was positively significantly correlated with soil silt content ( $r = 0.974$ ,  $p = 0.001$ ) and EC ( $r = 0.816$ ,  $p = 0.047$ ) (Table 4). Soil texture has been reported as a key determinant of microbial ecology (Stotzky, 1986) because soil texture affects other soil properties, such as water availability, nutrient supply (especially cations), and to some extent, pH values, which in turn determine microbial growth and activity (Stotzky, 1986; Ladd et al., 1996; Leirós et al., 2000). In the present study, DHA activity possessed no correlation with  $C_{org}$  and available N. This result agrees with that reported by Beyer et al. (1992). However, Leirós et al. (2000) reported a clear positive relationship between soil DHA activity and soil C. Probably, in our cropped lands soil microorganisms were nutrient- rather than C-limited, since DHA activity did not respond significantly to the variation of C contents or to the C/N ratio.

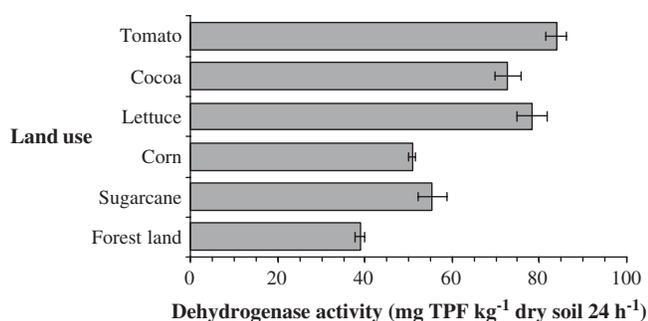
Soil phosphatase (PA) enzymes play an important role in the mineralization of soil organic P. Phosphatase enzyme activities are known to vary with soil chemical and physical properties and vegetation types, and they undergo seasonal variations. A negative relationship between soil PA and P fertility is recognized (Speir and Cowling, 1991). Our data showed that acid-PA and alk-PA activities were positively correlated to  $C_{mic}$  ( $r = 0.834$ ,  $p = 0.039$ ) (data not shown),  $C_{org}$  ( $r = 0.856$ ,  $p = 0.029$ ), and  $NH_4^+-N$  ( $r = 0.818$ ,  $p = 0.047$ ) (Table 4). The alk-PA activity was also positively correlated with

soil pH ( $r = 0.947$ ,  $p = 0.004$ ). A similar correlation has been reported in forested soils (Amador et al., 1997).

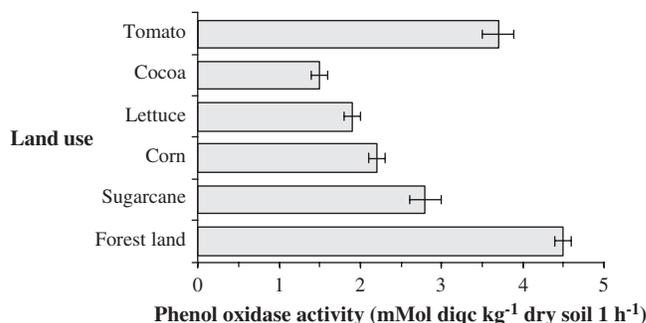
The  $\beta$ -glu activity is related to the carbon cycle and fulfils a central role in the cycling of organic matter. It is the most abundant of the enzymes involved in cellulose degradation, and is rarely substrate-limited (Turner et al., 2002). Similar to  $\beta$ -glu, phenox is associated with the carbon cycle and its presence in soil environments is important to the formation of humic substances (Matocha et al., 2004). Our data revealed a strong relationship between  $C_{org}$  and the activity of  $\beta$ -glu and a nonsignificant negative correlation between  $C_{org}$  and phenox activity in cropped lands (Table 4).

## CONCLUSIONS

Most enzymes were significantly activated to different degrees, which, however, varied with the type of cropping systems in the selected peri-urban agricultural areas, associated with different agricultural practices and soil physicochemical properties. Positive relationships between relevant soil properties and enzyme activities suggest that agricultural management practice increased microbial activity and/or diversity and C turnover, which subsequently led to greater enzyme synthesis and accumulation in the soil matrix. However, these agricultural practices had adverse effects on phenol oxidase activity,  $C_{mic}/C_{org}$  ratios, and  $C_{mic}/P_{mic}$ , often regardless of cropped land systems. They seemed to be more effective and consistent indicators of management-induced changes to soil health and are, therefore, suitable for an early appraisal of soil health.



**Fig. 7. Effect of land use on soil dehydrogenase activity. Average  $\pm$  standard deviation (three independent samples).**



**Fig. 8. Effect of land use on soil phenol oxidase activity. Average  $\pm$  standard deviation (three independent samples).**

## ACKNOWLEDGMENTS

We are thankful to the Alexander von Humboldt Foundation for a resumed period of research spent by the first author in Germany, under a Georg Forster Research Fellowship, and to the Gambinus Foundation of the University of Dortmund for an additional fellowship. The assistance of Marie-Claire Monkiedje of the Biyem-Assi high school of Yaounde, Cameroon in soil sample collection is gratefully acknowledged. We acknowledge the assistance from Dele Stülten and Jürgen Storp, University of Dortmund.

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