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Restoration of C content and earthworm population in a vertisol under pasture (Martinique)
Reconstitution des teneurs en carbone et de la population de vers de terre dans un vertisol sous prairie (Martinique)

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In Martinique (F.W.I), vertisols under intensive market gardening crops, are characterized by low carbon (C) content, and low earthworm densities. Conversely, under long-term pasture, C-content and earthworm densities are high. Interrelationships between organic matter and earthworms have often been studied. This study aims at knowing if there are temporal and spatial correlations between C-content dynamics and earthworm densities after pasture installation on a cultivated vertisol.
The experimental field (0.4 ha) was cultivated in market gardening from 1980 to 1990 and was turned into a fertilized, irrigated and grazed *Digitaria decumbens* pasture at the end of 1991. From 1992 (T0) to 1995 (T3), C-content and earthworm densities were measured each year at 96 sampling points (distance between two points was $\geq$ 1 m). A geostatistical analysis of the data was performed in order to determine the spatial structure of C-content and earthworm densities.
After three years of experiment, C-content increased from 14.6 mgC.g^{-1} soil (T0) to 17.4 mgC.g^{-1} soil (T3) on 0-30 cm. Geostatistical analysis showed an evolution of the C-content spatial structure and, an increase of the spatial microvariability ($\leq$ 3 m) of C-content with the pasture development in surface (0-10 cm). Recovery of earthworm population in soil (from 8 to 47 ind. m^{-2}) do not permit to reach the earthworm density which can be measured in old pastures (> 10 years), i. e. 186 ind. m^{-2}.
Despite an important increase of C-content and earthworm densities in three years of pasture, no spatial relation between these two phenomena has been observed.

Key words : humid tropics, vertisol, soil rehabilitation, pasture, soil organic carbon, endogeic earthworms, geostatistics, Martinique
Mots-clés : tropique humide, vertisol, réhabilitation du sol, prairie, carbone du sol, vers de terre endogés, géostatistique, Martinique

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Introduction

In soils, interactions between biological activities, physical properties and organic matter (OM) are generally dependent upon soil management. Land clearing and agriculture intensification deeply affect all those components as well as their relationships with each others. In the tropics, densities and biomasses of endogeic, geophagous earthworms and carbon (C) content are highly depleted after cultivation, while pastures tend to increase densities and biomasses of earthworms and C-content (Lavelle & Pashanasi, 1989 ; Cerri et al. 1991). Unfortunately, it is difficult to know if those modifications are direct (land use effects) or indirect (consequence of the C increase on earthworm density and vice-versa). In Martinique, vertisols under intensive market gardening are characterized by low densities of earthworms (2.5 ind.m^{-2}) and low C contents (11 mg C.g^{-1} soil, 0-10 cm), while pasture installation improves earthworm (*Polypheretima elongata*) population and C content (after 10 years, 186 ind.m^{-2}, and 30 mg C.g^{-1} soil, 0-10 cm) (Rossi et al., 1997 ; Albrecht et al. 1992). A laboratory experiment showed that the growth of *P. elongata* depends on the soil C content : the highest the C content, the most rapid the growth of earthworms. This field study aims at understanding better the interactions between soil organic C and earthworm population and at seeing particularly if the restoration of *P. elongata* population is spatially and temporally linked to an increase of C-content.

A 10 years old cropping field plot was converted to a *Digitaria decumbens* pasture to test the performance of that pasture in enhancing soil organic status and stimulating the development of earthworms. This study reports on the first three years of *D. decumbens* growth and it focuses on the relationship between the colonization of soil by earthworms and the dynamics of the restoration of soil organic matter. Experimental design enabled geostatistics to be applied.

MATERIALS AND METHODS

Site and soil characteristics

The field experiment is located in the Southeastern part of Martinique (French West Indies). The area is characterized by a tropical humid climate with a marked dry season (4-6 months); mean temperature is stable (26-28°C) all over the year, mean annual rainfall is 1400 mm; precipitations are concentrated from July to December. The soil is a magneso-sodic vertisol developed on andesite (Ca exchangeable : 50 % of the sum of cations, Mg exch. : 35 %, Na exch. : 15%). Soil depth in the plot varies from 0.4 to 1 m (mean : 0.8 m). Soil texture is relatively homogeneous, clay plus fine silt (0-20 µm) represent 70% in the upper 10 cm of soil.

Experimental design

Dimensions of the experimental field are 77 x 53 m (0.4 ha). The plot was cultivated in market gardening (melon, yam, tomato) for ten years, and it was turned into a *Digitaria decumbens* pasture at the end of 1991. Pasture installation was achieved by cuttings, space between two cuttings was 0.75 m to 1 m. The pasture was fertilized (100 kg $N.ha^{-1}.year^{-1}$) and irrigated (water amount of rain plus irrigation were about 120 $mm.month^{-1}$). It was regularly grazed by sheep (7 days in, 28 days out). At the beginning of 1992, 96 sampling points were chosen at random among the nodes of a square grid with a 1 m spacing. From 1992 (T0) to 1995 (T3), C-contents were measured at each sampling location for 0-10, 10-20, and 20-30 cm soil layers.

Soil analyses and earthworm sampling

Organic carbon and nitrogen contents were measured using a Carbon Nitrogen Sulfur Analyser NA 1500 (Carlo Erba Instruments). Earthworms were hand-sorted from 30x30x30 cm monoliths at each sampling location and at each date (from T0 to T3).

Geostatistical analyses

A geostatiscal analysis of the data was performed in order to determine the spatial structure of C-content and earthworm densities and in order to map their variation within the study plot at times T0 to T3. A description of the method can be found in Journel & Huijbregts (1978) and in Webster & Oliver (1990) for application to soil variables, and in Rossi et al. (1995) for application to biological variables.
We used the GEOEAS software (Englund & Sparks, 1988) for computing and fitting the experimental variograms, and for kriging the isarithmic maps.

RESULTS

C-content

C-content increased with time and this increase was slightly more important for the upper 10 cm of soil (+3,4 $mgC.g^{-1}$ soil, +121 % increase) than between 20 and 30 cm depth (+2,4 $mgC.g^{-1}$ soil, +119 % increase) after 3 years (Table 1). C-content standard deviation increased with time, particularly at T3, for the upper 20 cm of soil (Fig. 1). At 20-30 cm depth, C-content standard deviation was higher at T2 than T3 ; which was due to very small values of C-content at a few sampling points.

Table 1 : C-content (mg C.g^{-1} soil) at each date and depth (means and s.d., n=96).

Date	Depth					
	0-10 cm		10-20 cm		20-30 cm	
	m	*s*	*m*	*s*	*m*	*s*
T0	16.3a	2.6	14.8a	2.6	12.9a	4.2
T1	16.3a	3.8	14.3a	1.7	13.2a	3.8
T2	17.1b	3.3	14.2a	2.5	12.9a	6.1
T3	19.7c	7.8	17.4b	5.1	15.3b	4.1

m : means ; *s* : standard deviation. Values in the same column followed by the same letter are not significantly different at P< 0.05 according to Fischer's least significant difference mean separation test.

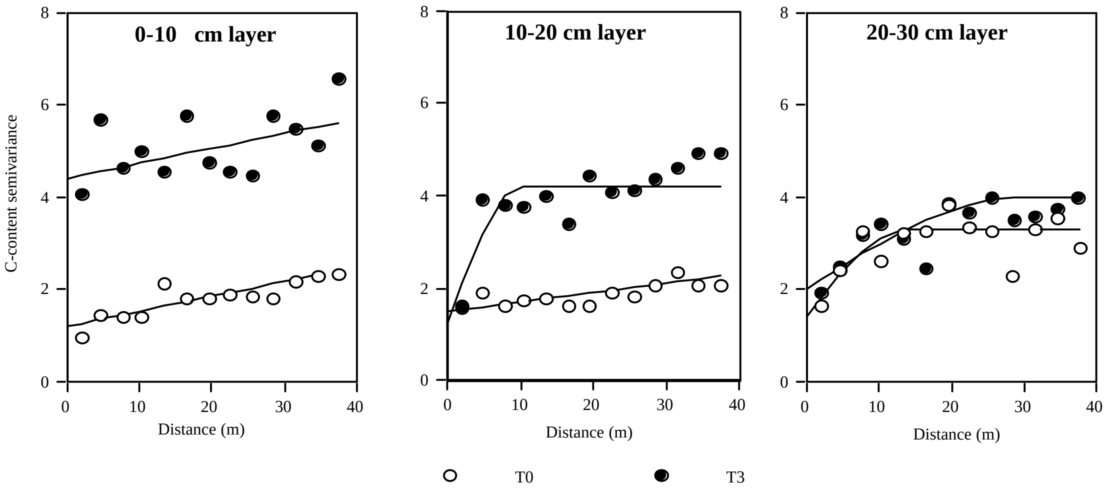

Figure 1 : C-content semi-variograms for each depth at T0 and T3.

C-contents were spatially structured irrespective of time and depth. Since differences in spatial structure between T0, T1 and T2 were small, the results only described the spatial structure of C-contents at T0 and T3 (Fig.1).

0-10 cm layer : The theoretical variogram model which best fitted to the empirical variograms was of linear type at T0 and T3. The nugget variance considerably increased from T0 to T3. Since the slope of the linear model remained almost the same between T0 and T3, it could be infered that the increase in variance of C-content from T0 to T3 mainly arose from an increase of the microvariations at a scale smaller than 1 m. Consequently, at T0 almost 50% of the variation in C-content was observed at lags longer than 1 m, whereas at T3 that proportion decreased to approximately 35%.

10-20 cm layer : In this layer the fitted models of variogram was of linear type at T0 and of spherical type at T3. Similarly to the 0-10 cm layer, the 10-20 layer exhibited a big increase in total variance between T0 and T3. However nugget variances are almost similar for T0 and T3, it still arose from an increase in variance at small lags between 3 and 6 m.

20-30 cm layer : At T0 and T3 the fitted variograms were of spherical type. In contrast to the upper layers, there was only a slight increase in total variance for T0 and T3. Furthermore, the estimated values of the nugget variance at T0 and T3 can be considered as being equivalent. Consequently, changes in the spatial structure of C-content in the 20-30 cm layer appeared very moderate.

Earthworm densities

The earthworm population essentially consisted of *Polypheretima elongata* (Megascolecidae) a geophagous tropical earthworm. At T0, earthworm density was very low (8.4 individual.m^{-2}). After a slight increase at T1, the density decreased at T2 and finally at T3 the density increased to 47 ind.m^{-2}. Note that small individuals and cocoons greatly contribute to the density increase (Table 2). The low densities at T0, T1 and T2 were not spatially structured. At T3, the fitted variogram was of linear type (Fig. 2).

Table 2 : Means (m) and standard deviations (s) of earthworm densities

Date	Earthworm densities							
	all individuals		large individuals		small individuals		Cocoon (*P.elongata*)	
	m	*s*	*m*	*s*	*m*	*s*	*m*	*s*
T0	8.4	13.4	5.1	7.6	2.2	10.2	1.1	4.3
T1	24.1	26.9	6.6	11.9	13.5	19.0	4.0	8.6
T2	11.3	16.4	3.5	7.6	5.3	10.5	2.5	5.7
T3	47.1	65.4	6.6	11.3	34.0	64.3	6.5	11.1

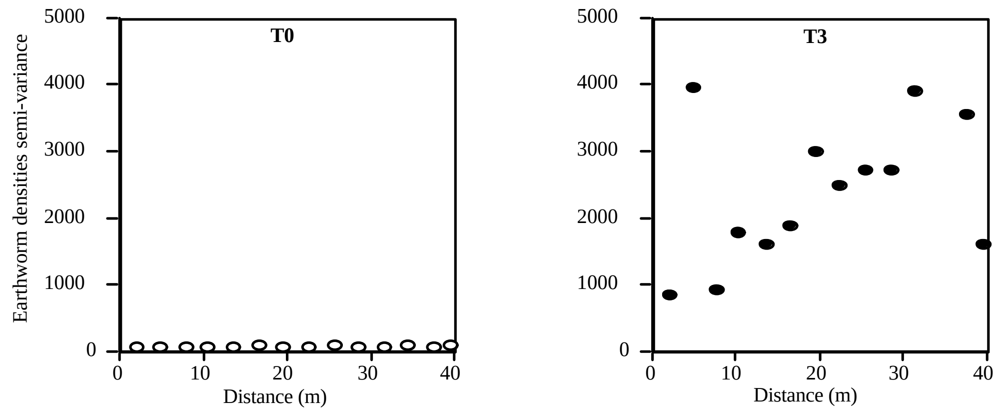

Figure 2 : Earthworm densities semi-variograms at T0 and T3

Correlation analyses

There is no significant correlation ($P < 0.05$) between C-content (0-30 cm) and earthworm densities (0-30 cm) at T0 ($r = 0.14$), T1 ($r = -0.10$), T2 ($r = 0.31$, $P = 0.1$) and T3 ($r = 0.14$).

DISCUSSION

C-contents

Pasture development on a cultivated soil led to an increase in C-content (from 14.6 to 17.4 mg C.g-1 soil at 0-30 cm into three years). Due to the clayey nature of vertisol the C-storage (9 tC.ha^{-1} in three years) is ranged among the highest values of C-storage data from literature. Temporal change in the spatial structure of C-content was significant only at T3. An increase of the microvariability of C-content (0-10 cm) was measured. The temporal evolution of spatial structure of C-content is mainly influenced by vegetation dynamics (Gonzalez & Zak, 1994).We can infer that microvariability is due to the heterogeneity of the plant cover. *D. decumbens* has a tuft habit indeed.

Earthworm densities

At T0, there is a relictual earthworm population around 8.4 ind.m^{-2}. That value is a little higher than the value of 2.5 ind.m^{-2} in vertisol under market gardening (Martinique) as measured by Rossi (1992). In both sites, the relictual population is not spatially structured. The increase of earthworm density is not continuous with time because after an increase at T1, there is a decrease at T2. That decrease may be explained by different moisture conditions between T2, T1 and T3. Despite the density increase at T3 (47 ind. m^{-2}) the population has not reached the earthworm density which can be measured in old pastures (> 7 years), i.e. 186 ind. m^{-2}. Two hypotheses on the dynamic settlement of soil by earthworms can be considered :

(1) The relictual population may be responsible for the settlement. The relative importance of cocoons and the central spot of high earthworm density on the kriged map (Fig. 3) confirm that hypothesis.

(2) External populations of the field experiment may be responsible for the settlement. The spatial pattern of earthworm population at T3 (Fig.3) showed strips of high density on the limit of the field and the density increases were essentially due to small individuals. Although endogeic tropical earthworms are described as animals which have limited spreading capacities (Lavelle et al. 1992), Rossi (1992) underlined that juvenile earthworms, in comparison to adults, may be able to do it. Furthermore, Tamis & Udo de Haes (1995) described an immigration from the earthworm-rich surroundings into the defaunated plot and found a high proportion of juveniles in earthworm population. Our observations give some proves to the immigration hypothesis.

As a conclusion relictual population and immigration may be both responsible for the settlement.

C-contents and earthworm densities

The increase in earthworm density and in C-content appeared at the same year (T3). Nevertheless, at T3, C-content and earthworm density were not correlated. The comparison between earthworm and C-content maps shows that earthworm settlement and C-storage had not the same spatial structure (Fig. 3 and 4). In a 10-years old pasture Rossi et al. (1997) came to the same conclusions : earthworm density and C-content were not spatially correlated. Those authors concluded that C-content was high enough and was not a limiting factor in earthworm development in pasture soil. Earthworm distribution in a pasture was then explained by intrisic properties of earthworm population dynamics. Tamis & Udo de Haes (1995) described a positif role of organic matter amendment in the recovery of earthworm population in cleaned soils. In our study, even for lower soil C-content, there was no spatial relation between C-content and earthworm density at the field scale. Nevertheless a laboratory experiment showed a better earthworm (*P. elongata*) growth in high C-content soil than in low C-content soil (Blanchart et al. in preparation). Then the small size of those animals within the three years old pasture can reveal an organic stock influence on the earthworm development. More than spatial distribution of OM quantities, spatial distribution of OM qualities might explain the spatial pattern of earthworm densities. Martin et al. (1992) showed that *M. anomala* preferably feed on coarse organic debris and Mariani (1996) found a correlation ($P = 0.034$) between *P. elongata* densities and coarse organic debris (> 500 µm) in vertisols; in that study there was no correlation between *P. elongata* densities and total C-content ($P=0.1$). Thus it would be interesting to study spatial distributions of coarse organic debris and earthworms. Furthermore, the absence of spatial correlation may be due to the high C-content microvariability. That high microvariability may obliterate correlation structures at smaller scale. A more detailled geostatistic study could attenuate that microvariability problem by filtering the nugget effect (Goovaerts & Webster, 1994).

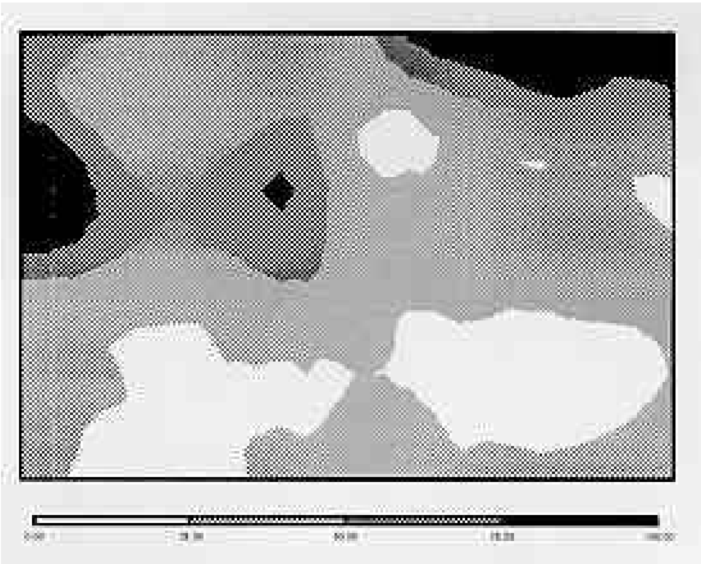

Figure 3 : Kriged map of earthworm densities (ind.m^{-2}) at T3 (0-30 cm)

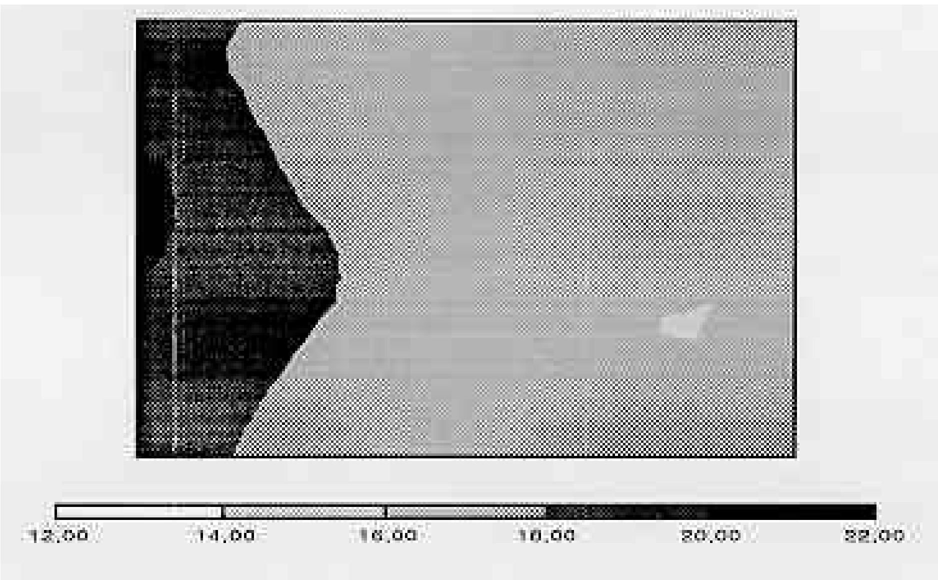

Figure 4 : Kriged map of C content (mg $C.g^{-1}$ soil) at T3 (0-30 cm)

Conclusion

After 3 years of pasture, the C stock increase was 9 $tC.ha^{-1}$ for 0-30 cm. The fast and intense increase of C-content seems essentially linked to the Digitgrass dynamics. The

very clayey nature and the high plant inputs, following on intensive pasture management partly explain the high value of C stock compared with litterature results. Nevertheless, the OM quality, labile or stable, has not been characterized. After 3 years, earthworm density did not reach the density observed under a long term pasture. The significant increase of earthworm density at T3 was temporally linked to a significant increase of C-content. However, there was no spatial correlation between C-content and earthworm density.

Key words : humid tropics, vertisol, soil rehabilitation, pasture, soil organic carbon, endogeic earthworms, geostatistics, Martinique
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