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Spatial and temporal changes of soil C after establishment of a pasture on a long-term cultivated vertisol (Martinique)

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Abstract

In 1991 in Martinique (F.W.I), a *Digitaria decumbens* pasture was established on a vertisol that had supported a market-gardening culture for more than 10 years. Organic matter stock restoration was investigated by measuring carbon contents (C contents) and carbon/nitrogen (C/N) ratios each year from 1992 to 1997. Relations between and soil properties (particle-size distribution, soil depth) and C contents were studied. Furthermore, geostatistical analyses of C contents were realised in order to characterise the C storage in soil at plot scale. The increase of C contents from 1992 (Y_0) to 1997 (Y_5) was 5 g C (kg soil)$^{-1}$ in the topsoil (0–10 cm) and 2.5 g C kg soil^{-1}, or 7.5 Mg C ha^{-1}, in the 0–30-cm layer. The intensity of organic C storage had a spatial pattern, although the C/N ratio remained homogeneous across the plot. However, there was no correlation between the C increase and the particle-size distribution or the depth of the soil. In the topsoil, the local variability of the C contents increased with time until 1995 and then there was a gradually spreading of this local variability. Plant-cover distribution and physical

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structure of vertisol could explain the evolution of spatial structure of the soil C content.

Keywords: vertisol; organic carbon; organic matter restoration; C/N; geostatistics; pasture; *Digitaria decumbens*

1. Introduction

Restoration of soil properties to sustain food production is a worldwide task. Impacts of land management on soil properties have been widely documented (Wood et al., 1991; Angers, 1992; Beare et al., 1994) and soil organic matter (OM) is recognised to be one of the most affected soil features by long period of continuous cropping (e.g., Feller et al., 1996). For example, in the French West Indies, several years of intensive farming led to an important decrease in soil OM content on vertisols (Albrecht et al., 1992a). There is now a need to restore the soil organic status of the vertisols in order to limit erosion processes (Albrecht et al., 1992b).

In general, the most common means used to enhance soil OM are organic inputs (cattle manure, residues...) or periods of fallow or pasture (Choné et al., 1991; Angers, 1992; Jastrow, 1996). However, under a tropical climate the efficiency of these two means is not the same. On one hand, Brossard et al. (1985) showed that organic inputs do not increase OM content of a vertisol on a long term since the inputs are completely mineralised within few years. And on the other hand Cerri et al. (1991) demonstrated that pasture limited soil organic carbon (C) decrease after deforestation of the Amazon rain forest, and even restored soil OM content to its initial level (observed before forest clearance) after eight years of pasture (*Brachiaria humidicola*). Similarly, Dalal et al. (1995) showed an increase in soil C concentration by 20% under grass and legume leys on vertisol in eastern Australia. The positive influence of pasture can also been assumed for soils in the West Indies. A survey undertaken by Albrecht et al. (1992a) in Martinique indicated that the organic status of clayey soils is at least twice greater under pasture than under food crops. Nevertheless, the mechanisms of the increase in organic carbon content after re-establishing pasture are still poorly understood. So far, many authors (Angers, 1992; Jastrow, 1996; Staben et al., 1997) analysed the relationship between soil aggregate formation or C mineralisation and concomitant accrual of soil OM to explain the mechanism and the origin of C storage in a re-grassed soil: they concluded that the formation of stable aggregates precedes the increase of soil OM content. This can be explained by the fact that stable aggregates protect OM against mineralisation (Gupta and Germida, 1988; Beare et al., 1994) and then allow OM storage in the soil. These studies explained how C storage increases at the aggregate scale but did not examine how it varies at the field scale in relation with soil properties. The analysis at the field scale is however essential for predicting and interpreting the evolution of the soil organic status at a scale at which agricultural management is reasoned and performed. In this paper we study the spatio-temporal evolution of C content and C/N ratio at the field scale on a vertisol in Martinique (FWI), during 6 years after re-grassing a cultivated plot with *Digitaria decumbens*. The main objectives were (i) to determine the patterns and changes in the spatial distribution of C content with the development of the pasture, and (ii) to relate these patterns to the variability of soil properties at the plot scale.

2. Materials and methods

2.1. Site and soil characteristics

The experimental plot, 0.4 ha large, is located in the southeastern part of Martinique, French West Indies (14°25′N/60°53′W) (Fig. 1). The area is characterised by a humid tropical climate. The mean daily temperature is stable (26°C–28°C) over the year, and rainfall mainly occurs from July to December with a mean annual value of 1400 mm. The soil (20-m elevation with a 5% slope) is classified as smectitic Leptic Hapludert (USDA classification; Soil Survey Staff, 1975) or Eutric Vertisol (FAO-UNESCO-ISRIC, 1988) developed on andesite. The clay mineralogy is dominated by smectites. Cation exchange

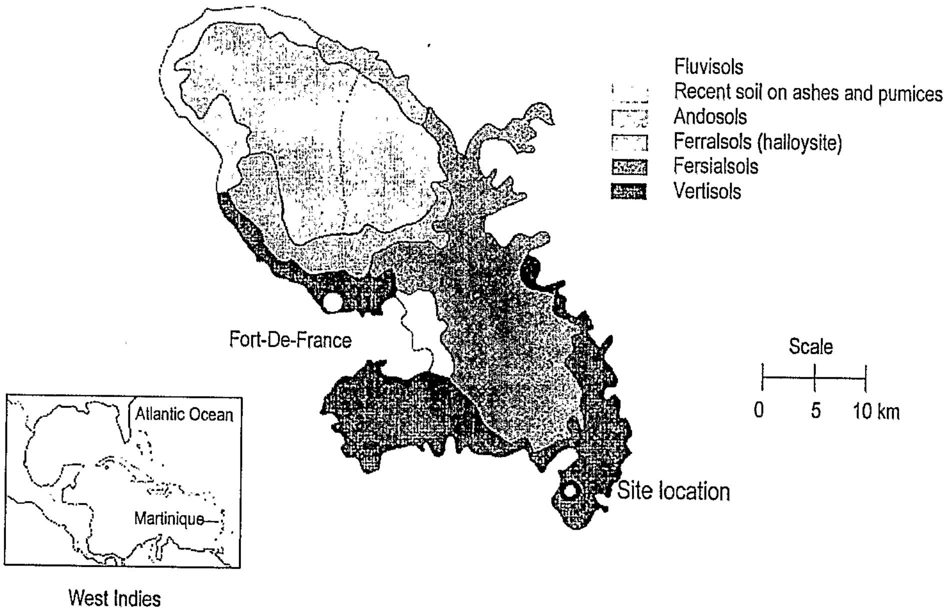

Fig. 1. Study site location.

capacity (CEC) values range from 35 to 40 cmol (+) kg^{-1} (exchangeable Ca: 55%, exchangeable Mg: 32.5%, exchangeable Na: 10% and exchangeable K: 2.5% of the CEC). The pH varies from 6 to 6.5 across the area. The bulk density is about 1.0 Mg m^{-3}. The plot was cultivated for market gardening (melon, yam and tomato) for at least 10 years, and was turned into a *D. decumbens* pasture at the end of 1991. Pasture establishment was achieved by cuttings separated from each other by 0.75 to 1 m. The pasture was fertilised (100 kg N ha^{-1} year^{-1}) and irrigated (water amount of rain plus irrigation was about 120 mm month^{-1}). Sheep (7 days in 35) regularly grazed it.

2.2. Experimental design

At the beginning of 1992, 96 sampling points were chosen at random among the nodes of a square grid with a 1-m spacing (Fig. 2). In 1992 (year Y_0), at all sampling points soil depth down to the bedrock was observed and texture was measured for the 0–10, 10–20 and 20–30-cm layers. From 1992 to 1997, which are referred after as years Y_0 to Y_5, C and N contents were measured once a year in January at the same sampling points and layers.

2.3. Soil analyses

Organic carbon and nitrogen contents were measured using a Nitrogen Carbon Sulphur Analyser NA 1500 (Carlo Erba Instruments). After soil OM destruction and complete soil dispersion, the soil texture was determined by laser granulometer (Mastersizer E, Malvern).

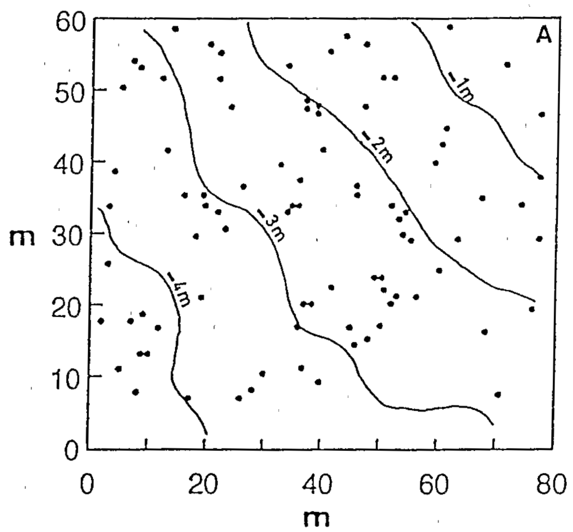

Fig. 2. Experimental design: altitude contours of the study plot (0.4 ha) and location of the 96 sampling points. *A* is the base point from which the altitude contours were calculated.

2.4. Geostatistical analyses

A geostatistical analysis of the data was performed for determining the spatial structure of soil texture, soil depth down to the bedrock and soil C content within the study plot. We used the GEOEAS software (Englund and Sparks, 1988) for computing and fitting the experimental variograms. The two following theoretical variogram models were found to fit satisfactorily the experimental variograms:

The pure nugget model,

$$\gamma(h) = c_0, \qquad \text{for } |h| > 0,$$
$$\gamma(0) = 0.$$

in which c_0 is the nugget variance. The pure nugget model indicates no spatial variability over the sampling area.

The spherical model,

$$\gamma(h) = c_0 + c\left\{\frac{3|h|}{2r} - \frac{1}{2}\left(\frac{|h|}{r}\right)^3\right\} \qquad \text{for } 0 < |h| \le r,$$
$$\gamma(h) = c_0 + c \qquad \text{for } |h| > r.$$
$$\gamma(0) = 0,$$

in which c is the sill and r is the range.

3. Results and discussion

3.1. Spatial variation of physical soil properties

Soil depth in the plot varied from 0.3 m, in the top area of the plot, to 1.4 m in the bottom area (Table 1). Soil texture was similar in the three top layers and only varied slightly laterally as is indicated by the small-observed standard deviations of all particle size classes. It must be noticed that clay plus fine silt represents 70% of total particle mass, which is characteristic of this vertisol.

3.2. Temporal evolution of the field average C content and C/N ratio

A significant increase in C content could be observed in the three soil layers from Y_0 to Y_5 (Table 2). *D. decumbens* pasture development on a cultivated soil led to an increase in C content which was statistically significant only after 3 years of pasture development (e.g., Talineau et al., 1980; Angers, 1992; Dalal et al., 1995). However, the rate of increase differed largely between the years and

Table 1
Soil depth down to the bedrock and particle-size distribution of the soil (mean, *m*, and standard deviation, *s*) ($n = 96$)

Soil depth (cm) down		Soil texture (100 g kg^{-1})														
to the bed rock		Depth	0–2 μm		2–20 μm		0–20 μm		20–50 μm		50–200 μm		> 200 μm	
m	*s*		*m*	*s*	*m*	*s*	*m*	*s*	*m*	*s*	*m*	*s*	*m*	*s*
77.4	24.5	0–10 cm	56.3	4.1	13.9	2.8	70.2	3	4.5	1	11.2	1.6	5.1	2
		10–20 cm	54.9	4.2	15.5	3.4	70.4	3.1	4.6	1.7	10.6	1.8	10.6	1.5
		20–30 cm	56.5	4.6	15.4	3.2	70.4	11.1	5.0	1.5	10.7	2.4	3.1	1.6

Table 2

Temporal evolution of C contents (g C (kg soil)$^{-1}$) and C/N ratios — mean, *m*, and standard deviation, *s* — for each soil layer ($n = 96$)

In a same column, two values followed by the same letter are not significantly different ($p = 0.05$).

Date	Soil layers											
	0–10 cm				10–20 cm				20–30 cm			
	C contents		C/N ratios		C contents		C/N ratios		C contents		C/N ratios	
	m	*s*	*m*	*s*	*m*	*s*	*m*	*s*	*m*	*s*	*m*	*s*
Y_0 (1992)	16.1a	1.6	10.4	0.8	14.9a	1.6	10.0	0.5	12.9a	2.0	9.8	0.6
Y_1	16.3a	1.9	10.3	0.5	14.3b	1.3	9.7	0.4	13.2a	1.9	8.7	0.7
Y_2	17.1b	1.8	10.2	0.7	14.2b	1.6	9.8	0.4	12.8a	2.4	9.4	0.6
Y_3	19.7c	2.8	11.1	0.6	17.4c	2.2	10.5	0.6	15.3b	2.0	10.2	0.7
Y_4	20.9d	3.8	12.1	1.0	16.4d	2.3	11.1	0.8	14.6c	2.2	10.7	1.0
Y_5 (1997)	20.8d	3.8	12.9	1.7	16.0d	2.7	11.9	1.6	14.1c	1.9	10.5	0.8

Table 3
Literature data on C stocks under re-grassed soils
Sa: C stocks quoted by the authors.
Se: Annual C storage indices.
Se′: Annual C storage indices per cm of soil.

Sites	Authors	Sa (Mg C ha^{-1})	Duration (years)	Depth (cm)	Se (Mg C ha^{-1} yr^{-1})	Se′ (MgC ha^{-1} cm^{-1} yr^{-1})
Martinique vertisols	this study	5	5	0–10	1	0.1
		1	5	10–20	0.2	0.02
		1	5	20–30	0.2	0.02
Tropical sites						
Ivory Coast sandy–clay ferallitic soil	Talineau et al. (1980)	2.4–4.2	2	0–25	1.2–2.1	0.05–0.08
Ivory Coast ferallitic soils	Picard (1976)	–	1	0–25	3–7	0.1–0.3
Mexico entisols	Garcia-Oliva et al. (1994)	2.3	3	0–6	0.8	0.1
Brazil oxisols (sandy–clayey soils	Desjardins et al. (1993)	12.5	10	0–20	1.3	0.06
Brazil oxisols (clayey soils)	Choné et al. (1991)	14	2	0–20	7	0.3
		45.8	8	0–20	5.7	0.3
Australia vertisols (clayey soils)	Dalal et al. (1995)	–	4	0–30	0.6	0.02
Temperate sites						
USA, Colorado (mean of several sites)	Wood et al. (1991)	0.8	4	0–5	0.2	0.04
Québec (clayey soils)	Angers (1992)	5–6	3	5–15	2.5–3	0.3
USA, Illinois fine–silty, mixed, mesic aquic Argiudoll	Jastrow (1996)	–	–	0–10	1.3	0.1

between the layers. In the top layer, the increase was statistically significant after two years of pasture, whereas it was significant only after three years in the other two layers. Moreover, the magnitude of the increase in C content over the five monitoring years decreased with depth from 30% at 0–10 cm to 17%–18% at 10–20 and 20–30 cm; the increase of C content over the three layers from Y_0 to Y_3 is 9 Mg C ha^{-1}. From Y_4, there was no further increase in C content in the 10–20 cm and 20–30 cm soil layers, and so there was a stabilisation in soil C content. If we model the C content increase by first-order kinetics ($y = 94.3$ $(1-0.83\ e^{-0.012t})$, $r^2 = 0.87$), the rate constant (0.012) found is the same as the rate found by Jastrow (1996). Furthermore, we can notice that our observed rate of increase in C content is well within the range of values already measured in other experiments as listed in Table 3. Examining Table 3 also shows that the differences in climatic conditions do not explain the variation in C content increase between the experiments, but that it can be rather related to differences in soil texture. Indeed, in clayey soils Choné et al. (1991), Angers (1992) and Dalal et al. (1995) observed similar or larger storage rates than ours, and in sandy soils Talineau et al. (1980), Wood et al. (1991) and Desjardins et al. (1993) observed lower C storage rates. The large increase in soil C content can also be related to the high productivity of the pasture. Indeed, intensive pasture management, e.g., irrigation, moving or grazing, improves root production and so can stimulate C storage (Picard, 1976). Thus, on a vertisol, near our study site, a stargrass fallow which is non-irrigated, non-fertilised and non-grazed increased the soil C content from 15 to 19 g C kg soil^{-1} only (0–10 cm) in 15 years (Hartmann et al., 1998). So, the soil C storage seemed to be directly linked to the plant productivity, higher in the upper layers than in deeper layers.

A slight decrease in C/N ratio could be observed from Y_0 to Y_1. But after Y_1, the C/N ratio increased in parallel to the soil C content, which suggests that the increase in C content arises mainly from the incorporation of plant debris. Nevertheless, it must be pointed out that the changes in C/N remained small.

3.3. Correlation analyses

Table 4 shows the correlation coefficients between annual average C content or annual average C increase (ΔC) and texture, soil depth and initial average C content for the three soil layers. There was no correlation between soil C content or ΔC and clay plus fine silt content in any layer. So, the texture variation, which is very small in this plot, cannot explain the C content variation over the field. By contrast, in the 0–10-cm layer, C content and soil depth down to the bedrock were correlated in the first years of the experiment (Y_0, Y_1, and Y_2). In the 10–20 and 20–30-cm layers, C content and soil depth were correlated until Y_4 except at Y_2 in 20–30-cm layer. This can be explained by soil losses induced by sheet erosion during long-term market gardening (Albrecht et al., 1992b). Indeed, shallow soils occur in the top part of the plot and their surface layer is

Table 4
Correlation coefficients between annual average C content or annual average C increase and texture, soil depth and initial average C content for the three soil layers
$n = 96$, $r = 0.27$, $a = 0.01$.
$r = 0.31$, $a = 0.001$.
C_{Y_x}, C contents at Y_x.
ΔC_x, C contents increase from Y_0 to Y_x.

	0–10-cm soil layer			10–20-cm soil layer			20–30-cm soil layer		
	Depth soil	0–20-μm particles	C content at Y_0	Depth soil	0–20-μm particles	C content at Y_0	Depth soil	0–20-μm particles	C content at Y_0
C_{Y_0}	0.46	−0.05	1.00	0.43	−0.03	1.00	0.40	−0.23	1.00
C_{Y_1}	0.31	−0.11	0.39	0.34	−0.22	0.54	0.33	−0.02	0.36
C_{Y_2}	0.29	0.02	0.19	0.32	−0.14	0.35	0.20	−0.25	0.19
C_{Y_3}	−0.03	0.05	0.11	0.33	0.10	0.56	0.43	−0.10	0.39
C_{Y_4}	0.08	0.12	0.23	0.29	0.01	0.27	0.28	0.01	0.26
C_{Y_5}	0.26	0.08	0.25	0.17	−0.10	0.32	0.14	−0.21	0.20
ΔC_3	−0.26	0.07	−0.42	0.03	0.14	−0.17	0.02	0.11	−0.56
ΔC_4	−0.12	0.14	−0.21	0.00	0.02	−0.40	−0.07	0.19	−0.56
ΔC_5	0.07	0.10	−0.17	−0.09	−0.08	−0.28	−0.22	0.03	−0.67

therefore more eroded than the surface layer of the deepest soils, which are located in the bottom areas of the field. Since the surface layer contains the largest amounts of C content, the shallow soils exhibited smaller C contents than the deep soils at the beginning of the experiment. But later with the growth of *D. decumbens*, which does not vary according to soil depth (Salette and Dumas, 1969), both the shallow and deep soils were progressively covered and protected against sheet erosion. Consequently, the soil depth and the C content were no longer correlated after 4 years of pasture development.

The only correlation found with ΔC was a negative correlation between ΔC and the initial soil C content (C_{Y_0}) until Y_4 in the 0–10-cm layer, and in all years in the 10–20 and 20–30-cm layers except at Y_3 in the 10–20-cm layer. This can be explained by a larger mineralisation of organic C at places where the C content was larger (Ladd et al., 1994). Nevertheless, C_{Y_0} must not be the major determinant of the C content increase (ΔC), particularly in the upper two layers where the correlation coefficients range from 0.17 to 0.42.

3.4. Temporal evolution of the spatial structure of C content

There is a strong positive correlation between the mean and the standard deviation of C content in the 0–10-cm ($r^2 = 0.97$) and in the 10–20-cm ($r^2 = 0.77$) layers but not in the deepest layer (Fig. 3). This suggests that the increase in the C content is not uniform over the field. In fact, the absence of correlation in layer 20–30 cm certainly arises from the fact that the increase in C content in this layer was small. By contrast, the spatial variation of the C/N

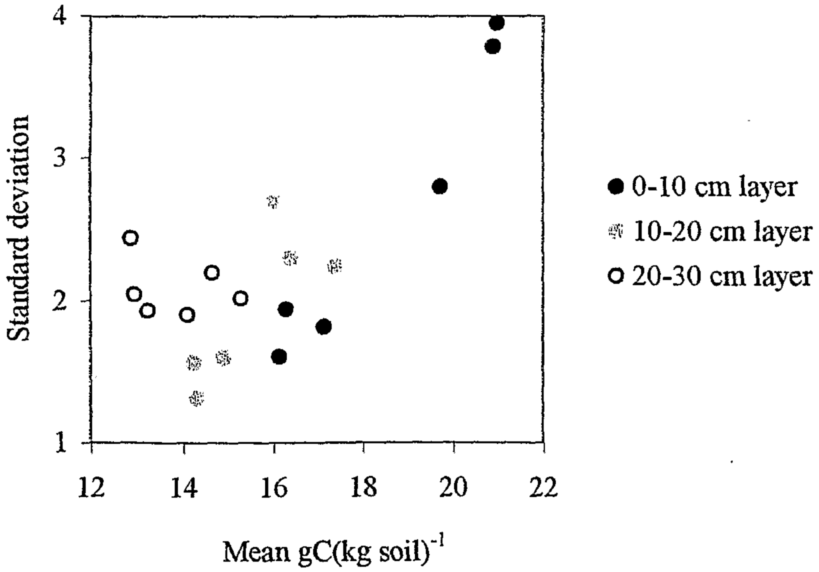

Fig. 3. Relation between mean and standard deviation of C content for each soil layer.

Table 5
Semi-variograms of C content for years Y_0, Y_3, Y_4 and Y_5
c_0, c and r are the fitted values of the nugget variance, the sill and the range.

Characteristics of the model	0–10 cm				10–20 cm				20–30 cm			
	Y_0	Y_3	Y_4	Y_5	Y_0	Y_3	Y_4	Y_5	Y_0	Y_3	Y_4	Y_5
c_0 (g C kg soil^{-1})^2	1.1	5.2	7	10.5	1.6	1.2	1.5	2	1.4	1.4	1.4	1.4
c (g C kg soil^{-1})^2	–	–	7	6	–	3	2.5	4.5	2.1	2.1	2.1	2.1
r (m)	–	–	12	12	–	7	12	12	17	17	17	17

ratio was very limited, as indicated by the small values of standard deviation. These results indicate that the intensity of organic C storage is spatially variable, but that the nature of the organic compounds remains homogeneous across the plot. The study of the temporal evolution of the spatial structure of C content should help to explain this phenomenon.

Like the changes in soil C content mean, the temporal changes in the spatial structure of soil C content, due to changes in land use, were significant only at Y_3, Y_4 and Y_5, and were more significant in the topsoil layers (0–10-cm and 10–20-cm layer). So, we describe hereafter only the spatial structure of C content at Y_0, Y_3, Y_4 and Y_5 (Table 5, Fig. 4).

In the 0–10-cm layer, the theoretical variogram models of C content in years Y_0 and Y_3 that best fitted to the empirical variograms were of pure nugget type. The nugget variance increased considerably between Y_0 and Y_3. So, the increase in variance of C content from Y_0 to Y_3 arose mainly from an increase in the variance of the microvariations at a scale smaller than 3 m, our smallest computed variogram lag. Then from Y_3 to Y_4 and Y_5, the variograms became of

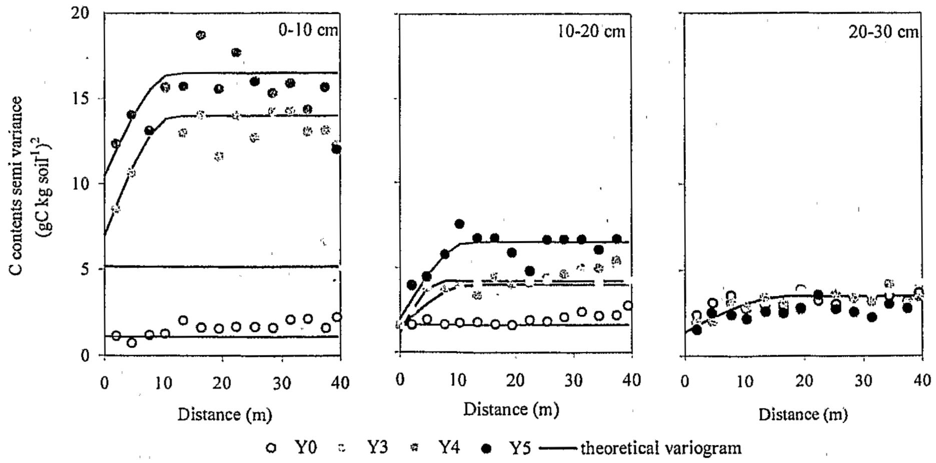

Fig. 4. Temporal evolution of C-content semi-variograms for each soil layer.

spherical type with constant nugget effect and constant range of 12 m but with sill increasing with time. Consequently, from Y_3 to Y_5 the increase in variance of C content arose from the increase in the spatial variation of C content at the medium scale between 3 and 12 m. This temporal evolution of the spatial structure of C content suggests that the increase in C content is initiated at points and then spreads gradually from these points.

In the 10–20-cm layer, the fitted variogram models were of the pure nugget type at Y_0. The variograms of 10–20-cm layer became spherical at Y_3, Y_4 and Y_5. The nugget effect remained constant but the range increased between Y_3 and Y_4 and the sill increased between Y_3 and Y_5. Consequently, from Y_0 to Y_3, Y_4 and Y_5 the increase in variance of C content arose from the increase in the spatial variation of C content at the medium scale between 7 and 12 m. Similarly to the 0–10-cm layer, the augmentation of soil C content seemed to spread gradually over the plot from points but started earlier than in the 0–10 cm.

In contrast to the upper layers, in the 20–30-cm layer, the fitted variograms were all spherical, and there was no increase in total variance between Y_0 and Y_5. In addition, given the magnitude of the estimation uncertainties, the values of the nugget variance at Y_0 and Y_5 can be considered equivalent. Consequently, changes in the spatial structure of C content in the 20–30-cm layer seemed to be very moderate which can be related to the fact that there was almost no change in the mean C content.

The short-range variation of soil C content in the upper two layers, and its variation with time, cannot be explained either by the spatial variation in initial C content, or by the spatial variation in particles size distribution or soil depth. An explanation can however be proposed by examining the possible sources of short-range spatial variation in organic inputs. As a first guess, there are two possible sources of variation: (i) the plant-cover distribution, which occurs in tufts and (ii) the cracking patterns and swelling–shrinking properties of the vertisols.

(i) The heterogeneity of the plant cover and growth in our study site is at a scale of approximately 0.8 m, since *D. decumbens* has a tuft habit. Root density is discontinuous in soil; it is denser under the tufts than between the tufts in the upper 10 cm of soil (Kabir et al., 1994), in which large temporal changes in short-range variance in C content are observed. Conversely, *D. decumbens* rooting is limited in the 20–30-cm layer, there is no difference in root biomass between inter-tuft and intra-tuft in this layer, and accordingly no changes in short-range variation of C content were observed. In another study, Gonzalez and Zak (1994) also concluded that the spatial structure of soil C content in a dry forest in Saint Lucia (West Indies) was mainly influenced by vegetation dynamics.

(ii) The swelling–shrinking behaviour of vertisols may also induce a heterogeneous distribution of organic C inputs at the meter scale, which is the scale of the crack network. This is related to two different processes. Firstly, plant debris or litter can preferentially fall down in the opened cracks during the dry season and thereby increase the C content in the vicinity of the cracks. Secondly, during the wet periods, it has been shown that soil moisture distribution follows the crack pattern (Cabidoche and Voltz, 1995): due to preferential infiltration the water content is higher close to the cracks than between the cracks. Consequently it can be assumed that the root activity is larger close to the craks, which in turn increases the C content nearby the cracks.

So these two factors, plant-cover distribution and physical structure of vertisol, can explain the evolution of the soil C content spatial structure. At the beginning of pasture establishment, the increases in soil C content were confined to local points, and with the development of *D. decumbens*, i.e., the spreading of the root system in soil, the C content of sites with high soil C content became proportionately larger and larger.

4. Conclusion

After 5 years of pasture the C stock increase was about 7.5 Mg C ha^{-1} for the upper 30 cm of soil and 5 Mg C ha^{-1} for the topsoil (0–10 cm); from Y_4 there was a stabilisation in soil C stock mean for the 10–20- and 20–30-cm soil layers. The heavy clayey soil and the high plant inputs for an intensive pasture management could explain partly the high values of C storage. The intensity of C storage, had a spatial pattern, but the C/N ratios, or the quality of OM in soil, remained homogeneous across the plot. The C content variations were short-range variations, local variability of soil C content (0–10 cm) increased with time, but there was also a gradually spreading of this local variability. This temporal evolution of the spatial structure of C content cannot be explained by the mineral particle-size distribution or the depth of the soil. *D. decumbens* dynamics and crack distribution seem to be the determinants of the C storage over the field. Thus, the spatial structure of C content should be studied at both at the ‘‘plant scale (Smith et al., 1994; Vogt et al., 1995) and at the field scale. To this aim, we believe that a nested sampling scheme in which a proportion of the sampling points are separated by distances smaller than the planting distance (Webster and Oliver, 1990), would allow to analyze in more detail the microvariations of C content and their relationships with plant growth.

References

Albrecht, A., Brossard, M., Chotte, J.L., Feller, C., 1992a. Les stocks organiques des principaux sols cultivés de la Martinique, Petites Antilles. Cahier ORSTOM, série Pédologie 22, 23–26.

Albrecht, A., Rangon, L., Barret, P., 1992b. Effets de la matière organique sur la stabilité structurale et la détachabilité d'un vertisol et d'un ferrisol (Martinique). Cahier ORSTOM, série Pédologie 22, 121–133.

Angers, D.A., 1992. Changes in soil aggregation and organic carbon under corn and alfalfa. Soil Science Society of America Journal 56, 1244–1249.

Beare, M.H., Cabrera, M.L., Hendrix, P.F., Coleman, D.C., 1994. Water-stable aggregates and organic matter fractions in conventional and no-tillage soils. Soil Science Society of America Journal 58, 777–786.

Brossard, M., Balesdent, J., Feller, C., Plenecassagne, A., Turenne, J.F., 1985. Etude de la matière organique des sols par fractionnement granulométrique. I. Décomposition au champ d'un compost enfoui dans plusieurs types de sols des Antilles. In: Proceedings of the 20th Caribbean Food Crops Society Meeting Sainte-Croix. pp. 68–73.

Cabidoche, Y.M., Voltz, M., 1995. Non-uniform volume and water content changes in swelling clay soil: II. A field study on a vertisol. European Journal of Soil Science 46, 345–355.

Cerri, C.C., Volkoff, B., Andreux, F., 1991. Nature and behaviour of organic matter in soils under natural forest, and after deforestation, burning and cultivation, near Manaus. Forest Ecology and Management 38, 247–257.

Choné, T., Andreux, F., Correa, J.C., Volkoff, B., Cerri, C.C., 1991. Changes in organic matter in an oxisol from the central amazonian forest during eight years as pasture, determined by carbon-13 isotopic composition. In: Berthelin, J. (Ed.), Diversity of Environmental Biogeochemistry. Elsevier, Amsterdam, pp. 398–405.

Dalal, R.C., Strong, W.M., Weston, E.J., Cooper, J.E., Lehane, K.J., King, A.J., Chicken, C.J., 1995. Sustaining productivity of a vertisol at Warra, Queensland, with fertilisers, no-tillage, or legumes. 1-Organic matter status. Australian Journal of Experimental Agriculture 35, 903–913.

Desjardins, T., Andreux, F., Volkoff, B., Cerri, C.C., 1993. Organic carbon and ^{13}C contents in soils and soil size-fractions, and their changes due to deforestation and pasture installation in eastern Amazonia. Geoderma 61, 103–118.

Englund, E., Sparks, A., 1988. GEO-EAS 1.2.1 User's Guide, EPA Report, Environmental Protection Agency, Las Vegas, NV, U.S.A.

FAO-UNESCO-ISRIC, 1988. FAO-UNESCO soil map of the world: revised legend. World soil resources report, FAO, Rome, Italie, 119 pp.

Feller, C., Albrecht, A., Tessier, D., 1996. Aggregation and organic matter storage in kaolinitic and smectitic tropical soils. In: Carter, M.R. (Ed.), Structure and Organic Matter Storage in Agricultural Soils. Advances in Soil Science CRC Press, Boca Raton, pp. 309–360.

Garcia-Oliva, F., Casar, I., Morales, P., 1994. Forest-to-pasture conversion influences on soil organic carbon dynamics in a tropical deciduous forest. Oecologia 99, 392–396.

Gonzalez, O.J., Zak, D.R., 1994. Geostatistical analysis of soil properties in a secondary tropical dry forest, St. Lucia, West Indies. Plant and Soil 163, 45–54.

Gupta, V.V.S.R., Germida, J.J., 1988. Distribution of microbial biomass and its activity in different soil aggregate size classes as affected by cultivation. Soil Biology and Biochemistry 20, 777–786.

Hartmann, C., Blanchart, E., Albrecht, A., Bonneton, A., Parfait, F., Mahieu, M., Ndandou, C.J.F., 1998. Nouvelles techniques de préparation des vertisols en culture maraîchère à la Martinique. Incidences pédologiques et agro-économiques. Agriculture et Développement 18, 81–89.

Jastrow, J.D., 1996. Soil aggregate formation and the accrual of particulate and mineral-associated organic matter. Soil Biology and Biochemistry 28, 665–676.

Kabir, M., Chotte, J.L., Rahman, M., Bally, R., Jocteur Monrozier, L., 1994. Distribution of soil fractions and location of soil bacteria in a vertisol under cultivation and perennial grass. Plant and Soil 168, 243–255.

Ladd, J.N., Amato, M., Zhou, L.K., Schultz, J.E., 1994. Differential effects of rotation, plant residue and nitrogen fertilizer on microbial biomass and organic matter in an Australian alfisol. Soil Biology and Biochemistry 26, 821–831.

Picard, D., 1976. Dynamique racinaire de *Panicum maximum Jacq.* et apport au sol de matière organique. PhD Univ. Clermont-Ferrand, 275 p.

Salette, J.E., Dumas, Y., 1969. In: Points de vue écologiques sur la place des cultures fourragères dans l'agriculture antillaise; exemple de l'utilisation du pangola dans l'étude des facteurs du milieu. In: Comptes rendus du 7ème congrès annuel Caribbean Food Crops Society, Martinique, Guadeloupe 7, pp. 219–229.

Smith, J.L., Halvorson, J.J., Bolton, H.J., 1994. Spatial relationships of soil microbial biomass and C and N mineralisation in a semi-arid shrub-steppe ecosystem. Soil Biology and Biochemistry 26, 1151–1159.

Soil Survey Staff, 1975. Soil Taxonomy. A Basic System of Soil Classification for Making and Interpreting Soil Surveys. U.S.D.A.-SCS, Agric. Handbook # 436. US Government Printing Office, Washington DC.

Staben, M.L., Bezdicek, D.F., Smith, J.L., Fauci, M.F., 1997. Assessment of soil quality in conservation reserve program and wheat-fallow soils. Soil Science Society of America Journal 61, 124–130.

Talineau, J.C., Bonzon, B., Fillonneau, C., Hainnaux, G., 1980. Contribution à l'étude d'un agrosystème prairial dans le milieu tropical humide de la Côte d'Ivoire: 2. Analyse des données relatives à l'état de la matière organique. Cahier ORSTOM, série Pédologie. 18, 29–47.

Vogt, K.A., Vogt, D.J., Absbjornsen, H., Dahlgren, R.A., 1995. Roots, nutrients and their relationship to spatial patterns. Plant and Soil 168-169, 113–123.

Webster, R., Oliver, M.A., 1990. In: Statistical Methods in Soil and Land Resource Survey. Oxford Univ. Press, Oxford UK, pp. 241–259, 316 p.

Wood, C.W., Westfall, D.G., Peterson, G.A., 1991. Soil carbon and nitrogen changes on initiation of no-till cropping systems. Soil Science Society of America Journal 55, 470–476.