CHAPTER 7

Soil Carbon Dynamics and Losses by Erosion and Leaching in Banana Cropping Systems with Different Practices (Nitisol, Martinique, West Indies)

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CONTENTS

7.1 INTRODUCTION

A strong link between increase in concentration of greenhouse gases (GHGs) in the atmosphere and the global temperature warrant: (1) assessment of soil as a potential sink for atmospheric CO_2 (Schlesinger, 1984; Detwiler, 1986; Bouwmann, 1989; Lugo and Brown, 1993), (2) determination of the fate of C translocated by erosion or leaching in C budgets, and (3) calculation of C budgets at different spatial scales (global, regional, local) (Turner et al., 1997; Lal, 2003). Furthermore, the maintenance or increase of soil C stocks deeply affects soil fertility (Feller et al., 1996). A change in soil C stocks at medium- or long-term has often been described as an indicator of agrosystem sustainability and environmental quality. This explains why agricultural practices, which increase soil C stocks, generally result in high crop productivity, decrease erosion, increase biodiversity, and also act as a sink for atmospheric C (Lal et al., 1998).

In Martinique, banana (*Musa spp.*) is the main cropping system. Banana crops occupied an area of 11,800 ha and produced more than 305,000 Mg of fruits in 1999 (Agreste DOM, 1999). Agricultural practices are very intensive and bananas are often cropped on steep slopes (from 10 to 40%), which can cause severe erosion due to intense tropical rains. This crop is also very sensitive to a range of pests or diseases (nematodes, insects, fungi). The traditional practices used to combat diseases and pests are based on the use of massive amounts of pesticides and frequent replanting. Every year an average crop is characterized by two or three applications of nematicides, one or two applications of insecticides, three to five applications of herbicides, four to twelve aerial applications of fungicides, and high doses of fertilizers (Chabrier and Dorel, 1998). The impact of such practices on the environment and human health are dramatic, and widespread incidence of soil and water pollution have been reported (Balland et al., 1998). Practices that improve soil and water quality, and favor agriculture sustainability, have been developed since 1990s. In 1999, the CIRAD (Centre de Coopération Internationale en Recherche Agronomique pour le Développement) set up an experimental site to test the effect of different cropping systems (rotations) on soil erosion, nutrient and pesticide erosion, and leaching (Khamsouk, 2001). Three rotations were tested: (1) a rotation with sugarcane (residues left on the soil surface), (2) a rotation with pineapple cropped on the flat and covered with organic residues, and (3) a rotation with conventional pineapple (intensive-till, residues buried, and ridged). Before the study, all plots were cropped with perennial banana. Runoff plots were set up for each rotation and those were compared to soil losses measured in perennial banana crops and "bare soil" treatments (Khamsouk, 2001; Khamsouk et al., 2002b). These experimental plots were used to measure soil C losses by erosion (in a solid or dissolved form) and leaching (in a dissolved form) and to follow C stock changes over two consecutive years. Input of C (rain, litter, roots) was used to prepare C budgets and to calculate the contribution of erosion and leaching to total soil C loss.

7.2 MATERIALS AND METHODS

7.2.1 Study Site

Martinique is a volcanic island of the West Indies in the Atlantic Ocean (14 to 16° N, 60 to 62° W, 1080 km^2). It has a hilly relief with high young volcanic mountains in the north (maximum 1393 m) and old volcanic mountains in the south (maximum 505 m). The climate is humid tropical with mean annual rainfall ranging from 1200 to 8000 mm, depending on the altitude, and mean annual temperature around 26°C. The climate is characterized by two contrasting seasons: a dry season from January to June and a rainy season marked by tropical storms and hurricanes. This study was established at a CIRAD experimental Station (Rivière-Lézarde) in the central part of the island (rainfall 2000 mm yr^{-1}, 70 m above sea level). Soil developed from volcanic pumices and ashes is described as a Nitisol (FAO classification) (Colmet-Daage and Lagache, 1965). It is acidic,

Table 7.1 Soil Characteristics of the Surface Layer (0 to 10 cm) of the Nitisol

Parameter	Value
Bulk density (Mg m^{-3})	0.77–0.92
pH (water)	4.9–5.7
Sand content (g 100 g^{-1} soil)	16
Silt content (g 100 g^{-1} soil)	16
Clay content (g 100 g^{-1} soil)	68
Organic matter content (g 100 g^{-1} soil)	2.7–3.3
Erodibility index K[a]	0.08–0.1

[a] According to the K index nomograph (Wischmeier et al., 1971).

clayey (mainly halloysite), with high organic matter content, low bulk density, strong resistance to sheet erosion and a low erodibility index K (Table 7.1) (Khamsouk et al., 2002b).

7.2.2 Experimental Plots

The present study comprised of different experimental plots representing: (1) conventional, perennial banana (*Musa paradisiacal*) crops with intensive practices and without rotations, and (2) new banana cropping practices involving rotations with other crops such as sugarcane (*Saccharum officinarum*) or pineapple (*Ananas comosus*) (Khamsouk, 2001). Bare fallow plots were also established to assess soil erodibility (Wischmeier and Smith, 1978). Three slope levels studied were: 10%, 25%, and 40%. A total of ten plots established at the beginning of 1999 comprised the following treatments:

- Three bare soil plots located on three slope levels 10, 25, and 40%, soil was tilled to 20-cm depth and levelled each year.
- Sugarcane, with residues left on the soil surface, was a new rotation proposed in banana crops in order to reduce soil erosion. Three plots were established on three slope levels; sugarcane was planted in 13 horizontal rows spaced 1.5 m apart, with reduced soil tillage and residues left as mulch in the interrows.
- Two perennial banana crops were studied (banana 1 and banana 2); crop residues were left in strips perpendicular to the slope. These two plots had a plant density of 1800 trees ha^{-1} and were located on 10% slope. These crops were tilled for 2 years prior to and during the experiment.
- Intensive-till pineapple (tilled twice with romeplow, residues buried, and ridged) was characterized by intensive practices conventionally used in Martinique. This plot was established on a 10% slope. Previous banana residues were buried. The plant density was 42,500 plants ha^{-1} in seven rows parallel to the slope.
- No-till pineapple was cropped on the flat and soil covered with organic residues, representing a new cropping system designed to reduce soil erosion. This plot was established on 10% slope. Previous banana residues were left at the soil surface in the interrows parallel to the slope.

A runoff plot was established on each of these 10 plots in order to measure soil and C losses by erosion. These plots were 200 m^2 (20 × 10 m), except bare soil runoff plots, which were 20 × 5 m (100 m^2). Plot replication was not implemented in this demonstration trial, as it is usually difficult in long-duration trials (Shang and Tiessen, 2000), especially when these include runoff plots, as was the case in this experiment.

Details concerning erosion, runoff, aggregate stability, water balance and nutrient losses are given by Roose et al. (1999), Khamsouk (2001), and Khamsouk et al. (2002a, b).

7.2.3 Soil C Stock Measurements

Soil C stocks were measured just before the establishment of these experimental plots (at the beginning of 1999) when all plots were cropped with perennial banana crops, and two years after the installation of experimental plots (at the beginning of 2001).

In 1999, eight pits were dug (just outside the location of next runoff plots): four pits in the 10% slope level, two pits in the 25% slope level, and two pits in the 40% slope level. These pits were 1-m deep except one pit in the 10% slope level, which was 2-m deep to measure soil C stock under the root zone. Soil C stocks were measured at different depths: 0 to 10, 10 to 20, 20 to 30, 30 to 40, and 50 to 60 cm depths. For the deepest pit, C stocks were also measured at 70 to 80, 110 to 120, and 150 to 160 cm. For each of these layers, soil bulk density was measured using five replications (1000 cm^3 each). Soil was then oven-dried at 105°C and weighed. Three composite samples were taken from each layer for C content analysis. Soil was oven-dried at 60°C and ground to pass through a 200 μm sieve. Soil C content was analyzed using a CNS analyzer (Carlo Erba 1500 NS). Soil C stocks were calculated as follows:

$$\text{Soil C stock (Mg C ha}^{-1}) = \text{C content (g kg}^{-1}) \times \text{bulk density (Mg m}^{-3}) \times \text{d (layer thickness, m)} \times 10 \quad (7.1)$$

Soil C stocks were calculated both on a volume basis and on an equivalent mass basis, the latter being more adapted to compare situations with changes in bulk density, which is the case in the present study (Ellert and Bettany, 1995). To compare soil C stocks on an equivalent mass basis, the chosen reference was the mass of soil in the first 30 cm under banana grown on 10% slope gradient in 1999 (i.e., 2205 Mg soil ha^{-1}). In 2001, a pit was dug toward the upstream side of each plot. Soil C stocks were measured the same way as in 1999.

Because C stock changes were detectable in the surface layers, results presented herein are from the 0 to 30 cm depth only.

Soil C stock was calculated from soil C content (Co) and bulk density (BD). Standard deviation of C stocks (SD_S) for each horizon was calculated by the following formula:

$$SD_{SH} = S \times [(SD_{Co}/Co)^2 + (SD_{BD}/BD)^2]^{1/2} \quad (7.2)$$

where Co is the mean C content, BD is the mean bulk density, and SD_{SH}, SD_{Co}, and SD_{BD} are the standard deviations of C stock of the horizon, C content and bulk density, respectively (Pansu et al., 2001). The standard deviation of C stock for the upper 30 cm was calculated by the following equation:

$$SD_S = [(SD_{SH1}{}^2 + SD_{SH2}{}^2 + SD_{SH3}{}^2]^{1/2} \quad (7.3)$$

where SD_{SH1}, SD_{SH2}, SD_{SH3} are the standard deviations of C stock of the three horizons (0 to 10, 10 to 20, and 20 to 30 cm).

7.2.4 C Losses by Runoff and Erosion

Runoff plots were rectangular, and the surface runoff (with sediments) discharged into calibrated storage tanks (Roose, 1980). Rainfall, runoff, and erosion were measured after each erosive event. Rainfall was characterized by its amount (mm), 30-min maximum rainfall intensity (Ipmax30, mm h^{-1}) and its erosivity (MJ mm (ha h)$^{-1}$) using an automatic meteorological station (Khamsouk, 2002b). Runoff was defined by the mean annual runoff coefficient Cram (%) which corresponds to the annual runoff water divided by the annual rainfall, and by the maximum runoff coefficient Crmax (%) which is the maximum runoff depth divided by its generating rainfall event. Annual erosion E (Mg ha^{-1} yr^{-1}) was determined by the total dry weight of whole soil loss, i.e., coarse (particles deposited at the bottom of storage tanks) and suspended sediments, for every erosive event. A part of the coarse and suspended sediments was separately sampled in order to analyze sediment C content for each erosive event. Dissolved C content in runoff water was analyzed using a Shimadzu TOC-5000. Because these measurements were made over two consecutive years with different rainfall amounts, C losses are reported as Mg C ha^{-1} 2 yr^{-1}.

7.2.5 C Losses by Leaching

Lysimeters were installed in perennial banana crops in order to measure C losses by leaching (Khamsouk, 2001). Five cylindrical lysimeters (90 cm diameter) were placed at 80 cm depth under banana trees. Seepage water was collected from storage tanks on a weekly basis. The amounts of seepage water and its dissolved C content were measured. Lysimeters were not installed in other plots. Thus, the dissolved C content for other plots was assumed similar to that of the banana.

7.3 RESULTS

7.3.1 Soil C Stocks Changes (Equivalent Mass Basis)

Soil C stocks in banana crops (slope 10%) were highly variable during 1999, just before the installation of experimental plots. Stocks in the 0 to 30 cm depth ranged from 27.5 to 33.5 Mg C ha^{-1} (mean 30.0 ± 2.9 Mg C ha^{-1}) in the upper 2205 Mg soil ha^{-1} (Table 7.2). Mean C stock was equal to 30.6 Mg C ha^{-1} for 25% slope, and it increased to 34.6 Mg C ha^{-1} for 40% slope.

There were no differences ($P < 0.05$) in C stock among treatments for the same plot gradient after 2 years of experimentation (Table 7.3). Irrespective of slope gradient, soil C stocks under sugarcane were higher than in bare soil treatment (with significant differences in the C content, $P < 0.05$). For 10% slope, there were only slight differences in C stock among plots growing sugarcane, bananas, no-till pineapple and intensive-till pineapple (29.5 in intensive-till pineapple to 33.7 Mg C ha^{-1} in banana plot). These values were higher than mean soil C stock in bare soil treatment (23.8 Mg C ha^{-1}).

Comparing data of 1999 and 2001, soil C stocks decreased in bare soil treatment (by 1.8 to 3.1 Mg C ha^{-1} yr^{-1} depending on slope gradient) and did not change significantly in intensive-till pineapple, no-till pineapple, sugarcane, and banana treatments (Table 7.4). The C stock in sugarcane treatment (40% slope) increased between 1999 and 2001 (by 3.1 Mg C ha^{-1} yr^{-1}).

7.3.2 Soil C Losses by Erosion and Leaching

7.3.2.1 Soil Losses by Erosion

The amounts of runoff and seepage water and of soil eroded during 2 years of the experiment are given by Khamsouk et al. (2002b). Only a small fraction of the rainfall was lost as runoff. Thus, the mean annual runoff coefficient Cram was < 15% (this value was measured in 2000 in the intensive-till pineapple treatment), and ranged between 0 and 4% in mulched plots (sugarcane, no-till pineapple, and banana). Total soil losses (coarse and suspended sediments) for the 2 years of measurements are given in Table 7.5. Soil losses were important in bare soil treatment (between 170 Mg ha^{-1} for 10% slope and 300 Mg ha^{-1} for 40 % slope during the 2 years). Soil losses were also relatively high in the intensive-till pineapple plot but low (< 1 Mg ha^{-1}) in other treatments.

7.3.2.2 C Losses by Erosion (Coarse and Suspended Sediments)

Soil C losses by erosion followed the same trend as soil losses, i.e., losses were more due to coarse than suspended sediments (Table 7.6). For bare soil treatments in which soil losses were mainly due to coarse sediments, C losses in coarse sediments increased with slope gradient from 2.5 to 6.0 Mg C ha^{-1} 2 yr^{-1}. Soil C losses were 580 kg C ha^{-1} 2 yr^{-1} in the intensive-till pineapple

Table 7.2 Bulk Density (Mg m^{-3}), Soil C Content (g C 100 g^{-1} Soil), and Soil C Stock (Mg C ha^{-1}) Measured at Three Depths at the Beginning of the Experiment (1999) for Each Slope Level (Mean and Standard Deviation SD) [a]

	10% Slope						25% Slope						40% Slope					
	Bulk Density		C Content		C Stock		Bulk Density		C Content		C Stock		Bulk Density		C Content		C Stock	
Soil Depth (cm)	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
0 to 10	0.772	0.036	1.677	0.253	12.95	3.31	0.83	0.054	1.545	0.191	12.82	2.55	0.802	0.047	2.045	0.064	16.40	1.30
10 to 20	0.728	0.053	1.245	0.037	9.06	0.59	0.749	0.032	1.360	0.071	10.19	0.79	0.876	0.039	1.345	0.007	11.78	0.47
20 to 30	0.705	0.061	1.137	0.067	8.02	0.73	0.748	0.096	1.215	0.078	9.09	1.12	0.838	0.058	1.220	0.028	10.22	0.66
Stock (volume basis)					30.03						32.10						38.41	
Stock (mass basis)[b]					30.03	3.44					30.62	2.90					34.61	1.53

[a] For bulk density, n = 20 at the 10% slope level and n = 10 at the other slope levels; for C content, n = 12 at the 10% slope level and n = 6 at the other slope levels.

[b] Reference being the soil mass of 0 to 30 cm layer under banana on 10% slope in 1999.

Table 7.3 Bulk Density (Mg m^{-3}), Soil C Content (g C 100 g^{-1} Soil), and Soil C Stock (Mg C ha^{-1}) Measured at Three Depths at the End of the Experiment (2001) for Each Cropping System (Mean and Standard Deviation SD) (n = 5 for Bulk Density, n = 3 for C Content)

	Sugarcane						Banana 1						Banana 2					
	Bulk Density		C Content		C Stock		Bulk Density		C Content		C Stock		Bulk Density		C Content		C Stock	
Soil Depth (cm)	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
10% Slope																		
0 to 10	0.800	0.039	1.62	0.18	12.96	2.39	0.750	0.031	1.99	0.13	14.93	1.99	0.803	0.078	1.83	0.36	14.69	5.41
10 to 20	0.822	0.079	1.29	0.10	10.60	1.35	0.738	0.056	1.34	0.12	9.89	1.31	0.809	0.047	1.25	0.03	10.11	0.56
20 to 30	0.861	0.025	1.24	0.09	10.68	1.00	0.716	0.067	1.24	0.07	8.88	0.86	0.783	0.036	1.18	0.05	9.24	0.57
Stock (volume basis)					34.24						33.69						34.05	
Stock (mass basis)[a]					30.79	2.92					33.70	2.53					31.81	5.47

	No-Till Pineapple						Intensive-Till Pineapple						Bare Soil					
	Bulk Density		C Content		C Stock		Bulk Density		C Content		C Stock		Bulk Density		C Content		C Stock	
Soil Depth (cm)	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
10% Slope																		
0 to 10	0.864	0.094	1.66	0.13	14.34	2.30	0.732	0.051	1.57	0.31	11.49	3.61	0.758	0.084	1.34	0.30	10.16	3.16
10 to 20	0.808	0.047	1.26	0.02	10.18	0.52	0.738	0.093	1.25	0.03	9.23	0.90	0.729	0.046	1.06	0.03	7.73	0.42
20 to 30	0.782	0.066	1.12	0.15	8.76	1.44	0.786	0.038	1.19	0.20	9.35	1.90	0.592	0.050	0.83	0.10	4.91	0.55
Stock (volume basis)					33.28						30.07						22.80	
Stock (mass basis)[a]					30.49	2.76					29.47	4.18					23.84	3.23

Table 7.3 Bulk Density (Mg m^{-3}), Soil C Content (g C 100 g^{-1} Soil), and Soil C Stock (Mg C ha^{-1}) Measured at Three Depths at the End of the Experiment (2001) for Each Cropping System (Mean and Standard Deviation SD) (n = 5 for Bulk Density, n = 3 for C Content) (Continued)

	Sugarcane						Bare Soil					
	Bulk Density		C Content		C Stock		Bulk Density		C Content		C Stock	
Soil Depth (cm)	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
25% Slope												
0 to 10	0.733	0.023	1.92	0.3	14.07	4.23	0.733	0.023	1.85	0.15	13.56	2.06
10 to 20	0.743	0.035	1.30	0.16	9.66	1.58	0.772	0.121	1.11	0.12	8.57	1.46
20 to 30	0.748	0.063	0.97	0.16	7.26	1.25	0.817	0.017	0.69	0.29	5.64	1.64
Stock (volume basis)					30.99						27.77	
Stock (mass basis)[a]					30.80	4.69					26.96	3.01

	Sugarcane						Bare Soil					
	Bulk Density		C Content		C Stock		Bulk Density		C Content		C Stock	
Soil Depth (cm)	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
40% Slope												
0 to 10	0.833	0.029	2.44	0.29	20.33	5.92	0.887	0.032	1.71	0.15	15.17	2.33
10 to 20	0.846	0.047	1.56	0.09	13.20	1.34	0.711	0.039	1.24	0.35	8.82	3.10
20 to 30	0.782	0.026	1.4	0.140	10.95	1.56	0.788	0.026	0.72	0.02	5.67	0.19
Stock (volume basis)					44.47						29.66	
Stock (mass basis)[a]					40.88	6.27					28.35	3.88

* Reference being the soil mass of 0 to 30 cm layer under banana on 10% slope in 1999.

Table 7.4 C Stock Changes (on an Equivalent Mass Basis) (in Mg C ha^{-1} yr^{-1}) after 2 Years of Experiment (1999 and 2000)[a]

Slope Gradient (%)	Bare Soil	Sugarcane	Banana 1	Banana 2	No-Till Pineapple	Intensive-Till Pineapple
10	−3.09	+0.38	+1.83	+0.89	+0.23	−0.28
25	−1.83	+0.09				
40	−3.13	+3.13				

[a] None of the changes is significantly ($P < 0.005$) different among treatments.

Table 7.5 Total Soil Losses (Coarse and Suspended Sediments) (in Mg ha^{-1}) during 2 Years of Experiment (1999, 2000) in Different Experimental Plots

Slope Gradient (%)	Bare Soil	Sugarcane	Banana 1	Banana 2	No-Till Pineapple	Intensive-Till Pineapple
10	171.6	0.11	0.8	1.0	0.08	34.3
25	254.9	0.10				
40	294.8	0.22				

Data from Khamsouk, B. 2001. Impact de la culture bananière sur l'environnement. Influence des systèmes de cultures bananières sur l'érosion, le bilan hydrique et les pertes en nutriments sur un sol volcanique en Martinique (cas du sol brun-rouille à halloysite). PhD ENSA-Montpellier, France, pp. 174.

Table 7.6 C Losses (in kg C ha^{-1} 2 yr^{-1}) by Erosion and Leaching during 2 Years of Experiment (1999, 2000) in Different Experimental Plots

Slope Gradients (%)	Bare Soil	Sugarcane	Banana 1	Banana 2	No-Till Pineapple	Intensive-Till Pineapple
			Coarse Sediments			
10	2488	2	23	19	2	580
25	4537	2				
40	5984	4				
			Suspended Sediments			
10	9.2	1.1	4	2.9	0.8	8.5
25	11.2	1.2				
40	13.1	2.1				
			Runoff (Dissolved)			
10	25.4	3.2	18.1	13.2	9	52.4
25	24.2	2.8				
40	19.7	3.3				
			Leaching (Dissolved)			
10	53	80	62.5	62.5	79.1	51.9
25	57.3	85.8				
40	59.3	84.1				
			Total			
10	2575.6	86.3	107.6	97.6	90.9	692.8
25	4629.7	91.8				
40	6076.1	93.5				

plot and only few kg C ha^{-1} 2 yr^{-1} in other plots. Soil C losses in suspended sediments were low with a high value of 13 kg C ha^{-1} 2 yr^{-1} in bare soil treatment for 40% slope. Finally, dissolved C losses in runoff water were generally low, but were high in the intensive-till pineapple plot (52.4 kg C ha^{-1} 2 yr^{-1}), low under sugarcane (3 kg C ha^{-1} 2 yr^{-1}) and intermediate in other treatments.

7.3.2.3 C Losses by Leaching and Runoff

There was low runoff under sugarcane and no-till pineapple, and most rainfall infiltrated. Thus, soil C losses by leaching were relatively important for these treatments and were about 80 kg C ha^{-1} 2 yr^{-1}. Dissolved C losses by leaching were slightly lower in other treatments (between 50 and 60 kg C ha^{-1} 2 yr^{-1}; Table 7.6). Losses of dissolved C in runoff water were much lower than those by leaching (from 3 in sugarcane to 25 kg C ha^{-1} 2 yr^{-1} for bare soil) except for intensive-till pineapple in which case losses by leaching and runoff were similar.

7.3.2.4 Total C Losses

Total C losses in solid (coarse and suspended sediments) and dissolved (in runoff and leaching) forms were high in bare soil treatments, and they increased with slope gradient from 2.5 to more than 6 Mg C ha^{-1} 2 yr^{-1}. Losses were relatively high in intensive-till pineapple treatment (693 kg C ha^{-1} 2 yr^{-1}) and low in mulched crops with similar losses in sugarcane, no-till pineapple, and banana plots (ca. 90 to 100 kg C ha^{-1} 2 yr^{-1}; Table 7.6).

7.4 DISCUSSION

7.4.1 Effects of Agricultural Systems on C Losses

Aside from bare soils treatments, three soil responses can be discerned concerning C losses by erosion and leaching:

1. Treatments that lost high amounts of C, especially in the form of coarse sediments (84% of total C losses) and in the dissolved form (15%). Intensive-till pineapple in which soil tillage and ridging parallel to the slope increased runoff and erosion.
2. Treatments in which C losses were not important but where coarse sediments and runoff water represented a relatively important part of C losses (21 and 15% of total losses, respectively). Established banana crops in which surface litter limited soil erosion. These results are in agreement with those obtained for banana crops in Burundi, since the authors reported that C and soil losses are proportional to the amount of litter on the soil surface (Rhishirumuhirwa and Roose, 1998). Moreover C losses by erosion and leaching reported herein are similar to those reported by Roose and Godefroy (1977) from Ivory Coast.
3. Treatments in which C losses were small, and coarse sediments and runoff water played a minor role in total C losses (3 and 3 to 10% of total losses, respectively). Most of C losses occurred in dissolved form in seepage water (87 to 92% of total C losses): sugarcane and no-till pineapple for which organic residues located in the inter-rows protected soil surface against runoff and erosion.

These results are in accord with those synthesized by Roose (2002), and show the importance of mulch in controlling soil and C erosion and especially particulate C erosion. In mulched crops (sugarcane, banana, no-till pineapple), C losses by erosion were mainly in dissolved form in seepage water, while in crops without mulch or in bare soil, most of eroded C was made up of particulate (associated with sediments) C (Rodriguez et al., 2002). The amount of dissolved carbon (in seepage and runoff) in mulched crops was 40 kg ha^{-1} yr^{-1} (i.e., 4 g m^{-2} yr^{-1}), which is in the range of the common value of continental export (3 to 10 g m^{-2} yr^{-1}; Moore, 1998).

7.4.2 Soil C Budgets at the Plot Scale

In order to compute the C budgets at the plot scale, several data such as C inputs, C outputs, and C stock changes in the system for a given period are needed (Figure 7.1 and Figure 7.2).

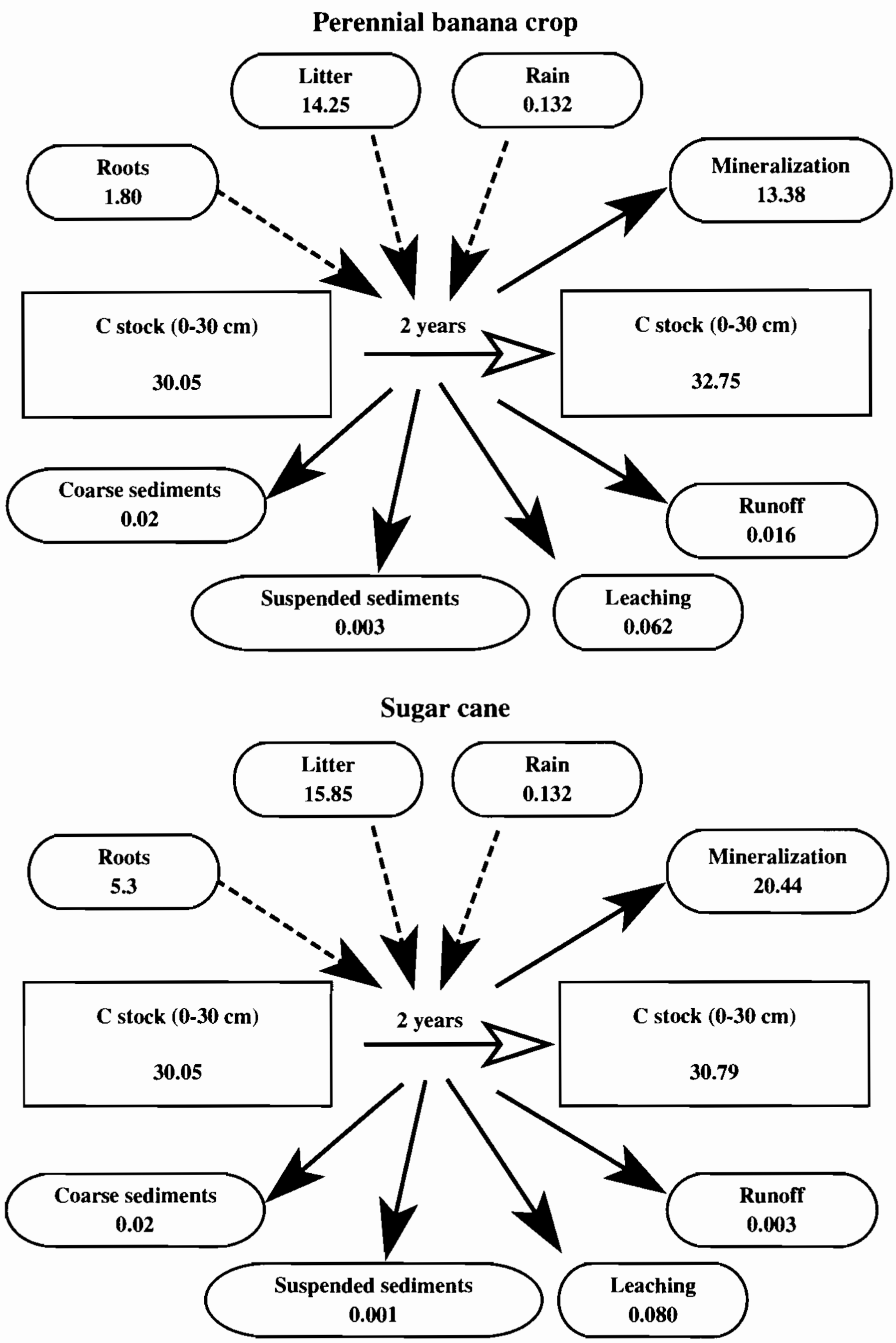

Figure 7.1 C budget in banana and sugarcane treatments (10% slope) showing C stock changes in 2 years (equivalent mass basis) (in Mg C ha^{-1}), C inputs (litter, root, and rain) and C outputs (erosion, leaching, and mineralization) (in Mg C ha^{-1} 2 yr^{-1}).

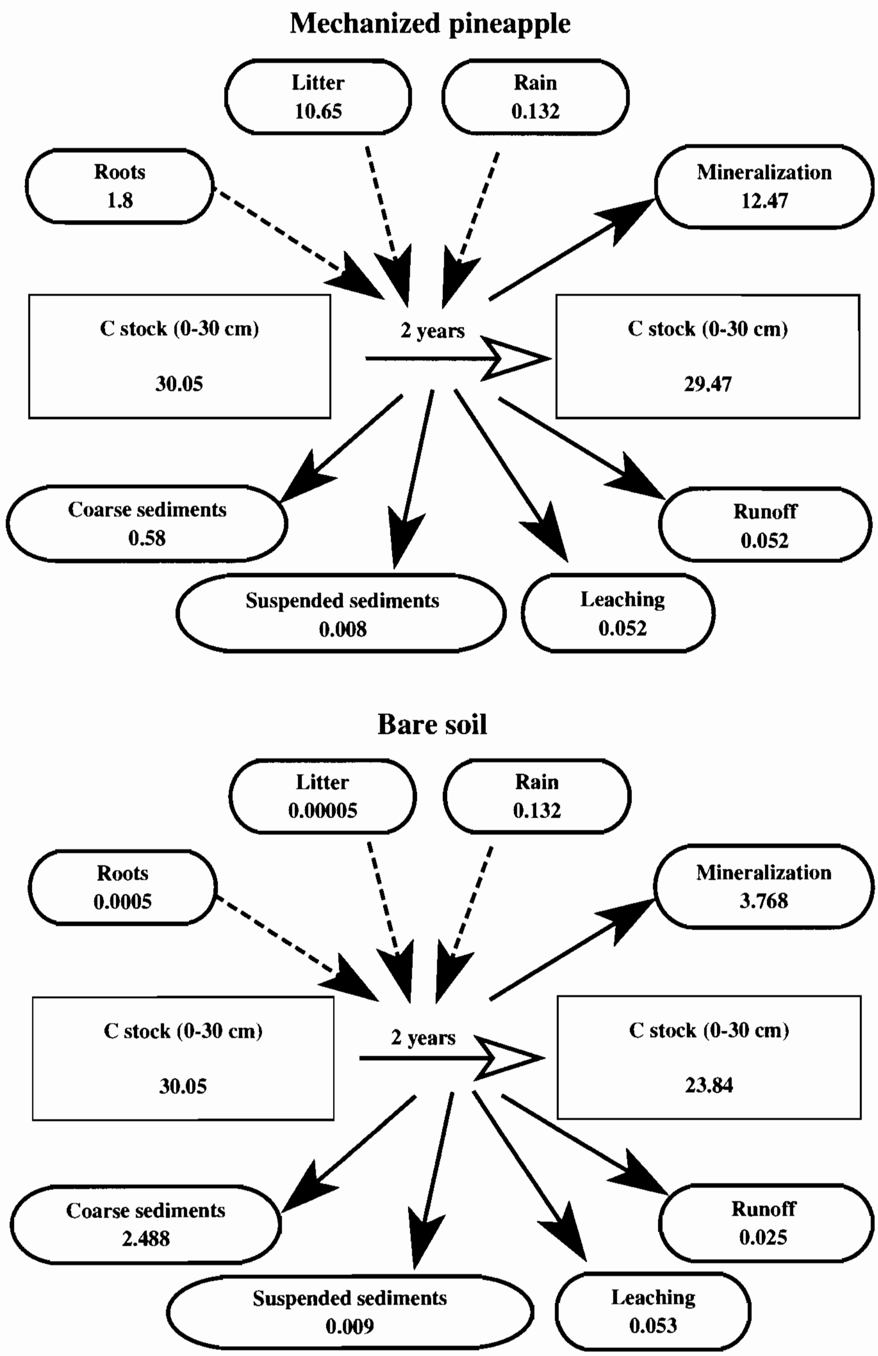

Figure 7.2 C budget in intensive-till pineapple and bare soil treatments (10% slope) showing C stock changes in 2 years (equivalent mass basis) (in Mg C ha^{-1}), C inputs (litter, root, and rain) and C outputs (erosion, leaching, and mineralization) (in Mg C ha^{-1} 2 yr^{-1}).

7.4.2.1 Soil C Outputs

The amounts of solid and dissolved C losses were studied in our experiment; nevertheless, gaseous C losses (i.e., emission of CO_2 and CH_4) were not. These data can be calculated from the other budget components.

7.4.2.2 Soil C Stock Changes

C stock changes during 2 years of experiment were measured, and can be used to calculate C budgets.

7.4.2.3 Soil C Inputs

Aerial C inputs were calculated from the measurement of litter amount at the soil surface (initial inputs from banana crops and inputs during the 2 years of experiment) (Kamsouk, 2001), from literature data, and from litter C content (Marchal and Mallessard, 1979; Lassoudière, 1980). These calculations were based on the assumption that all residues are decomposed within a year, C inputs by litter were estimated to be as high as 14.3, 15.9, 10.7, and 10.7 Mg C ha^{-1} 2 yr^{-1} in banana, sugarcane, no-till pineapple, and intensive-till pineapple crops, respectively. In bare soil, C inputs by weeds were estimated at 50 g C ha^{-1} 2 yr^{-1}.

Nonetheless, root C inputs cannot be precisely estimated since they can be lower or higher than aerial C inputs. In banana, because of a weak root development, they are relatively low and estimated at 1.8 Mg C ha^{-1} 2 yr^{-1} (Godefroy, 1974; Lassoudière, 1980). In pineapple, root C inputs were calculated at 1/6th of aerial C input, i.e., 1.8 Mg C ha^{-1} 2 yr^{-1} (Godefroy, 1974). In sugarcane, root production within a year is equal to about one third that of aerial production (Cerri, 1986; Brouwers, pers. comm.), i.e., 5.3 Mg C ha^{-1} 2 yr^{-1} in our experiment. In bare soil treatments, root C input was estimated to be as high as aerial C input (i.e., 50 g C ha^{-1} 2 yr^{-1}).

Rainfall is another source of C input in ecosystems (Roose, 1980). Based on local measurements and literature data, we used a mean value of 3 ppm, which in our two-year experiment, and considering the total amount of rainfall, gave a C input as high as 0.13 Mg C ha^{-1} 2 yr^{-1}.

7.4.2.4 C Budgets

Knowing C stock changes (increase, decrease, or no change) in 2 years due to C inputs (by litter, roots, and rain) and C outputs (by erosion and leaching), it is possible to build C budgets and to estimate gaseous C losses:

$$\Delta SOC = (SOCa + A) - (E + L + M) \qquad (7.3)$$

where ΔSOC is the change in stock (for a given period), SOCa is the antecedent stock, A is C inputs, E is erosion, L is leaching and M is mineralization (Lal, 2003).

Gaseous C losses reached 12.5 Mg C ha^{-1} 2 yr^{-1} in banana crops, 20.4 Mg C ha^{-1} 2 yr^{-1} in sugarcane, and 12.5 Mg C ha^{-1} 2 yr^{-1} in intensive-till pineapple (Figure 7.1 and Figure 7.2).

Thus, for the cropping systems studied in this pedoclimatic area, C losses were mainly due to mineralization of organic matter (more than 10 Mg C ha^{-1} 2 yr^{-1}) while solid and dissolved C losses were small: ca. 0.1 Mg C ha^{-1} 2 yr^{-1} for sugarcane, banana, and no-till pineapple, and 0.7 Mg C ha^{-1} 2 yr^{-1} for intensive-till pineapple. In bare soil treatments (for which C inputs, C outputs and C stock changes were precisely known), gaseous C losses were as high as 4.8 Mg C ha^{-1} 2 yr^{-1}, and were similar to C losses by erosion and leaching, which ranged from 2.5 to 6 Mg C ha^{-1} 2 yr^{-1} depending on slope gradient (Figure 7.2).

7.5 CONCLUSION

In Martinique, banana cropped on Nitisol are characterized by relatively low soil and C losses by erosion as long as soils are mulched with crop residues. This is the case in banana, sugarcane, and no-till pineapple. Apart from significant gaseous C losses, C losses in mulched crops are mainly due to leaching and runoff in a dissolved form. Rotations with sugarcane or pineapple (either on the flat with residues or intensive-tilled and ridged) induce changes in C losses. For sugarcane and pineapple grown on the flat with crop residue mulch, C losses (in dissolved and solid form) decreased compared with that from banana crops. Conversely, conventional intensive-till pineapple increased C losses (seven times more), because of soil tillage and the lack of crop residue mulch on the surface.

In bare soil, C losses by erosion and leaching were similar to those by mineralization. Losses by gaseous emission are estimated at 2.4 Mg C ha^{-1} yr^{-1} (4.8 Mg C ha^{-1} 2 yr^{-1}), and similar losses, due to the mineralization of soil organic matter, may also occur in cropped treatments.

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CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
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A TAYLOR & FRANCIS BOOK

On the cover: A typical landscape of red ferrallitic soils on the high plateau of central Madagascar near Antananarivo during the rainy season. The hilltop is covered by overgrazed grassland deeply eroded around the cattle trails which join the village and the springs in the valley. The hills lose carbon, nutrients, soil, and water, but might be nourishing the rice paddies below.

Published in 2006 by
CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

ISBN-13: 978-1-56670-688-9 (hbk)

Library of Congress Card Number 2005050888

Library of Congress Cataloging-in-Publication Data

Soil erosion and carbon dynamics / edited by Eric J. Roose ... [et al.].
p. cm. —(Advances in soil science)
Papers presented at a symposium held in Montpellier, France, September 23-28, 2002.
Includes bibliographical references and index.
ISBN 1-56670-688-2 (alk. paper)
1. Soil erosion—Congresses. 2. Carbon cycle (Biogeochemistry)—Congresses. 3. Soils—Carbon content--Congresses. I. Roose, Eric. II. Advances in soil science (Boca Raton, Fla.)

S622.2S64 2005
631.4'5--dc22 2005050888

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SOIL EROSION AND CARBON DYNAMICS

In addition to depleting nutrients necessary for healthy crops, soil erosion processes can affect the carbon balance of agroecosystems, and thus influence global warming. While the magnitude and severity of soil erosion are well documented, fluxes of eroded carbon are rarely quantified. **Soil Erosion and Carbon Dynamics** brings together a diverse group of papers and data from the perspectives of world-renowned soil scientists, agronomists, and sedimentologists to resolve whether soil erosion on carbon is a beneficial or destructive process.

This book collects quantitative data on eroded organic carbon fluxes from the scale of the agricultural plot to that of large basins and oceans. It quantifies the magnitude of eroded carbon for different soil management practices as compared to normal carbon sequestration and discusses the fate of the eroded carbon and whether or not it is a source or sink for atmospheric CO_2. Finally, the book offers data reflecting the impact of soil erosion on soil, water, and air quality. Other important topics include solubilization, carbon transfer, and sediment deposition, as well as carbon dioxide emissions, global warming potential, and the implications of soil erosion on the global carbon cycle and carbon budget.

Features

- Defines basic concepts and general approaches to the global carbon cycle, carbon sequestration, erosion, and eroded carbon
- Addresses the great debate on "missing" or "fugitive" carbon
- Includes arguments and data that support contrasting viewpoints on the effects of the carbon cycle
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ISBN 1-56670-688-2
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