SHORT COMMUNICATION

Impact of pasture establishment on CO_2 emissions from a Vertisol: Consequences for soil C sequestration (Martinique, West Indies)

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Institut de Recherche pour le Développement IRD, UR179-SeqBio, 911 avenue Agropolis, BP 64501, 34394 Montpellier cedex 5, France (e-mail: tiphaine.chevallier@mpl.ird.fr).
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Chevallier, T., Blanchart, E., Albrecht, A., Feller, C. and Bernoux, M. 2006. **Impact of pasture establishment on CO_2 emissions from a Vertisol: Consequences for soil C sequestration (Martinique, West Indies).** Can. J. Soil Sci. **86**: 779–782. Establishing pasture on cultivated tropical Vertisols can increase soil organic carbon (SOC), but it is not known whether this increase results solely from enhanced inputs or also from suppressed mineralization. We measured CO_2 emissions from a Vertisol under market gardening, and under "young" and "old" *Digitaria decumbens* pastures. Emissions of CO_2-C increased in pastures, compared to market gardening, but relative SOC mineralization (CO_2-C/SOC) decreased, implying the protection of SOC against mineralization with pasture establishment.

Key words: Tropical pasture, carbon fluxes, soil organic carbon, physical protection, C storage

Chevallier, T., Blanchart, E., Albrecht, A., Feller, C. et Bernoux, M. 2006. **Impact de l'installation d'une prairie sue les émissions de CO_2 d'un vertisol : Conséquence sur la séquestration du carbone dans le sol (Martinique).** Can. J. Soil Sci. **86**: 779–782. La mise en prairie de vertisol cultivé augmente le stock de carbone organique du sol, SOC, mais on ne sait pas si cette augmentation est seulement le résultat d'une augmentation des entrées de carbone ou aussi le résultat d'une diminution des pertes par minéralisation. Nous avons mesuré in situ les émissions de C-CO_2 d'un Vertisol sous maraîchage et sous prairie « jeune » et « vieille ». Les émissions de C-CO_2 augmentent mais les taux de minéralisation relatif (C-CO_2/SOC), c'est-à-dire la biodisponibilité du SOC aux microorganismes, diminuent avec la mise en prairie.

Mots clés: Prairie tropicale, minéralisation, carbone organique, protection physique, stockage de carbone

Rising levels of atmospheric CO_2 have focused attention on carbon (C) stocks in terrestrial biomes, notably in soils and phytomass (alive and dead). Much attention has been given to the CO_2 exchange in native or managed forested ecosystems, and on lands converted from or to forests, but other land conversions, such as from cropland to pasture, are also important in many regions. Especially needed are field measurements for different land uses and management in tropical regions.

Converting cultivated soil to pasture or forest can increase soil C stocks (Dugas et al. 1999). Davidson et al. (2000) observed that annual CO_2 emissions were lower from pasture soils (10–15 Mg C ha^{-1} yr^{-1}) than from forest soils (18–20 Mg C ha^{-1} yr^{-1}) in eastern Amazon. In a Vertisol in Martinique (French West Indies), the SOC stock in a market garden soil re-grassed with *Digitaria decumbens* increased by 6 Mg C ha^{-1} in the upper 20 cm of the soil after 5 yr (Chevallier et al. 2001). It was not known whether this rapid increase in the SOC stock resulted solely from increased annual C inputs from the pasture or also from higher protection against mineralization. Protection of SOC against mineralization can occur by (i) chemical stabilization, (ii) inaccessibility to microorganisms or their enzymes of SOC linked to mineral particles, (iii) changes in soil microbial communities and their activity or (iv) physical protection in soil aggregates (Six et al. 2002). Protection within soil aggregates, an important mechanism in some Vertisols (Chevallier et al. 2004), has been demonstrated in the laboratory (Balesdent et al. 2000), but we are not aware of in situ measurements of relative SOC mineralization decrease upon re-grassing.

Our objectives were: (1) to measure the CO_2-C emissions from market garden, young pasture and old pasture field plots; and (2) to evaluate the SOC bioavailability using the CO_2-C/SOC ratio (Wang et al. 2003).

The experimental site was in the southeastern part of Martinique in the West Indies (14°25′N / 60°53′W), an area with a humid tropical climate. The daily air temperature is stable throughout the year with a minimum mean of 23.2 ± 1.5 and a maximum mean of 29.8 ± 0.8°C (Meteo France data).

Abbbreviations: **CEC**, cation exchange capacity; **MG**, market garden; **P**, old *D. decumbens* pasture; **Pr**, young *D. decumbens* pasture

Most of the annual precipitation (1400 mm yr^{-1}) falls from July to December. The soil (20 m elevation with a 5% slope; mean depth = 0.8 m) developed on andesite and was classified as a smectitic Leptic Hapludert by the USDA classification (Soil Survey Staff 1975) or an Eutric Vertisol by the FAO classification (FAO-UNESCO-ISRIC 1988). Cation exchange capacity (CEC) ranged 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 (1:2.5 soil/water solution) varied from 6 to 6.5 across the experimental site. The texture of the soil was clayey, with particles <20 μm comprising 70 to 80% of the total mineral content in the top 20 cm (Chevallier et al. 2001). The bulk density of soils ranged from 0.94 to 1.07 (Feller et al. 2001).

We compared soils in three adjacent unreplicated plots (0.5–1 ha), on which the spatial variability of soil had been evaluated; soil texture and soil depth appeared homogeneous across the plots (Chevallier et al. 2000). The three plots – market garden (MG), young *Digitaria decumbens* pasture (Pr), and old *D. decumbens* pasture (P) – were in sugar cane from 1970 to 1978. In 1978, MG and Pr were converted into market gardening and P into pasture. In 1991, Pr was further converted from market gardening to pasture. All plots were irrigated (120 mm mo^{-1}) and fertilized (200 kg N ha^{-1} yr^{-1} for market gardening and 100 kg N ha^{-1} yr^{-1} for pasture).

We measured CO_2-C emissions in four spatial replicates of MG and P plots and in 16 spatial replicates of the Pr plot, which has a wide range of SOC stocks. CO_2-C emissions were measured each hour (from 0800 to 1800) on 4 successive days. These 4-d periods were distributed over the year (June to September 1997 and January to April 1998). Mean CO_2-C emissions from plots were then calculated from 160 values in MG and P and 640 values for Pr. CO_2-C emissions from the soil surface were measured using a closed-chamber method (Jensen et al. 1996). Before putting the chambers into soils, the grass leaves were cut and removed (litter was left). The vegetables in the MG plots were not present. The soils were irrigated for 24 h and allowed to drain for 24 h, and the non-insulated stainless steel chambers were inserted 10 cm into the soil, enclosing an area of 700 cm^2 with a head space volume of 11 730 cm^3. Chambers were vented 5 min before measurement to homogenize the CO_2 concentration inside the chamber, and air was sampled once (5 min) during the deployment (1 h). The air sample was dried with magnesium perchlorate and CO_2 concentration was measured with a infrared gas analyzer (MUTIWARN II SP IR CO2, Dräger, Lübeck, Germany). After each measurement, the chambers were opened and re-closed for a second hour-long measurement. Previous measurements in the same treatments at the site showed linear changes in CO_2 with time of chamber closure (between 0 and 2 h); nevertheless it is possible that our measurements underestimated CO_2 fluxes because increasing CO_2 concentration during deployment can cause a negative feedback on CO_2 emissions (Anthony et al. 1995).

The CO_2-C emissions (mg CO_2-C m^{-2} h^{-1}) were calculated as follows:

$$CO_2\text{-}C = (\Delta C \times V \times 1/t \times 1/S) \times 12/44, \quad (2)$$

where t is the time of CO_2 accumulation in the chamber, ΔC is the accumulation of CO_2 inside the chamber during time *t*; V is the volume of the chamber; S is the soil surface under the chamber.

The infrared gas analyzer had a precision of about 0.01%, corresponding to a systematic error of ± 8.5 mg CO_2-C m^{-2} h^{-1} (from 3 to 5% of mean of CO_2-C emissions).

Soil (at a depth of 10 cm) and air temperature in the chamber were determined during each measurement of CO_2-C emission. Soil moisture content (0–10 cm depth) was determined each sampling day. After CO_2 measurements, soil under each chamber was sampled (0–10 cm) for analysis of SOC content and particulate organic matter (including both living and dead roots as well as incorporated litter). Total SOC was measured with a Carbon Nitrogen Sulphur Analyser NA 1500 (Carlo Erba). No correction for carbonates was required. Particulate organic matter was measured by soil dispersion in NaOH solution and sieving at 200 μm. Plant and mineral particles (> 200 μm) were separated by floatation in water. The bioavailability of SOC (mg kg^{-1} h^{-1}) [based on the SOC content (g C kg^{-1}) of the upper 10 cm of soil below the chamber] was calculated as follows

$$CO_2\text{-}C/SOC = CO_2\text{-}C/SOC \times 10 \quad (1)$$

As the experimental design is unbalanced, we used several tests (HSD Tukey, Scheffe, LSD Fisher with Statistica software) to compare mean CO_2-C emissions among treatments.

The CO_2 concentration inside the chambers increased by 0.05 to 0.7% (on average, 0.3%) in 1 h. The CO_2-C emissions ranged from 93 to 422 mg C m^{-2} h^{-1}; coefficient of variation for all measurements in a replicate was about 20%. Emissions followed the order: MG ≤ Pr ≤ P (Table 1). Soil and air temperatures under the chamber, 29.5 ± 0.4°C and 37.8 ± 0.8°C respectively, did not vary between spatial replicates or among the 4-d measurement periods. Soil moisture was close to 75% of field capacity (between 50 and 75% of the water filled pore space) for all plots and measurements.

The SOC and particulate organic matter contents paralleled trends in CO_2-C emissions (MG < Pr < P) (Table 1). In Pr, SOC in the 16 replicates varied widely, ranging from 15 to 31 g C kg^{-1}. CO_2-C emissions were positively correlated to SOC content ($P < 0.05$), and also to particulate organic matter ($P < 0.01$) for mean data from all sampling locations in the three fields (Fig.1a, b). The CO_2-C emissions increased less than SOC with pasture establishment, the estimate of the correlation was 4.01 ± 1.55 ($P = 0.017$). This is illustrated in Fig. 2.

There was no correlation between CO_2-C emissions and temperature or moisture, reflecting uniform temperatures and moisture (the latter because of irrigation). CO_2-C emissions were in the same range as values reported in the

Table 1 Soil characteristics and mean CO_2-C emissions in market gardening (MG), long-term pasture (P) and re-grassed pasture (Pr)

	MG				P				Pr			
Parameters	m	min	max	es	m	min	max	es	m	min	max	es
Particulate organic matter (gC kg^{-1})	5*a*	3	7	0.7	22*b*	18	31	2.6	14*c*	8	24	0.9
SOC (g kg $soil^{-1}$)	12.7*a*	9.9	15.3	1.1	36.9*b*	35.8	38.0	0.5	23.2*c*	15.4	31.4	1.1
CO_2-C (mg m^{-2} h^{-1})	162*a*	93	223	24	281*b*	168	422	49	215*ab*	154	286	10
CO_2-C/SOC (mg $kg^{-1}h^{-1}$)	126*a*	80	149	14	76*b*	59	112	13	96*ab*	56	131	6

m = mean; es = standard error; min = minimum; max = maximum.
a–c In the same line, values followed by the same letter are not significantly different ($P < 0.05$, HSD Tukey test, other statistical tests gave similar results).

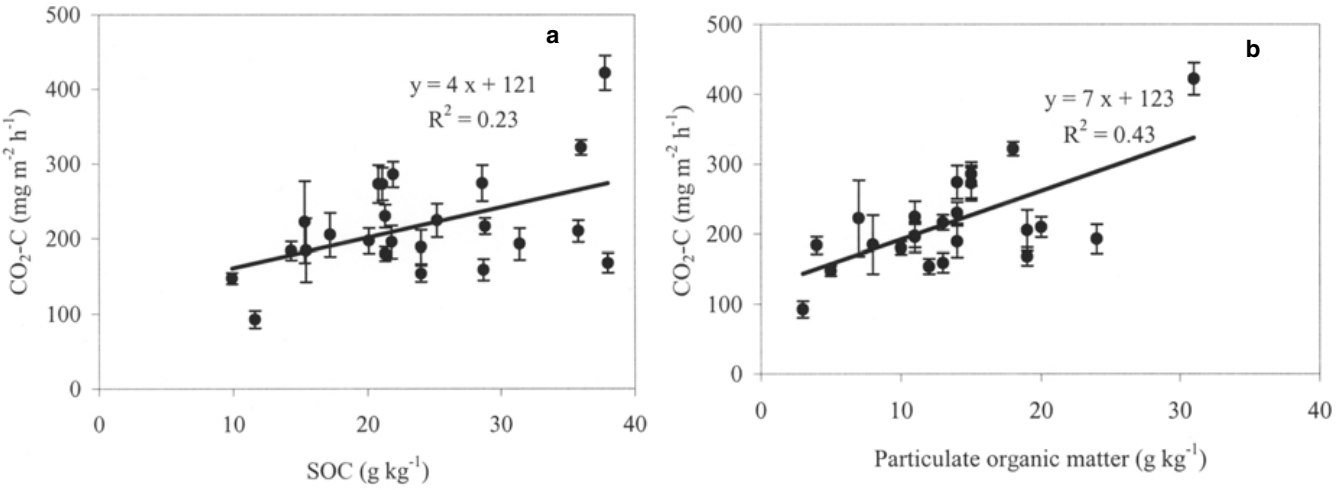

Fig. 1. Relationship between CO_2-C emissions (mg CO_2-C m^{-2} h^{-1}) and (a) soil organic carbon (SOC) (g C kg^{-1} soil) and (b) particulate organic matter content (g dry matter kg $soil^{-1}$) including root biomass and coarse plant debris in soil (>200 μm). Bars denote standard errors.

literature (60 to 500 mg CO_2-C m^{-2} h^{-1}) (Feigl et al. 1995; Davidson et al. 2000; Michelsen et al. 2004). Differences among treatments followed a trend (MG ≤ Pr ≤ P) similar to that observed by Dugas et al. (1999) in a sorghum field (177 mg CO_2-C m^{-2} h^{-1}), a 1-yr-old Bermuda grass pasture (196 mg CO_2-C m^{-2} h^{-1}), and a native grassland (275 mg CO_2-C m^{-2} h^{-1}). The increase in SOC content and root biomass under pasture and their positive correlations with CO_2-C emissions explained this result. This was shown many times by soil respiration measurements in the laboratory and to a lesser extent in field. The increase of CO_2-C emissions under pasture was the result of a larger quantity of C substrate for microbial respiration and also from enhanced root respiration. Separating CO_2-C emissions of the SOC from those of root respiration was difficult, because root respiration is a variable proportion (13 to 90%) of emissions (Dugas et al. 1999). Our analysis suggests, however, that particulate organic matter (including live and dead roots and litter) accounted for 43% of total respiration (Fig. 1b).

Did SOC accumulate in Pr soil because of higher C inputs or because of a smaller fraction of SOC lost to respiration? The relative C mineralization rate (CO_2-C/SOC) in soils decreased as SOC increased (Fig. 2), implying that the bioavailability of SOC decreases as its amount increases. The microbial biomass represented 3 and 6% of the total SOC content in MG and P, respectively (Kabir et al. 1994). The metabolic quotients of microbial biomass, as a first approximation (because microbial biomass was measured at the same site but not in the same time) were 100 and 30 μg CO_2-C $gC_{microbial}^{-1}$ (0–10 cm) for MG and P, respectively, suggesting that SOC in pasture soil is chemically stabilized or located in aggregates or pores not accessible to microorganisms or their enzymes. Blanchart et al. (2004) observed increased soil aggregation with pasture establishment because of no-tillage and root growth. Furthermore, previous laboratory studies showed that aggregation could decrease SOC bioavailability. The amount of this protected pool of labile organic matter increased with SOC content and was four times higher in pasture than in market gardening soil (Chevallier et al. 2004). Nevertheless, the amount of protected SOC in soil aggregates accounted only for 1–3% of the SOC content. Other protective mechanisms have also been observed or postulated for pasture soils (Six et al. 2002).

Our study showed lower bioavailability of SOC in pasture soil compared with a cultivated soil, perhaps explaining in part the accumulation of SOC under pasture. This observation in our field study, while still tentative, is in keeping with those from laboratory experiments and merits further attention.

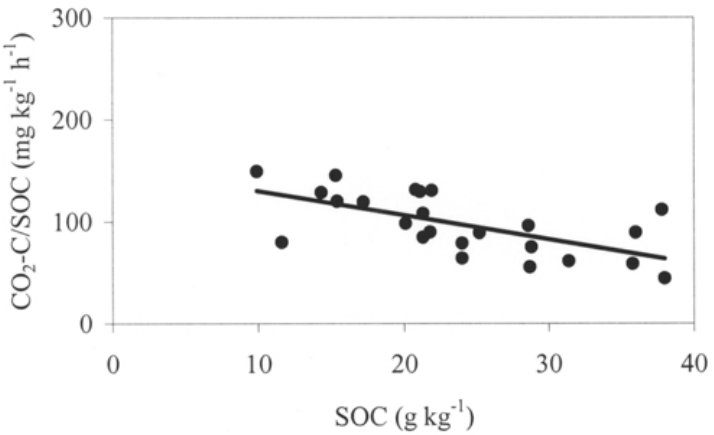

Fig. 2. Relationship between soil organic carbon, SOC (g kg^{-1}) content and the ratio CO_2-C/SOC (mg kg^{-1} h^{-1}). Error bars are standard errors.

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