CO_2 evolution from soil and physical protection of soil organic carbon in a young pasture on Vertisol

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Introduction

Long periods of continuous cropping were recognised to affect soil organic matter (SOM) content and to increase soil erosion. For example, in Martinique several years of intensive farming on vertisols led to an important decrease in SOM and soil aggregation and to an important increase in soil erosion. There is now a need to restore the soil organic matter in order to preserve the soil resources. In literature, pastures seem to be one of the best agrosystems for enhancing the SOM stock in cultivated soils. In Martinique, planting a Digitaria decumbens pasture on a cultivated vertisol increased the soil organic carbon (SOC) stock from 31 to 37 MgC ha^{-1} (0-20 cm) within 5 years (Chevallier et al., 2000). This high storage value could be explained partly by the heavy clayey soil and the high plant inputs.

Nevertheless, we did not know so far if this increase of SOC stock was a result only of an increase of annual organic carbon (OC) inputs from the D.decumbens pasture or also of a decrease of OC outputs by mineralisation. **The first objective** of this study was to show by field CO_2 measurements if that the SOC storage in vertisols could be explained by a relative decrease of SOM mineralisation.

This decrease in SOM mineralisation could be due to a chemical stabilisation of SOM or a physical protection of SOM in soil aggregates to biodegradation. That protection effect was already mentioned in the literature, but few data are available for tropical soils (Beare et al. 1994). In Martinique, Albrecht et al. (1992) observed that soil C promoted the vertisol aggregation as a binding agent. **Our second objective** was to verify throughout laboratory measurements if SOC protection to mineralisation exits in the aggregates of vertisol under pasture.

Materials and methods

The experiment was located in the south-eastern part of Martinique, French West Indies (14°25'N / 60°53'W). The area is characterised by a humid tropical climate. The soil was a smectitic Leptic Hapludert (USDA classification) or Eutric Vertisol (FAO-UNESCO classification) developed on andesite. It has about 50-60% of clay. The soil was irrigated (rain plus irrigation amounted to about 120 mm $month^{-1}$).

Comparative measurements of CO_2 in field and in laboratory were conducted on several plots under different land use systems as long term market gardening (18 years), re-grassed pasture after fifteen years of market gardening and long term pasture (18 years), providing a range of soil carbon content.

1-Field CO_2 evolution measurement

In the field, CO_2 evolutions were measured by the closed chamber method with an infrared gas analysis. Different replicates in time and space were assumed. Each chamber location was defined by its SOC content measured with a Carbon Nitrogen Sulfur Analyser, NA 1500, (Carlo Erba). The contribution of root respiration in total soil respiration was estimated by comparison of CO_2 emissions between untreated soil and soil treated with systemic herbicide, applied 15 days before measurement.

To test the bioavaibility of SOC to microorganisms, we defined an index (I_{CO2}) of daily CO_2 emission relative to the SOC content. For simplification we only use the SOC content of the upper 10 cm. This index (gCO_2-C kgC^{-1} day^{-1}) was calculated as followed:

I_{CO2}= (**C-CO$_2$ $_{annual}$** / 365) / **C**, where **C-CO$_2$ $_{annual}$** is the C-CO_2 annual evolution and **C** is the soil C.

2-Laboratory CO_2 measurements

Soil was sampled, fragmented in clods (diameter 1-2 cm), and air-dried. The air-dried clods of soil were either not crushed or crushed and sieved to 200 µm. Then the soil samples were incubated in a closed vessel at 28 °C during 21 days. The CO_2 produced is absorbed in sodium hydroxide and quantified by titration.

Results and discussion

1- CO_2 evolved from soil measured in the field.

The annual CO_2 flux increased with the duration of the pasture from 14 Mg CO_2-C ha^{-1} yr^{-1} in market gardening to 18-20 Mg CO_2-C ha^{-1} yr^{-1} in five years old pasture and to 25 Mg CO_2-C ha^{-1} yr^{-1} in a long-term pasture. Data for soil respiration rates from tropical pasture in literature (4.7 to 21 Mg C ha^{-1} yr^{-1}) were generally inferior or equal to these values. This could be explained by lower soil moisture in these soils compared to the regularly irrigated soil in our study.

Combining the data of each chamber location, we found a significantly positive correlation (r^2=0.42, $p<0.01$) between SOC stock and CO_2 fluxes (Fig.1). Since soil respiration is the sum of microorganisms respiration and root respiration, the high CO_2 evolution in the richer SOC soils could be related to a higher root respiration according to the presence of more roots. We compared the soil respiration between plots without living roots (herbicide application) and plots with living roots, and assumed that in this pasture the contribution of root respiration was about 12 %, to the total soil respiration. This value did not explain all the extra CO2 evolved from richer SOC soils. A larger SOC content in soils gave a larger quantity of OC substrates for soil microorganisms metabolism and then a larger CO_2 emissions from soils. This was even verified by many laboratory measurements but more sparsely by field measurements.

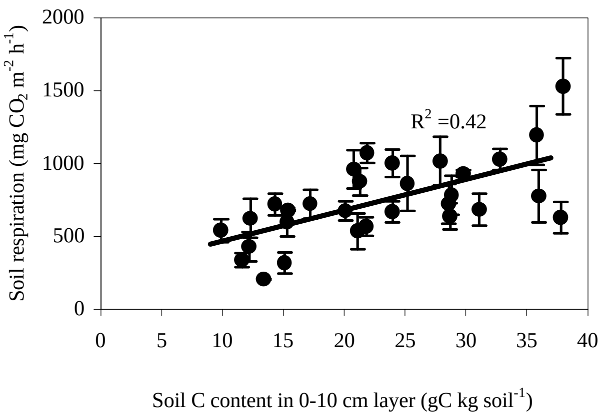
The index (I_{CO2}) of daily CO_2 emission relative to the SOC content decreased with the duration of the pasture and with the C content (r^2= 0.40, $p< 0.01$, Figure 2). In spite of continuous larger C inputs in the re-grassed soil, the bioavaibility of the SOC decreased with the pasture establishment. These results illustrate a protection of SOC against mineralisation and subsequently a storage of OC in soils with the pasture establishment. This process of SOC protection against mineralisation could be a chemical stabilization of organic compounds, or a limited access of the SOM to microorganisms (physical protection). The second part of this study was to verify or not this latter hypothesis.

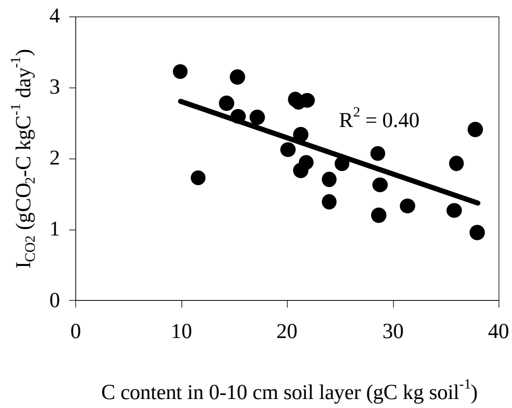
2- Bioavailability of SOC *characterised in standard conditions*

In standard conditions, as well as in the field, the CO_2 evolved was higher in richer SOC content soil, from 0.26 to 1.04 gC kg $soil^{-1}$ for clod samples (Figure 3). These values were higher when the samples were crushed (Figure 3), there was then a "de-protection" of some organic materials when the soil has been crushed before incubation. This amount of organic carbon protected in soil structure (200 µm – clods) was higher when the SOC content was higher (Figure 3). Moreover in the long term pasture soil drying-rewetting treatments, which are known to affect intimately the soil structure, also increase C mineralisation more than in the market gardening soil (Figure 3).

These results were comparable to Beare et al. (1994) and Gijsman and Sanz (1998) results, where experiences of tropical soil incubation were conducting in quite the same conditions as in our study (crush to 250 µm and un-crushed samples and soil incubation of 20 and 41 days) (Figure 4). Nevertheless, the increase of CO_2 emission after crushing seemed to be generally lower in temperate conditions than in tropical conditions and larger in cultivated soils than in virgin soils. But few data were available to really conclude.

The second hypothesis mentioned after field CO_2 measurement was verified. In pasture, no soil disturbance plus the development of root enmeshment is promoting soil aggregation. Indeed, Angers (1992) and Jastrow (1996) in temperate re-grassed soil observed an increase of soil aggregation before the OCaccumulation in the soil. The SOC can then promote the vertisol aggregation as a binding agent (Albrecht et al. 1992) and in positive feedback, the soil aggregation can promote the SOC storage. Recent C inputs in regrassed soil from D.decumbens could be then incorporated in soil aggregates (Golchin et al. 1994) and then be partly physically protected from mineralisation (Beare et al. 1994).





In Chevallier et al. (2000) we calculated that 15 % of the total C inputs in five years were stored in this vertisol.

Figure 1a Relationship between CO2 evolution and SOC stock

Figure 1b Correlation between ICO_2 and SOC stock

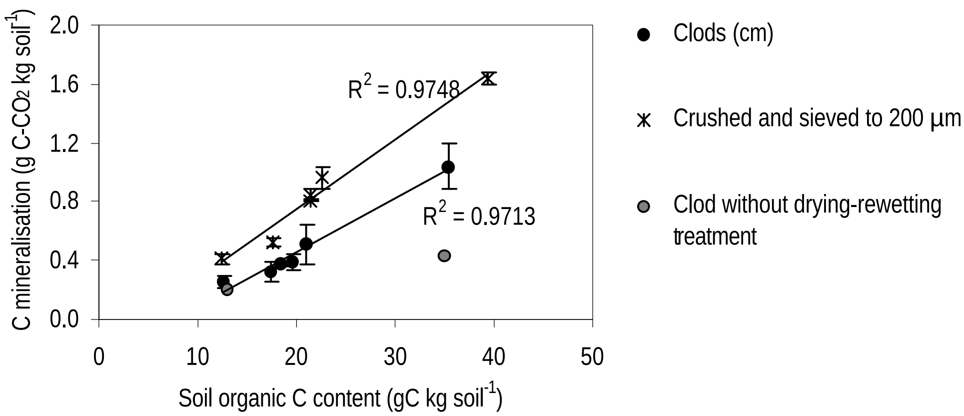


Figure 2 Correlation between soil respiration and SOC content in standard conditions on clods and crush samples.

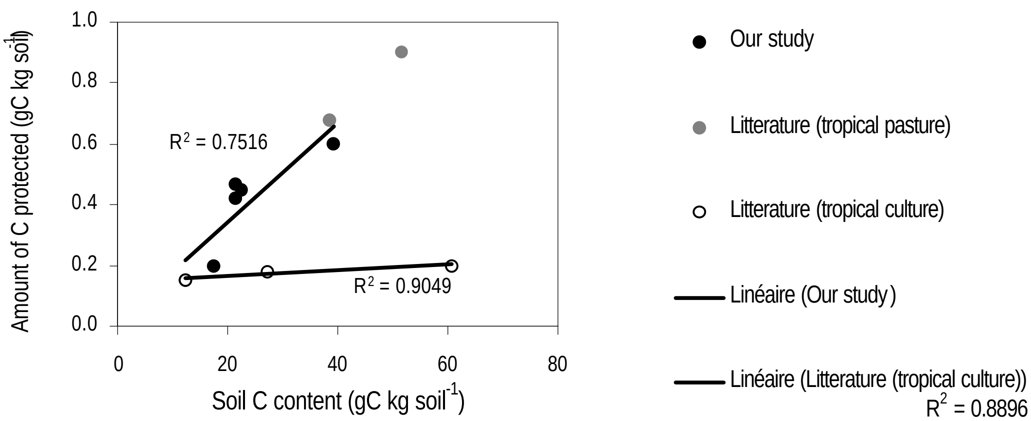


Figure 3 Correlation between SOC content and amount of protected SOC against mineneralisation in our study and other tropical study (Beare et al. 1994, 20 days of incubation; Gijsman and Sanz 1998, 41 days of incubation).

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