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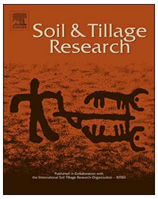

Predicting the in situ rate constant of soil carbon mineralisation from laboratory-based measurements in tropical soils under contrasting tillage management systems

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ABSTRACT

Predicting soil organic carbon (SOC) mineralisation in the field is crucial to assessing the impact of changes in land use and tillage practices. Although soil data from long-term field experiments are essential to calibrate model parameters for SOC mineralisation, these are frequently lacking regarding some parts of the tropics. The aim of this study was to develop and test an indicator for the in situ SOC mineralisation rate constant using data obtained during soil incubation in the laboratory. Sixty-nine plots corresponding to four soil types (andosol, nitisol, ferralsol and vertisol) under six crops (banana, sugarcane, vegetables, yam, melon and pineapple) involved in 12 tropical cropping systems were analysed. Soil sampling and laboratory incubation procedure were designed to reflect the long-term impact of cropping systems on SOC dynamics. Data from long-term experiments were obtained from a previous study performed on the same cropping systems in Guadeloupe (Caribbean). While SOC contents and stocks were only controlled by soil type, mineralised SOC in the laboratory (C_{min}) was controlled to the same degree by both soil type and crop. Moreover, the C_{min}/SOC ratio, which is an indicator of the more active SOC fraction, was only controlled by the crop. Although C_{min} and C_{min}/SOC were not affected by recent C inputs from crop residues, they were negatively correlated with the rate constant of SOC mineralisation observed in the field (k_{field}). These results indicate that differences between the cropping systems (i.e. perennial vs. annual crops) concerning the management of soil tillage markedly affected depletion of the mineralisable SOC fraction. Overall, the results showed that C_{min} measured under regulated laboratory conditions could be helpful to estimate k_{field}. This is important in tropical regions in order to anticipate the effects of changes in land use and tillage management before changes in SOC stocks become noticeable in the field.

1. Introduction

The accurate prediction of soil organic carbon (SOC) mineralisation under field conditions is of crucial importance from both the agronomic and environmental points of view (Oelbermann et al., 2017). In the long-term (e.g. decade or century), predicting SOC mineralisation is necessary to assess the impact of changes in land use, farming practices and tillage management on soil quality and C emissions (Lal, 2004). Although some authors used soil incubations to estimate the rate constants to be included in models devoted to conceptualising and describing SOC mineralisation in the field (Brisson et al., 2003), an alternative procedure involves the statistical fitting of data obtained from diachronic measurements of SOC content in the field (e.g. Andriulo et al., 1999; Sierra et al., 2015). The advantage of this method over laboratory incubations is that it integrates all aspects of managing the plant-soil system over many years, including the impacts on SOC turnover of crop residue management and soil tillage (Cerri et al., 2007). However, this method requires a relatively important soil database including information on the farming practices that affect SOC turnover (e.g. rotations, amount and quality of crop residues, management of organic amendments, intensity of soil tillage), which may be unavailable, particularly in tropical regions (Sierra et al., 2017).

Although changes in agricultural management may influence the mineralisation rate constant, the ability of the models of SOC dynamics to assess the impact of such changes depends on including of farming practices in the model framework. For example, only a few models of SOC dynamics have explicitly considered the increase in SOC decomposition following soil tillage (Bortolon et al., 2009), which is a major process that affects the SOC balance (Martínez et al., 2017). In the case of the Century model adapted to the conditions of Southern Brazil, soil tillage is represented by a cultivation parameter which operates as a multiplier to enhance the mineralisation rate constant of SOC fractions

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Table 1

Some soil properties of the 0–0.25 m soil layer corresponding to the 12 cropping systems analysed during this study. For each property, mean values followed by different letters are significantly different at $P < 0.05$. SOC: soil organic C; SON: soil organic N; C_{min}: mineralised C accumulated during the 15-wk laboratory experiment.

Soil	Crop	Number of plots	Bulk density $Mg\,m^{-3}$	pH	SOC $g\,kg^{-1}$	SON	SOC/SON ratio	SOC stock $Mg\,ha^{-1}$	C_{min} $g\,C\,kg^{-1}$	C_{min}/SOC ratio %
Andosol	Banana	6	0.81d	5.9 b	40.8 a	4.0 a	10.0 a	82 a	1.63a	4.2bc
Andosol	Vegetables	5	0.82d	5.9 b	32.8 a	3.2 a	10.0 a	66 a	1.12b	3.4c
Nitisol	Banana	5	0.92c	5.1 c	19.9 b	2.0 b	9.9 a	45 c	1.20b	6.2a
Nitisol	Vegetables	5	0.92c	5.0 c	21.2 b	2.1 b	9.8 a	48 c	0.51e	2.4d
Ferralsol	Banana	5	1.05b	5.2 c	24.1 b	2.4 b	9.9 a	63 ab	1.05bc	4.6b
Ferralsol	Sugarcane	6	1.05b	5.2 c	21.4 b	2.1 b	10.0 a	56 b	0.55e	2.5d
Ferralsol	Yam	5	1.07b	5.2 c	21.3 b	2.1 b	9.9 a	56 b	0.59e	2.8d
Ferralsol	Pineapple	6	1.03b	5.1 c	21.1 b	2.1 b	10.0 a	55 b	0.89cd	4.2bc
Vertisol	Sugarcane	8	1.14a	7.1 a	21.8 b	2.1 b	9.9 a	60 b	0.74de	3.4c
Vertisol	Vegetables	6	1.12a	7.2 a	21.4 b	2.2 b	10.0 a	59 b	0.78de	3.6bc
Vertisol	Yam	5	1.14a	7.0 a	21.6 b	2.1 b	10.0 a	59 b	0.80de	3.7bc
Vertisol	Melon	7	1.15a	7.2 a	21.6 b	2.2 b	10.0 a	59 b	0.73de	3.4c

during the two months that follow tillage operations (Bortolon et al., 2011). However, it may be difficult to extrapolate this empirical approach based on local information about farming practices to other tropical regions such as the Caribbean, where these practices may vary considerably as a function of farmer's resources and the orientation of agricultural production; e.g. perennial crops such as sugarcane and banana vs. annual food and vegetable crops (IFAD, 2014). For example, Sierra et al. (2017) found that vegetable crop systems in Guadeloupe, an archipelago in the Caribbean, could be represented by five farm types that applied contrasting tillage systems on very different soil types, ranging from manual cultivation to more labour-intensive strategies which include up to six tillage operations per year. By contrast, soil tillage under perennial crops is only applied once every five or six years, at the time of planting (Raphael et al., 2012).

Compared with complex models of SOC dynamics, simple models of the annual SOC balance require minimal data inputs and few parameters (Saffih-Hdadi and Mary, 2008) and are therefore well suited to situations with scarce agricultural data, such as in the Caribbean. This also concerns the lack of suitable model parameters regarding most tropical food and vegetable crops (Nin-Pratt et al., 2011). Undoubtedly, such models may be less robust than process-based models, so that their accuracy in assessing the impact on SOC dynamics of new cropping systems or changes of farming practices needs to be tested (Coucheney et al., 2015). In this context, the use of soil indicators of the SOC mineralisation rate constant calibrated from long-term field experiments may be helpful to predict SOC changes under new agricultural scenarios. This is important in tropical regions in order to anticipate the effects of changes in land use (e.g. conversion of food to energy crops) and practices (e.g. manual vs. mechanical soil tillage) (FAO Subregional Office for the Caribbean, 2013), before changes in SOC stocks may be noticed in the field.

In a previous study, Sierra et al. (2015) designed the MorGwanik model of SOC dynamics adapted to the pedoclimatic conditions of the Caribbean in order to assess SOC changes under export and diversified agriculture at the level of the Agro-Ecological Region (AER). The aim of the present study was to evaluate the ability of an indicator based on SOC mineralisation under laboratory conditions to predict the mineralisation rate constants obtained by these authors from long-term field studies, which involved twelve cropping systems under contrasting tillage management. To achieve this, four conditions were imposed to the laboratory experiment: i- only soils under monoculture were selected for the trial in order to best reflect the impact of the management of each crop, ii- soil sampling from each selected plot was carried out on sub plots that did not receive crop residues following the harvest of the previous crop, in order to reduce their effect on the mineralisable C fraction, iii- soil samples were neither dried nor disrupted to reduce the presence of artefacts linked to sample handling during soil incubation (e.g. the Birch effect; Jarvis et al., 2007) and, iv- relatively long-term soil incubation periods (i.e. 15 wk) were applied to obtain a substantial amount of mineralised C so as to ensure the reliability of the analysis. Under these conditions, we hypothesise that SOC mineralisation during the laboratory experiment reflects the impact of the cropping systems on SOC dynamics in the field. The goal was therefore to develop and to test an indicator that could be used during future research concerning the impact of new agricultural practices on SOC stocks in the soils of the Caribbean region. The study was carried out in the Guadeloupe archipelago (Lesser Antilles) which within a small area displays nearly every physical landscape and cropping system found in the Caribbean.

2. Materials and methods

2.1. Study location

The study was carried out in the Guadeloupe archipelago in the eastern Caribbean. Guadeloupe is composed of two main islands (Basse-Terre: 848 km^2 and Grande-Terre: 586 km^2) and several smaller islands. Only the soils of the two main islands were analysed during this study. Although Grande-Terre is characterised by a gently undulating surface, Basse-Terre Island is dominated by a volcanic mountain chain oriented northwest to southeast with elongated hills with convex slopes in the lowlands. We analysed four soil types (FAO, 2006):

- Andosols located in the uplands of southern Basse-Terre, which had developed on young ash deposits. These soils are acidic (Table 1) and characterised by high allophanic clay contents (75%). The mean temperature in this region is 23.9 °C and the mean annual rainfall is 3800 mm.
- Nitisols located in the lowlands of southern Basse-Terre, which had developed on old ash deposits. These soils are acidic and rich in halloysite clay (70%). The mean temperature is 25.0 °C and the mean annual rainfall is 2200 mm.
- Ferralsols located in the northern and eastern parts of Basse-Terre, which had developed on old ash deposits. These soils are acidic and rich in kaolinite clay (70%) and active aluminium and iron hydrous oxides. The mean temperature is 25.4 °C and the mean annual rainfall is 2300 mm.
- Vertisols located in Grande-Terre, which had developed on coral reef limestone. These soils are relatively alkaline and characterized by a high clay content (80%) dominated by smectite. The mean temperature is 26.5 °C and the mean annual rainfall is 1100 mm.

In all of these regions there is a dry season from December to May; it is less pronounced in the uplands of southern Basse-Terre (i.e. 45% of annual rainfall during the dry season) and more marked in Grande-Terre (i.e. only 30% of annual rainfall during the dry season).