Soil organic carbon content and stock in Martinique – relations to near infrared spectra

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DATA ARTICLE

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Soil organic carbon content and stock in Martinique – relations to near infrared spectra

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Abstract

This data paper presents observations on soil organic carbon (SOC) gravimetric and volumetric contents (SOCg, in g kg^{-1}, and SOCv, in g dm^{-3}, respectively) for 98 profiles at least 30 cm deep (1 m deep for 59 of them), in rural areas of the Martinique island, in relation to soil types and land uses and management. The paper also presents particle size distribution down to 30 cm, and near infrared reflectance (NIR) spectra for the main soil types. This dataset allows evaluating the effects of land use, soil type and texture on SOC content and stock, at regional scale. It also allows inferring SOCg, SOCv and particle size distribution from NIR spectra. Such information is useful for studying and managing soils in the Martinique island and in other tropical volcanic regions.

KEYWORDS

land use and management, near infrared diffuse reflectance, particle size distribution, soil type

1 | INTRODUCTION

Martinique is a 1128-km^2 tropical island of volcanic origin located in the Lesser Antilles (West Indies; ca. 14–15° N, 61° W). A study was carried out to characterize soil organic carbon (SOC) for the main combinations of soil types and rural land uses in this island (Venkatapen, 2012; Venkatapen et al., 2004). In 2019, the island was covered by around 40% forest, 20% agriculture, 20% artificial surfaces and constructions, and 20% unused and abandoned areas; moreover, main agricultural uses were grassland (≈80 km^2), banana (≈50 km^2), sugarcane (≈40 km^2), and market gardening and staple crops (≈20 km^2; Agreste, 2019). According to Colmet-Daage and Lagache (1965) and to the IUSS Working Group WRB (2015), the soil types in the island are as follows:

- Andosols, with allophanes (non-crystalline aluminosilicates), derived from recent volcanic materials under very humid climate (rainfall >2500 mm year^{-1} in average), on mountain slopes;
- Nitisols, with halloysite (1:1 clay), derived from less recent volcanic materials under wet climate (rainfall between 1300 and 2500 mm year^{-1} in average), which form like a crown around mountains;
- Ferralsols, with halloysite and kaolinite (1:1 clays), derived from still older volcanic materials under wet climate (rainfall between 1600 and 2300 mm year^{-1} in average), in piedmont positions;

- Vertisols, with montmorillonite (2:1 clay), derived from volcanic or coral materials under subhumid climate (rainfall <1300 mm year^{-1} in average), in lower areas;
- and to a lesser extent, Regosols, derived from very recent materials (ashes and pumices, or sandy alluvial deposits), and Alisols, which are intermediate between Ferralsols and Vertisols.

2 | MATERIALS AND METHODS

A range of fields was selected to represent the main rural land uses for the main soil types, with similar use for at least 3 years (this condition was not achieved for three fields: BP3 and Ma5, with pineapple, which is always grown for less than 3 years; and Sch1, with market gardening for 2 years; the abbreviations of sampling site names are specified in the fourth column of the data table); moreover, fields accessible by car were preferred. Ninety-eight fields were sampled, in 22 municipalities (out of 34 in the Martinique island), and in particular, in the main agricultural areas (Table 1).

The GPS/UTM coordinates (Global Positioning System/Universal Transverse Mercator projection) collected on the sampling sites were converted to latitudes and longitudes using the ArcGIS software version 10.1 (projection WGS84, that is, World Geodetic System 1984, UTM zone 20N). However, latitudes and longitudes were approximated to the minute (i.e., less than 1-km grid spacing) so that fields could not be identified precisely, to preserve confidentiality.

In each field, one pit was dug using spades and shovels, and soil samples were collected either using a 1-dm^3 cylinder (intact soil), for bulk density determination, or using a knife (disturbed soil), for other determinations. Most pits were dug down to 100 cm depth (with sampling at 0–10, 10–20, 20–30, 30–40, 60–70 and 90–100 cm; 59 pits), but some down to 70 cm (9 pits), 40 cm (27 pits) or 30 cm only (3 pits). In total, 516 soil depth layers were sampled.

Highlights

- The paper presents data on SOC content, SOC stock and particle size distribution in Martinique.
- They allow studying the effects of soil type and land use on SOC in tropical volcanic areas.
- The data also include NIR spectra, which can be used for inferring SOC and texture.
- The sampling density (≈ 0.1 profile km^{-2}) ensures a good representation of Martinique rural soils.

Intact soil samples were dried at 105°C then weighed, and bulk density (Db) was calculated as the ratio of sample dry weight to sample volume (Pansu et al., 2001). All other analyses were performed on fine earth (<2 mm) originating from disturbed soil samples, after they had been air-dried then gently broken up to pass a 2-mm sieve; while coarse particles >2 mm were weighed to determine their proportion in the total soil, at least when they were noticeable (otherwise the weight of coarse particles >2 mm was considered negligible).

Total carbon and nitrogen gravimetric contents in the fine earth (g kg^{-1} soil <2 mm) were determined by dry combustion on 0.2-mm ground aliquots using an elemental analyser CHN (Carlo Erba NA 1500, Milan, Italy; Pansu & Gautheyrou, 2006). Soil inorganic carbon (as carbonates) has not been observed in the island, and so all carbon was considered organic (soil organic carbon, SOC). According to Poeplau et al. (2017), the volumetric SOC content of the total soil (SOCv; gC dm^{-3} total soil)

TABLE 1 Number of fields studied, and in brackets, number of fields where stocks could be calculated for the 0–100 cm soil layer, according to soil types and land uses.

	Banana	Forest	Grassland	Market gardening[a]	Orchard	Pineapple	Sugarcane	Other uses[b]	Total
Andosols	3 (3)	3 (3)	4 (3)	2 (0)	0 (0)	1 (1)	2 (1)	1 (0)	16 (11)
Ferralsols	3 (2)	1 (1)	2 (2)	0 (0)	0 (0)	0 (0)	7 (3)	0 (0)	13 (8)
Nitisols	7 (7)	4 (3)	4 (3)	7 (4)	4 (4)	0 (0)	4 (3)	1 (0)	31 (24)
Regosols on ashes and pumices	3 (0)	0 (0)	1 (1)	1 (0)	0 (0)	1 (0)	5 (2)	0 (0)	11 (3)
Vertisols	1 (1)	4 (2)	9 (5)	3 (2)	0 (0)	0 (0)	3 (1)	0 (0)	20 (11)
Other soils[c]	1 (0)	0 (0)	2 (1)	2 (0)	0 (0)	0 (0)	2 (1)	0 (0)	7 (2)
Total	18 (13)	12 (9)	22 (15)	15 (6)	4 (4)	2 (1)	23 (11)	2 (0)	98 (59)

[a]Market gardening and staple crops.
[b]Flower crops and traditional 'creole garden'.
[c]Alisols and Regosols on sandy alluviums.

TABLE 2 Soil organic carbon (SOC) stock at 0–40 cm depth according to soil type and land use.

Soil type or land use[a]	SOC stock at 0–40 cm ($kg\ m^{-2}$) Number of profiles	Mean	Standard deviation
Alisols	4	5.2	1.9
Andosols	16	6.6	2.0
Ferralsols	13	6.6	2.6
Nitisols	31	4.8	1.5
Regosols on ashes and pumices	11	3.1	1.2
Regosols on sandy alluviums	2	3.8	0.0
Vertisols	18	6.9	2.2
Banana	18	4.1	1.6
Forest	12	8.0	1.8
Grassland	20	6.1	2.0
Market gardening and staple crops	15	4.4	1.7
Orchard	4	3.9	0.7
Pineapple	2	4.4	1.4
Sugarcane	22	6.0	2.2

[a]Flower crops (one field) and traditional 'creole garden' (one field) not considered.

was calculated as the product of gravimetric SOC content (SOCg; $gC\ kg^{-1}$ soil <2 mm) and Db (kg total soil dm^{-3} total soil) weighted by the proportion of fine earth in the total soil (kg soil <2 mm kg^{-1} total soil). Then SOC stock at the profile level ($kgC\ m^{-2}$) could be calculated as the sum of SOCv over the profile considered, for a given soil depth (for depth layers 40–60 and 70–90 cm, which were not sampled, SOCv could be interpolated from SOCv determined at 30–40, 60–70 and 90–100 cm) or a given soil mass (Ellert & Bettany, 1995).

The particle size distribution was determined by the pipette method after the removal of organic matter by 30% hydrogen peroxide (H_2O_2): fractions 500–2000, 200–500, 50–200 and 0–50 μm were extracted by wet sieving at 500, 200 and 50 μm, respectively, fractions 0–20 and 0–2 μm by sedimentation, and fractions 20–50 and 2–20 μm were calculated by difference (Pansu & Gautheyrou, 2006).

Soil diffuse reflectance spectra were measured in the near infrared (NIR) between 1100 and 2498 nm at 2 nm interval using a Foss NIRSystems 5000 spectrophotometer (Laurel, MD, USA; instrument purchased in 2003). After 12-h oven drying at 40°C, samples were placed in a ring cup with a quartz bottom, gently packed using a round cardboard, then scanned through the quartz window using a feeder for ring cups. Each NIR spectrum resulted from the averaging of 32 co-added scans. For each sample, spectra were acquired on two subsamples, then averaged and converted into absorbance [absorbance = $\log_{10}(1/\text{reflectance})$].

Gravimetric SOC and total nitrogen (Nt) contents ($g\ kg^{-1}$ soil <2 mm) and Db were measured for 516 soil layers. Stocks of SOC and Nt at 0–30, 0–40, 0–70 and 0–100 cm could be calculated for 98, 95, 68 and 59 fields, respectively (Table 1). The particle size distribution was determined on all 294 samples collected at 0–10, 10–20 and 20–30 cm depth. Near-infrared reflectance spectra were acquired on 407 samples. All the data were presented in Barthès et al. (2023), with metadata including the location, sample depth, soil type and land use (with its duration and previous use, when known).

3 | EXAMPLES OF RESULTS

The dataset represents soils from Martinique, which are representative of other tropical regions from volcanic origin, in the West Indies and elsewhere. Different results could be drawn from the data presented here, regarding, for instance, the effect of soil type and land use on SOC (SOCg and SOCv contents, SOC stock). As an example, Table 2 presents the effects of soil type and land use on SOC stock at 0–40 cm, which, for instance, tended to be higher in Vertisols, Andosols and Ferralsols, and lower in Alisols, Nitisols and Regosols; SOC stock also tended to be higher under forest, grassland and sugarcane, and lower under market gardening, pineapple, banana and orchard.

The data presented could also be used for inferring soil properties from NIR spectra. The prediction of SOCg using NIR spectra is presented as an example, and was achieved using the WinISI software version 4.20 (Foss NIRSystems/Tecator Infrasoft International, State College, PA, USA).

For this purpose, a principal component analysis was firstly performed on the total set of spectra, to identify spectra with Mahalanobis distance >5, which were considered outliers (i.e., spectra far away from the set average spectrum in the principal component space, as calculated with the Mahalanobis distance; Mark & Tunnell, 1985): 10 outlier samples, from a spectral viewpoint, were removed from the total set, which then included 397 samples. This sample set was divided into a calibration set, which included the first half of samples when ranked alphabetically (201 samples, from AB1_1 to RS3_6, cf. the first column of the data table), and an external validation set, which included the remaining samples (196 samples, from SA1_1 to SP6_5); so samples from a given municipality either belonged to the calibration set or to the validation set. All spectra were pretreated using first-order detrending, which is a common mathematical transformation for removing linear trends on powdered samples (Barnes et al., 1989), and has been considered appropriate for SOC predictions (Cambou et al., 2021). In the calibration set, detrended spectra were then fitted to observed SOCg values using partial least squares regression (Wold et al., 2001), which is currently the most popular regression procedure for NIR predictions, regarding soil properties especially (Barthès & Chotte, 2020); this procedure is based on latent variables, the number of which was determined by minimizing the root-mean-square error of four-group cross-validation over the calibration set. Then the calibration equation was applied to detrended NIR spectra of the external validation set, to predict their SOCg content: the comparison between observed vs. NIR-predicted SOCg values yielded a root-mean-square error of prediction (RMSEP) of 3.6 g kg^{-1}, $R^2 = 0.83$ and RPD = 2.4 (ratio of standard deviation of observed values in the external validation set to RMSEP), which, according to Chang et al. (2001), is accurate (Figure 1). This result is remarkable considering that the studied validation set covered a large diversity in terms of sampling depth (0–10 to 90–100 cm), clay content (7 to 86%) and mineralogy (Andosols with allophanes, Nitisols and Ferralsols with 1:1 clays, Vertisols with 2:1 clay). Other soil properties included in the dataset could also be inferred from NIR spectra, for instance, the particle size distribution (cf. Barthès et al., 2008), SOCv or SOC stock (cf. Cambou et al., 2021), which are tedious and/or costly to determine conventionally.

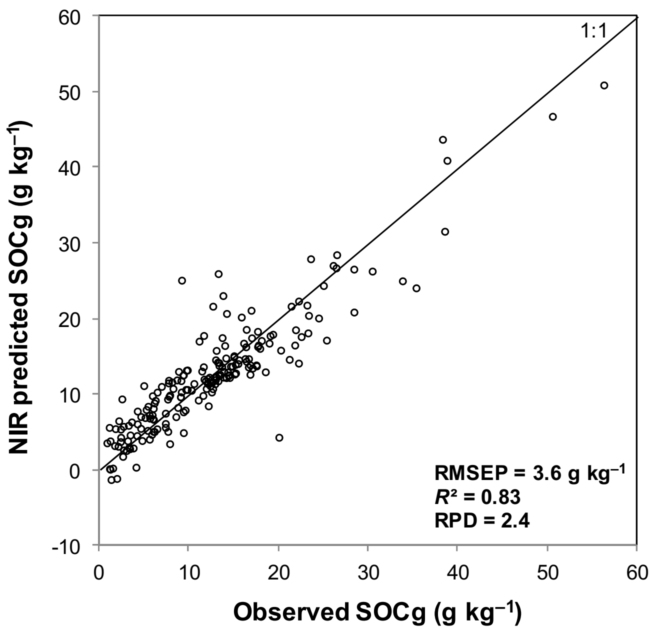

FIGURE 1 Comparison between observed and NIRS-predicted values of gravimetric soil organic carbon content (SOCg, in g kg^{-1}) over the external validation set. RMSEP, root-mean-square error of prediction.

4 | DISCUSSION AND CONCLUSION

Several datasets that document soil properties are available. Some of them cover large areas and include infrared data, for instance, in Australia (Baldock et al., 2013, with spectra in the mid-infrared, MIR), the USA (Dangal et al., 2019, with MIR spectra) or EU (Panagos et al., 2022, with visible and NIR spectra). The soil properties considered are often usual ones (SOCg, pH, clay and carbonate contents, etc.), but variables more tedious to determine conventionally are available sometimes, such as Db and SOCv in the abovementioned Australian and US datasets. However, these datasets involved less dense sample collection than the present one (<1 to 5 vs. 87 sites 1000 km^{-2}, respectively), and more superficial sampling (0–30 cm depth). So the present dataset allows detailed study of SOCg and SOCv down to 100 cm depth in relation to NIR spectra, soil type, texture, current and previous land use, at regional scale. To our knowledge, such regional dataset on SOC (and NIR) has not been widely disseminated yet. Moreover, this dataset can be useful for the study of other tropical volcanic areas.

AUTHOR CONTRIBUTIONS

Bernard G. Barthès: Writing – original draft; methodology; visualization; formal analysis; data curation; validation. **Corinne Venkatapen:** Conceptualization; methodology; investigation; formal analysis. **Aurélie Cambou:** Visualization; writing – review and editing. **Eric Blanchart:** Conceptualization; methodology; supervision; project administration; resources; funding acquisition.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY STATEMENT

The data and related documentation attached to this data paper are openly available in DataSuds repository (IRD, France) at https://doi.org/10.23708/C2TV6W. They have been licensed under a Creative Commons Attribution-NonCommercial 4.0 International License (CC-BY-NC).

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