Assessing organic soil carbon stock in extensive livestock system based on native grasslands

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Key words: livestock production, soil classification, Uruguay, natural capital

Abstract

Soil organic carbon content is a central characteristic for sustaining the productive system and the provision of important ecosystem services, including carbon sequestration. Knowing the carbon stock in the soil is important in order to design and manage strategies for its conservation and capture. The main objective of this work is to characterize the carbon stock in livestock systems in Uruguay and explore estimation methods based on satellite information.

Twelve farms with extensive mixed livestock production (cattle and sheep) located on the basaltic slope geomorphological region of Uruguay were evaluated. Three categories of soil were defined (superficial, medium and deep) with an average depth of 9.0, 18.5 and more than 30 cm depth respectively. This classification of soils was done through the normalized vegetation index (NDVI) obtained for selected dates when low soil water content was evident. The ability to maintain green vegetation due to soil water content is strongly linked to depth. Ten sites were randomly selected for each soil category also considering the representativeness of the main soil cartographic units (CONEAT) where 20 soil core samples up to 30 cm deep were extracted with a drill and divided into four strata: 0 to 5, 5 to 10, 10 to 20 and 20 to 30 cm. A specific sampling was performed for determining bulk density. The organic carbon stock was calculated for each soil category. The sampling locations were geo-referenced and the soil carbon values and average NDVI for the last 5 or 10 years was calculated for determination of correlations. The determined carbon stocks we found varied between 16 Mg/ha in extremely superficial soils and 144 Mg/ha up to 30 cm deep in deep soils. Based on these results, we now propose to develop a reliable method for estimating carbon stocks across the basaltic slope region using models based on remote sensing variables.

Introduction

Soil organic carbon content is a central characteristic for sustaining a productive livestock system and the provision of important ecosystem services, including carbon sequestration. Knowing the carbon stock in the soil is important to manage and design strategies for its conservation and capture.

The heterogeneity of soils in the conditions of the native grasslands of Uruguay makes it essential to categorize them using remote sensing tools which are complementary to available cartography and carry out exhaustive sampling to determine the carbon contents. On the other hand, given the few studies carried out in the basaltic slope region of the country, this work seeks to provide a referential baseline and demonstrate the association of the soil carbon content with the physicochemical characteristics of the soils.

The objective of this study was to characterize soil carbon stocks in livestock systems in this region, analyzing the relationships with other soil physical variables and the possible influences of livestock management.

Methods

Study sites and sampling design

Twelve farms located on the basaltic slope geomorphological region in the north of Uruguay, corresponding to extensive mixed livestock farming (cattle and sheep), were evaluated.

For the field sampling design, a classification of soils was carried out according to soil depth based on the normalized vegetation index (NDVI) obtained from Sentinel images. These images are selected on dates with marked water deficit, which allows us to differentiate the water retention capacity and therefore maintain green vegetation, where higher NDVI values indicate deeper soils. Three categories of soil were defined: superficial. medium and deep. In each of these categories, 10 sampling sites were randomly selected and identified on the map. Moreover, a national cartography of soils -CONEAT- (MGAP, 2024) was overlapped to assure equitable representation of soil type classification in the sampling design (Fig 1).

Field sampling

Soil sampling was carried out by extracting columns 30 cm deep with a drill, which were then divided into strata from 0 to 5, 5 to 10, 10 to 20 and 20 to 30 cm. In each sampling unit, samples were composed of sub-samples (30 in average) taken from a virtual circle of 15 m radius. For soil categories that did not reach 30 cm in depth, the depth of soil until contact with the rock in each subsample was determined, thus obtaining an average depth for each site. Additionally, with the same stratification, samples were taken in metal cylinders of 5 cm deep and 5 cm diameter to determine the bulk density.

In the laboratory, the first step is the drying of samples for grinding and the removal of roots, rocks and remove any fraction that exceeds 2 mm. In the sieved samples, organic carbon in soil was determined by dry combustion of the sample and subsequent detection of CO2 by infrared. Determinations of organic carbon was done in INIA´s soil laboratory, using a Leco CN-2000 dry combustion analyzer, with a test method conforming to Wright and Bailey (2001). Additionally, soil texture analysis was performed at each sampling site.

Stock calculation

In the last stage. the calculation of the soil organic carbon stock was carried out for each depth, multiplying the value obtained in the laboratory by the bulk density and depth of the stratum. By adding the different strata, the quantity in the profile for a unit of area was obtained, providing the stock in Mg C/ha. The final SOC stock for each soil category was obtained by multiplying the total surface area of each soil category by the soil carbon stock

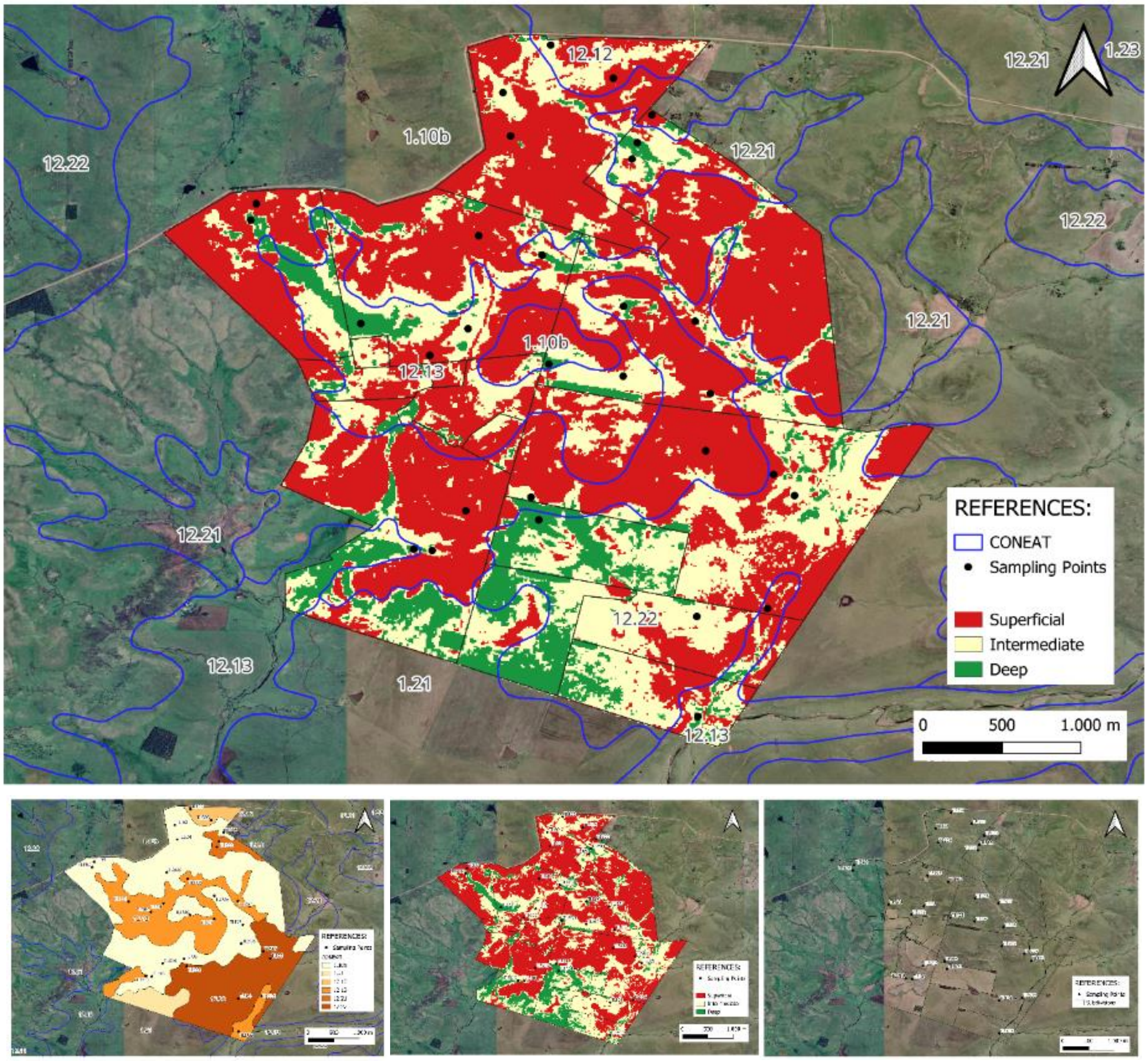

Fig 1- Example of sampling design considering the three categories of soil determined by NDVI (superficial. intermediate and deep) and the representation of the CONEAT cartogtaphy.

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Results

Physical-chemical variables

The result of analysis showed a tendency for reduced carbon contents and increased bulk density in deeper strata. Within each depth strata, no differences were detected for different soil depth categories or CONEAT soil categories. Table 1 shows the average values of the variables determined in the soil samples.

Table 1 – Results of physical-chemical analysis of soil

Depth strata (cm)	Organic carbon (%)	Sand (%)	Silt (%)	Clay (%)	Bulk density (g/cm^3)	pH	Org. carbon Mg/ha
0-5	5.32 ±1.45a	20.3±14.2a	32.6±12.0a	47.1±11.6a	0.92±0.17c	5.8±0.5d	22.9±5.6b
5-10	3.68 ±0.87b	17.8±17.8ab	30.3±12.4ab	51.9±13.9ab	1.06±0.14b	6.0±0.5c	17.2±5.4c
10-20	3.30±0.75c	14.7±11.5ab	28.3±12.1ab	57.0±13.2bc	1.11±0.16a	6.3±0.6b	29.2±11.1a
20-30	2.85±0.61d	13.2±10.4b	26.7±10.1b	60.2±12.4c	1.12±0.13a	6.5±0.6a	24.0±11.5b

Table 2 shows the average depth of each soil category, the proportion of area for the different categories in the farms and the total carbon stock by hectare are presented.

Table 2- Contents of organic carbon, depth and proportion occupied in farms for each soil class.

Soil class	**Depth cm (mean ± SD)**	**Proportion (%)**	**Org. C stock Mg/ha (mean ± SD)**
Deep	30.00±0.00	46.3±18.9	118.4±17.3
Intermediate	18.50±7.71	36.0±12.5	60.7±25.6
Superficial	8.95±6.99	17.7±12.8	26.9±11.4
Farm average			82.0±10.6

Within each strata correlations between organic carbon content and texture were intermediate, ranging from 0.43 and 0.57 with clay content and -0.9 and -43 with sand content. The strongest correlation was obtained for bulk density ranging from -0.59 and -0.74.

In the exploratory analysis, no significant correlations were found between soil carbon content at each sampling point and the NDVI average of the last 5 and 10 years.

Discussion

The results show a large stock of carbon in the soil, with an average of 82 tons per hectare, even when about 54% of the area did not reach a 20 cm of soil depth. Shallow soil depth creates a real challenge to increase soil carbon stocks and sequester carbon, although some studies predict a potential (Dondini et al, 2023). However, it emphases the importance of grazing land use to maintain large amounts of carbon in the soil.

As expected, the carbon content decreases with soil depth, which is probably partly explained by the heavy textural horizon of these types of soil that prevents a massive penetration of roots deeper in the soil profile.

Considering the different types of soil according to CONEAT cartography or the three depth categories, no differences were found in the soil carbon contents within the same depth strata. This indicates that any variations found between different farmers and points within the same farm should be explained by other variables. We consider that one of these variables may be the management history of the farm or paddock within a farm, which could have led to change in vegetation biomass and consequently change in soil carbon stock over time. This possibility is impossible to verify given the absence of this information, but it indicates that conditions unrelated to the texture or type of soil may explain any changes in carbon stocks.

The NDVI extracted from Sentinel has not allowed us to detect differences in soil carbon content between different points in basaltic soils, perhaps because of the very small variations in the carbon stock found in this study. Future work to predict carbon stocks using models should be based on other remote sensing variables, such as radar images or combinations of multispectral measures. Use of models supported by remote sensing variables would undoubtedly be an important step forward in carrying out faster analyses, without consuming so much time and effort, and which could be extrapolated to large areas.

Acknowledgements

We want to thank all the farmers involved in the project, as well as the textile companies Chargeurs Luxury Fibers and Lanas Trinidad SA with which the cooperative project was developed.

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