SOIL ORGANIC CARBON (SOC) STOCKS IN THE BRAZILIAN CITRUS BELT: COMPARISON OF SOC MAP DATA AND ON-FARM SOC DATA

Lauro Rodrigues Nogueira Junior[1], Rogerio Resende Martins Ferreira[1], Carlos Cesar Ronquim[1], Vinicius Morales[1], Vinicius Trombin[2], Roseli Reina[2], Fernando Delgado[2]

[1]Embrapa Territorial, Av. Soldado Passarinho, 303, Fazenda Chapadão, CEP 13070-115 – Campinas SP, lauro.nogueira@embrapa.br, rogerio.ferreira@embrapa.br, carlos.ronquim@embrapa.br, vinicius.morales@colaborador.embrapa.br; Fundecitrus, Av. Adhemar Pereira de Barros, 201, Vila Melhado, CEP 14807-040 – Araraquara SP, vinicius.trombin@gmail.com, roseli.reina@fundecitrus.com.br, fernando.delgado@fundecitrus.com.br.

ABSTRACT

The study aimed to estimate the soil organic carbon (SOC) stock in the citrus belt of São Paulo and West/Southwest Minas Gerais States (The main Brazilian Citrus Belt - BCB) and to compare the estimated data with measured data from on-farm orange groves and environmental conservation areas. The Brazilian SOC map was used to estimate SOC stock (topsoil; 0 to 30 cm) across 496,720 hectares of the BCB. Carbon content and soil bulk density were analyzed to determine the C stocks in orange groves and native vegetation areas of representative citrus farms in five sectors of the BCB. Approximately 19,761 million Mg of C was estimated, with 67% stored in orange groves (39.4 Mg C ha^{-1}) and 33% in environmental conservation areas (40.59 Mg C ha^{-1}). On-farm SOC analysis in orange groves (32.27 Mg C ha^{-1}) and native vegetation areas (40.1 Mg C ha^{-1}) is highly valuable for understanding SOC stock estimation results provided by the digital SOC map.

Key words — Atlantic forest, carbon map, orange groves, environment conservation, savannah.

1. INTRODUCTION

The carbon stock of citrus farms in the citrus belt of São Paulo and West/Southwest Minas Gerais states, here referred to as the 'Brazilian Citrus Belt' (BCB) [1], is receiving increasing attention due to its role in the carbon balance of orange production and in climate change mitigation. Given the growing trend in greenhouse gas (GHG) emissions from the agricultural sector, some Brazilian agribusiness chains, such as citrus, have sought to reduce GHG emissions and store more carbon in plant biomass and soil. This effort will support adaptation and mitigation of the potential negative impacts of climate change.

In agricultural lands, soil is the largest reservoir of organic carbon. The global Soil Organic Carbon (SOC) stock for topsoil (0 to 30 cm) is 680 Petagrams, where the Brazilian soils representing 5.2% (35.4 Pg) [2]. Important for agriculture, the topsoil is the most affected by land use and land use change (LULUC). For this some digital SOC maps [2] [3] [4] [5] have been elaborated to provide SOC stock estimates in agricultural lands. This is useful for GHG emission inventory in some scales (country, region, state, provinces, watersheds and farm). However, SOC stock estimates based on digital maps may contain varying levels of error. This study aimed to estimate the SOC stock in the BCB and to compare these estimates with measured data from on-farm orange groves and native vegetation areas.

2. MATERIAL AND METHODS

The Brazilian Citrus Belt (BCB) covers approximately 496,720 hectares, with 68% occupied by mature (3 years old or more) *Citrus sinensis* (L. Osbeck) orange groves and 32% by environmental conservation areas (Figure 1). The 337,091 hectares of mature orange groves are based on data from the "Inventory of Trees in the Citrus Belt of São Paulo and West/Southwest Minas Gerais States: Scenario in March 2023" [1]. The 159,629 hectares of environmental conservation areas (including permanent preservation areas, legal reserves and surplus native vegetation areas) were calculated using data from the National Rural Environmental Registry System (SICAR) [6] and Embrapa Territorial methodology [7]. The BCB spans the Brazilian Savannah and Atlantic Forest biomes, recognized globally as biodiversity hotspots [8].

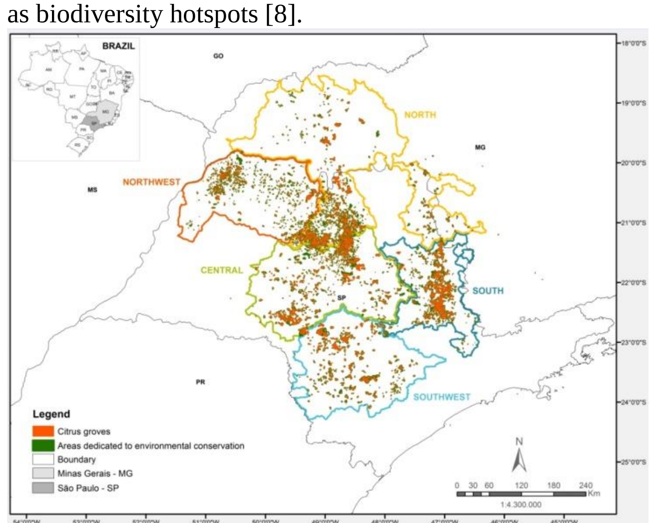

Figure 1. Localization, sectors, orange groves and environmental conservation areas of the Brazilian Citrus Belt.

The 2021 Brazilian SOC map [3] was used for estimating the SOC in topsoil (0 to 30 cm) of the BCB. Geographic Information System (GIS) procedures were employed to extract SOC stock data by clipping the Brazilian SOC map (raster) using the BCB's map (shape file) and estimating SOC stock in both orange groves and environmental conservation areas (Figure 2). As SOC stock estimates from secondary sources [3], may be overestimated or underestimated, soil sampling was also conducted in orange groves and native vegetation on five citrus farms across the BCB's sectors (North, Northwest, Central, South, and Southwest) to support data discussion. Soil analysis samples were taken from three points, spaced 30 meters apart, within both orange groves and native vegetation areas on each farm (Figure 2). The SOC data from each pixel where sampling occurred were used for comparison with field measured data. Vegetation and soil types for each sampling point are presented in Table 1.

Soil C content and soil bulk density were analyzed. Non-deformed samples were collected at each point in volumetric rings at 0-10, 10-20, and 20-30 cm depths, performing 90 samples in total for bulk density determination (g dm^{-3}). Additionally, composite samples were created from twelve (12) single samples collected at each depth 0-10, 10-20 and 20-30 cm, resulting 90 composite samples for C content analysis (g kg^{-1}). Each composite sample was analyzed using dry combustion method in a LECO C elemental analyzer, model C-144. SOC stock (Mg C ha^{-1}) for groves and native vegetation was then calculated by multiplying the soil volume (m^3) of 1 ha of topsoil (0-10, 10-20 and 20-30 cm) by bulk density and C content for each depth layer (0-10, 10-20 and 20-30 cm). ArcGIS and QGIS were used for the GIS procedures and analysis.

Citrus Farm	Vegetation	Soil
North	wooded Savannah with gallery Forest	dystrophic Red Latosol
Northwest	contact Savannah with seasonal Forest	eutrophic Red Argisol
Central	forested Savannah	eutrophic Red Argisol
South	contact Savannah with seasonal Forest	dystrophic Red Latosol
Southwest	grassy-woody Savannah with seasonal Forest	dystrophic Red-Yellow Latosol

Table 1. Vegetation and soil types of the sampling points in citrus farms across five sectors of the Brazilian Citrus Belt. Source: [9] [10] [11].

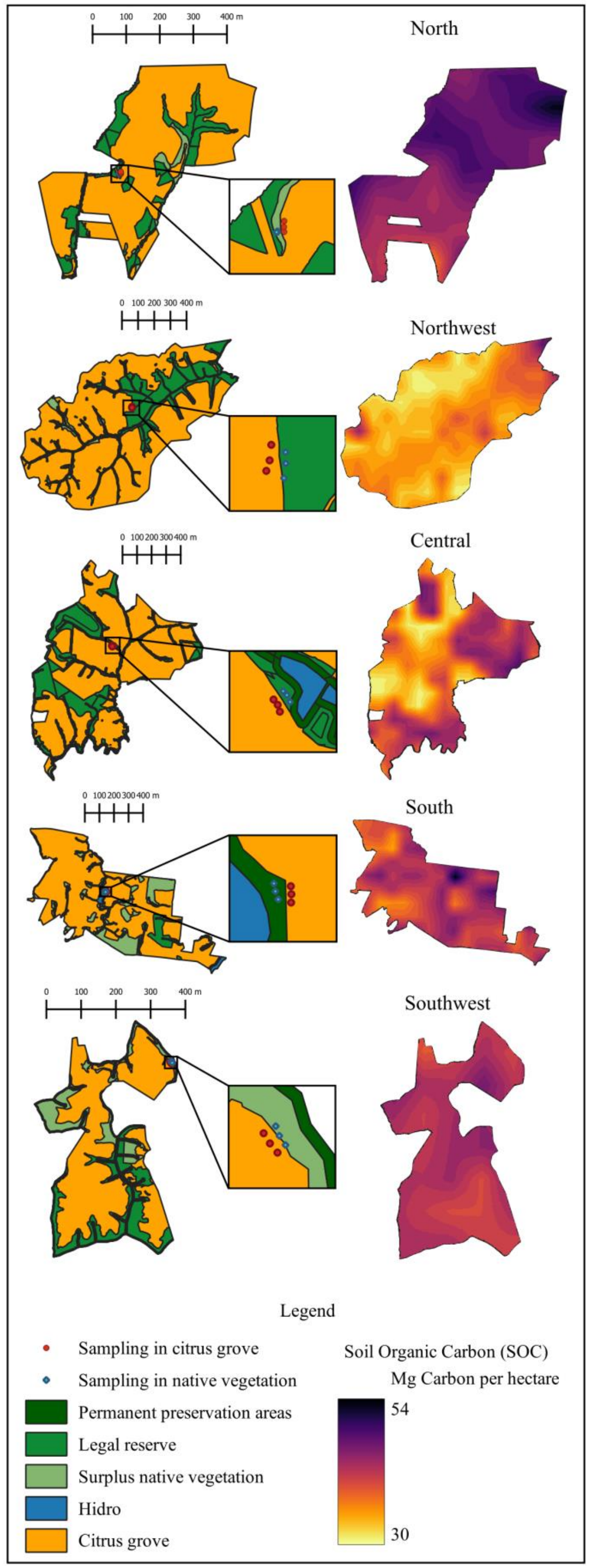

Figure 2. Soil organic carbon (SOC) sampling points and maps (SICAR data - shape file and Brazilian SOC map - raster) for citrus grove and environmental conservation areas (native vegetation) in citrus farms across the Brazilian Citrus Belt.

3. RESULTS AND DISCUSSION

The SOC stock (Figure 3) in the Brazilian Citrus Belt is approximately 19.761 million Mg C: 67% in orange groves and 33% in environmental conservation areas. These estimates indicate the SOC stock potential in orange groves and environmental conservation areas.

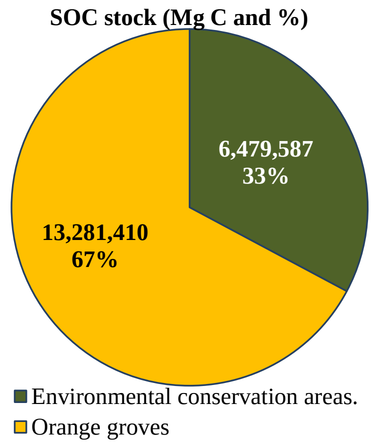

Figure 3. Estimate of soil organic carbon (SOC) stock (0-30 cm layer) in orange groves and environmental conservation areas in the Brazilian Citrus Belt.

As expected, mean SOC stock per hectare (Mg C ha^{-1}) in the topsoil is higher in environmental conservation areas (native vegetation) than in orange groves (Figure 4). The difference is small, averaging 1.19 Mg C ha^{-1} more in native vegetation areas (40.59 Mg C ha^{-1}) compared to orange groves (39.4 Mg C ha^{-1}). The evaluated data confirm that native vegetation areas have a higher SOC stock (40.1 Mg C ha^{-1}) than the orange groves (32.27 Mg C ha^{-1}). The estimated SOC stock for native vegetation areas (40.59 Mg C ha^{-1}) was close to the evaluated stock (40.1 Mg C ha^{-1}), while the estimate for orange groves (39.4 Mg C ha^{-1}) was higher than the evaluated stock (32.27 Mg C ha^{-1}) in the same land cover.

By analyzing results by sector (citrus farm) and land cover (orange grove and native vegetation), some patterns emerge, particularly regarding under and overestimation (Figure 5). The smallest differences between estimated and evaluated means for native vegetation areas occurred in the North (-1.4 Mg C ha^{-1}; -3%) and Northwest (-2.1 Mg C ha^{-1}; -6%) sectors. The greatest underestimation was in the South sector, with -16.7 Mg C ha^{-1} (-40%) for native vegetation areas and -10.6 Mg C ha^{-1} (-25%) for orange groves. Overestimation was more common, especially in orange groves, with overestimates of 13.7 (31%), 7 (20%), 12 (37%), and 13.9 Mg C ha^{-1} (34%) in the North, Northwest, Central, and Southwest sectors, respectively. For native vegetation, overestimation occurred in the Central (7.1 Mg C ha^{-1}; 19%) and Southwest (12 Mg C ha^{-1}; 29%) sectors.

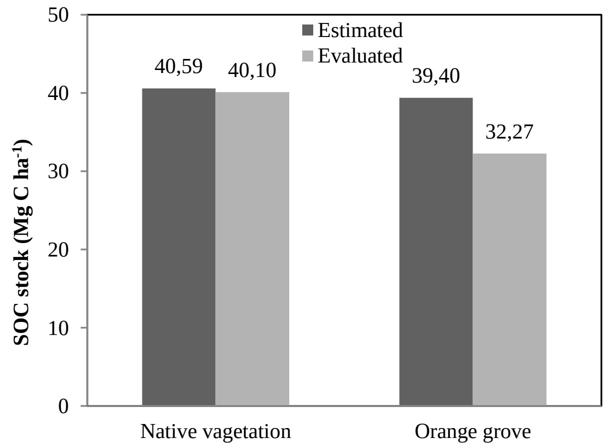

Figure 4. Estimated and evaluated soil organic carbon (SOC) stock per hectare (0-30 cm layer) in orange groves and environmental conservation areas (native vegetation) of the Brazilian Citrus Belt.

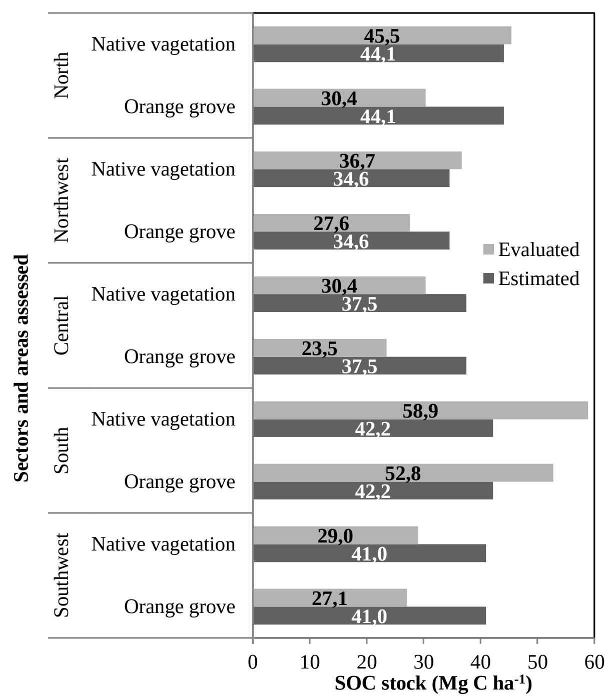

Figure 5. Estimated and evaluated soil organic carbon (SOC) stock per hectare (0-30 cm layer) in orange groves and environmental conservation areas of citrus farms in five sectors of the Brazilian Citrus Belt.

The SOC stock underestimation or overestimation is not necessarily problematic, but should be considered. The GSOCMap [2] reports a mean overestimation of 4.585 Mg C ha^{-1} for mineral soils with less than 150 Mg C ha^{-1}. The Brazilian SOC map technical report [11] shows mean SOC predictions across Brazil ranging from 6.0 to 315.7 Mg C ha^{-1}, with a mean of 38.5 Mg C ha^{-1}. R^2 values for training and validation are 0.77 and 0.47, respectively, with mean absolute errors of 1.3 and 2.8 Mg C ha^{-1} and root mean square errors of 4.0 and 10.3 Mg C ha^{-1}.

Estimations errors can arise from factors such as soil attributes (physical, chemical and biological), land use, and management practices. Notably, the farm in the South sector (Figure 5) adheres to an internationally certified management standard (Farm Sustainable Assessment - FSA Gold), that emphasizes ecosystem protection, sustainable agriculture, and improved rural livelihoods, which may be contributing to higher SOC stocks in orange groves and environmental conservation areas.

SOC maps are not perfect; they cannot replace the accuracy of soil sampling and lab analysis due to factor like local variability within 10 m to 100 m 1 km and environmental uncertainties that can amplify errors [12]. Soil sampling provides an independent quality check for SOC maps and should be part of the validation process. Due to the large BCB area, only 30 sampling points were analyzed. Ninety non deformed and ninety deformed samples were collected over a 10-day field campaign. Thus, soil sampling is labor-intensive and should be weighed in SOC studies.

4. CONCLUSIONS

Estimated SOC stock for BCB is 19.761 million Mg C, with 67% in orange groves and 33% in environmental conservation areas. Evaluated SOC stocks in five citrus farms reveal the limitations of the Brazilian SOC Map regarding under- and overestimations. On-farm SOC analysis in orange groves and native vegetation areas is essential for accurate SOC stock estimations. These SOC estimates should be used as a reference but with caution.

5. AKNOWLEDGEMENTS

We thank to Innocent Drinks CO for financial support through the Farmer Innovation Fund and for their valuable input on this study. We are also grateful to the owners and employees of the citrus farms involved and to the FlorAgro team members who assisted in fieldwork and soil sample preparation. Without their contribution of financial, human, and material resources, conduct this important study for the citrus belt of São Paulo and West/Southwest Minas Gerais would not have been possible.

6. REFERENCES

[1] FUNDECITRUS; MARKESTRAT; FEA-RP/USP; FCAV/UNESP. Inventário de árvores do cinturão citrícola de São Paulo e Triângulo/Sudoeste Mineiro: retrato dos pomares em março de 2023. Araraquara: Fundecitrus, 2023. Available at: https://www.fundecitrus.com.br/pdf/pes_relatorios/2023_06_05_Invent%C3%A1rio_e_Estimativa_do_Cinturao_Citricola_2023-2024.pdf. Accessed at: 19 mar. 2023.

[2] FAO and ITPS. Global Soil Organic Carbon Map (GSOCmap) Technical Report. Rome. 162 (pp), 2018.

[3] VASQUES, G. de M.; DART, R. de O.; BACA, J. F. M.; CEDDIA, M. B.; MENDONÇA SANTOS, M. de L. Soil Organic Carbon Stock at 0-30 cm Map for Brazil (90 m - Version 2021). Rio de Janeiro: Embrapa Solos, 2021. Available at: http://geoinfo.cnps.embrapa.br/maps/3175. Accessed at: 6 mar. 2023.

[4] BERNOUX, M. et al. Brazil's soil carbon stocks. Soil Science Society of America Journal, 66, 888-896 (pp), 2002. https://doi.org/10.2136/sssaj2002.8880

[5] MAPBIOMAS. Mapeamento anual do estoque de carbono orgânico do solo no Brasil 1985-2021 (coleção beta), MapBiomas Data, V1, , 2023. https://doi.org/10.58053/MapBiomas/DHAYLZ.

[6] SICAR. Sistema Nacional de Cadastro Ambiental Rural. Cadastro Ambiental Rural. Available at: https://www.car.gov.br/publico/municipios/downloads. Accessed at: 6 mar. 2023.

[7] EMBRAPA TERRITORIAL. Agricultura e preservação ambiental: uma análise do Cadastro Ambiental Rural. Campinas, 2020. Available at: www.embrapa.br/car. Accessed at: 12 nov. 2022.

[8] IBGE. Instituto Brasileiro de Geografia e Estatística. Mapa de Biomas do Brasil. 1: 250.000. Rio de Janeiro: IBGE, 2019. Available at: <https://www.ibge.gov.br/geociencias/downloadsgeociencias.html> Accessed at: 12 nov. 2022.

[9] IBGE. Instituto Brasileiro de Geografia e Estatística. Mapa de Vegetação do Brasil. 1: 250.000. Rio de Janeiro: IBGE, 2018. Available at: <https://www.ibge.gov.br/geociencias/downloadsgeociencias.html> Accessed at: 12 nov. 2022.

[10] ROSSI, M. Mapa pedológico do Estado de São Paulo: revisado e ampliado. São Paulo: Instituto Florestal, 2017. 118p.

[11] FEAM. Fundação Estadual do Meio Ambiente. Mapa de Solos de Minas Gerais: legenda expandida. UFV/CETEC/UFLA/FEAM. Belo Horizonte: Fundação Estadual do Meio Ambiente, 49p, 2010.

[12] VASQUES, G. de M.; DART, R. de O.; BACA, J. F. M.; CEDDIA, M. B.; MENDONÇA SANTOS, M. de L. Soil Organic Carbon Stock at 0-30 cm Map for Brazil – Technical Report. Rio de Janeiro: Embrapa Solos, 2p, 2021. Available at: https://geoinfo.dados.embrapa.br/catalogue/#/document/4752. Accessed at: 16 oct. 2024.