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# Digital mapping of soil carbon in a viticultural region of Southern Brazil

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ABSTRACT

There is a need for soil C assessment in the soils of tropical and subtropical areas. We have aimed to quantify the spatial extent of SOC concentration and stocks under different land use and soil types in an 8118 ha area in southern Brazil. Common soils are Inceptisols, Ultisols and Mollisols, and the dominant land use is forest and vineyard. SOC data were modeled by 5 depths deriving values from spline functions. Regression kriging was used to model SOC concentration for each depth to 100 cm, and for producing a soil depth map. Uncertainty was estimated by empirical approach, using sequential Gaussian geostatistical simulation of the residuals. The Projected Natural Vegetation Soil Carbon (PNVSC) approach was used to evaluate changes in soil carbon due to land use change. Bulk density was estimated by pedotransfer functions. SOC stocks were calculated using the SOC prediction, bulk density and the soil depth map, and the stocks were corrected by cumulative mass coordinates. The models for SOC concentration prediction explained about 44% of the variance at 30–60 cm depth and with slightly lower values for other depths. Important covariates for prediction were Soil Order (Entisols), coordinate *X*, Aspect and the DEM. The model for the prediction of soil depth explained 43% of variance and important covariates were Soil Order (Entisol, Mollisol, Ultisol), Valley Depth and TWI. Soils under forest accumulated more carbon in the top 30 cm whereas soils under pasture had higher SOC levels with depth. Soils under arable crops and vineyard had the lowest SOC concentration. SOC concentration decreases by depth, as well as prediction intervals of uncertainty, until 60 cm depth. The SOC stocks (0–100 cm) varied between 104 t C/ha in vineyards on Alfisols, and 280 t C/ha in pasture areas on Oxisols. The PNVSC analysis showed that most soils had lost SOC compared to when they were projected to be under forest.

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## 1. Introduction

Assessing the amount and distribution of soil organic carbon (SOC) levels is important as it provides information about soil fertility, rates of sequestration of carbon, recovery of degraded soil, or the impact of land use changes. Mapping the SOC concentration and stocks is challenging because of the considerable variation and dynamics. Spatial and temporal SOC changes are affected by natural and anthropic factors including management practices and land use changes.

Several recent studies have predicted and mapped SOC (Adhikari et al., 2014; Padarian et al., 2012; Kirsten et al., 2015; Malone et al., 2009; Mendonça-Santos et al., 2010; Ross et al., 2013; Zhang and Shao, 2014) and the estimation is based on relation between covariates (land use, soil type, slope, aspect, etc.) and SOC levels. Different covariates were found in models to explain SOC distribution. Thompson and Kolka (2005) found that more than 71% of SOC variation could be explained by slope, aspect, curvature, topographic wetness index and overland flow distance. Wiesmeier et al. (2014) found that the most important factors to predict SOC stocks were land use, soil type, soil moisture and climate. Adhikari et al. (2014) predicting SOC concentration, at different soil depths, reported that the importance of variables differed by depth. Minasny et al. (2013) synthesized a large number of digital SOC mapping studies and concluded that different covariates could explain the variation of SOC depending on the complexity of the landscape.

The majority of SOC inventory assessments to date focused the 0–20 cm or 0–30 cm surface layers, whereas considerable amounts of SOC may be present deeper in the soil profile (Lal, 2005; Rumpel and Kögel-Knabner, 2011; Minasny et al., 2013; Boddey et al., 2010). Sisti et al. (2004) studied SOC stocks down to 100 cm depth with zero tillage and conventional tillage and found, in rotations with vetch planted as a winter green-manure crop, significantly higher soil carbon and nitrogen concentrations under zero tillage, with most of the differences occurring at 30–85 cm depth. Angers and Eriksen-Hamel (2008) showed different interpretation of SOC stocks when considering different depths, in no till and full-inversion tillage. Full-inversion tillage could accumulate more

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carbon at the bottom of the plow layer, but the SOC does not completely offset the gain under no till in the surface horizon. The authors highlight the importance of taking into account the whole profile to understand the distribution of SOC stocks.

Land use has major impacts on SOC concentration and stocks. However, these effects are also affected by soil class and depth (Hartemink and McSweeney, 2014; Nieder and Benbi, 2008). Changes in land use impacts the SOC levels and modifies soil characteristics. Several studies explained the changes of SOC with land use change. Conant et al. (2001), reviewing 115 studies, found that conversion from native land (mostly rain forest) to pasture increased soil C content for nearly 70% of the studies. Guo and Gifford (2002), compiling 74 publications, found that SOC stocks declined after land use changed from pasture to plantation (−10%), native forest to plantation (−13%), native forest to crop (−42%), and pasture to crop (−59%). However, the SOC stocks increased when the native forest was converted to pasture (+8%), crop to pasture (+19%), crop to plantation (+18%), and crop to secondary forest (+53%). Cerri and Andreux (1990) showed that C levels after 50 years of sugarcane cultivation, in São Paulo, Brazil, were 46% of the levels under primary forest.

Although there is a considerable body of research on the digital mapping of SOC in temperate regions, few studies have been conducted in the tropical and subtropical areas. Examples include Berhongaray et al. (2013) estimating SOC stocks in Argentine Pampas, Cheng et al. (2004) predicting SOC concentration in a subtropical area in China, Vasques et al. (2010) estimating SOC stocks in a subtropical watershed in Florida. Digital soil mapping has been used in Brazil (Giasson et al., 2006; Mendonça-Santos and Santos, 2007) and examples of SOC predictions include the studies by Mendonça-Santos et al. (2010) whom used regression-kriging for evaluate the SOC stocks in Rio de Janeiro State, and de Souza et al. (2014) using regression-kriging to predict SOC and clay content in Rio Doce Basin (Minas Gerais State). There have been other studies (e.g., Cerri et al., 2007; Tornquist et al., 2009b) where ecosystem models such as Century or Rothamsed C Model were applied to estimate SOC dynamics in the upper soil layers from different areas in Brazil.

The present study aimed to analyze the distribution of soil C in the grape growing region of Vale dos Vinhedos, in Rio Grande do Sul State, Brazil. The objectives were as follows: (i) to quantify and understand the spatial variation of SOC concentration by depth through digital soil mapping, and to assess the uncertainty, (ii) to quantify and map SOC stocks, and (iii) to estimate SOC changes due to land use change.

## 2. Materials and methods

### 2.1. Study area

The study was conducted in the Vale dos Vinhedos (Vineyard Valley) which is a wine production region in northeastern Rio Grande do Sul State (Fig. 1). The study area covered 8118 ha. The climate is classified as Cfb, subtropical with a mild summer, mean annual temperatures of 17.2 °C and 1736 mm annual rainfall (EMBRAPA, 2008). The dominant lithology is effusive rocks mostly from the Mesozoic Era (IBGE, 1986). Lower sequence comprises mostly basalts and diabase dikes, whereas the upper sequence has predominantly acid effusive rocks such as rhyolite and dacites.

Average soil depth is 150 cm (range from 25 to >250 cm) and many soils are stony and rocky (average 4.5% of fragments > 20 mm in diameter). In the study area, Inceptisols cover about 44%, Ultisols 29% and Mollisols almost 15% (Fig. 2). Mollisols are mostly present at lower elevations close to valley bottoms in the northern part of the study area. Soils in the western part of the study area are mainly Argissolos (Ultisols and Alfisols), Chernossolos (Mollisols), and Neossolos (Entisols and Mollisols). The eastern part has more rugged terrain and the dominant soils are Neossolos (Entisols) and Cambissolos (Inceptisols), with association of Argissolos (Ultisols and Alfisols), Latossolos (Oxisols) and Nitossolos (Oxisols and Ultisols) (Flores et al., 2012).

Forest (44%) and vineyard (31%) are the dominant land use in the study area. Deciduous forest is the main vegetation in plateau rugged areas, and Araucaria forest in flatter areas (IBGE, 1986).

### 2.2. Soil and environmental data

The soil data were obtained from the soil survey project “Os Solos do Vale dos Vinhedos” (Flores et al., 2012). Sample points were selected along predefined paths representing different landscape units (Flores et al., 2012). Sampling was done with 163 total pedons, comprising 580 soil horizons. The soils were analyzed following Brazilian standard methods (Santos et al., 2006): SOC analysis by Walkley–Black wet oxidation.

Additionally, in 2014, samples were obtained from 10 pedons (34 horizons) for an estimate of soil bulk density of the Flores et al. (2012) soil survey, allocated by contrasting land uses (vineyard, forest/planted forest, pasture, arable crops, and fallow) and soil classes. The 10 measured bulk density were used to evaluate three pedotransfer functions, which were chosen based on studies that include data from subtropical

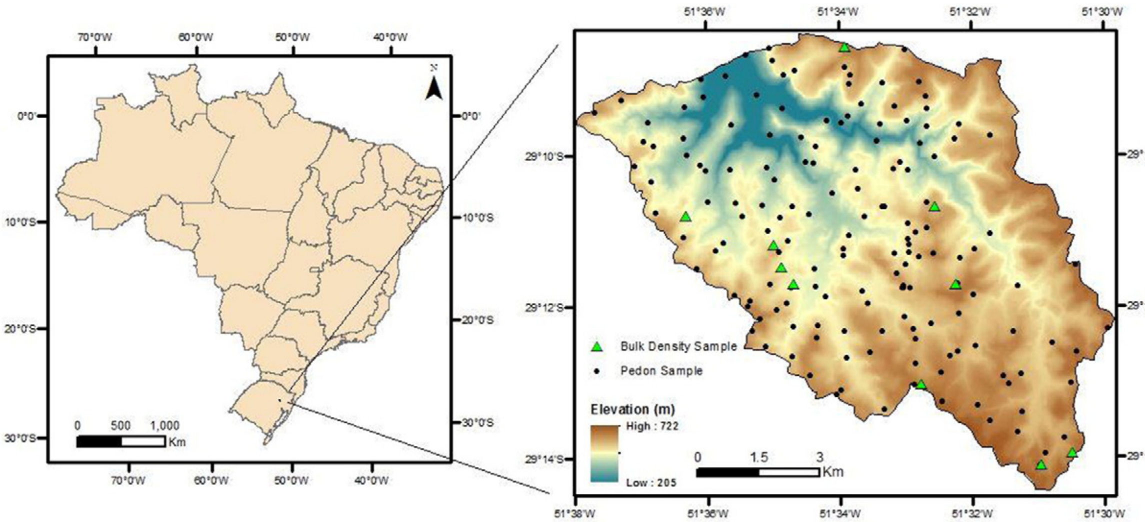

**Fig. 1.** Study area (Vale dos Vinhedos) in Rio Grande do Sul, Brazil (8118 ha) and location of the 163 pedons and 10 bulk density pedon sampling points.