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Carbon Inventory South Tyrol Quantitative analysis and stability assessment of SOC stocks in South Tyrol's agricultural areas

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Introduction

The European Union (EU) aims to achieve climate neutrality by 2050, as outlined in the Paris Agreement and the European Green Deal (European Commission 2019). The Land Use, Land-Use Change, and Forestry (LULUCF) sector, which includes agriculture, has set an even more ambitious goal of climate neutrality by 2035 (Vikolainen 2022; European Parliament and Council of the European Union 2023). Understanding the interrelationship between major carbon pools is crucial for effective carbon emission management. According to the Guidelines for National Greenhouse Gas Inventories (IPCC 2019), these pools comprise living biomass, dead organic matter, and soil carbon within the biosphere. Although estimating carbon in biomass is relatively straightforward and may only be a minor contributor to certain land uses, such as grasslands, the quantification and assessment of soil organic carbon (SOC) stocks are considerably more complex, particularly in mountainous regions with small-scale landscape variations. Recent global studies have examined SOC stocks (FAO 2018; FAO & ITPS 2019; Poggio et al. 2021). However, regional soil organic carbon modeling is becoming increasingly important due to the limitations of global models in capturing small-scale landscape complexities (Yigini & Panagos 2014; Kotzé & Van Tol 2023; Rota et al. 2024). Developing tailored strategies that address the specific characteristics of small-scale landscapes is therefore needed (Zhang et al. 2023). Regional approaches are vital for informing decisions related to agricultural land-use conversions and supporting climate neutrality efforts. These approaches are essential for carbon conservation, carbon sequestration, and initiatives such as carbon farming. The 'Carbon Inventory South Tyrol' (CIS) project aims to assist the European Union's objectives within the agricultural sector at a regional level. The primary goal is to address the knowledge gaps in quantifying the agricultural soil organic carbon (SOC) stock within the Italian province of South Tyrol. SOC stock is estimated using a soil organic carbon mapping (SOCM) approach. The initial step involves sourcing completed and ongoing soil studies from relevant literature specific to the study area. The subsequent sections will briefly report on the process and preliminary results of collecting soil data from the literature.

Methodology

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This study examined the agricultural regions in South Tyrol, which is the northernmost province of Italy. South Tyrol encompasses an area of 7,400 km², with 37 % designated for agricultural use. The agricultural land is generally categorized as follows:

59 % pastures, 27 % hay meadows, 8 % orchards, 3 % vineyards, and 3 % arable land. Notably, 94,000 hectares are classified as intensively utilized agricultural areas (Schönafinger et al. 2024).
As part of the CIS project, which aims to assess SOC stocks using machine learning methodologies for SOCM, the process of generating input data involved acquiring existing soil information from literature sources, which have been gathered from completed and ongoing projects primarily within the boundaries of South Tyrol. To achieve this objective, institutions that have conducted soil surveys were contacted to provide their data. The collected datasets were standardized to create a comprehensive database containing all available soil information. Emphasis was placed on acquiring data concerning SOC content, as well as physical measurements necessary for modeling SOC stock, such as bulk density and coarse fragments. Furthermore, it has been essential that the soil data are georeferenced to facilitate the interpolation of empirical soil data across agricultural areas in South Tyrol.
In addition to the digital collection of georeferenced soil data, Martin Thalheimer from the Institute for Fruit and Viticulture at Research Centre Laimburg has curated an extensive literature collection on soil information for South Tyrol. The collection includes significant contributions such as Avanzini et al. (2007), Biologisches Landeslabor (1986), Fischer & Wetzel (1996), Gruber et al. (2019), Klotzner (1938), Magazzini (2001), Mair (2010), Minerbi (2003), Nitsch (2016), Peer (1969), Porro et al. (2018), Sartori (1978), Schröder (2010), Staffler et al. (2003), and Wenzel et al. (1996). These studies and reports will be used as additional data source and will be digitized when opportunities and needs arise.

Intermediary Results

An extensive collection of soil data has been compiled from literature, resulting in over 34,000 records from various sources (Table 1). In South Tyrol's agricultural regions, the dataset covers 19,203 locations (Figure 1), with 97 % of these records containing information on SOC content.

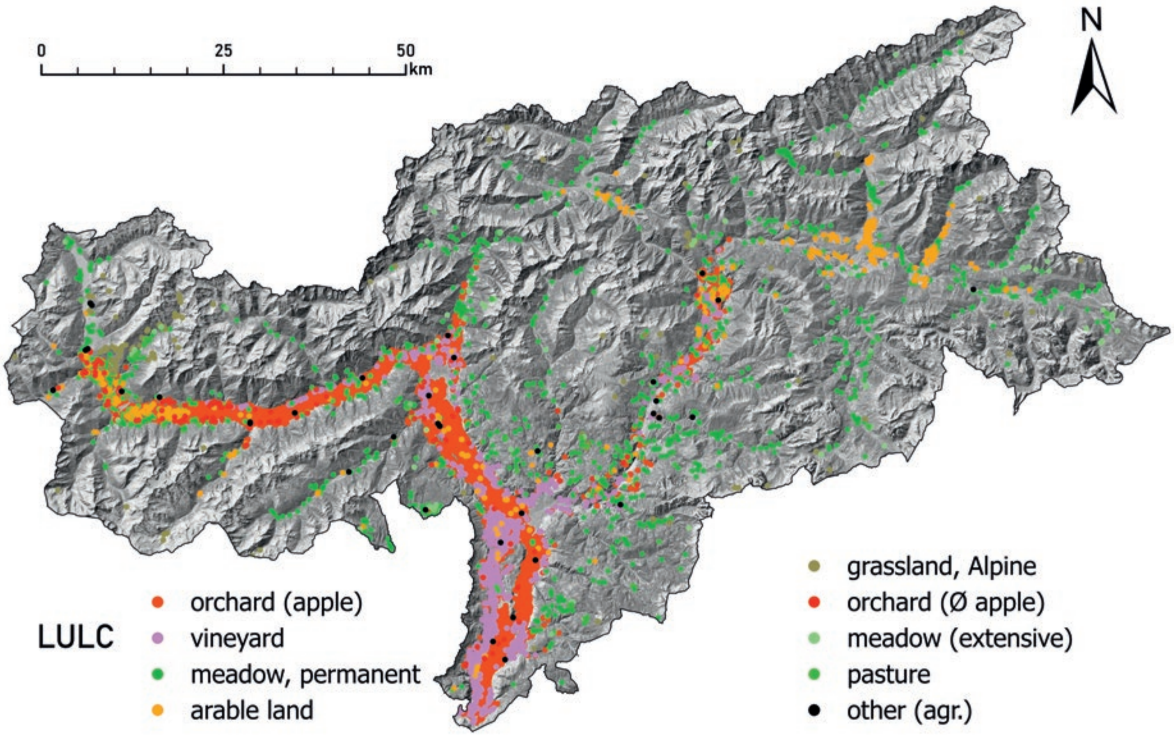

Figure 1: Soil data point distribution on South Tyrol's agricultural land classified by land-use/land-cover (LULC) based on Autonome Provinz Bozen (2021).

Table 1: A comprehensive overview of studies concerning soil properties, including the measurement of soil organic carbon (SOC) in South Tyrol.

ID	Sample period	Data count	Land use	Reference
1	2006–2016	28,964	arable land, (forests), fruit orchards, grassland, vineyards	(Genova et al. 2022)
2	2002–2005	1,033	forests, grassland	(Tasser 2023)
3	1997–2019	747	arable land, grassland	(Burchia 2021)
4	2023–2025	635	fruit orchards, grassland	(INNONährstoffe 2024)
5	2023	504	vineyards	(BioViSo 2025)
6	1998–2002	491	fruit orchards, grassland	(Stimpfl et al. 2006a, 2006b)
7	2019–2023	460	arable land, forests, fruit orchards, grassland, riparian areas, settlement, vineyards, wetland	(Hilpold et al. 2023)
8	1997	403	forests, grassland	(Tasser et al. 2001)
9	2014–2015	326	forests, grassland, vineyards	(Geitner et al. 2017)
10	2011	153	larch meadows	(Nagler et al. 2015)
11	2015	107	forests, fruit orchards, grassland	(LT(S)ER Matsch 2023)
12	2009–2018	103	forests, fruit orchards, grassland, vineyards	(Panagos et al. 2022, 2012; ESDAC et al. 2025)
13	2010–2011	91	grassland	(Niedrist 2023)
14	2010–2016	70	grassland	(Pasolli et al. 2014)
15	2022	56	glacier forefield	(Ramskogler et al. 2023)
16	2010	52	grassland, forests, wetland	(Niedrist et al. 2011)
17	2022	10	fruit orchards	(SCOOP 2025)
18		10	arable land, grassland	(Batjes et al. 2019)
19	2008	6	grassland	(Meyer et al. 2012)
20	2023	3	vineyards	(Callesen et al. 2023)

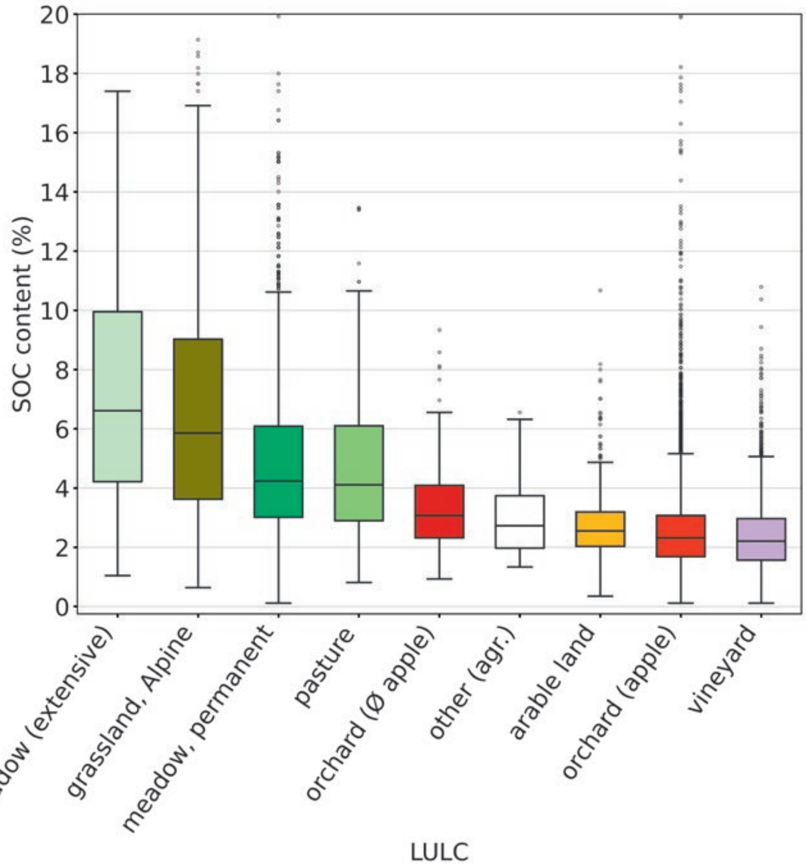

Figure 2: Soil organic carbon (SOC) content variations in the collected literature data classified by agricultural land-use/land-cover (LULC) types based on Autonome Provinz Bozen (2021).

The distribution of soil data points is uneven throughout the study area, primarily located at valley bottoms and largely concentrated in apple orchards, followed by vineyards and permanent meadows.
Based on the data presented (Figure 2), Alpine grasslands (7.38 % ± 0.38) and extensively used meadows (7.18 % ± 0.27) have the highest amount of SOC on average. In contrast, arable land (2.78 % ± 0.05), apple orchards (2.52 % ± 0.01), and vineyards (2.41 % ± 0.02) contain the lowest levels of SOC.

Discussion and directions for future research

The evaluation of data has revealed notable gaps in spatial coverage, particularly the lack of surveys in remote areas such as Alpine grasslands. In contrast, apple orchards, vineyards, and permanent meadows have extensive soil data coverage. Furthermore, there is an insufficiency in the coverage of physical parameters, with only a few soil surveys addressing bulk density and coarse fragments. To address these gaps, an additional field survey has been initiated, which will commence in late summer and autumn of 2024 and conclude in spring 2025.
The objective of this project is to develop a SOC stock map for all agricultural areas in South Tyrol. Moreover, carbon flux has been measured for apple orchards and meadows, and it is currently being monitored for pastures and vineyards. These measurements will be utilized to validate SOC stocks in their stability and to identify potential differences in agricultural land use and land cover (LULC) behavior, determining whether certain LULC types function as carbon sinks or sources.

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