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Land use change effects on soil organic carbon store. An opportunity to soils regeneration in Mediterranean areas: Implications in the 4p1000 notion

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ABSTRACT

The knowledge about land management effects on soil capacity to store carbon is necessary to planning effective strategies by managers and decision-makers. In this study we analyzed the land use change (LUC) effects on soil organic carbon stocks (SOC-S) for long term in the Sardinia region - Italy (Mediterranean area).

Throughout the 20th century, the studied area has undergone different LUC. The first LUC was in 1938, from forest to agricultural land under three different uses: vineyards, hay crop and pasture, later (1966) some of this agricultural land were abandoned to seminatural ecosystem (second LUC). The different LUC affected to SOC-S causing decarbonization, carbonization and recarbonization processes along the soil profile.

The different land uses studied chronologically were: i) natural forest - cork oak forest (Cof), ii) tilled vineyard (Tv), iii) no tilled grassed vineyard (Ntgv), iv) hay crop (Hc), v) pasture - silvopastoral and silvoarable practices (P), and vi) former vineyard - vineyards abandoned and naturally revegetated (Fv). The first LUC (Cof to Tv, Ntgv, Hc and P) caused 5.1% and 37.5% reduction on SOC-S for Tv and Ntgv (soil decarbonization), however, the SOC-S increased 47.1% and 51.3% for Hc and P respectively (soil carbonization). The second LUC (Tv and Ntgv to Fv) increased the SOC-S on average 66.3% (soil recarbonization). In general, these effects were observed principally in depth.

This study shows the importance of land use and LUC with respect to SOC-S, and that the human action can degrade and/or regenerate the soil, affecting to soil functions. Consequently, is necessity to promote good environmental practices to improve the soil functions and to reduce the greenhouse gases (ecosystem services). On the presumption that the SOC sequestration through of agricultural management can reduced the atmospheric CO_2 concentration (4p1000 target in the XXI Conference of the Parties – Paris, 2015). Therefore, the soils regeneration via carbonization and/or recarbonization is an opportunity to prevent the climate change.

1. Introduction

The soil is a dynamic system over time (Hartemink, 2016), that is related to spatial and temporal aspects involving variation over space and alteration over time (Brevik and Arnold, 2015). Therefore, there is a strong link between "time" and "soil formation processes" (Stevens and Walker, 1970), highlighting the relationship between time, land management and land use change (LUC) by anthropogenic factors (Montanarella et al., 2016) in relation to soil evolution.

The human actions over time has modified the landscape in Europe according to their necessities and benefits, affecting to ecosystem services (ES). During the last century, this ecosystems alteration by LUC have been accelerated particularly in Mediterranean areas (Steffen et al., 2011). This alteration usually has been based in the forest to agricultural land conversion followed by an agriculture intensification and the land abandon derived from the lack of economic benefits (Fedele et al., 2018). LUC is considered the major driving forces of change in ecosystem functions in landscape pattern in Europe (Cernusca et al., 1996). In this line, LUC from forest to agricultural land is the origin of serious threats to soil stability and health, being the prime concerns the soil loss and degradation processes. Soil degradation by LUC is a serious global problem (Pereira and Martinez-Murillo,

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2018), all of this without forgetting that the LUC impact is conditioned by land use type and by others abiotic factors (Schrumpf et al., 2011).

The Mediterranean forests were extensively transformed to agroforestry systems, and in many Mediterranean areas the agriculture abandonment determined the agroforestry systems formation again. Due to low yields and the high cost of modern tillage equipment, the agricultural lands were abandoned, suffering a second LUC, from the agricultural land to a new vegetation cover due to land abandonment. This land abandonment implies an soil risks derived from LUC such as soil erosion and soil degradation, but in some cases, offers to soil the opportunity to restore its quality and functions by revegetation (naturally in some cases, and induced in others). By reforestation-revegetation these soils can increase their capacity to store soil organic carbon (SOC) (Guo and Gifford, 2002; Metz et al., 2007).

The most extensive agroforestry systems in Europe is the Mediterranean evergreen oak woodlands (MEOW) with more than 3.1 Mha (million ha) (Moreno and Pulido, 2009). These ecosystems were created by clearing the natural Mediterranean forest. The MEOW has been considered habitats to be preserved, therefore they are an example of sustainable land use (these systems have multiple uses and exploitations - e.g., livestock rearing, cereal cropping, cork and firewood harvesting, and hunting), although their conservation has been threatened in the last few decades (Moreno and Pulido, 2009). In these ecosystems, the trees act as “ecosystem engineers”, facilitating the grass production maintenance in poor soils under semiarid climate (Parras-Alcántara et al., 2015a). In addition, the MEOW (dehesa or savanna ∼ oak woodlands) offers ES (MEA, 2005; Marañón et al., 2012), and one of the most important ES offered by this forests land is the soil carbon (C) storage (TEEB, 2010), therefore, the forest soils playing an important role in the C balance at global scale (Bayer et al., 2017). But we must not forget that at worldwide scale the soil C storage is decreasing (Jandl et al., 2007) and that Mediterranean forests are vulnerable to C storage loss (Badalamenti et al., 2017). The amount of C stored in forests soils is a substantial part of the total C storage in the world. Six et al. (2002) estimated that SOC stored in forest soils was 70–73% of the global SOC amount. But more recently, Pan et al. (2011) quantified the global forest C sinks and estimated the total SOC stock (SOC-S) in 861 Pg (383 Pg: 45% in soil (1 m depth); 363 Pg: 42% in above and belowground biomass; 73 Pg: 8% in deadwood and 43 Pg: 5% in litter).

In forest soils, the trees modify the microclimatic conditions (principally moisture and temperature regimes) and increase the organic matter (OM) inputs and thus improving the soil quality (Bouwman and Leemans, 1995). In addition, the tillage absence in these systems improves the soil microbial and fauna communities and the formation of stable aggregates (Jégou et al., 2000), providing protection against to OM decomposition (Del Galdo et al., 2003). Therefore, Mediterranean forest soils have a great capacity to C store and C sequestration - C sink (Roig and Rubio, 2009).

Different *meta*-analysis have shown that the main factors that contributing to SOC-S restoration after revegetation include: the prior land use, the tree types planted, the soil clay content and the climate (Li et al., 2012; Olaya-Abril et al., 2017, 2018). Accordingly, by reforestation and/or revegetation of these soils can increase their SOC store capacity (carbonization and/or recarbonization) (Guo and Gifford, 2002; Metz et al., 2007). However, the LUC from forest to agricultural land implies an important soil C loss (decarbonization) and its incorporation (via emission) to the atmosphere, contributing to global warming (Lal, 2005; Schulp et al., 2008). Despite this, the soils with permanent crops such vineyards, olive groves, nuts, and almonds in Mediterranean areas (with greater than 3 Mha) contribute to 3% of the total SOC-S (Gómez, 2017).

In this sense, the 4p1000 initiative is a brilliant idea proposed by the French minister of agriculture Stéphane Le Foll during COP 21 in 2015 (Soils for Food Security and Climate in Paris climate conference of the United Nations Framework Convention on Climate Change). This proposal was an international programme to increase the global soil OM stocks by 0.4% per year to compensate the global emissions of greenhouse gases by anthropogenic sources. This proposal would involve a SOC-S increase of 0.6 tons of C per hectare per year on average globally in the first 40 cm soil depth (Chabbi et al., 2017; Minasny et al., 2017) initially for 20 years (Poulton et al., 2017). With this proposal, it would be possible to eliminate from the atmosphere the annual CO_2-C emissions from fossil fuels (8.9 Gt C). Really it is a good initiative, but we must be careful, as it has certain limitations (Chabbi et al., 2017; Lal, 2016; Minasny et al., 2017; Poulton et al., 2017; Baveye et al., 2018). But, as Lal (2016) says, “the 4p1000 proposal should be more about the concept than any specific numbers”.

To determine exactly the LUC effects on soil C amount we must consider the SOC and the SOC-S quantification in the surface layer (topsoil) and in the subsurface horizons (subsoil). In this line, many researchers like Lozano-García et al. (2017) and Francaviglia et al. (2017a) …among others, in agroforestry systems and in forest soils respectively, demonstrate the importance of the C amount store in subsoils and its significance in the soil role as C sink in Mediterranean areas. Therefore, it is necessary to study entire soil profile and not exclusively the soil surface horizon (topsoil), in addition, it is crucial the sampling method (by horizons or by soil control sections - fixed depths) so that can affect to SOC-S quantification (Parras-Alcántara, et al., 2015b; Francaviglia et al., 2017a). This simple consideration can affect to SOC-S quantification so that the SOC-S may be overestimated or underestimated when the sampling is by soil control sections. Hence, sampling by horizon in entire soil profiles is recommended if the target is to evaluate and certify the SOC-S at regional scales, as sampling should be based on soil natural properties (genetic horizons). Considering these matters, three key factors must be considered in relation to SOC pools: (i) related to measurement scale, (ii) related to the methodology for SOC-S quantification and (iii) related to the sampling methodology (entire soil profile by genetic horizon or soil control section at a specific depth). Subjects that should be obvious but show uncertainty, in this line, Lal (2005) already indicated these considerations with respect to complexity in the forest soils (sampling protocol and scale of measurement). But more recently, Lal (2018) recommended at least 50-cm depth, and preferably to 1 m depth to assessing the SOC-S changes at different depths (0.3, 0.4, 0.5 and 1.0 m depth) over 5 year period in relation to land use and management.

The main goal of this research was to quantify over time the effects in the SOC-S, evaluating two LUC’s to assess the LUC effects in the SOC-S within the entire soil profile, and its involvement in the 4p1000 concept. And the specific objectives of this study were: i) determine the conversion effects from Mediterranean forest (natural forest - cork oak forest) to different agricultural uses (tilled vineyard, no tilled grassed vineyard, hay crop, pasture - silvopastoral and silvoarable practices) on SOC-S and ii) determine the effect of natural revegetation to a semi-natural condition on SOC-S after the abandonment agricultural land (vineyards).

2. Materials and methods

2.1. Site characterization

The study was carried out in the Berchidda Municipality (Olbia-Tempio, Sardinia, Italy), and comprises an area of 1,470 ha, located between 40°46′ N; 9°10′ E (Fig. 1). This area is a hilly basin, with an average altitude of 302 m.a.s.l. (meters above sea level), ranging between 275 and 340 m.a.s.l. The relief is smooth with slopes ranging from 3% to 8% and may reach values of 30%. The materials are intrusive natural granite accompanied by quartz and porphyry (Bevivino et al., 2014). This region has pluvi-seasonal oceanic (low) *meso*-Mediterranean and (low) sub-humid climate. The long-term mean annual air temperature is 15.0 °C ranging from 13.8 °C to 16.4 °C, and the annual mean rainfall is 623 mm, varying between 367 and 811 mm in the

Fig. 1. Study area. Berchidda Municipality (Olbia-Tempio, Sardinia, Italy). UTM:32 T 513860.59 m – E 4515004.17 m.

period 1985–2006 (Servizio Agrometeorologico Regionale of Sardinia Region). In general, the climate is warm temperate with dry and hot summers (Csa) according to the Köppen-Geiger updated classification (Kottek et al., 2006). The most representative soils in the studied area are dystric and eutric Cambisols (IUSS Working Group WRB, 2015) derived from granitic rocks. The soils are characterized by acid pH (5.1–6.2) and moderate base saturation, low fertility, poor physical conditions (loamy sand, sand, and sandy loam textures) and a marginal capacity for agricultural use (Lagomarsino et al., 2011; Francaviglia et al., 2014).

The natural vegetation it is mainly formed by cork oak forest (*Quercus suber*), a type of MEOW under extensive agroforestry system, considered an example of sustainable land use (Bagella and Caria, 2011). This cork oak forest (Cof) was partially converted to other land uses in the last century: vineyard under two different managements - tilled vineyards (Tv) and no-tilled grassed vineyards (Ntgv); hay crop (Hc) and pasture (P) under silvopastoral and silvoarable practices (first half of the 20th century). Then, in the middle of the 20th century, some vineyards were abandoned and were naturally revegetated to semi-natural systems (Fv) composed of scrublands, Mediterranean maquis, and Helichrysum meadows. These six land uses were described in detail in Francaviglia et al. (2014).

2.2. *Experimental design.*

The different land uses studied chronologically were: Cof, Tv, Ntgv, Hc, P and Fv. The first LUC was from Cof to Tv, Ntgv, Hc and P (first half of the 20th century ≈ 1938) and the second LUC was from Tv and Ntgv to Fv (in the middle of the 20th century ≈ 1966) (Fig. 2). Samples from 26 soil profiles were collected under the six different land uses: 4 sampling points in Tv, 4 in Ntgv, 5 in Hc, 4 in P, 2 in Cof and 7 in Fv. Soils were dystric Cambisols in Cof, Tv and P; and both dystric and eutric Cambisols in Ntgv, Hc and Fv according to (IUSS Working Group WRB, 2015). The sampling points number has not been done at random, since a previous geo-statistical analysis allowed to assess the SOC spatial variability as a land use function (Francaviglia et al., 2014). Consequently, a higher number of samples were collected in the more heterogeneous land uses (Tv, Ntgv, P and Hc) in which samples were collected in open areas (under the plants and in the inter-rows). Nevertheless, a lower number of samples in Cof where collected, since vegetation was homogeneous. In the case of Fv land use was sampled under different conditions of natural revegetation (scrublands, Mediterranean maquis, and meadows).

2.3. *Soil sampling, analytical methods, and statistical analyses*

Soil samples were collected along the different soil horizons for each profile, thus avoiding the mixing of the pedogenic horizons and allowing for a proper determination of physical and chemical soil properties (Lal, 2005; Parras-Alcántara et al., 2015b; Francaviglia et al., 2017a). A random sampling scheme was adopted, pits were digged with a mini excavator, and samples for a general characterization of entire soil profiles were collected along the different soil horizons using a hand trowel. The maximum sampling distance was 1.6 km (between Tv and Fv).

Samples were dried at a constant room temperature (25 °C) and sieved (2 mm). The remaining gravel was weighed. Three laboratory replications were performed for each soil sample. The analytical methods used in this study to determine different soil properties are reported in Table 1.

The effect of land use and soil depth on SOC-S was analyzed using ANOVA (SPSS 13.0 for Windows). Data were tested for normality to verify the model assumptions, and differences of $p < 0.05$ were considered statistically significant.

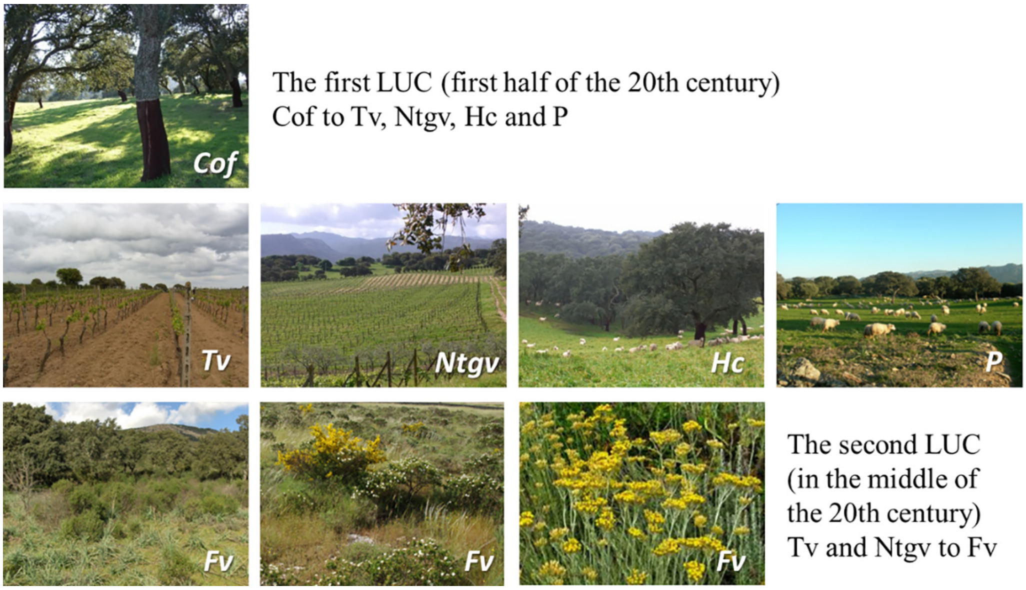

Fig. 2. Land uses studied chronologically (chronosequence). Cof: Cork oak forest, Tv: tilled vineyards, Ntgv: no-tilled grassed vineyards, Hc: hay crop, P: pasture under silvopastoral and silvoarable practices, Fv: vineyards abandoned and naturally revegetated to semi-natural systems (scrublands, Mediterranean maquis, and Helichrysum meadows).

Table 1
Analytical methods used in this study.

Parameters	Method
Bulk density (Mg m^{-3})	Core method (Blake and Hartge, 1986)
Particle size distribution	Robinson pipette method (USDA, 2004)
Soil Organic C (g kg^{-1})	Walkley and Black method (Nelson and Sommers, 1982)
SOC-S(Mg ha^{-1})	SOCS = SOC concentration × BD × d × (1 − δ2mm%) × 10^{-1} (IPCC, 2003)
T-SOC-S(Mg ha^{-1})	TSOCS = $\Sigma_{\text{soil section } 1\ldots.n}$ SOCS $_{\text{soil section}}$ (IPCC, 2003)

3. Results and discussion

3.1. Basic soil properties

The studied soils were dystric and eutric Cambisols according to IUSS Working Group WRB (2015), exhibiting differences in their physical and chemical properties with respect to land use and depth (Lagomarsino et al., 2011; Seddaiu et al., 2013; Francaviglia et al., 2014). Overall, the soils were deep, with sandy texture (loamy sand, sand, sandy loam, and sandy clay loam), with high gravel content in some cases (Table 2). Similar outcomes were obtained by Álvarez et al. (2007) and Lozano-García and Parras-Alcántara (2013) in Cambisols in Sierra Morena (Southern Spain) for Cof and Cof with olive trees respectively, indicating that the physical soil properties in these soils are affected by the lithology (granite), while their development is conditioned by their formation age (Porta et al., 2003).

Soil depth was variable in the different land uses examined, with maximum values in the range 101–130 cm for all land uses, except for Cof where depth was limited by rock fragments at 60 cm depth (Table 2). The surface horizon thickness (A-horizon) was not significantly different ($p < 0.05$) in Tv (18.3 cm), Ntgv (20.2 cm) and Cof (A1 + A2 = 20 cm), however, significantly differences were founding in comparison with Fv (25.4 cm), P (26.6 cm) and Hc (28.1 cm). These small variations can be justified by slope steepness, length, topographic curvature, and relative topographic position regarding to different soil positions in the study (Parras-Alcántara et al., 2013). Other authors such as Bakker et al. (2005) in Greece for different LUC justified these soil thickness variations by management news associated to LUC with heavy machinery.

The gravel content was very heterogeneous, ranging on average between 9.4% and 60.7% for Cof (Bw-horizon) and Ntgv (C-horizon) respectively (Table 2). In general, the trend was to increase in depth except for Cof and P that decreased. This behavior may be due to the stone line presence as postulated Symith and Montgomery (1962) and by the tillage used that removes large amount of stones and boulders (Fernández-Romero et al., 2014). It is important to point out that soil gravel content is a very important factor so that it affects to SOC-S estimation. In this line, IPCC (2003) and Stolbovoy et al. (2005,2007) in soil sampling protocol indicated that the gravel content should be considered in the SOC-S estimations.

Due to lithology (medium-grained granite), the studied soils were characterized by high sand content in all studied cases. This behavior was like the gravel content (increasing in depth), except for Cof that decreased (Table 2). The minimum sand content was found in Cof (Bw-horizon, 62.5%) and the highest value in Tv (C-horizon, 93.9%). With respect to the clay content, it is important to note the low values found in the studied soils, ranging from 7.2% (Ntgv: Bw) to 20.2% (Cof: Bw). For all land uses, bulk density (BD) increased in depth (Table 2). One crucial point which needs to be highlighted is the soil texture, so that, it does not affect to the SOC-S quantification directly, however, it can affect to SOC-S indirectly, producing changes in BD, SOC content, and other soil properties (e.g., liquid and gaseous components distribution within soil). Similar results were found by Parras-Alcántara et al. (2014) in Los Pedroches Valley (Southern Spain) in Cambisols (land use: Cof; lithology: granite), who using Pearson's correlation matrix identified significant linear correlations between: sand and silt content, sand and clay content, SOC and BD, silt and clay content, BD and sand content, and thickness and BD… among others.

The SOC analysis in top soil (A-horizon) showed the highest SOC concentration in Cof (59.2 and 13.5 g kg^{-1} in A1 and A2 horizons respectively, with a weighted average of 36.4 g kg^{-1}) and the lowest concentrations in Ntgv with 10.3 g kg^{-1} (Table 3). This low concentrations in Ntgv according to Francaviglia et al. (2014) is due to Ntgv only the pruning residues being left on the soil, without another organic amendment. However, in Tv, an organic fertilization was applied (12.5% organic nitrogen, 40% organic carbon and 70% organic matter) at the end of January at the rate of 500 kg ha^{-1} being incorporated in the first 20 cm of soil with a rototiller; it provides 200 kg ha^{-1} of organic carbon and 62.5 kg ha^{-1} of N. Also, the pruning residues are removed from the field. Regardless of land use, the SOC concentrations decreased in depth. It is important to noted that the studied soils under Cof had higher SOC concentrations than other Cambisols with the same land use in other locations (Mediterranean areas). Thus, in Southern Spain, Corral-Fernández et al. (2013) found

Table 2
Physical soil properties evaluated (average ± SD*) in the entire soil profile by horizons in the study area.

Land Use	Hor.	Depth (cm)	TH (cm)	Gravel (%)	Texture	Sand (%)	Silt (%)	Clay (%)	BD (Mg m^{-3})
Cof CM-dy $n = 2$	A1	0–3.5	3.50 ± 0.71c	14.5 ± 3.18c	SL	73.6 ± 4.01b	13.4 ± 2.70b	12.9 ± 1.31a	1.14 ± 0.00c
	A2	3.5–20.0	16.5 ± 6.36c	30.8 ± 8.27c	SL	76.7 ± 25.5b	12.0 ± 2.54a	11.3 ± 0.01a	1.49 ± 0.01b
	Bw	20.0–60.0	40.0 ± 10.2b	9.40 ± 2.42d	SCL	62.5 ± 1.91c	17.3 ± 1.84a	20.2 ± 1.16a	1.60 ± 0.03a
Tv CM-dy $n = 4$	Ap	0–18.3	18.3 ± 2.63b	54.6 ± 6.75a	LS	82.9 ± 3.75a	4.85 ± 4.65d	12.2 ± 1.53a	1.51 ± 0.07a
	Bw	18.3–50.6	32.3 ± 13.8b	55.2 ± 10.7a	LS	82.7 ± 3.78a	5.33 ± 3.35b	12.0 ± 0.83a	1.53 ± 0.04a
	BC	50.6–103.6	53.0 ± 9.85a	55.0 ± 8.26a	S	88.3 ± 2.27a	3.36 ± 2.58c	8.31 ± 0.85b	1.54 ± 0.04a
	C	103.6–130.3	26.7 ± 5.77a	59.7 ± 14.1a	S	93.9 ± 0.77a	1.25 ± 0.43a	4.84 ± 0.82a	1.51 ± 0.05a
Ntgv CM-dy $n = 4$	Ap	0–20.2	20.2 ± 4.92b	33.9 ± 5.20b	LS	79.9 ± 0.91a	8.60 ± 1.30c	11.5 ± 1.18a	1.51 ± 0.06a
	Bw	20.2–64.7	44.5 ± 10.5a	51.2 ± 13.6a	LS	87.0 ± 5.62a	5.82 ± 2.74b	7.21 ± 3.06b	1.53 ± 0.03a
	C	64.7–101.4	36.7 ± 15.3b	60.7 ± 15.6a	S	87.7 ± 6.64a	3.92 ± 2.92c	8.42 ± 4.69b	1.58 ± 0.04a
Hc CM-dy $n = 5$	Ap	0–28.1	28.1 ± 13.9a	32.2 ± 5.45b	SL	70.5 ± 9.31b	17.1 ± 10.0a	12.4 ± 13.7a	1.40 ± 0.09b
	Bw	28.1–60.0	31.9 ± 19.6b	32.4 ± 11.2c	SL	74.6 ± 2.62b	13.7 ± 1.50a	11.6 ± 1.38a	1.56 ± 0.03a
	C	60.0–120.0	60.0 ± 42.4a	54.3 ± 14.9a	LS	85.6 ± 28.6a	3.66 ± 2.68c	10.7 ± 0.18b	1.57 ± 0.01a
P CM-dy $n = 4$	A	0–26.6	26.6 ± 8.79a	26.9 ± 4.45b	SL	73.1 ± 1.06b	13.5 ± 0.96b	13.4 ± 0.89a	1.45 ± 0.04b
	Bw	26.6–64.3	37.7 ± 19.1b	36.2 ± 21.4c	SL	79.0 ± 4.23a	10.3 ± 3.02a	10.7 ± 16.1a	1.56 ± 0.03a
	BC	64.3–122.8	58.5 ± 33.2a	24.0 ± 2.93c	SL	74.2 ± 2.11b	9.43 ± 5.88b	16.3 ± 5.67a	1.60 ± 0.01a
Fv CM-dy $n = 7$	A	0–25.4	25.4 ± 8.08a	33.9 ± 13.6b	SL	78.9 ± 3.60a	10.7 ± 3.73c	10.4 ± 3.26a	1.44 ± 0.03b
	Bw	25.4–55.7	30.3 ± 5.54b	41.5 ± 13.4b	LS	82.6 ± 3.41a	7.36 ± 0.27b	10.0 ± 3.13a	1.48 ± 0.06b
	C	55.7–105.5	49.8 ± 10.6a	42.1 ± 21.4b	LS	84.0 ± 6.39a	5.92 ± 2.53b	10.0 ± 4.31b	1.60 ± 0.03a

SD*: Standard deviation; Hor.: Horizon; TH: Thickness; BD: Bulk density; Texture (USDA, 2004), LS: Loamy sand, S: Sand, SL: Sandy loam, SCL: Sandy clay loam.
Cof: Cork oak forest; Tv: Tilled vineyard; Ntgv: No tilled grassed vineyard; Hc: Hay crop; P: Pasture; Fv: Former vineyard.
CM-dy: Dystric Cambisols (IUSS Working Group WRB, 2015); n = Sample size.
Numbers followed by different lower-case letters are significantly different ($p < 0.05$) for the same horizon among different land uses considering the same property.

11.4 g kg^{-1} (A-horizon: 20 cm) under Cof, Peregrina et al. (2014) found SOC concentrations in the top 20 cm under vineyards ranging from 6.2 to 10.1 g kg^{-1}, in Sardinia (Italy), Salis et al. (2015) reported SOC concentrations of 21.1 g kg^{-1} in the topsoil (30 cm) under natural pastures, and 15.6 g kg^{-1} after a LUC to forage crop, Novara et al. (2013) after vineyards abandonment in Sicily (Italy), found SOC concentrations ranging from 14.7 to 26.3 g kg^{-1} as a function of abandonment age with different vegetation covers in the top-soil (30 cm). This variability in the SOC concentration (A-horizon) could be due to soil thickness, tree density, or even MEOW-Cof management (Corral-Fernández et al., 2013).

3.2. Land use change 1: From agroforestry system to agricultural land. Effects on SOC-S (Decarbonization and Carbonization)

The starting point was the MEOW - Cof system in the year 1938. The SOC-S concentrations in Cof were 44.2 Mg ha^{-1} and 63.0 Mg ha^{-1} respectively for topsoil (0–20 cm: A1 + A2 horizon) and for in the whole soil profile (0–60 cm) (Fig. 3, Table 3). These values are in agree with Chiti et al. (2012) in agroforestry systems in Italy, who found SOC-S concentrations between 40 and 70 Mg ha^{-1} and with Rodríguez-Murillo (2001) who determined 71.4 Mg ha^{-1} for Cambisols and 50.8 Mg ha^{-1} for Cof in Spain. The differences in the SOC-S between agroforestry systems in Italy, soil groups in Peninsular Spain and the studied soils may be caused by soil thickness, since we used entire soil profiles (60 cm depth), Chiti et al. (2012) used top soil (30 cm) and

Table 3
Physical soil properties evaluated (average ± SD*) in the entire soil profile by horizons in the study area.

Land Use	Hor.	SOC (g kg^{-1})	SOC-S (Mg ha^{-1})	SOC-S SH/SSH (Mg ha^{-1})	T-SOC-S (Mg ha^{-1})
Cof CM-dy n = 2	A1	59.2 ± 13.1	20.5 ± 7.78	44.2 ± 10.0a	63.0 ± 8.50a
	A2	13.5 ± 0.48	23.7 ± 12.3	18.8 ± 5.42a	
	Bw	3.25 ± 1.81	18.8 ± 5.42		
Tv CM-dy n = 4	Ap	14.4 ± 5.51	17.6 ± 6.82	17.6 ± 6.82b	59.8 ± 12.8a
	Bw	10.1 ± 4.41	22.7 ± 26.3	42.2 ± 14.8b	
	BC	4.75 ± 4.58	17.4 ± 17.4		
	C	1.36 ± 0.45	2.11 ± 0.80		
Ntgv CM-dy n = 4	Ap	10.3 ± 6.26	18.5 ± 9.90	18.5 ± 9.90b	40.5 ± 10.4b
	Bw	5.59 ± 5.48	16.7 ± 14.6	21.9 ± 10.7a	
	C	2.90 ± 4.26	5.25 ± 6.82		
Hc CM-dy n = 5	Ap	21.8 ± 8.65	54.6 ± 25.3	54.6 ± 25.3c	92.7 ± 13.7c
	Bw	6.08 ± 2.56	17.5 ± 7.22	38.1 ± 7.99c	
	C	5.43 ± 0.01	20.6 ± 8.76		
P CM-dy n = 4	A	18.3 ± 4.21	49.8 ± 16.0	49.8 ± 16.0c	95.3 ± 14.7c
	Bw	6.18 ± 2.27	23.7 ± 19.3	45.5 ± 14.1b	
	BC	3.24 ± 0.74	21.8 ± 8.90		
Fv CM-dy n = 7	A	17.3 ± 3.72	41.8 ± 14.6	41.8 ± 14.6a	83.4 ± 12.3d
	Bw	13.2 ± 4.50	36.5 ± 22.2	41.6 ± 11.2b	
	C	1.11 ± 0.01	5.12 ± 0.14		

Tv: Tilled vineyard; Ntgv: No tilled grassed vineyard; Hc: Hay crop; P: Pasture; Cof: Cork oak forest; Fv: Former vineyard
CM-dy: Dystric Cambisols (IUSS Working Group WRB, 2015)
SD*: Standard deviation. Hor: Horizon; TH: Thickness; BD: Bulk density; SOC: Soil organic carbon; LS: Loamy sand, S: Sand, SL: Sandy loam, SCL: Sandy clay loam.
Land uses as in Table 1.
Numbers followed by different lower case letters are significantly different ($p < 0.05$) for the same horizon among different land uses considering the same property.

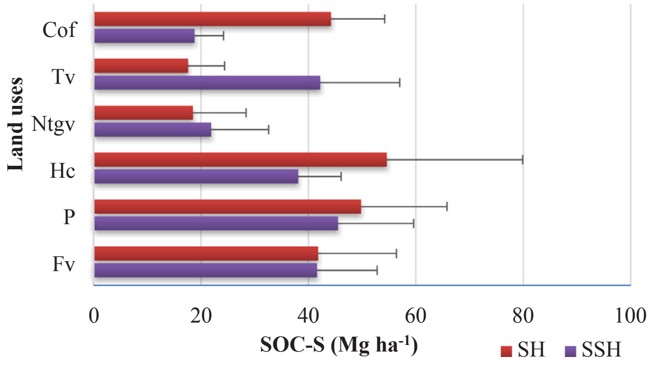

Fig. 3. SOC-S (Mg ha^{-1}) (average ± SD). A comparison between the surface and the subsurface horizons. SD: standard deviation. Land uses are Tv: Tilled vineyard; Ntgv: No tilled grassed vineyard; Hc: Hay crop; P: Pasture; Cof: Cork oak forest; Fv: Former vineyard. SH: superficial horizon. SSH: subsurface horizons.

Rodríguez-Murillo (2001) used soil profiles descriptions deeper than 1 m.

Cof is a unique ecosystem, and it is the most widespread agroforestry system in Mediterranean Europe integrating forestry, agricultural and livestock practices (Romanya et al., 2007). In general, the vegetation cover and the SOC-S are lower than in others natural forests in Europe. Nowadays, many researches have determined the Cof contribution to C sequestration and the preliminary results indicate a large capacity of these areas for SOC accumulation - C sink (Roig and Rubio, 2009) especially in Mediterranean areas. In addition, different tree species store SOC in different ways and quantities (Jandl et al., 2007), being the *Quercus* sp. one of the highest forest type in terms of SOC storage (140, 111, 87 and 116 Mg ha^{-1} of SOC-S in Mediterranean pines, Mixed conifers, Standard Oak and Oak evergreen respectively) (de Vries et al., 2003).

The first LUC was from Cof to Tv, Ntgv, Hc and P (first half of the 20th century ≈ 1938). The principal consequence of this LUC was a soil decarbonization (Tv and Ntgv) and a soil carbonization (Hc and Ap) with respect to the original land use (Cof). In the decarbonization case (Cof to Tv and Ntgv) the SOC-S was reduced a 5.1% and 37.5% for Tv and Ntgv respectively, however in the carbonization case (Cof to Hc and P) the SOC-S was increased a 47.1% and 51.3% for Hc and P with respect to Cof (Table 3).

In the case of soil decarbonization processes, two things happened; firstly, there was a strong SOC-S loss in the surface horizon (A-horizon) in both cases (Tv and Ntgv) after the LUC. SOC-S losses were higher than 60% (Cof: 44.2 Mg ha^{-1} to Tv: 17.6 Mg ha^{-1} and Ntgv: 18.5 Mg ha^{-1}); secondly, there was a SOC-S increase in depth especially important in Tv (124.5%) (Table 3), but despite these changes only were found significant differences ($p < 0.05$) between Cof (63.0 Mg ha^{-1}) and Ntgv (40.5 Mg ha^{-1}) with respect to total SOC-S along to soil entire profile. The SOC-S values in both types of vineyards were lower than the average values calculated in Italy and France. In this line, Chiti et al. (2012) found 41.9 Mg ha^{-1} in the first 30 cm for vineyards in Italy, Arrouays et al. (2001) found, also in the first 30 cm, values ranging between 15 and 39 Mg ha^{-1}, depending on the soil type, however, the SOC-S in soil entire profile (Fig. 2) was in line with those obtained by Rodríguez-Murillo (2001) in Spanish vineyards considering 1 m in depth. These differences in depth with respect to SOC-S could be conditioned by the soil thickness (Cof: 40 cm, Tv: 112 cm and Ntgv: 81.2 cm) (Table 2). Without forgetting that low SOC concentrations could also be explained by the soils texture, so that, the aggregates formation between soil OM and mineral fraction is reduced, favoring high levels of transformed OM in sandy soils (González and Candás, 2004). Also, it must be taken into consideration that there were differences among soil profile in depth and the land uses, making it difficult to achieve accurate comparisons (Table 2). Other researches have shown that the LUC from native forest to agricultural land reduces the surface SOC concentration, mainly by reducing biomass inputs to the soil and increasing soil erosion (Yu and Jia, 2014; Bruun et al., 2015). These same effects have been reported after LUC from agroforestry systems (Cof) to perennial crops (olive groves) in Spain by Lozano-García et al. (2016).

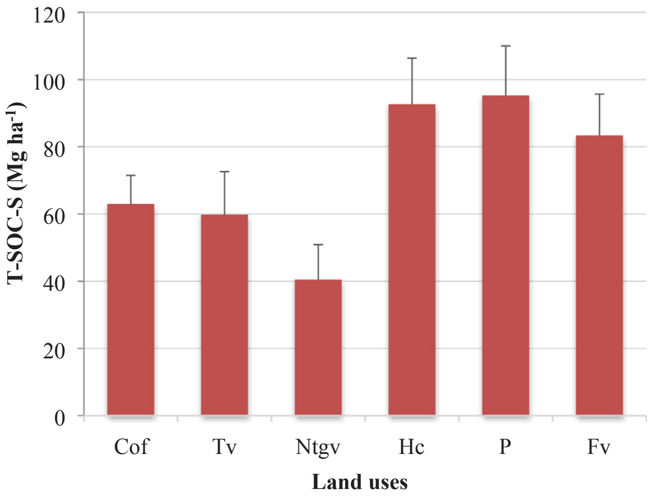

Fig. 4. Total SOC-S (Mg ha^{-1}) (average ± SD) in the different land uses. SD: standard deviation. Land uses are Tv: Tilled vineyard; Ntgv: No tilled grassed vineyard; Hc: Hay crop; P: Pasture; Cof: Cork oak forest; Fv: Former vineyard.

However, for the soil recarbonization processes (Cof to Hc and P), the LUC did not cause a negative impact on SOC-S (Table 3 and Figs. 3 and 4). Conversely, the SOC-S increased, in this sense, our results are in agree with several studies that showed increase or no change in SOC-S after the LUC from forests to pastures or grasslands. Murty et al. (2002) found that the LUC from forest to pasture (as in the studied soils), did not imply changes in the SOC-S concentrations, in fact, in more than half of the pastures SOC did not significantly increase. Fujisaki et al. (2015) also observed a slight increase on SOC-S concentrations in pastures compared to forests (+6.8%) after the LUC from forest. The main reason for explaining this SOC-S increases in pastures due to LUC is that pastures is favored by the high root biomass and grasses activity (Schnabel et al., 2001), which provides enough C to offset the mineralization of native forest C (Fisher et al., 1994). In addition, this significant increase in Hc and P (Cof: 63.0 Mg ha^{-1} to Hc: 92.7 Mg ha^{-1} and P: 95.3 Mg ha^{-1}) (Table 3), it could be caused by top soil accumulation of harvest residues and by the different climatic conditions under the trees (temperature, the shade effect and the differences in the incidence of rainfalls) which produce more slow mineralization and more intense humification (Don et al., 2007).

An important issue to consider in both cases (decarbonization and carbonization) is that in all cases there was a SOC-S increase in depth due to the LUC (Cof: 18.8 Mg ha^{-1} to Tv: 42.2 Mg ha^{-1}, Ntgv: 21.9 Mg ha^{-1}, Hc: 38.1 Mg ha^{-1}, and P: 45.5 Mg ha^{-1}). And this SOC-S increase in depth could be due to the mixing of the soil layers during soil tillage (Novara et al., 2012), by stabilization mechanisms of the clays (Bw-horizon) (Leifeld et al., 2015) or by C translocation in the form of dissolved organic C, soil fauna activity, and/or the effects of deep-rooting crops (Shrestha et al., 2004). All this shows the soil potential for C sequestration, so that the roots transfer large amounts of C into the soil slowly and contribute to the increase of C content in depth, which accumulates over time.

However, there is an inherent but not quantifiable source of variation in the data, due the different time periods after the conversion from Cof to P and Hc that were established in the 70 s, and Tv and Ntgv in the 90 s (Francaviglia et al., 2017b). After all, our results showed that all

LUC's from forest to agricultural land had not a negative impact in the soil capacity to storage SOC, except for Ntgv. Therefore, it is important to study the different alternatives before transforming a natural area into agricultural land.

3.3. Land use change 2: From agricultural land abandonment and naturally revegetated to seminatural systems. Effects on SOC-S (Recarbonization)

The second LUC was from Tv and Ntgv to Fv (in the middle of the 20th century ≈ 1966), due to the vineyard's abandonment because of low yields and high agricultural costs. These areas were naturally reconverted through secondary succession into an ecosystem very similar to Cof. This second LUC caused a SOC-S increase (recarbonization) in comparison with the previous state in vineyards (Tv and Ntgv to Fv), increasing the total SOC-S a 39.5% and 106% from Tv to Fv and from Ntgv to Fv, respectively. Increasing even the total SOC-S with the original situation (Cof) a 32.4% (Cof: 63 Mg ha^{-1}; Tv: 59.8 Mg ha^{-1}; Ntgv: 40.5 Mg ha^{-1} and Tv: 83.4 Mg ha^{-1}). Therefore, it is important to emphasize that not only a soil carbonization process was produced (from Tv and Ntgv to Fv), but also a recarbonization process took place, so that the SOC-S increased with respect to the initial situation (Cof) (Table 3), assuming that soil recarbonization (SOC sequestration) implying an additional net transfer of C from the atmosphere to the soil via biomass (Lorenz et al., 2011).

In topsoil, this LUC (Tv and Ntgv to Fv) caused a SOC-S increase (Tv: 17.6 Mg ha^{-1}; Ntgv: 18.5 Mg ha^{-1}; Fv: 41.8 Mg ha^{-1}), however, in depth these changes were lower (Tv: 42.2 Mg ha^{-1}; Ntgv: 21.9 Mg ha^{-1}; Fv: 41.6 Mg ha^{-1}) (Table 3). In this line, it is known that after a disturbance, the SOC-S accumulation following a favorable LUC is more rapid at the beginning, and it stops when a new equilibrium is reached (Muñoz-Rojas et al., 2015), and that the period required to reach this new equilibrium depends on the climatic conditions and vegetation type…, among others. In temperate areas of Europe a few decades are necessary to achieve this balance (Arrouays et al., 2001), while hundred years are needed in other locations, e.g. boreal regions (Smith, 2004). In our case, the LUC after the land abandonment was 41 years (1966–2007). Post and Kwon (2000) identified different factors that determine the SOC-S increases: i) increase in the OM inputs, ii) changes in the soil OM decomposition which increase the organic C light fraction, iii) deeper OM location either directly by increasing below-ground inputs, or indirectly by improving surface mixing by soil organisms and iv) increase in the physical protection by intra-aggregates and/or organo-mineral complexes.

Our findings are in agree with the results obtained by different authors at worldwide who find an opportunity for C sequestration after the LUC from marginal arable land to permanent and perennial vegetation (Paustian et al., 1997; Post and Kwon, 2000; Guo and Gifford, 2002; Muñoz-Rojas et al., 2015). Paustian et al. (1997) stated that in North America and Europe, the LUC from marginal arable land to permanent perennial vegetation allows the fragile soils protection, the agricultural surpluses reduction, and provides an environmental benefit via SOC sequestration. In addition, in different *meta*-analyses, Post and Kwon (2000) and Guo and Gifford (2002) found SOC-S increases at different rates, when cropland is converted to forest. More recently, Muñoz-Rojas et al. (2015) studying the LUC impact on SOC-S in the south of Spain between 1956 and 2007 found changes from arable land to forest leading a SOC-S increase, and these results occurred in different soil types and this changes were more marked in the surface layer (top soil).

All of this indicates that the removal of natural vegetation (Cof) to plant vineyards (Tv and Ntgv) was the cause of SOC-S decreasing and that the vineyard abandonment and subsequently natural restoration provoked an increased in SOC-S values.

3.4. Soil recarbonization. 4 per mile initiative

The soil can act as both C sink and source depending on management, biomass input levels, micro-climatic conditions, and bioclimatic change (Zomer et al., 2017). Therefore, it is necessary to know the uptake capacity of land-based sinks (soil, forest, and wetlands) (Lal, 2016). Precisely this was one of the targets of the "4p1000 initiative: Soils for Food Security and Climate" in the United Nations Framework Convention for Climate Change: Conference of the Parties (UNFCCC-COP 21) in Paris. The objective of this proposal was to increase 0.6 tons of C per ha yr^{-1} on average globally in the first 40 cm soil depth to compensate the annual CO_2-C emissions from fossil fuels.

In the studied area, different processes have occurred (decarbonization, carbonization and recarbonization) due to LUC. Let us focus on the second LUC (from agricultural land abandonment and naturally revegetated to seminatural systems – Tv and Ntgv to Fv). This LUC started in 1966 and ended in 2007, therefore this LUC has lasted 41 years. Many uncertainties arise when interpreting these data to check the 4‰ strategy, uncertainties such as the soil thickness to consider or the number of years to study…among others. In this sense, other authors such Chabbi et al. (2017) or Poulton et al. (2017) also raise these questions.

The LUC studied (Tv and Ntgv to Fv) in entire soil profiles (Tv:130.3 cm; Ntgv: 101.4 cm; Fv: 105.5 cm) for 41 years resulted on average a SOC-S increase of 33.25 Mg ha^{-1} (Tv: 59.8 Mg ha^{-1}; Ntgv: 40.5 Mg ha^{-1}; Tv/Ntgv average: 50.2 Mg ha^{-1}; Fv: 83.4 Mg ha^{-1}) (Tables 2 and 3), therefore, the average increase has been of 0.81 tons per ha yr^{-1} which would be a 5.4‰, slightly better results than those set out in the 4‰ initiative.

If the thickness is reduced and only the first and the second soil horizons is consider so that this depth is more similar to 40 cm that 4‰ initiative proposes (Tv: 50.6 cm; Ntgv: 64.7 cm: Fv: 55.7 cm), the increase was 40.6 Mg ha^{-1} (Tv: 40.3 Mg ha^{-1}; Ntgv: 35 Mg ha^{-1}; Tv/Ntgv average: 37.7 Mg ha^{-1}; Fv: 78.3 Mg ha^{-1}) therefore, the average increase has been 0.99 tons per ha yr^{-1} (6.6‰). But if we limit it to the top soil (A-horizon) (Tv: 20.0 cm; Ntgv: 18.3 cm; Fv: 25.4 cm), the increase was 23.7 Mg ha^{-1} (Tv: 17.6 Mg ha^{-1}; Ntgv: 18.5 Mg ha^{-1}; Tv/Ntgv average: 18.1 Mg ha^{-1}; Fv: 41.8 Mg ha^{-1}), the average increase has been 0.58 tons per ha yr^{-1} (3.9‰). Chabbi et al. (2017) pointed out that the SOC storage implementation under the 4‰ initiative is feasible assuming total soil (0–1 m) for removal 6 Gt C yr^{-1} from the atmosphere (2/3 of the annual anthropogenic CO_2 emissions) by applying economically viable agronomic practices and good environmental practices. This is in line with our results, since if we assume an average thickness of 112.4 cm the LUC (Tv and Ntgv to Fv) causes an SOC-S increase in accordance with 4‰ initiative (112.4 cm average thickness, 0.81 tons per ha yr^{-1}, 5.4‰). However, our best results are obtained by Tv: 50.6 cm, Ntgv: 64.7 cm and Fv: 55.7 cm, with an average increase of 0.99 tons per ha yr^{-1} (6.6‰), due to Bw-Horizon with a SOC-S increase (Novara et al., 2012; Leifeld et al., 2015; Shrestha et al., 2004; Parras-Alcántara et al., 2013).

3.5. The need to increase the SOC stocks as European policy.

The SOC reduction is one of the eight soil threats identified in the European Union (EU) Thematic Strategy for Soil Protection (EC, 2006 and 2012), and therefore one of the most important aims is to maintain and improve the SOC-S throughout the EU countries. In this line, it is important to highlight that SOC-S in the agricultural soils within the EU is 17.63 Gt, therefore, the EU agricultural policy should use the SOC as the main soil quality indicator and as a strategy for offsetting CO_2 emissions by C sequestration in the soil (ESDAC, 2018).

The Roadmap to a Resource Efficient Europe (EC, 2011), established the goal of enhancing current SOC levels in the EU by 2020 (Lugato et al., 2014). In addition, under Common Agricultural Policy (CAP), farmers are called up to maintain the agro-ecosystem by rural development measures coupled with the environmentally sustainable farming practices promotion. Therefore, farmers must achieve soil erosion protection, soil structure maintenance and soil OM levels under the EU cross-compliance scheme (Lugato et al., 2014).

Permanent crops, such as vineyard, olive and orchard contribute for only 3% of the total SOC-S in Europe (Lugato et al., 2014), and these land uses are mainly located in Mediterranean areas (Spain, Italy and France) where natural vegetation was previously present, resulting in an extremely complex, expensive and non-environmentally friendly crop management. Consequently, farmers and politicians must avoid converting natural areas to agricultural land before an exhaustive study about the possible effects has been completed (ESDAC, 2018).

Our results are useful in understanding the C cycle in Mediterranean environments and they are in agree with previous reports based on abandoned vineyards (Novara et al., 2013). Thus, the natural revegetation after abandonment and/or the artificial re-naturalization, are promising practices to recover the SOC-S; however, further studies are needed to evaluate all pros and cons in this LUC.

4. Conclusions

This study shows the importance of land use and LUC in Mediterranean areas with respect to SOC-S, and that the human action can degrade and/or regenerate the soil via Carbonization, Decarbonization and Recarbonization processes. The studied soils exhibited differences in their physical, and chemical properties with respect to land use and depth. SOC and SOC-S were some of the soil chemical properties that were most affected by LUC.

The first LUC was from Cof to Tv, Ntgv, Hc and P (first half of the 20th century ≈ 1938), the principal consequence was a soil decarbonization (Tv −5.1% and Ntgv −37.5%) and a soil carbonization (Hc + 47.1% and Ap + 51.3%) with respect to Cof. In the case of the second LUC (from Tv and Ntgv to Fv), in the middle of the 20th century ≈ 1966, the result was a soil recarbonization increasing the total SOC-S a + 39.5% and + 106% from Tv to Fv and from Ntgv to Fv respectively.

If we apply the 4p1000 initiative to the study area in the recarbonization process (from Tv and Ntgv to Fv), we can verify that this idea is possible, and can even reach 6.6‰ depending on the soil depth that we consider. Finally, indicate that in certain parts of the world, under certain characteristics (Mediterranean areas) with friendly practices the 4p1000 proposal is possible (with its limitations and uncertainties). This study demonstrates the importance of SOC-S assessment under different land uses and after LUC for a proper management planning in Mediterranean areas.

Declaration of Competing Interest

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.

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