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Exploring the multiplicity of soil–human interactions: organic carbon content, agro-forest landscapes and the Italian local communities

Luca Salvati · Pier Matteo Barone · Carlotta Ferrara

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Abstract Topsoil organic carbon (TOC) and soil organic carbon (SOC) are fundamental in the carbon cycle influencing soil functions and attributes. Many factors have effects on soil carbon content such as climate, parent material, land topography and the human action including agriculture, which sometimes caused a severe loss in soil carbon content. This has resulted in a significant differentiation in TOC or SOC at the continental scale due to the different territorial and socioeconomic conditions. The present study proposes an exploratory data analysis assessing the relationship between the spatial distribution of soil organic carbon and selected socioeconomic attributes at the local scale in Italy with the aim to provide differentiated responses for a more sustainable use of land. A strengths, weaknesses, opportunities and threats (SWOT) analysis contributed to understand the effectiveness of local communities responses for an adequate comprehension of the role of soil as carbon sink.

Keywords Soil organic carbon · Topsoil organic carbon · Socioeconomic indicators · Multidimensional analysis · Mediterranean region

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L. Salvati
Consiglio per la Ricerca e la sperimentazione in Agricoltura, Centre for the Study of Plant–Soil Interactions (CRA-RPS), Via della Navicella 2-4, 00184 Rome, Italy

P. M. Barone
Archaeology and Classics Program, The American University of Rome, Via Pietro Roselli 4, 00153 Rome, Italy

C. Ferrara (✉)
Department of Agriculture, Forests, Nature and Energy (DAFNE), Viale dell'Agricoltura, 02015 Cittaducale, Rieti, Italy
e-mail: ferrara@fis.uniroma3.it

Introduction

Soil constitutes a fundamental element for ecosystem functioning and agricultural productivity. In a recent study, Adewopo et al. (2014) highlighted the role of soils in carbon (C) cycling regulation or in facilitating ecosystem services including C storage. The soil organic carbon content (namely, topsoil organic carbon and soil organic carbon: Jones et al. 2004) is a key element in the C cycle, with a great influence on soil functions and attributes. It improves the physical–chemical properties of soils (Leeper 1993) and contributes to soil erosion containment, increasing the productivity of the agriculture (Randerson 2004) and improving the overall quality of soils (e.g. stability, water balance, biodiversity conservation) especially in non-cultivated forest and natural land (FAO 2003). Many factors influence the soil carbon content such as climate, parent material, land topography, vegetation cover and human pressure, with agricultural development sometimes causing huge losses in soil carbon content (Smith 2004). This has resulted in a significant differentiation of the C content at the global scale (Amundson 2001; Lala 2003; Batjes 2014; Jörn et al. 2014).

The quantification of soil carbon stock has taken an increasing importance in Europe (Lugato et al. 2007; Albaladejo et al. 2013; Leone et al. 2013). Podmanicky (2011) illustrated an impact assessment of European land-use changes on soil carbon content. A recent estimation model, due to different climate-emission scenarios up to 2100, indicated that higher soil respiration was offset by higher C input because of increased CO_2 atmospheric concentration and favourable crop growing conditions, especially in northern Europe (Lugato et al. 2014).

The relationship among land-use, vegetation, climate (and other environmental conditions) and the C content in the soil has been considered in many studies (Corona et al. 1997; Post and Kwon 2000; Smith 2004; Smith and Falloon 2005; Panagos et al. 2010; Schmidt et al. 2011; Liu et al. 2011; Bai et al. 2013; lbaladejo et al. 2013, Sommer and Bossio 2014, among others). However, the intimate links between rural development, local communities, and the socio-ecological context were explored in relation to soil carbon content only in few cases. Among them, Proyuth et al. (2012) have analysed the socioeconomic and environmental aspects of bamboo production and the positive impact on soil organic C content. Otherwise, Bationo et al. (2007) have investigated soil organic C as a source and sink for nutrients and its vital role in soil fertility maintenance, focussing on ways to alleviate socioeconomic constraints with the aim to increase soil fertility.

In a period of climate variations, socio-cultural and population changes, uneven landscape transformations coupled with variable international market forces (Lambin and Meyfroidt 2010; Abu Hammad and Tumeizi 2012; Romm 2011; Salvati and Carlucci 2013), it appears of great importance to reach a comprehensive knowledge of the capability of local communities to preserve organic C stocks (Pearce and Turner 1990; Daliy 1994; Azqueta and Soltelsek 2007; Briassoulis 2011; Colantoni et al. 2014; Dong et al. 2012). The relationship among local communities, the environmental conditions and the soil used for primary production can be evaluated with the aim to identifying specific socioeconomic local contexts where soil organic C is better preserved.

This approach requires a comprehensive understanding of the spatial distribution of organic C stocks at a very local scale together with a fine-grained socioeconomic analysis contrasting areas (e.g. municipalities, local districts or other local-level spatial units) with high and low soil C content. Research in this field contributes to define context-based, effective policies to mitigate human pressure and to reduce soil C loss especially in socio-ecological fragile areas (Blaikie and Brookfield 1987, Costanza et al. 1997; Deutsch et al. 2003; Roseta-Palma et al. 2010; Imeson 2012).

Based on these premises, the present study is aimed at investigating the complex relationship between the socio-ecological context and the soil organic C content in Italy, with a local-scale analysis covering the whole country at the level of municipalities. A multivariate exploratory data analysis based on 133 indicators is proposed here with the aim to identify the socio-ecological attributes that had better characterised the Italian municipalities with respect to the level of both topsoil organic carbon and soil organic carbon (respectively TOC and SOC). A strengths, weaknesses, opportunities and threats (SWOT) analysis based on the resulting outputs, was proposed to outline future intervention scenarios. The approach presented in this paper can be considered an original contribution to soil analysis, regional studies, planning and sustainability science.

Methodology

The study area

The area investigated in this paper covers 301,330 km^2 (the whole Italian territory divided in 23 % flat, 42 % hilly and 35 % mountainous land: Salvati and Carlucci 2011). A traditional north–south division in both environmental (climate regimes, landscapes, vegetation, environment and soil resources), and socioeconomic variables (demography and settlements, labour market and human capital, economic structure, agriculture and cropping systems, quality of life, etc.) characterises the study area. The country is administered by 20 regions and about 8100 municipalities. The reason of choosing the spatial reference unit from the 2001 administrative asset (Istat, 2006) is that it gives a full correspondence between socioeconomic and environmental data. It is worth to notice that the local governance system changed only moderately in 2013 with 8094 municipalities administering the Italian territory. Italy can be considered an emblematic area for investigating the spatial distribution of organic C in the soil in relation with the socioeconomic context due to the millenary interactions between local communities, landscape and the environment. The intrinsic country-scale variability in most of the factors considered here—from both the ecological and the socioeconomic point of view—provides another motivation for the designation of Italy as the study area (Salvati et al. 2013).

Assessing soil organic carbon

The European Soil Bureau of the Joint Research Centre in Ispra (Italy) assessed TOC content in Europe based on the European Soil Database in combination with land cover, climate and topography databases (Jones et al. 2004, 2005). The same Bureau determined that SOC content of agricultural soils in Europe based on a model running a combination of climate, soil, land-use and management practices (e.g., irrigation, mineral and organic fertilisation, tillage, etc.) derived from public archives (Lugato et al. 2014). Using the spatial analysis routine of ArcGIS software (ESRI Inc., Redwoods, USA), the values of TOC and SOC in each Italian municipality were derived by overlapping the respective maps available online from the JRC, European Soil Portal (at http://eusoils.jrc.ec.europa.eu/ESDB_Archive/octop/octop_data.html) to the shape file illustrating the municipalities' borders provided by the Italian National Statistical Institute (Istat). The resulting output was used as starting point in the following statistical analysis (see 'Statistical analysis').

Territorial indicators

More than 100 indicators describing the most relevant socioeconomic characteristics of local communities in Italy were derived from Istat statistics and the European Soil Bureau data archive (European Soil Bureau 2014) referred to a time interval between 1999 and 2001 (see full description in Table S1). These years represent the most up-to-date point in time with an enough large availability of socioeconomic indicators on the highest spatial scale (i.e. municipalities). Data collected in most recent years are partial for some variables and presented lacks and incomparability due to modifications in the survey techniques. Moreover, the acquisition of a vast dataset for the current period was prevented by the late dissemination schedule for a number of relevant census variables. Variables for every Italian municipality were based on 7 research themes and 19 analysis' dimensions (Table 1 and Table S1), and they were calculated for a total of 133 indicators and three territorial variables (elevation, south–north gradient and urbanisation level), following Blaikie and Brookfield (1987), Trisorio (2005), Perini et al. (2008), Basso et al. (2012), Salvati (2014) and Salvati and Zitti (2009).

Statistical analysis

The exploratory data analysis carried out in this study includes (i) a Spearman rank correlation analysis assessing the pair-wise correlation between each indicator and both TOC (or SOC) separately and (ii) a principal component analysis (PCA) summarising indicators into few relevant factors that describe the local socio-economic contexts found in Italy, and the relationship with the spatial distribution of TOC (or SOC). The subsequent steps were aimed at (iii) profiling the Italian municipalities based on a comparative evaluation of the results derived from the two statistical analyses and (iv) performing a SWOT analysis to outline optimal intervention strategies for containing soil organic carbon

Table 1 Research themes and analysis dimensions explored by the indicators used in the present study (for the list of indicators, see supporting Table S1)

Research theme	Analysis' dimension	Number of indicators
Demography and settlements	Population dynamics, human settlements, population structure	15
Labour market and education	Job market, education	20
Economic structure	Production base (as economic specialisation and competitiveness), tourism	23
Quality of life	Income and wealth, crime and society	17
Agriculture and rural development	Land tenure, crop intensity, innovation and quality in agriculture, human capital	26
Landscape and water	Landscape structure and composition, water resources	14
Environment and soil resources	Land degradation, natural resources, soil quality and soil degradation	18
		133

loss especially in ecologically fragile and economically marginal municipalities.

The non-parametric Spearman rank correlation analysis was carried out to study the correlation between the estimated TOC (or SOM) in every Italian municipality and each socioeconomic indicator. Only indicators with significant Spearman correlation coefficients were considered testing at $p<0.001$ after Bonferroni's correction for multiple comparisons. A two-step PCA was used to evaluate and summarise spatial heterogeneity and regional disparities in the selected indicators in Italy and to investigate the intimate relationships with TOC (or SOC). Due to the high number of input variables, a two-step PCA was developed: The first step was based on a separate PCA on the indicators belonging to each of the seven research themes (see Table 1) producing a total of 12 analysis' runs (for both TOC and SOC). The explained variance and the number of the extracted components (based on the threshold described above) were considered to illustrate the overall performance of the first-step PCA. Components loadings >|0.5| were used to study the correlation of the individual indicators with each extracted component.

The second-step PCA was run on the full matrix formed up by all selected indicators by column and municipalities by row. Loadings and scores were used to characterise the extracted components and to identify latent factors shaping the relationship between TOC (or SOC) and the selected indicators. The three supplementary variables describing relevant geographical gradients in Italy (see 'The study area') were also correlated with each component using non-parametric Spearman rank coefficients testing at $p<0.001$ after Bonferroni's correction for multiple comparisons. Based on the previous analyses (Spearman correlation and two-step PCA), a summary of the correlations (significance and sign) found between TOC (or SOC) and the selected indicators was proposed. The indicators totalising comparable results in terms of both sign and significance of the correlation with TOC or SOC were highlighted.

Based on these results, a SWOT analysis was finally implemented to outline optimal intervention strategies for containing soil organic carbon loss in municipalities with specific socioeconomic profiles. In particular, we have examined the following: (i) the strengths–opportunities (SO) strategy (in which the existing strengths are used to take advantage of opportunities), (ii) the weaknesses–opportunities (WO) strategy (which seeks to reduce points of weakness to get into position to exploit the opportunities), (iii) the strength–threats (ST) strategy (in which existing strengths are used to reduce the threats) and, finally, (iv) the weaknesses–threats (WT) strategy (in which trying to reduce the impact of threats on the system's weaknesses).

Results

Descriptive statistics

The spatial distribution of topsoil organic carbon (TOC) and soil organic carbon (SOC) in the Italian municipalities illustrates the diverging distribution in TOC and SOC along the country, with concentration of the higher SOC classes in northern Italy and with TOC being associated with the elevation gradient and particularly abundant along the mountain chains of Alps and Apennines (Fig. 1). The selected territorial attributes of Italian municipalities by SOC class (Table 2) outline the correlation between the spatial distribution of environmental and socioeconomic variables and soil C content. A negative correlation was found between TOC (or SOC) and resident population, annual growth rate, cultivated lands or ESA index. Overall, SOC shows less significant correlations with the territorial indicators than TOC due to the lower intrinsic spatial variability and the higher dependence on the characteristics of the long-established agricultural system. This trend is partly confirmed by the variables cultivated land and cultivated land/agricultural area, with decreasing C content in areas high higher values observed for both variables. Both TOC and SOC increased with elevation (183 m vs 485 m and 308 m vs 419 m). In addition, the highest differences in the TOC are more likely related to the decrease in cropland surfaces with elevation. Finally, the ESA index confirms in both cases the negative association between C content in the soil and the level of the environmental sensitivity to land degradation.

The relationship between TOC (or SOC) and socioeconomic indicators

Spearman rank correlation analysis respectively identified 38 and 8 variables with significant (positive or negative) correlation with TOC and SOC (Table 3). These findings corroborate the results derived from the descriptive analysis with a significant correlation of both TOC and SOC with land-use intensity. SOC and TOC decreased with the average number of components per

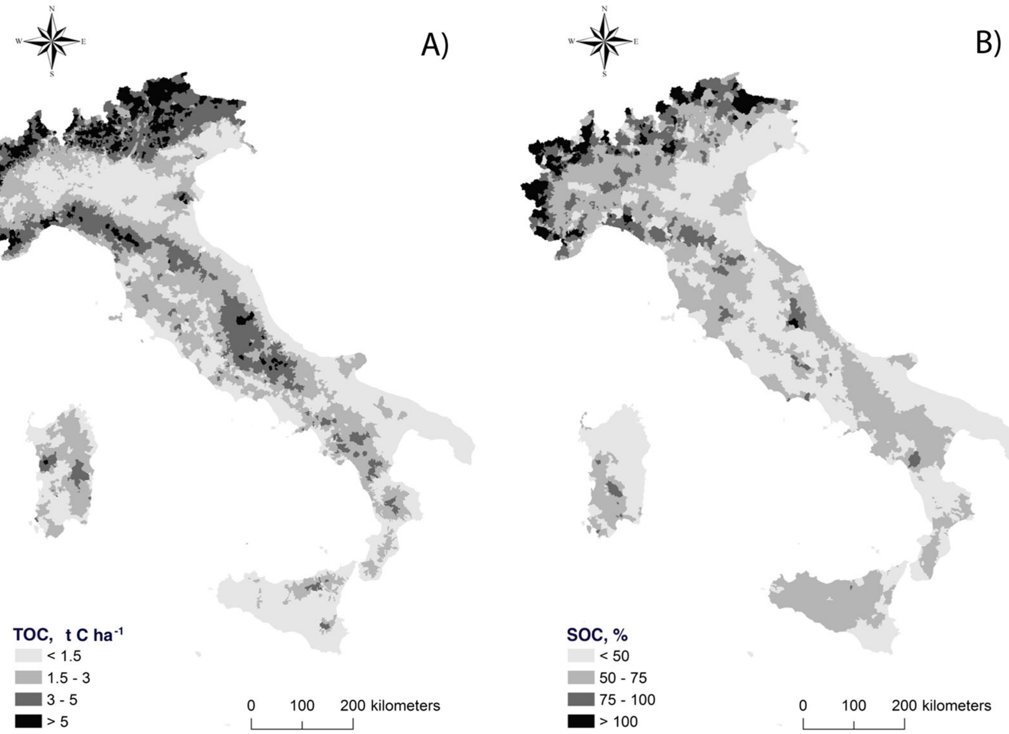

Fig. 1 Topsoil organic carbon (**a**) and soil organic carbon (**b**) in the Italian municipalities

family, literate population without formal education degree and the illiterate population, crop intensity index, the ratio of perennial crop to agricultural utilised area and the ratio of pastures and meadows to total agricultural land.

Negative correlations for TOC were also found with population density, density of workers per municipality surface area, the ratio of resident population to the total number of stores, the ratio of agricultural utilised area to the total agricultural land, the ratio of irrigated land to the total agricultural utilised area, the ratio of arable land to agricultural utilised area and, finally, the degree of urbanisation. All these variables indicate, in a direct or indirect manner, a more intense use of land in different

Table 2 Selected territorial attributes of Italian municipalities by soil organic carbon class

Variable	TOC		SOC	
	Low	High	Low	High
Number of municipalities	3412	4689	4464	3637
Average municipality surface (km^2)	38.9	36.0	42.4	30.8
Resident population (%)	60.7	39.3	65.9	34.1
Population density (inhabitants/km^2)	261	133	198	173
Annual population growth rate (%)	3.1	0.1	0.6	2.2
Surface area (%)	44.0	56.0	62.8	37.2
Cultivated land (% on total area)	56.6	33.8	47.3	37.9
Cultivated land/agricultural area (%)	0.84	0.54	0.71	0.61
Elevation (m)	183	485	308	419
Environmentally sensitive area index (ESAI)	1.41	1.32	1.37	1.34
Annual change in the ESAI (1990–2000, %)	0.044	0.042	0.050	0.034

Table 3 Spearman rank correlation analysis (only significant coefficients at $p<0.001$ after Bonferroni's correction for multiple comparisons are shown)

Research theme	Variable	TOC	SOC	
Demography and settlements	I1	−0.40		Population density
	I5	0.36		Non-occupied houses
	P1	−0.45	−0.33	Average number of family components
Labour market and education	L4	−0.31		Unemployment rate of young people
	F5	−0.37	−0.40	Literate population without formal education degree
	F6	−0.38	−0.34	Illiterate population
Economic structure	S2	−0.33		Density of workers per municipality surface area
	S10	0.32		Workers in hotel and restaurant services
	T7	−0.41		Resident population/total number of stores
Quality of life	Q8		0.33	Per capita income tax amount
	Q11		0.33	Per capita disposable income
	D1	−0.36		Crime intensity index
Agriculture and rural development	SR-A2	0.33		Agricultural land owned by the state
	SR-A5	−0.62		Agricultural utilized area/total agricultural land
	SR-M2	−0.47		Irrigated land/total agricultural utilised area
	SR-M4	−0.70	−0.31	Crop intensity index
	SR-Q8	−0.44		Agricultural utilised area applying sustainable irrigation
Landscape and water	SR-P2	−0.55		Arable land/agricultural utilised area
	SR-P3	−0.33	−0.36	Perennial crop/agricultural utilised area
	SR-P4	0.70	0.31	Pastures and meadows/total agricultural land
	SR-P6	0.66		Woodland
	SR-P8	−0.73		Agricultural landscape diversity
	A1	0.33		Per capita distributed water
	A3	0.34		Consumed water/inhabitants
	A4	0.32		Proportion of water distributed to civil uses
	A5	0.44		Number of reservoirs
	A6	0.33		Reservoir capacity
Environment and soil resources	E00	−0.74		Environmentally Sensitive Area Index
	E60	−0.43		Long-term change in the ESAI (1960–1990)
	pH	−0.39		Soil pH
	Con	−0.38		Potential soil contamination footprint
	Lri	0.61		Landslide risk index
	Mec	0.53		Agricultural pressure to soil compaction index
	Pas	0.52		Environmental pressure from grazing index
	Sal	−0.37		Soil salinisation risk index

economic sectors (agriculture, industry and services). Interestingly, the unemployment rate of young people is also negatively correlated with TOC.

The highest positive correlations were found between TOC and non-occupied houses, workers in hotel and restaurant services, agricultural land owned by the state, woodland and water-related variables. The spatial pattern observed for variables related with environmental and soil resources confirms the previous trends with the highest negative correlations observed between TOC and agricultural landscape diversity, agricultural utilised area applying sustainable irrigation, the ESAI score, soil pH and potential soil contamination footprint, characterising areas with higher human pressure.

Finally, highly positive correlations were found between TOC and landslide risk index, agricultural pressure to soil compaction index, environmental pressure from grazing index and soil salinisation risk index.

Principal component analysis

Results of the first-step PCA carried out on the matrix composed by 8101 Italian municipalities and 133 indicators (including TOC and SOC) are reported in Table 4. The factor model may be satisfactorily applied to the original dataset as illustrated by both the Keiser–Meyer–Olkin measure of sampling adequacy and Bartlett's test of sphericity ($p<0.001$). For each research theme, PCA loadings explain a cumulated variance higher than 30 % of the total matrix variance; this percentage is considered satisfactory due to the considerable number of input variables. In the following analysis, each component is meaningfully associated to indicators' loadings >|0.5|. Based on this, 40 variables on a total of 133 were—positively or negatively—matched with a principal component of the different themes (Table 4).

Thematic PCA confirms the general trend of the previous Spearman rank correlation analysis highlighting a higher level of correlation between TOC and specific variables (four and three components show significant positive and negative correlations, respectively) whilst the SOC shows only two significant components, respectively with positive and negative coefficients. Demography and settlements variables are, on average, correlated negatively with the TOC, indicating, as expected, a negative influence of the increasing human pressure on soil C stocks. Marginal areas characterised by high soil C content are those experiencing the highest unemployment rate and the lowest participation and activity rates together with the lowest educational levels in the country. The indicators of the economic structure at the local scale were indirectly associated with population concentration and land-use intensity (e.g. higher proportion of workers in

Table 4 Thematic PCA results

Research theme	PC	%	Correlation with		Significant loading with
	#	Variance	TOC	SOC	
Demography and settlements (cum. var. 43.9 %)	1	31.4	−0.33	−0.15	I2(+),I5(−),P1(+),P2(−),P3(−),P4(−),P5(−)
	2	12.5	0.09	0.06	
Labour market and education (cum. var. 67.7 %)	1	38.5	0.22	0.30	L1(+),L2(+),L3(−),L4(−),L5(+),L6(+),L7(−),L8(−),F5(−),F6(−)
	2	10.9	0.04	−0.05	
	3	10.6	−0.39	−0.18	L9(+)
	4	7.7	0.09	0.05	
Economic structure (cum. var. 31.1 %)	1	12.7	−0.25	−0.01	
	2	10.4	0.16	0.06	
	3	8.0	−0.38	−0.25	S9(+),T7(+)
Quality of life (cum. var. 50.7 %)	1	34.9	0.03	−0.1	
	2	15.8	−0.32	−0.34	Q3(+),Q8(−),Q11(−)
Agriculture and rural development (cum. var. 45.2 %)	1	13.0	0.57	0.24	SR-A2(+),SR-M4(−),SR-Q2(−),SR-Q6(−),SR-L6(−)
	2	9.8	−0.24	−0.08	
	3	9.0	0.19	−0.05	
	4	7.0	0.37	0.29	SR-A6(−),SR-L1(−)
	5	6.4	−0.04	−0.1	
Landscape and water, environment and soil resources (cum. var. 39.8 %)[a]	1	19.2	0.77	0.39	SR-P2(−),SR-P4(+),SR-P8(−),A1(+),A3(+),A5(+),
	2	8.5	0.15	0.25	E00(−),E60(−),Lri(+),Mec(+)
	3	6.7	−0.2	−0.15	
	4	5.4	−0.02	−0.15	

To compare the trend of the variables in Table 4 with that in Table 3, it is necessary to multiply the sign of each loading for the sign of correlation

[a] For the purpose of this analysis, the two research themes were considered together

commerce and store density) and showed a negative correlation with the soil C stock. Quality of life indicators indirectly confirm the results illustrated above being characterised, for both TOC and SOC, by a positive correlation with per capita income tax amount and per capita disposable income and by a negative correlation with the number of deposits per bank, which was higher in peri-urban, industrial and intensive-agricultural areas. As far as agricultural and rural development indicators is concerned, a negative association between SOC and crop intensity, the area cultivated with protected designation of origin grapevines, agricultural utilised area under sustainability certification, family farms, Pielou's evenness on farm size distribution and employees in the primary sector was observed. Finally, landscape, water, environment and soil resources were negatively associated, both in the TOC and the SOC, with the proportion of arable land, pastures and meadows, and with agricultural landscape diversity, per capita distributed and consumed water, number of water reservoirs, the level of sensitivity to land degradation and its changes over time, landslide risk index and agricultural pressure due to soil compaction. These relationships shed light on the complex picture of anthropogenic pressures driven by socioeconomic factors on the biophysical environment and soils in particular. Some indicators possibly correlated at the local scale with the spatial distribution of soil C showed component loadings bordering the selected thresholds. This is the case for fire risk indexes (For, Fir) that are weakly negatively associated to component 2.

The second-step significant PCA loadings (only for component 2, which is significantly correlated with TOC and SOC; the remaining components were found not correlated with both TOC and SOC) are reported in Fig. 2. Component loadings confirm the Spearman rank correlation analysis and the first-step PCA results with a positive correlation between TOC (and SOC) and the proportion of pastures and meadows, elevation, non-occupied houses, landslide risk index, workers in hotel and restaurant services, number of water reservoirs and elderly index. These variables primarily identify municipalities concentrated in internal and mountain areas characterised by low or very low human pressure, extensive agriculture, landscape diversification with the predominance of forests and pastures, an economic structure centred on tourism and, more generally, on non-industrial activities, together with a high proportion of secondary residence houses. On the contrary,

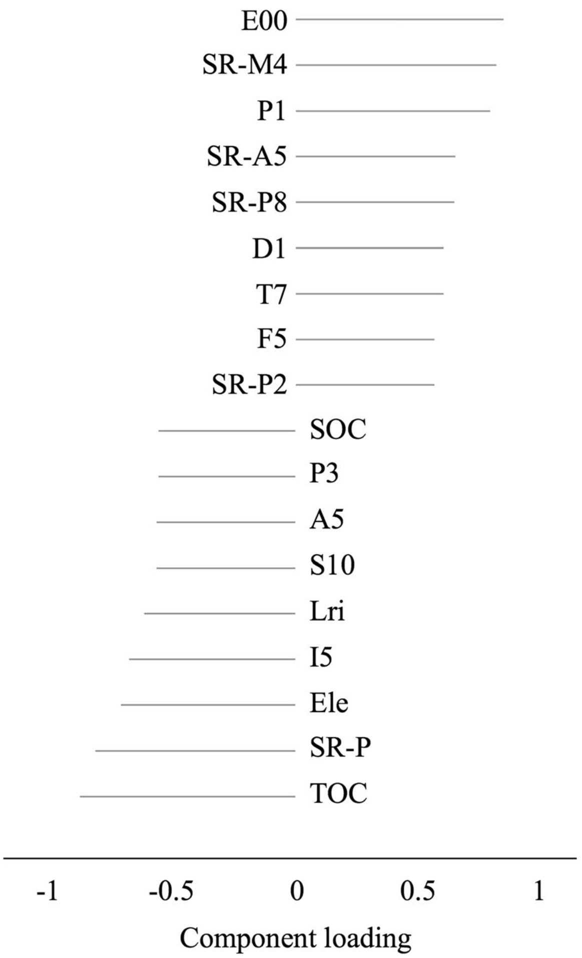

Fig. 2 Total principal components analysis loadings. Component 2

indicators of high human pressure—reflected into a higher intensity in the use of land—are negatively associated to both TOC and SOC (proportion of arable land, literate population without formal education degree, resident population/total number of stores, crime intensity index, agricultural landscape diversity, agricultural utilised area/total agricultural land, average number of family components, crop intensity index and the level of land sensitivity to degradation).

A summary overview

A comparative evaluation of the most relevant findings from Spearman rank correlations and the two-step PCA is proposed in Table 5. A total of 58 variables was identified and listed as having a significant correlation either with TOC and/or SOC. Various indicators with consistent correlation signs in the three statistical

Table 5 A summary overview of the results derived from the three statistical analyses developed in this study

Research theme	Variable		Spearman		Thematic PCA		Total PCA	
			TOC	SOC	TOC	SOC	TOC	SOC
Demography and settlements	I1		–					
	I2				–			
	I5	Non-occupied houses	+		+		+	+
	P1		–	–			–	–
	P2				+			
	P3				+		+	+
	P4				+			
	P5				+			
Labour market and education	L1					+		
	L2					+		
	L3					–		
	L4		–			–		
	L5					+		
	L6					+		
	L7					–		
	L8					–		
	L9				–			
	F5	Literate pop. without formal education degree	–	–		–	–	–
	F6		–	–		–		
Economic structure	S2		–					
	S9				–			
	S10		+				+	+
	T7	Resident population/tot. n. of stores	–		–		–	–
Quality of life	Q3				–	–		
	Q8			+	+	+		
	Q11			+	+	+		
	D1		–				–	–
Agriculture and rural development	SR-A2				+			
	SR-A5		–				–	–
	SR-A6				–			
	SR-M2		–					
	SR-M4	Crop intensity index	–		–		–	–
	SR-Q2				–			
	SR-Q6				–			
	SR-Q8		–					
	SR-L1				–			
	SR-L6				–			
Landscape and water	SR-P2	Arable land/agric. utilized area	–		–	–	–	
	SR-P3			–				
	SR-P4	Pastures and meadows/total agric. land	+	+	+	+	+	+
	SR-P6		+					
	SR-P8	Agric. landscape diversity	–		–	–	–	–
	A1				+	+		

Table 5 (continued)

Research theme	Variable		Spearman		Thematic PCA		Total PCA	
			TOC	SOC	TOC	SOC	TOC	SOC
	A3				+	+		
	A4				+	+		
	A5	Number of reservoirs	+		+		+	+
	A6		+					
Environment and soil resources	E00	ESAI	–		–	–	–	–
	E60		–		–	–		
	pH		–					
	Con		–					
	Lri	Landslide risk index	+		+	+	+	+
	Mec		+		+			
	Pas		+					
	Sal		–					

The sign for the PCA is that as results by multiplying the signs of the loading (variable) with the sign of the respective component (TOC and SOC)

analyses described in the previous sections were identified as correlated with TOC and/or SOC: literate population without formal education degree, resident population/total number of stores, crop intensity index, arable land/agricultural utilised area, agricultural landscape diversity and environmentally sensitive area index (negative correlation with TOC and/or SOC), and non-occupied houses, pastures and meadows/total agricultural land, number of reservoirs and landslide risk index (positive correlation with TOC and/or SOC). The above-mentioned variables include a core indicator set representing a coherent association between the TOC (and/or the SOC) and proxies for human pressure and land-use intensity.

SWOT analysis

Based on the findings described above, a SWOT analysis was developed, and results are reported in Table 6. The in-depth analysis of the intimate spatial relationship

Table 6 SWOT analysis applied to local communities classified at 'low' topsoil carbon content (in italics are highlighted the variables selected in Table 5)

	Helpful to achieve the objective	Harmful to achieve the objective
Internal origin	Strength Low impact residential tourism Presence of pastures and meadows Prevalence of forests and natural landscapes Low water consumes (*I5*; S10) (*SR-P4*) (SR-P6) (A3; A4)	Weaknesses Low education level Crime intensity index High intensity and impact agriculture Specific environmental concerns (environmental sensitivity, soil conditions and characteristics) (*F5*; F6) (D1) (SR-A5; SR-M2; *SR-M4*; SR-Q8; *SR-P2*; SR-P3; *SR-P8*) (E00; E60; pH; Con; Mec; Sal)
External origin	Opportunities High share of land owned by the state High per-capita municipal revenues Water resource availability Sustainable grazing in abandoned lands Altitudinal socio-ecological gradient (SR-A2) (Q8; Q11) (A1; *A5*; A6) (*Lri*; Pas) (Ele)	Threats Population impacts Unemployment and labour market North–south territorial divide Urbanization (I1; P1;) (L4; S2; *T7*) (Sou) (Urb)

between soil organic C content and the socioeconomic context found at the local scale in Italy suggests some logical combinations of strength and weakness attributes and of opportunity and threat factors informing intervention strategies to contain soil C loss, taken as an important soil degradation process in Italy. Due to the SO combination factors, some actions are proposed to exploit strengths and opportunities for rural communities and agro-forest systems in the light of preserving soil carbon stocks: (i) to stimulate sustainable tourism in mountain areas and wooded areas of high nature value giving economic value to the common land or to farms managed by the state and (ii) to support agricultural and pastoral activities in mountain and inland areas with local and regional funds and incentives to multi-functional activities (agro-tourism, renewable energy, biomass, etc.). Some actions to reduce system's weakness and to exploit system's opportunities, based on the WO combination factors were identified as follows: (i) the increase in the educational level of local population encouraging the adoption of sustainable land management practices (pasture conservation, fire control, overgrazing containment and sustainable use of water resources) and a more effective collection of revenues from municipal taxes aimed at improving the quality of the local environment and preventing the abandonment of marginal land; and (ii) a high share of land owned by the state encouraging the adoption of land management plans aimed at counterbalancing specific environmental concerns (e.g. soil degradation phenomena such as erosion, landslide and compaction).

Actions may be suggested by analysing the ST combination factors, including (i) to preserve forests and natural landscapes with the aim to maintaining high environmental quality and ecosystem functioning and to avoid indirect processes of depopulation and unemployment and (ii) to consider the territorial divide observed along the urban–rural and elevation gradients as an opportunity to promote local culture, landscape, traditional food and agro-tourism taken as an alternative development model to the traditional land-intensive economic structure typical of industrial and peri-urban areas. Finally, actions to reduce the impact of threats on territorial weaknesses, based on the combination of WT factors, include (i) tackling unemployment and the difficulty of the labour market by improving the level of education and lifelong training, (ii) rehabilitating traditional rural villages and (iii) countering the depopulation of the inland areas and unemployment through the adoption of measures to contain land degradation processes.

Discussion

The proposed framework, based on descriptive, multivariate statistical and inferential analyses, was aimed to evaluate the multifaceted interactions between TOC and SOC, and the socio-ecological characteristics of the Italian local communities. This approach may provide effective responses for a more sustainable use of land aimed at preserving the soil C content. The adoption of effective and sustainable policies related to the protection of soil C may also contribute to the global reduction of greenhouse gases, to improve soil fertility and water quality, to increase the ability of soil water regulation with positive effects on land stability and the quality of the landscape and the environment (Carvalho-Ribeiro et al. 2010; Cowie et al. 2011; Booker et al. 2013; Ferrara et al. 2014b; Edmondson et al. 2014).

Results of the statistical analysis indicate a complex socioeconomic profile with almost 40 factors spatially associated with soil C content. Factors include specific demographic and socio-spatial processes, education level, economic and labour market structure, landscape characteristics and environmental variables. These results corroborate the findings of previous studies regarding the influence of human pressures on soil C stocks and confirm the hypothesis, described in the introduction to this article, on the existence of a latent nexus between soil C content and defined socioeconomic profiles characterising local communities (Smith 2004). Based on the deep knowledge of these undergoing mechanisms, it is particularly important to facilitate integrated and effective responses to complex and multi-dimensional issues such as soil erosion and land degradation, which further require cooperative efforts and trust between experts, stakeholders, policy makers and institutions (Cramb 2006).

In particular, the socioeconomic factors that mostly negatively affect the local community profile in terms of TOC and SOC are as follows: (i) the low level of education, strictly related to the quality of the land management; (ii) population dynamics, in turn connected to north–south territorial divides, that in many areas have severe impact on soil and land degradation; (iii) the high intensity agriculture when it is related to critical environmental conditions; and (iv) the quality of policies and governance, having direct and indirect impacts on the sustainable use of natural resources.

Based on our results, the SWOT analysis outlines a wide range of possible interventions and provides elements for the development of strategies integrating soil conservation with socioeconomic growth and rural development. In particular, the SO and WO combinations highlight the central role of sustainable land management, with the enhancement of local conditions, land-use and landscapes. This opportunity is intended to be realised in an integrated system of eco-tourism activities linked to agricultural and pastoral activities as a key element to combat the abandonment of inland areas and the preservation of natural land from soil erosion and landslides (Ferrara et al. 2014a). The increased levels of academic and professional qualification also stimulate the adoption of models of sustainable use of land contrasting unemployment and the consequent depopulation of the inland areas. Frequently, the possibility to involve skilful experts regarding transfer activities has helped to positively improve the formation of local managers, and it has provided relevant training potentials for stakeholders and regional planners (Kelly et al. 2015). The logical framework proposed in this study may therefore represent an operational framework to integrated environmental-economic policies specifically affecting TOC and SOC and also a vast set of other soil determinants. Finally, our findings clarify the role of different geographical and socioeconomic gradients possibly influencing the level of soil carbon content and loss in organic matter in Italy.

To conclude, it seems clear that improving the effectiveness of local communities' responses contributes to an adequate comprehension of the importance of soils, as carbon sink cannot be achieved without a thorough comprehension of the socioeconomic and territorial contexts influencing soil resources. An in-depth knowledge of the influence of the socioeconomic context on soil characteristics and conservation measures may inform sustainable land management policies targeting soil degradation processes and preserving SOC and TOC content. Improvements in different decision-making procedures for land-use change monitoring are also needed (e.g., Lavalle et al. 2011; Salvati et al. 2013). Coupled with detailed soil maps, a permanent multi-factor assessment of local community attributes may definitely improve the effectiveness of national soil conservation strategies.

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