Journal of Environmental Planning and Management
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/cjep20

Land use dynamics and soil quality in agro-forest systems: a country-scale assessment in Italy

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Published online: 19 Nov 2013.

Journal of Environmental Planning and Management, 2015
Vol. 58, No. 1, 175–188, http://dx.doi.org/10.1080/09640568.2013.849235

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(*Received 1 April 2013; final version received 24 September 2013*)

The present study compares the spatial distribution of selected rural land use classes in Italy with two soil indicators (a Soil Quality Index [SQI] and the Maximum potential Water Capacity of the soil [MWC]) at three points in time (1960, 1990 and 2006). Results of the analysis showed that landscape changes reflect a 'migration' of both semi-natural (forests, pastures) and agricultural (arable land, vineyards) uses towards areas with lower-quality soils. In particular, the agricultural 'mosaic' and shrubland-pasture classes that occupied land in 2006 had significant lower values of both the SQI and MWC compared to 1960. These processes may have implications for the stability of agro-forest ecosystems in the medium term. Due to its versatility, the procedure illustrated represents a monitoring tool for sustainable land management at the regional and country scales.

Keywords: landscape transformations; Soil Quality Index; ecosystem stability; Italy

1. Introduction

In the last century the increasing environmental impact of economic growth led to new landscape structures, with loss in biodiversity and depletion of natural resources (Blondel 2006). Landscape transformations are moulded by the mutual relationship between biophysical factors (e.g. topography, climate, soil and water) and the (changing) socio-economic context (Serra, Pons, and Saurí 2008). A given land cover can be modified, consumed or degraded and a new landscape generated according to the drivers mentioned above (Scalenghe and Ajmone Marsan 2009). Socio-economic variables can be seen as faster drivers of change compared to biophysical factors and therefore require permanent monitoring (Corona and Ferrara 1989). A comparison between past and present uses of land allows the identification of trajectories of land use changes and the intimate relationship between socio-economic factors and the (changing) agro-forest systems (Turner and Ruscher 1998; Antrop 2000; Thornes 2004). Modifications in landscape structure and composition caused by socio-economic factors are widely reported at the regional and local scales. Examples can be found for several developed regions, such as Japan (Shoyama and Braimoh 2011), North America (Amundson, Guo, and Gong 2003) and Europe (Antrop 2004; Otto, Krusi, and Kienast 2007; Sirami *et al*. 2010; Feranec *et al*. 2010; Verburg *et al*. 2010).

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The Mediterranean region, one of the most important biodiversity hotspots on earth (Myers *et al*. 2000), is an example of long-term interactions between natural ecosystems and human activities. Agriculture has been traditionally practised in this region (Antrop, 2005) leading to a complex and biodiversity-rich landscape mosaic resilient to ecological disturbances (Garcia Latorre, Garcia Latorre, and Sanchez-Picon 2001). However, after the Second World War the residential population increased, particularly around coastal and flat areas, resulting in territorial imbalances, landscape modifications and ecosystem degradation (Simeonakis, Calvo-Cases, and Arnau-Rosalen 2007).

In the last 50 years, anthropogenic factors (such as urbanisation, the rapid expansion of tourism-related activities, forest fires and deforestation, land abandonment and crop intensification) have determined land use changes in the Mediterranean region (Bonet 2004; Sluiter and de Jong 2007; Feranec *et al*. 2010). With these changes, rural landscapes underwent considerable transformations, including forest recovery in mountain areas (Falcucci, Maiorano, and Boitani 2007), sprawl-driven land fragmentation in coastal areas and around the major cities (Salvati and Zitti 2012), and modifications from extensive to intensive agriculture in both uplands and flat areas (Salvati and Bajocco 2011).

Soil is an important resource, contributing to the stability of the ecosystem and the productivity of human activities (Jones, Montanarella, and Jones 2005). However, soil degradation processes are accelerating in many parts of Europe due to inappropriate or unsustainable human activities (European Environment Agency 2006). As reported by Montanarella (2007), changes in the use of land in the Mediterranean basin have led to an acceleration of soil degradation processes, including erosion, a decline in organic matter, local and diffused contamination, sealing, compaction and salinisation. All these processes negatively impact soil functions and ecosystem services (Cerdà 1997; Helldén and Tottrup 2008).

The United Nations Convention to Combat Drought and Desertification (UNCCD) considers soil as a natural resource representing the most important land capital supporting agricultural production, the related human activities and the services provided by the ecosystem. Moreover, the UNCCD Annex IV identified soil degradation as one of the most important drivers of desertification in the northern Mediterranean basin (Costantini *et al*. 2009). The European Commission has also recognised the crucial role of soil in ecosystem conservation and sustainable land management (European Environment Agency 2002). Soil conservation measures were therefore introduced in the European Common Agricultural Policy, and a specific thematic Strategy for Soil Protection (European Commission 2006) has been proposed, with the aim of establishing criteria to assess the quality of soils and landscapes and coordinating national and regional policies for soil protection at the country level.

Together with land use change monitoring, the assessment of soil properties, soil quality and land degradation processes is necessary to preserve soil functions and prevent natural resource depletion (Marzaioli *et al*. 2010). Unfortunately, diachronic studies dealing with the transformation of rural landscapes and soil quality are relatively scarce in the Mediterranean region and, when available, cover only restricted areas for time intervals encompassing no more than 10 years (e.g. Jones, Montanarella, and Jones 2005).

As a contribution to this deserving issue, the present study investigated, at the country scale, the relationship between selected indicators of soil quality and rural land use changes in Italy. The 'migration' of natural and semi-natural land use types towards soils with different qualities (e.g. Marathianou *et al*. 2000; Serra, Pons, and Saurí 2008; Salvati and Zitti 2012) was monitored by combining diachronic land use data at three points in time (1960, 1990 and 2006) with two soil indicators that had national coverage. The study considers two separate time windows (1960–1990 and 1990–2006) with the aim of highlighting the impact of different socio-economic contexts on landscape transformations in Italy (Salvati and Zitti 2012). The first investigated period (1960–1990) represents the massive settlement expansion driven by a growing population coupled with mixed crop intensification and land abandonment as well as increasing human pressure on woodlands, e.g. due to forest fires. The following period (1990–2006) was mainly characterised by low-density settlement diffusion with stable (or weakly changing) population, agricultural land abandonment in uplands and forestation observed in economically-marginal rural areas (Salvati and Bajocco 2011). The choice for these two time intervals reflects the availability of comparable high-resolution land use maps covering the whole national territory. Results of the analysis contribute to inform sustainable land management practices mitigating soil degradation.

2. Methods

2.1. Study area

The investigated area covers the whole of Italy with a total surface area extending for nearly 301,330 km^2, much of the land being either hilly or mountainous. Italy is surrounded by the Tyrrhenian Sea to the west, the Adriatic Sea to the east, the Ionian Sea in the south and by the Alps to the north. A second chain of mountains, the Apennines, runs down the centre of the country from north to south. Its coastline (including the islands) extends for nearly 7400 km. The mountainous topography, latitudinal extension and proximity to the sea account for much of the variation in the climate, soil, vegetation and landscape (Venezian Scarascia, Di Battista, and Salvati 2006).

2.2. Land use data

The present study is based on three land use maps covering the time period from 1960 to 2006: (1) the CORINE-like ‘Land Cover Map of Italy’ (LUM60) developed by the National Research Council and the Italian Touring Club in the early 1960s (Falcucci, Maiorano, and Boitani 2007); and two CORINE Land Cover (CLC) maps of Italy (LUM90 and LUM06), respectively dated (2) 1990 and (3) 2006 (Salvati and Zitti 2012). The CORINE (COoRdinate INformation on the Environment) CLC project aimed at providing pan-European land-cover maps and was coordinated by the European Environment Agency (EEA). The CLC inventory is based on computer-assisted visual interpretation of satellite images as the primary information source. The choice of scale (1:100,000), Minimum Mapping Unit (25 ha) and minimum width of linear elements (100 m) for CLC mapping represent the trade-off between production costs and land cover information details (Salvati and Bajocco 2011). The approach of computer assisted visual interpretation of satellite images was chosen as the CLC mapping methodology. Raw satellite images were pre-processed and enhanced to yield a geometrically correct document in national projection. Ortho-corrected Landsat-7 ETM satellite images were provided with an RMS error below 25 m. Detailed topographic maps, and in some cases orthophotos, were used to achieve this accuracy. Geospatial information was validated in the field according to sampling procedures (see European Environment Agency 2012). The standard CLC nomenclature includes three hierarchical levels with 5, 15 and 44 classes of land use respectively for the first, second and third levels.

The LUM60 is a standard map covering the whole Italian territory at 1: 200,000 scale based on topographic maps provided by the Italian Touring Club and the Italian Geographical Military Institute and referring to the period 1949–1962. This map was prepared integrating topographic maps with cadastral maps, an extensive field survey and statistical data at a fine spatial scale. The LUM60 cartography adopted a nomenclature system formed by 22 land use classes and was compatible to that developed in the framework of the CLC project (Salvati and Bajocco 2011). The map was extensively used in studies dealing with landscape transformations at the regional and national scale in Italy (e.g. Falcucci, Maiorano, and Boitani 2007; Salvati and Zitti 2012). For the purposes of the present study, LUM60 categories were reclassified into 10 land use classes compatible with the second hierarchical level of CLC nomenclature (Table 1) and organised into five agricultural classes, three natural and semi-natural classes, one built-up urban class and a residual class including bare land, water bodies, burned and rocky areas. The reason to explore a larger number of agricultural land use classes compared to the semi-natural classes considered here is that, for exploring the spatial distribution of soil indicators, and particularly the relationship between the MWC (see section 2.3) and agro-forest dynamics, it is important to provide a representative classification of the different agricultural landscapes occurring in Italy. Since the aim of the study was to evaluate the possible mismatch between soil quality and the distribution of agricultural and semi-natural land uses over time, a reduced nomenclature was developed with the aim of reporting trends in three main uses of land: cultivated land, natural landscapes and built-up areas (urban parks and gardens were included in built-up urban areas).

2.3. Soil indicators

The ability of soil to perform any of its functions depends on its physical, biological and chemical characteristics. Soil properties are conditioned by natural (e.g. slope steepness) and anthropogenic factors, referred to as external factors (Montanarella 2007). Humans, amongst the most influential agents, directly or indirectly impact the performance characteristics of soil, thus limiting or enhancing its productive capacity (Amundson, Guo, and Gong 2003). Because of the multifaceted association of soil quality to natural resource management that is difficult to define objectively, in part because soils are inherently variable and susceptible to multiple uses for the benefit of humans, soil quality is regarded as a multidimensional concept representing the ability of a soil to sustain agricultural production and/or natural vegetation (Sposito and Zabel 2003).

Two indicators were considered in the present study: (1) a Soil Quality Index and (2) the Maximum potential Water Capacity of the soil. These indicators can be considered together as a proxy to estimate soil resources from both the environmental and agronomic points of view. Due to the national coverage of the present study, only easily available and homogeneous indicators at an adequately detailed resolution scale which were derived from national technical services and official (e.g. statistical) data sources were selected (Salvati and Bajocco 2011). In our experience, the layers used are reliable, updated and referenced data currently available to be used in the regional and country assessment of soils in Mediterranean Europe (see also Salvati *et al*. 2009 for a discussion on supply-demand of statistical data in soil degradation matters). Although other physical, chemical or biological variables may provide important indications dealing with soil quality, they are generally mapped at a local scale or in larger areas but at a lower spatial resolution (Marzaioli *et al*. 2010), and for this reason they were excluded from the analysis.

Table 1. CORINE land-use/land cover classification system used in this study.

Code	CORINE description	New code	New code's description
111	Continuous urban fabric	1	Urban areas
112	Discontinuous urban fabric	1	
121	Industrial or commercial units	1	
122	Road and rail networks	1	
123	Port areas	1	
124	Airports	1	
131	Mineral extraction sites	1	
132	Dump sites	1	
133	Construction sites	1	
141	Green urban areas	1	
142	Sport and leisure facilities	1	
211	Non-irrigated arable land	2	Non-irrigated arable land
212	Permanently irrigated land	3	Irrigated arable land
213	Rice fields	4	Rice field
222	Fruit trees and berry plantations	5	Orchards
221	Vineyards	6	Vineyards and olive groves
223	Olive groves	6	
241	Annual crops	7	Heterogeneous agricultural areas
242	Complex cultivated patterns	7	
243	Agriculture and some natural vegetation	7	
244	Agro-forestry areas	8	Woodlands
311	Broad-leaved forests	8	
312	Coniferous forests	8	
313	Mixed forests	8	
324	Transitional woodland-shrubs	8	
231	Pastures	9	Shrublands and pastures
321	Natural grasslands	9	
322	Moors and heathland	9	
323	Schlerophyllous vegetation	9	
333	Sparsely vegetated areas	9	
331	Beaches, dunes, sands	10	Other uses
332	Bare rocks	10	
334	Burnt areas	10	
335	Glaciers and perpetual snow	10	
411	Inland marshes	10	
412	Peat bogs	10	
421	Salt marshes	10	
422	Salines	10	
423	Intertidal flats	10	
511	Water courses	10	
512	Water bodies	10	
521	Coastal lagoons	10	
522	Estuaries	10	
523	Sea and ocean	10	

The Soil Quality Index (SQI) proposed by the European Environment Agency (2009a) was adopted in this study and was calculated using the information contained in the European Soil Database produced by the Joint Research Centre, Ispra (Finke *et al*. 1998). It was integrated with data taken from a database of agricultural soil characteristics with national coverage, eco-pedological and geological maps of Italy and a 20 m Digital

Elevation Model (Perini *et al*. 2008), together with a land system map produced by the Italian National Centre of Pedological Cartography. These datasets can be considered as the standard, homogeneous soil information available in Italy at 1: 250 000 scale (Zitti, Salvati, and Perini 2013).

This index was widely used in the Environmentally Sensitive Area (ESA) framework to assess the level of sensitivity to soil and land degradation (Salvati and Bajocco 2011). Based on data provided by European Environment Agency (2009b), the SQI is a composite index based on four variables: parent material, soil depth, texture and slope angle. These variables can be considered as proxy information for other soil quality indicators (e.g. organic matter content, resistance or tendency to compaction; Zitti, Salvati, and Perini 2013). A set of sensitivity scores derived from statistical analyses and the fieldwork performed by previous authors (Conacher and Sala 1998; Marathianou *et al*. 2000; Montanarella 2007; Salvati *et al*. 2009) was assigned to each analysed variable (see Table 2 for the list of the quality scores). The SQI was thus estimated as the geometric mean of the different scores attributed to the four selected variables and ranged from 1 (the highest soil quality) to 2 (the lowest soil quality). The index was made available in raster format and disseminated at 1 km^2 spatial resolution (Perini *et al*. 2008). Despite its acknowledged importance as a tool to detect soil quality, the SQI presents some shortcomings due to the restricted number of variables considered (Zitti, Salvati, and Perini 2013).

The Maximum Water Capacity (MWC) expressing the maximum potential water capacity (mm) a soil can store in optimal climatic and agronomic conditions and depending on soil structure (Salvati *et al*. 2009), was derived from a national database of soil characteristics ('Map of the potential water capacity of agricultural soils in Italy') generated by the Italian Ministry of Agriculture and was based on nearly 18,000 soil samples (Venezian Scarascia, Di Battista, and Salvati 2006). It was integrated with homogeneous regional soil databases and ancillary cartographies collected from the National Centre of Soil Cartography (CNCP) of the Italian Agricultural Research Council into a comprehensive soil map of Italy at the 1: 250,000 scale (see http://www.soilmaps.it/ for further details). The spatial distribution of the SQI and MWC indicators throughout Italy is shown in Figure 1. A geo-database containing both variables disseminated in their native digital format is available in Perini *et al*. (2008).

Both the SQI and the MWC indexes were regarded as static during the examined period (Salvati and Bajocco 2011). The relatively long investigated time period and the national coverage of the study prevented us from using diachronic soil mapping available at the very local scale. However, it should be noted that, among the considered variables, soil depth can vary along prolonged time intervals and in places with specific territorial characteristics possibly due to the effect of soil erosion (Zitti, Salvati, and Perini 2013). The national coverage of the present study makes the results potentially more interesting than a pilot study confined to a limited test area. However, data material used in the study has obvious shortcomings. This may be acceptable when the purpose is to study a whole country, since the cost of mapping is insurmountable for an individual research survey (Marzaioli *et al*. 2010).

2.4. Statistical analysis

The single polygons forming each land use layer (i.e. LUM60, LUM90 and LUM06) were chosen as the elementary unit of analysis (Salvati and Zitti 2012) and overlaid to the soil raster database (SQI and MWC) described above. The ArcGIS (ESRI Inc., Redwoods,

Table 2. Variables entering the SQI and the related scores.

Description	Score
Parent material	
Coherent parental material: limestone, dolomite, non-friable sandstone, hard limestone layer	1.0
Parental material moderately coherent: Marno-limestone, friable sandstone	1.5
Parental material soft to friable: calcareous clay, clay, sandy formation, alluvium and colluviums	2.0

Class	Description	Score
Soil depth		
Very deep	Soil thickness greater than 1.2 m with a substrate non-penetrable by the roots or thickness higher than 1 m on a movable substrate	1.00
Moderate to deep	Depth from 0.8 to 1.2 m with a coherent substrate or from 0.5 to 1 m with a movable substrate	1.33
Not deep	Depth from 0.5 to 0.8 m with a coherent substrate or from 0.3 to 0.5 m with a movable substrate	1.66
Very thin	Depth lower than 0.3 m	2.00
Soil texture		
Texture not very light to average	Loamy-sandy, sandy-loamy, balanced	1.00
Texture thin to average	Loamy-clayey, clayey-sandy, sandy-clayey	1.33
Thin texture	Clayey clayey-loamy	1.66
Coarse texture	Sandy to very sandy	2.00
Slope angle		
A	Level (dominant slope ranging from 0 to 8%)	1.00
B	Sloping (dominant slope ranging from 8 to 15%)	1.33
C	Moderately steep (dominant slope ranging from 15 to 25%)	1.66
D	Steep (dominant slope over 25%)	2.00

Source: European Environment Agency (2009b).

USA) ‘zonal statistics’ tool was applied to the SQI and MWC raster maps to assign an average SQI score and MWC value to the 10 investigated land use classes for the three investigated years separately (1960, 1990 and 2006).

The low deviation from normality in the statistical distribution of both SQI and MWC indexes, together with the low value of the coefficient of variation, indicates the average as an honest indicator of the central tendency of the distribution. The percentage variation in the SQI and MWC values was calculated for 1960–1990 and 1990–2006 by each land use class. Changes in the distribution of the SQI and MWC between 1960 and 2006 were evaluated for significance in each land use class using the Mann–Whitney U statistic testing at $p < 0.05$. The spatial distribution of the SQI and MWC in the 10 land use classes was correlated pair-wise using Spearman co-graduation coefficients testing at $p < 0.05$.

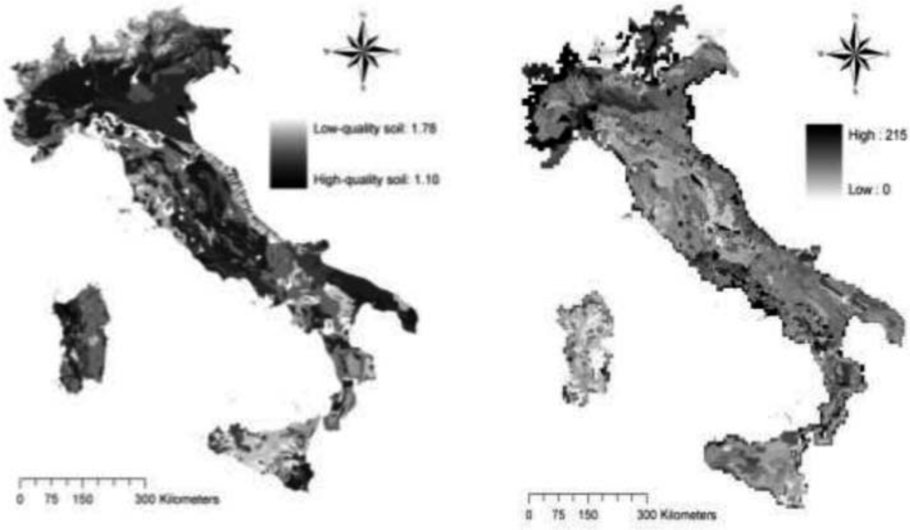

Figure 1. The spatial distribution of the Soil Quality Index (left) and the Maximum potential Water Capacity (mm) of the soil (right) in Italy.

3. Results

The analysis of land use changes in Italy identified two main processes of landscape transformations (Table 3): urbanisation mainly at the expense of agricultural areas (with built-up areas increasing from nearly 1% in 1960 to 5% in 2006), and the abandonment of rural land (cropland covered 54% of the investigated area in 1960 and only 49% in 2006), while natural areas decreased only moderately (from 42% in 1960 to 41% in 2006). Taken together, results indicate that land use changes were more intense between 1960 and 1990 than in the following period, possibly due to the more rapid growth of population and settlements. Following landscape transformations, land use classes occupied soils with different properties and quality during the investigated period (Tables 4 and 5). Between 1960 and 2006, the expanding built-up areas occupied land with higher soil quality, while the reverse trend was observed for cropland and, to a lesser extent, for natural and semi-natural areas. In fact, the average SQI score observed in built-up areas decreased from 1.50 in 1960 to 1.49 in 2006 (indicating the consumption

Table 3. The percentage composition of four basic land-use classes in Italy between 1960 and 2006.

Land use class	1960	1990	2006	Change (%) 1960–1990	Change (%) 1990–2006
Urban areas	1.4	4.4	4.9	3.0	0.5
Croplands	53.7	48.9	48.7	−4.8	−0.2
Natural areas (including forests and pastures)	41.7	41.1	41.0	−0.6	−0.1
Other (minor) uses	3.2	5.5	5.4	2.3	−0.1

Table 4. Average Soil Quality Index (SQI) score in Italy (1960–2006) by land-use class (higher SQI scores indicate lower soil quality).

Land-use class	1960	1990	2006	[a]	Annual change (%) 1960–1990	Annual change (%) 1990–2006
Urban areas	*1.496*	*1.492*	*1.492*	*	*−0.008*	*−0.003*
Non-irrigated arable land	1.543	1.516	1.517	*	−0.057	0.002
Irrigated arable land	1.448	1.455	1.457	*	0.016	0.006
Rice fields	1.415	1.413	1.413	*n.s.*	−0.004	0.001
Orchards	1.518	1.539	1.539	*	0.046	0.000
Vineyards and olive groves	1.515	1.531	1.530	*	0.036	−0.004
Heterogeneous agricultural land	1.515	1.530	1.532	*	0.032	0.010
Croplands	*1.492*	*1.497*	*1.498*	*	*0.011*	*0.002*
Woodlands	1.547	1.547	1.547	*n.s.*	0.000	0.000
Shrublands and pastures	1.543	1.562	1.562	*	0.041	−0.001
Natural areas	*1.545*	*1.554*	*1.554*	*	*0.021*	*−0.000*
Other (minor) uses	1.570	1.562	1.560	*	−0017	−0.007

Note: [a]Significant changes in the SQI between 1960 and 2006 were evaluated by land-use class using Mann–Whitney U-test (*$p < 0.05$; *n.s.* = not significant).

of high-quality soils), while increasing in agricultural areas from 1.49 in 1960 to 1.50 in 2006 (Table 4).

In 1960, rice fields and irrigated arable land occupied soils with the highest observed quality, while the lowest SQI score was observed in non-cultivated and non-forest land. Heterogeneous agricultural land, irrigated arable land and, to a lesser extent, perennial cultivation, experienced the highest SQI increase in the study period, indicating that these classes have progressively occupied soils with low quality. Following rural land use changes, shrubland and pastures moved to lower-quality soils between 1960 and 1990, while woodlands were found to be associated with soils with a comparable quality over the whole study period. The SQI recorded for the remaining classes (e.g. burnt areas, bare land and rocks, dunes) decreased from 1.57 in 1960 to 1.56 in 2006.

Table 5. Average maximum potential water capacity (mm) of soils associated to each land-use class in Italy by year.

Land use class	1960	1990	2006	[a]	Annual change (%) 1960–1990	Annual change (%) 1990–2006
Urban areas	*78.9*	*77.7*	*77.6*	*n.s.*	*−0.05*	*−0.01*
Non-irrigated arable land	74.4	78.2	78.3	*	0.17	0.01
Irrigated arable land	86.5	84.1	84.0	*n.s.*	−0.09	0.00
Rice fields	86.1	87.4	87.3	*n.s.*	0.05	−0.01
Orchards	69.9	68.1	68.4	*n.s.*	−0.09	0.02
Vineyards and olive groves	74.7	75.1	75.4	*n.s.*	0.02	0.03
Heterogeneous agricultural land	77.6	73.2	72.4	*	−0.19	−0.07
Croplands	*78.2*	*77.7*	*77.6*	*n.s.*	*−0.02*	*−0.01*
Woodlands	66.4	65.5	65.5	*n.s.*	−0.04	−0.01
Shrublands and pastures	61.5	57.9	57.6	*	−0.20	−0.03
Natural areas	*63.9*	*61.7*	*61.5*	*n.s.*	*−0.12*	*−0.02*
Other (minor) uses	72.6	70.7	70.4	*n.s.*	−0.09	−0.03

Note: [a]Significant changes in the MWC between 1960 and 2006 by land-use class evaluated by Mann−Whitney U−test (*$p < 0.05$; *n.s.* = not significant).

Table 6. Range (Max–Min) of the SQI score and MWC observed in each land use class in Italy by year.

Variable	1960	1990	2006	Annual change (%)[c]	
				1960–1990	1990–2006
Soil Quality Index[a]	0.155	0.149	0.149	−0.13*	−0.01[ns]
Maximum available water content in the soil[b]	25.0	21.9	21.8	−0.41*	−0.01[ns]

Notes: [a]Calculated as the difference in the SQI score recorded in the highest and lowest soil quality land-use class.
[b]Calculated as the difference in the MWC value recorded in the land-use classes with soil scoring the highest and the lowest water quantity.
[c]Annual changes significantly different from zero tested using Mann–Whitney U test (*$p < 0.05$, [ns] not significant).

The spatial distribution of the MWC index indicates that, on average, soils with the lowest potential water capacity in Italy were found to be associated with shrubland and pastures while the reverse pattern was observed for irrigated arable land (Table 5). This may confirm MWC as an honest indicator for the identification of optimal areas for agriculture. Between 1960 and 2006, croplands and natural areas moved to soils with progressively lower MWC values. Due to land use changes, the agricultural 'mosaic' class experienced the highest decrease in the MWC, occupying soils with an average potential water capacity of 78 mm and 72 mm in 1960 and 2006, respectively. Only vineyards and olive groves have occupied soils with higher MWC in the investigated period.

Notably, the spatial variability observed in the two soil variables (expressed as the range observed among the 10 land use classes) declined between 1960 and 2006 (Table 6). For SQI scores, the range observed between the land use classes occupying soils with the highest and the lowest quality decreased from 0.16 in 1960 to 0.15 in 2006. The same pattern was observed for the variability in the MWC index, passing from 25 mm in 1960 to 22 mm in 2006. Interestingly, the change over time (1960–2006) observed in each land use class area (Figure 2) was found correlated with the variation observed in the average SQI score assigned to each class ($r_s = -0.44$, $p < 0.05$, $df = 9$) while not correlated to the change in the MWC index ($r_s = 0.20$, $p > 0.05$, $df = 9$). This finding may indicate the SQI as a more comprehensive index for the study of soil/land use dynamics in Italy.

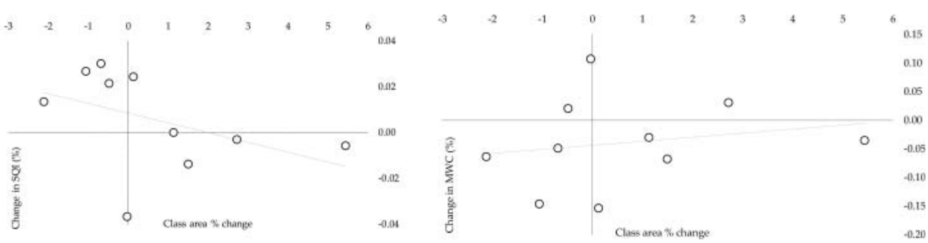

Figure 2. The relationship between percentage change in class area (1960–2006) and (left) percentage variation in the Soil Quality Index or (right) in the Maximum potential Water Capacity of the soil occupied by each land use class.

4. Discussion

By comparing the spatial distribution of selected soil indicators with changes in the use of land observed in Italy over the last 50 years, this paper introduces a methodology evaluating soil quality in regions experiencing rapid landscape transformations (Antrop 2005). The study contributes to the long-term monitoring of soil resource depletion due to urbanisation, land abandonment or other land use changes at national or supra-national level, which seems to be relatively scarce in biodiversity rich and structurally diverse soils of southern Europe (European Commission 2006). Data used in the present study are adequate to develop a quantitative assessment of the (changing) spatial relationship between land use dynamics and soil quality at the national and regional scales and to inform sustainable land management strategies (Salvati *et al*. 2009).

Results indicate that land use changes in Italy reflect a 'migration' of both natural and agricultural classes towards areas characterised by soils with lower quality, with negative implications for ecosystem stability and agricultural productivity. The crop mosaic formed by perennial cultivation, heterogeneous agricultural areas and patches of forest and pasture land (a typical agro-forest landscape occurring in various regions of the northern Mediterranean basin; Conacher and Sala 1998) was found to be the class progressively occupying land with the lowest soil quality and reduced water capacity. This finding was already observed in a local scale study (Salvati 2013) which explored a time horizon of nearly 60 years after the Second World War.

This result suggests that land use changes may selectively impact the natural and biodiversity-rich environments that preserve high-quality landscapes not only via well-known habitat fragmentation processes (Marathianou *et al*. 2000; Hill *et al*. 2008; Salvati and Zitti 2012) but also via alteration of the pristine soil-vegetation equilibrium (Millennium Ecosystem Assessment 2005). This scenario may involve both natural areas (forests, shrublands and pastures) and cultivated areas, thus preventing a sustainable and economically-viable management of land (Portnov and Safriel 2004).

Previous works have demonstrated how landscape transformations are associated with long-term ecological processes (e.g. climate aridity, soil erosion or salinisation, forest fires; Bajocco, Salvati, and Ricotta 2011) together with socio-economic, cultural and institutional factors that may increase human pressure on agro-forest systems (Garcia Latorre, Garcia Latorre, and Sanchez-Picon 2001; Scalenghe and Ajmone Marsan 2009; Salvati and Bajocco 2011). In the Mediterranean basin, these conditions may be exacerbated by unsustainable land management practices in rural areas (Bonet 2004; Blondel 2006; Falcucci, Maiorano, and Boitani 2007; Costantini *et al*. 2009; Briassoulis 2011) and by urbanisation-driven land consumption in peri-urban areas (Salvati 2013). Sustainable land management strategies are therefore urged to address the feedback relationship between landscape transformations and soil degradation processes (Simeonakis, Calvo-Cases, and Arnau-Rosalen 2007; Sluiter and de Jong 2007; Sirami *et al*. 2010), also in the light of climate changes impacting this complex and possibly fragile system (Salvati *et al*. 2009).

Within the framework of the EU Soil Thematic Strategy (COM(2006)231), policies aimed at mitigating environmental degradation processes should be informed by permanent monitoring schemes acting at the regional and country scale. The approach illustrated in the present study is suited to meet this objective because it quantifies target variables (soil quality and land use changes) by using easily and freely accessible homogeneous data from field surveys and digital cartography that can be regularly updated. Because of its versatility, the illustrated procedure represents a tool for landscape conservation, the management of protected areas and rural development, particularly in Mediterranean regions characterised by low-quality soils.

Diachronic, high-resolution land use maps (such as the CLC cartography) covering large areas with homogeneous nomenclature and updated at regular intervals of 6−10 years are especially needed as input data. In this perspective, future research should better focus on the difference between net and gross land use changes and the possible implications for soil quality monitoring. Until now, gross land use changes have been mainly assessed (e.g. Feranec *et al*. 2010). An example of this process is the increase in built-up areas and the contemporary decrease in agricultural areas with stable forest area. These could be the result of more complex patterns of net changes where built-up areas expanded into agricultural area and agricultural areas expanded into the forest. High-resolution, multi-temporal land use maps have considerable potential for covering up such complex net changes. Finally, in-depth pilot studies can contribute to ascertain local trends and site-specific processes that cannot be revealed through a country-wide analysis.

Acknowledgements

The authors wish to thank T. Ceccarelli and L. Perini (CRA-CMA) who provided technical support and critical reading of the manuscript. The authors of this paper have been partly financed by the 'Agroscenari' project (research unit 6a) funded by the Italian Ministry of Agricultural and Forestry Policies.

References

Amundson, R., Y. Guo, and P. Gong. 2003. "Soil Diversity and Land Use in the United States." *Ecosystems* 6: 470–482.

Antrop, M. 2000. "Changing Patterns in the Urbanized Countryside of Western Europe." *Landscape Ecology* 15 (3): 257–270.

Antrop, M. 2004. "Landscape Change and the Urbanization Process in Europe." *Landscape and Urban Planning* 67 (1–4): 9–26.

Antrop, M. 2005. "Why Landscapes of the Past are Important for the Future." *Landscape and Urban Planning* 70 (1–2): 21–34.

Bajocco, S., L. Salvati, and C. Ricotta. 2011. "Land Degradation vs. Fire: A Spiral Process?" *Progress in Physical Geography* 35: 3–18.

Blondel, J. 2006. "The 'Design' of Mediterranean Landscapes: A Millennial Story of Humans and Ecological Systems During the Historic Period." *Human Ecology* 34: 713–729.

Bonet, A. 2004. "Secondary Succession of Semi-Arid Mediterranean Old-Fields in South-Eastern Spain: Insights for Conservation and Restoration of Degraded Lands." *Journal of Arid Environments* 56 (2): 213–233.

Briassoulis, E. 2011. "Governing Desertification in Mediterranean Europe: The Challenge of Environmental Policy Integration in Multi-Level Governance Contexts." *Land Degradation and Development* 22 (3): 313–382.

Cerdà, A. 1997. "Soil Erosion after Land Abandonment in a Semiarid Environment of Southeastern Spain." *Arid Soil Research and Rehabilitation* 11: 163–176.

Conacher, A.J., and M. Sala. 1998. *Land Degradation in Mediterranean Environments of the World*. Chichester: Wiley.

Corona, P., and A. Ferrara. 1989. "Individual Competition Indices for Conifer Plantations." *Agriculture, Ecosystems & Environment* 27 (1): 429–437.

Costantini, E.A.C., F. Urbano, G. Aramini, R. Barbetti, F. Bellino, M. Bocci, G. Bonati, G. et al. 2009. "Rationale and Methods for Compiling an Atlas of Desertification in Italy." *Land Degradation and Development* 20 (3): 261–276.

European Commission. 2006. *Thematic Strategy for Soil Protection*. COM(2006)231 final, 22.9.2006. Brussels: European Commission.

European Environment Agency. 2002. *Environmental Signals 2002 – Benchmarking the Millennium*. København.

European Environment Agency. 2006. *Urban Sprawl in Europe. The Ignored Challenge*. København.

European Environment Agency. 2009a. "Soil Quality Index Map." København http://www.eea.europa.eu/data-and-maps/figures/soil-quality-index-map

European Environment Agency. 2009b. "Desertification in the Mediterranean Region." København. http://www.eea.europa.eu/data-and-maps/data/desertification-in-the-mediterranean-region

European Environment Agency. 2012. "Corine Land Cover – Part 1: Methodology." København. http://www.eea.europa.eu/publications/COR0-part1

Falcucci, A., L. Maiorano, and L. Boitani. 2007. "Changes in Land-use/Land-cover Patterns in Italy and their Implications for Biodiversity Conservation." *Landscape Ecology* 22 (4): 617–631.

Feranec, J., G. Jaffrain, T. Soukup, and G. Hazeu. 2010. "Determining Changes and Flows in European Landscapes 1990–2000 Using CORINE Land Cover Data." *Applied Geography* 30: 19–35.

Finke, P., R. Hartwich, R. Dudal, J. Ibanez, M. Jamagne, D. King, L. Montanarella, and N. Yassoglou. 1998. *Georeferenced Soil Database for Europe, Manual of Procedures, Version 1*. Ispra: European Soil Bureau.

Garcia Latorre, J., J. Garcia Latorre, and A. Sanchez-Picon. 2001. "Dealing with Aridity: Socio-Economic Structures and Environmental Changes in an Arid Mediterranean Region." *Land Use Policy* 18: 53–64.

Helldén, U., and C. Tottrup. 2008. "Regional Desertification: A Global Synthesis." *Global and Planetary Change* 64: 169–176.

Hill, J., M. Stellmes, T. Udelhoven, A. Roder, and S. Sommer. 2008. "Mediterranean Desertification and Land Degradation: Mapping Related Land Use Change Syndromes Based on Satellite Observations." *Global and Planetary Change* 64 (3–4): 146–157.

Jones, A., L. Montanarella, and R. Jones. 2005. *Soil Atlas of Europe*. Luxembourg: European Soil Bureau, Office for Official Publications of the European Communities.

Marathianou, M., C. Kosmas, S. Gerontidis, and V. Detsis. 2000. "Land-use Evolution and Degradation in Lesvos (Greece): A Historical Approach." *Land Degradation and Development* 11 (1): 63–73.

Marzaioli, R., R. D'Ascoli, R.A. De Pascale, and F.A. Rutigliano. 2010. "Soil Quality in a Mediterranean Area of Southern Italy as Related to Different Land Use Types." *Applied Soil Ecology* 44: 205–212.

Millennium Ecosystem Assessment. 2005. *Ecosystems and Human Well-being: Synthesis. World Resources Institute*. Washington DC: Island Press.

Montanarella, L. 2007. "Trends in Land Degradation in Europe." In *Climate and Land Degradation*, edited by M.V. Sivakumar and N. Diangui, 83–104. Berlin: Springer.

Myers, N., R. A. Mittermeier, C.G. Mittermeier, G.A.B. da Fonseca, and J. Kent. 2000. "Biodiversity Hotspots for Conservation Priorities." *Nature* 403: 853–858.

Otto, R., B.O. Krusi, and F. Kienast. 2007. "Degradation of an Arid Coastal Landscape in Relation to Land Use Changes in Southern Tenerife (Canary Islands)." *Journal of Arid Environments* 70: 527–539.

Perini, L., L. Salvati, M. Zitti, S. Sorrenti, and T. Ceccarelli. 2008. *La Desertificazione in Italia*. Roma-Acireale: Bonanno.

Portnov, B.A., and U.N. Safriel. 2004. "Combating Desertification in the Negev: Dryland Agriculture vs. Dryland Urbanization." *Journal of Arid Environments* 56 (4): 659–680.

Salvati, L. 2013. "Urban Expansion and High-Quality Soil Consumption – An Inevitable Spiral?" *Cities* 31: 349–356.

Salvati, L. and S. Bajocco. 2011. "Land Sensitivity to Desertification Across Italy: Past, Present, and Future." *Applied Geography* 31 (1): 223–231.

Salvati, L. and M. Zitti. 2012. "Monitoring Vegetation and Land Use Quality Along the Rural Urban Gradient in a Mediterranean Region." *Applied Geography* 32: 896–903.

Salvati, L., M. Zitti, T. Ceccarelli, and L. Perini. 2009. "Building-up a Synthetic Index of Land Vulnerability to Drought and Desertification." *Geographical Research* 47 (3): 280–291.

Scalenghe, R., and F. Ajmone Marsan. 2009. "The Anthropogenic Sealing of Soils in Urban Areas." *Landscape and Urban Planning* 90: 1–10.

Serra, P., X. Pons, and D. Saurí. 2008. "Land-cover and Land-use Change in a Mediterranean Landscape: A Spatial Analysis of Driving Forces Integrating Biophysical and Human Factors." *Applied Geography* 28 (3): 189–209.
Shoyama, K., and A.K. Braimoh. 2011. "Analyzing about Sixty Years of Land-Cover Change and Associated Landscape Fragmentation in Shiretoko Peninsula, Northern Japan." *Landscape and Urban Planning* 101: 22–29.
Simeonakis, E., A. Calvo-Cases, and E. Arnau-Rosalen. 2007. "Land Use Change and Land Degradation in Southeastern Mediterranean Spain." *Environmental Management* 40: 80–94.
Sirami, C., A. Nespoulous, J. P. Cheylan, P. Marty, G.T. Hvenegaard, P. Geniez, B. Schatz, and J.L. Martin. 2010. "Long-term Anthropogenic and Ecological Dynamics of a Mediterranean Landscape: Impacts on Multiple Taxa." *Landscape and Urban Planning* 96: 214–223.
Sluiter, R., and S.M. de Jong. 2007. "Spatial Patterns of Mediterranean Land Abandonment and Related Land Cover Transitions." *Landscape Ecology* 22: 559–576.
Sposito, G., and A. Zabel. 2003. "The Assessment of Soil Quality." *Geoderma* 114: 143–144.
Thornes, J.B. 2004. "Stability and Instability in the Management of Mediterranean Desertification." In *Environmental Modelling: Findings Simplicity in Complexity*, edited by J. Wainwright and M. Mulligan, 303–315. Chichester: Wiley.
Turner, M.G., and L.C. Ruscher. 1998. "Changes in Landscape Patterns in Georgia, USA." *Landscape Ecology* 1: 241–251.
Venezian Scarascia, M.E., F. Di Battista, and L. Salvati. 2006. "Water Resources in Italy: Availability and Agricultural Uses." *Irrigation and Drainage* 55 (1): 115–127.
Verburg, P.H., D.B. van Berkel, A.M. van Doorn, M. van Eupen, and H.A.R.M. van den Heilingenberg. 2010. "Trajectories of Land Use Change in Europe: A Model-Based Exploration of Rural Futures." *Landscape Ecology* 25 (2): 217–232.
Zitti, M., L. Salvati, and L. Perini. 2013. "Fifty Years on: Understanding the Long-term Spatio-Temporal Patterns of Sensitivity to Desertification across Italy." *Land Degradation and Development* DOI: 10.1002/ldr.2226.