Soil organic carbon in Mediterranean cropping systems and the influence of climate change on soil physical qualities

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Abstract

Many soil properties are deemed to change significantly in response to climate change. However, soil management has been demonstrated to potentially cause much larger effects on soil features, thus there is the need to understand the interactions between climate and management on soil variations in the different cropping systems. This research work was aimed at estimating the climate change impacts on soils under main Mediterranean cropping systems. To this aim, we decoupled the impact of climate from that of agricultural husbandry through investigating the soil-climate interactions in four areas, where specific soil types and cropping systems were placed along well defined climosequences of the past (1961-1990), present (1981-2010) and future (2021-2050). Soil C stock, bulk density, available water capacity, erodibility, crusting and compaction susceptibility, and erosion rate, were the variable of interest. Soil profiles analyzed in the past were re-sampled and re-analyzed. The interaction between climate, soil, and crop system differed between the studied climosequences. Vertisols of Sicily under cereal system, and Luvisols of Po Plain, with forage and livestock, were the most sensitive to climate change, but with opposite trends. Olive tree cultivation in Andosols of Campania and meadows on Luvisols of Sardinia showed lower sensitivity to climate changes.

Keywords: SOC, climosequence, cropping systems, Mediterranean, climate change, Luvisols, Andisols, Vertisols, Italy

Introduction, scope and main objectives

Agricultural production is dramatically affected by climate variability and changes (Parry et al., 2004; Lal, 2004; Lobell et al., 2011). Producers, land managers, and other decision makers need information about the effects of climate changes on cropping systems, to develop mitigation and adaptation strategies, and policy measures (Olesen and Bindi, 2002). Due to the great variability of climate and soil cover, however, adaptation measures should be tailored according to specific conditions, to be really effective (Thornton et al., 2009).

Although land use and management changes are expected to play a greater role than climate changes on soil properties and functions (Lal et al., 2011; Fantappiè et al., 2011), projected climatic conditions are considered to jeopardize several soil qualities and functions (Lal, 2004). Soil organic matter and its components, including biological activity, are the most sensitive and dynamic properties and therefore privileged indicators for monitoring land degradation processes, as well as adaptation and restoration strategies, also because they affect many other chemical, physical and hydrological soil properties and qualities (Kirschbaum, 1995; Costantini et al., 2016). Soil physical and hydrological characteristics, in spite of being mainly indirectly related to climate changes, are of particular interest, for their paramount importance in shaping soil services (Powlson et al., 2011).

Soil organic matter content (SOM) variations observed along climatic gradients (climosequence) can provide information about potential fluctuations in past or future climatic scenarios.

This research work was aimed at estimating the climate change impacts and vulnerabilities of soils under main Mediterranean cropping systems. To this aim, we decoupled the impact of climate from that of agricultural husbandry through investigating the soil-climate interactions in specific soil types and cropping systems placed along well defined climosequences of the past (1961-1990), present (1981-2010) and future (2021-2050).

Methodology

Cereal monocultures on Vertisols of Sicily (about 354,000 ha), permanent pastures and meadows on sandy loam Luvisols of Sardinia (169,000 ha), olive tree cultivation in medial Andosols of Campania (4,000 ha), and forage and livestock production on loamy Luvisols of Po Plain (150,000 ha) were the Mediterranean cropping systems that we selected for the investigation. These are among the most characteristic and widespread cultivations in the agricultural areas of Mediterranean countries and, at same time, among the least affected by the dynamic of land use and management; therefore, their soils were expected to reflect better than others the possible modifications caused by climate changes.

The test areas were placed and dimensioned so to encompass well-characterized climates and transition environments within a cropping system, cultivated on the same soil type. The areas were all located in Italy, spanning from the 37° to the 46° parallel north, including the main climatic conditions of Mediterranean agricultural soils, namely, Mediterranean sub-oceanic, sub-continental, and subtropical (Costantini and Lorenzetti, 2013). The considered time series were the 1961-1990 30-year period, selected as the baseline climate by most authors (e.g., IPCC, 2006), named period 1, the decade closest to the present climate (1981-2010, period 2), and the future climate projection (2021-2050, period 3).

The sampling sites in each study area were selected from the national soil database (CNCP), taking all the georeferenced soils profiles located along a climatic gradient, belonging to the same soil typology, placed on similar morphological position and parent material, and under the same cropping system. As a whole, 59 sites were identified, sampled in the time period from 1960 to 2000. The sites were re-sampled in 2010-2011, to check the occurred changes in soil characteristics. To improve the spatial representativeness of the soil-climate relationship, the sample size of all climosequences was increased, and further 55 sampling sites were selected and investigated. The permanence along time of the same crop system in each sampling site (old and new) was checked through a multi-temporal remote analysis.

Physical and chemical characterization of the surface soil layer (0-30 cm) was made according to internationally recognized analytical methods : pH, electrical conductivity (EC 1:2.5), total organic carbon (TOC), total nitrogen (N), total limestone ($CaCO_3$), bulk density (BD) and plant available water capacity (AWC). The soil particle size distribution was determined by the Sedigraph X-ray attenuation method (Andrenelli et al., 2013). Soil data were used to estimate soil carbon stock and several physical qualities, namely, bulk density, available water capacity, erodibility (Torri et al., 1997), crusting and compaction susceptibility (Vignozzi et al., 2007), and erosion rate.

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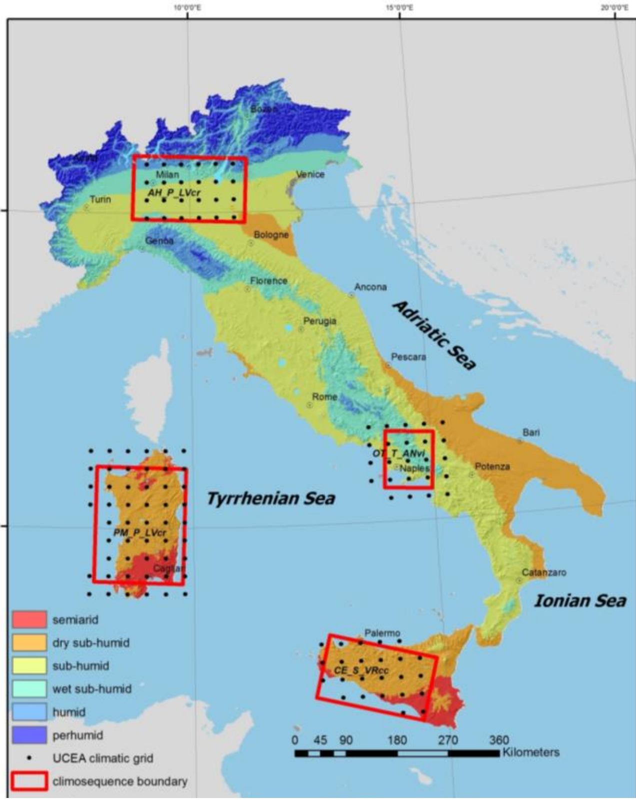

Fig. 1: study areas and climatic regimes

Several climatic indices were calculated on a 30 km grid and downscaled to 500 m using DEM and distance from the sea as covariates. Future climate was inferred for four stations placed inside the studied areas according to Tomozeiu et al. (2010) and related to SOC variations.

Results

The Index of de Martonne (P/T +10; IDM) resulted the most correlated to SOC among the studied climatic indices and was taken as a reference for the next elaborations. The IDM values in the investigated areas in the first (1961-1990) and second (1980-2010) periods resulted generally lower, pointing to a significant increase in aridity, apart from Sicily, where it remained stable.

The linear relationships between IDM and SOC found in the first (1961-1990) and second (1980-2010) period resulted both statistically significant in each studied area. The correlation in the two periods was not significantly different, therefore we could assume that the influence of climate on SOC content is relatively stable, and could be applied to future climatic scenarios. The estimated climatic condition during the third period (2021-2050) pointed to a significant increase in temperature in the four areas, but with variable rainfall regime. Therefore, aridity was deemed to severely increase in Sicily but lower in Po Plain, whereas Sardinia and Campania did not show important variations.

The relationship between IDM and soil qualities were all significant, except for bulk density and available water capacity, but rather different between the four soil types. Vertisols under cereals and Andosols under olive trees were the most vulnerable, that is, easily affected by small climatic variations, while Luvisols of Po Plain and Sardinia resulted relatively more resilient.

Applying the relationship between IDM and SOC in each area to the future climatic scenario, we obtained the estimation of the future SOC content in the studied cropping systems. The projected value of SOC and climatic parameters allowed to calculate the future values of the considered soil qualities.

Table 1: Descriptive statistics (mean values and ranges) of IDM index and main soil qualities related to the organic carbon content and erosion rate by RUSLE model for the three compared decades (1961-1990, 1981-2010 and 2021-2050).

Decade	Study area	IDM	C stock (kg m^{-2})	K	Compaction susceptibility (dimensionless)	Crusting susceptibility (dimensionless)	Erosion rate (Mg ha^{-1} y^{-1})
1961-1990	Sicily	21.8 (12.1)	5.76 (2.28)	0.0276 (0.0005)	1.6461 (0.1281)	0.6370 (0.1102)	40.6 (369.3)
	Sardinia	20.4 (14.0)	4.19 (2.43)	0.0462 (0.0023)	1.9009 (0.1235)	1.1782 (0.3489)	0.1 (5.0)
	Campania	42 (32.6)	8.58 3.48)	0.0489 (0.0032)	2.0141 (0.1035)	0.9740 (0.2538)	20.7 (147.7)
	Po Plain	41.4 (24.3)	5.92 (4.54)	0.0531 (0.0048)	2.0531 (0.2343)	1.3162 (0.6137)	29.4 (887.3)
1981-2010	Sicily	23.1 (18.7)	6.10 (3.53)	0.0292 (0.0008)	1.7443 (0.1357)	0.6750 (0.1703)	43.0 (570.8)
	Sardinia	19.4 (14.0)	3.98 (2.43)	0.0439 (0.0023)	1.8077 (0.1174)	1.1204 (0.3489)	0.1 (5.0)
	Campania	35.5 (24.1)	7.25 (2.57)	0.0413 (0.0024)	1.7024 (0.0875)	0.8233 (0.1876)	17.5 (109.2)
	Po Plain	36.0 (24.1)	5.15 (4.50)	0.0462 (0.0048)	1.7853 (0.2037)	1.1445 (0.6086)	25.6 (880.0)
2021-2050	Sicily	19.7 (16.0)	5.41 (3.12)	0.0294 (0.0006)	1.7743 (0.1297)	0.7128 (0.1632)	35.9 (501.8)
	Sardinia	20.2 (14.6)	4.10 (2.37)	0.0438 (0.0024)	1.8013 (0.1147)	1.1003 (0.3327)	0.2 (5.5)
	Campania	33.6 (30.9)	7.09 (2.46)	0.0414 (0.0024)	1.7073 (0.09.7)	0.8340 (0.1952)	18.3 (113.1)
	Po Plain	41.4 (24.4)	6.15 (4.70)	0.0451 (0.0061)	1.7398 (0.1935)	1.0138 (0.5320)	30.4 (1035.0)

Discussion

In the future scenario of generalized temperature raising, but regionally variable rainfall distribution, the cereal cropping system on Vertisols of Sicily results to be the most vulnerable. In fact, the soil C stock reduction here is estimated to be larger than 11%. The SOC content decline shows a clear influence on all soil physical qualities and, in particular, causes an increase of the compaction and crusting susceptibility, as well as of the erodibility index. In spite of that, the marked decrease in precipitation will produce a significant lowering of the soil erosion losses, which however will remain higher than tolerable rate.

The elaborations depict a very dissimilar scenario for the fodder and livestock cropping system of Po Plain. The decreased aridity is going to induce a distinct increase of the SOC content and C stock of loam Luvisols, and a consequent improvement of their physical qualities. On the other hand, the expected increase in rainfall will produce an erosion rate more than 18% higher, which will not be set off by the improvement of soil physical conditions.

The slight aridity decrease that was estimated to occur in Sardinia will produce a moderate increase in SOC content and C stock of sandy loam Luvisols under pastures and meadows. This improvement however will be only marginally reflected in an improvement of soil physical qualities. The erosion rate instead is deemed to increase notably, although the grass cover that characterize the land use, as a consequence of the augmented precipitation. The Andosols of Campania under olive tree cultivation, in spite of their high vulnerability and sensitivity to climatic variation, do not show important modifications of SOC content, C stock and physical soil qualities. Also erosion rate and soil losses are estimated not to vary considerably.

Conclusions

The foreseen climate change will produce in the soils of the years 2021-2015 important modifications, not only related to soil organic matter. Actually, changes in erosion rate will on average exceed carbon stock variations. Also crusting susceptibility results to vary markedly, in dependence of soil organic carbon. It must be stressed, however, that local variations will be surely greater than the general trend. Therefore the study points to strong interactions between climate change, soil type and cropping system.

The results of this study suggest that the implementation of conservative practices, such as conservation agriculture, are particularly to be encouraged for Vertisols under cereal cultivation in dry sub-humid climatic conditions. The study also demonstrates that soil climosequences can be recommended to relate soil qualities variations to climatic changes.

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