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# Application of CarboSOIL model to predict the effects of climate change on soil organic carbon stocks in agro-silvo-pastoral Mediterranean management systems

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### 14 Abstract

15

CarboSOIL model and climate outputs from two GCMs (GISS and HadCM3), three time horizons 16 (2020, 2050, 2080), and two emission scenarios (A2 and B2) according to IPCC were used to study 17 the effects of climate change on SOC dynamics in a Mediterranean region (Northeast Sardinia, 18 Italy). CarboSOIL is an empirical model based on regression techniques and developed to predict 19 SOC contents at standard soil depths of 0-25, 25-50 and 50-75 cm. The area is characterized by 20 21 extensive agro-silvo-pastoral systems, and six land uses with different levels of cropping intensification were compared: Tilled vineyards (TV), No-tilled grassed vineyards (GV), Hay crop 22 23 (HC), Pasture (PA), Cork oak forest (CO), and Semi-natural systems (SN). The main objectives were: i) to validate the model predictions with the measured SOC stocks, and ii) to predict SOC 24 changes in future climate projections for the different land use types. 25 The model proved its ability to predict SOC stocks at different soil depths, and can be used as a tool 26

- 27 for predicting SOC changes under different climate change scenarios.
- The results suggest that future climatic scenarios can have a negative effect on SOC stocks in the upper sections of the soil profile, mainly due to a very low increase in the 0-25 cm section and a sharp decrease in the 25-50 cm soil section, in particular in a long term perspective (2080) and under the emission scenario A2.
- 32 Important decreases of SOC stocks were found in the upper soil sections of the vineyards.
- 33

Keywords: Mediterranean systems, soil organic carbon, climate change, emission scenarios, land
 use, CarboSOIL

- 36
- 37 **1. Introduction**
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Soil organic carbon (SOC) positively affects soil functions with regard to habitat, biological
diversity, soil fertility, crop production potential, erosion control, water retention, exchange of gases
and chemicals between soil, atmosphere and water, and the filtering, buffering and transforming
capacity (Huber et al., 2001; Kirchmann and Andersson, 2001).

Since soil organic matter (SOM) is constantly built up and decomposed, SOC contained in the organic matter is released to the atmosphere as  $CO_2$  and recaptured through photosynthesis. Soil C sequestration is achieved by increasing the net flux of C from the atmosphere to the terrestrial biosphere, by storing more of the C from net primary production in the longer-term C pools in the soil, or by slowing down decomposition (Smith, 2005). As a consequence, C sequestration via agricultural soils has a potential to contribute significantly to climate change mitigation, and can be affected by management practices (Conant et al., 2001).

50 Many studies have focused on SOC distribution in biologically active layers of topsoil, where SOC 51 and nutrient cycling is most dynamic (Jarecki and Lal, 2005; Wright et al., 2007; Yoo et al., 2006; 52 Young et al., 2005). But a global consensus is still lacking about the depth to which SOC and other 53 soil parameters should be measured and modelled, and how climate affect SOC distribution down 54 the soil profile (Grüneburg et al., 2010; Li et al., 2007; Malmoud et al., 2009).

The IPCC carbon accounting method estimates the change in SOC storage for the top 30 cm of a soil profile (IPCC, 2006), but questions remain as to SOC concentrations below this depth (Don et al., 2007).

58 SOC estimates are more uncertain in areas with heterogeneous land uses and pedoclimatic 59 conditions as Mediterranean environments, which are more prone to land degradation due to the 60 combined effect of high temperatures during the summer, which enhance SOC degradation and 61 depletion, and erosive processes on the hills due to heavy rains in winter (Cerda et al., 2010). 62 Indeed, these effects will be enhanced by global warming and climate change.

Most of the known factors acting on SOC dynamics have been implemented in simulation models 63 which take into account the interactions among climate, pedology, cropping system, soil and crop 64 management (Francaviglia et al., 2012). Moreover, well-validated models can be used to predict 65 66 SOC changes under different management and climatic conditions that may occur in the future (Jones and Donnelly, 2004). Among SOC models, CENTURY (Parton et al., 1994) and RothC 67 68 (Coleman and Jenkinson, 1996) are particularly suitable to describe the turnover of the different SOC pools. Both models have been extensively applied worldwide under a variety of pedoclimatic 69 70 and cropping conditions, and have a similar structure, containing pools with a rapid turnover 71 (month-year), moderate turnover (decadal), and slow turnover (millennial or inert). The first model 72 is more complex and requires a high number of input parameters, while the second requires a low number of parameters easy to be collected, but it only simulates processes in the topsoil layer (e.g.
20-25 cm).

Both models have been applied in the Mediterranean region to simulate SOC changes (AlvaroFuentes et al., 2012; Francaviglia et al., 2012; Lugato and Berti, 2008; Mondini et al., 2012).
Nonetheless, few modelling studies consider different soil layers or the entire profile in the
assessment of projected SOC stocks under climate change in the Mediterranean region (Bernardoni
et al., 2012; De Sanctis et al., 2012; Farina et al., 2011; Muñoz-Rojas et al., 2013).

- In this study, the CarboSOIL model (Muñoz-Rojas et al., 2013) together with climate outputs from 80 81 two GCMs (GISS and HadCM3), three time horizons (2020, 2050, 2080), and two emission scenarios (A2 and B2) according to Intergovernmental Panel on Climate Change (IPCC, 2007) was 82 used to study the effects of climate change on SOC dynamics in a Mediterranean region (Northeast 83 Sardinia, Italy); the area is characterized by extensive agro-silvo-pastoral systems typical of similar 84 85 areas of the Mediterranean basin. CarboSOIL is an empirical model based on regression techniques and developed to predict SOC contents at standard soil depths of 0-25, 25-50 and 50-75 cm 86 87 (Muñoz-Rojas et al., 2013). The main objectives were: i) to validate the model predictions with the measured SOC stocks, and ii) to predict SOC changes in future climate projections for the different 88 89 land use types.
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#### 91 **2. Materials and methods**

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#### 93 2.1 Model description

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95 CarboSOIL was developed to predict SOC stocks and changes in Mediterranean areas under 96 different scenarios of climate and land use at different soil depths (Muñoz-Rojas et al, 2013) and it 97 has been incorporated in the land evaluation decision support system MicroLEIS DSS (De la Rosa 98 et al., 2004).

99 The model consists of four modules or submodels that predict soil organic carbon contents at 100 different depths: (a) CarboSOIL25 (0–25 cm), (b) CarboSOIL50 (25–50 cm) and (c) CarboSOIL75 101 (50–75 cm). The required input parameters include (I) climate variables (mean winter/summer 102 temperature and annual precipitation), (II) site variables (elevation, slope, erosion, type of 103 drainage), (III) soil (pH, N, cation exchange capacity, sand/clay content, bulk density and field 104 capacity), and (IV) land use, with a total of 15 independent variables and soil organic carbon as 105 predictor variable (Table 1). A dataset with detailed description of 1756 soil profiles was used for the design of CarboSOIL,
which was built as an empirical model based on multiple linear regression and Box–Cox
transformation techniques (Muñoz-Rojas et al., 2013).

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110 *2.2 Study area* 

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CarboSOIL model was applied to an area of about 1450 ha (Fig. 1) in north-eastern Sardinia (Italy)
(40°46'N, 9°10'E, mean altitude 285 m a.s.l.), characterized by extensive agro-silvo-pastoral
systems typical of similar areas of the Mediterranean basin (e.g. the Iberian Peninsula).

The local climate is warm temperate with dry and hot summers, with a mean annual rainfall of 623
mm (range 367–811 mm) and mean annual temperature of 15.0°C (13.8–16.4°C).

Soils are Dystric Endoleptic Cambisols (WRB, 2014), while cork oak forest (*Quercus suber* L.) is the potential native vegetation which has been converted to managed land with pastures and vineyards in recent years (Lagomarsino et al., 2011; Francaviglia et al., 2012; Bagella et al, 2013a,b; Francaviglia et al., 2014). Six land uses with different levels of cropping intensification were compared: Tilled vineyards (TV), No-tilled grassed vineyards (GV), Hay crop (HC), Pasture (PA), Cork oak forest (CO), and Semi-natural systems (SN).

TV is ploughed every year to 40 cm, is under organic farming management, but pruning residues 123 are removed from the field. GV is grassed, the pruning residues are left on the soil, and 124 supplementary drip irrigation is applied in summer if needed. The HC land use is cereals and annual 125 legumes for 5 years for hay production, and intercropped by spontaneous herbaceous vegetation in 126 the sixth year. It is ploughed to 40 cm and grazing is allowed with 3-4 sheep ha<sup>-1</sup>. The PA land use 127 is 5 years of spontaneous herbaceous vegetation, and one year of intercropping with a hay crop. It is 128 tilled 1 year out of 6 and is grazed with 6 sheep ha<sup>-1</sup>. The CO land use represents the natural 129 vegetation of the area, and is used for cork production and cattle grazing (1.5 heads  $ha^{-1}$ ) in the 130 clearings. The SN land use (Mediterranean maquis and scrublands, and thermophilous meadows 131 with Helichrysum) arise from the natural re-vegetation of former vineyards set-aside about 30 years 132 133 ago.

Both PA and HC include scattered cork-oak stands, which are key components of the "Dehesa" agroforestry system (grazing system with Quercus L.) typical of other areas of southern Mediterranean Europe (Portugal and Spain). Dehesas are often converted to more profitable land uses such as vineyards (Francaviglia et al., 2012; Muñoz-Rojas et al., 2013) or olive groves (Lozano-García and Parras-Alcántara, 2013).

The six land uses are common in the study area, but samplings refer to smaller monitoring areas 142 chosen on existing available soil surveys, which indicated that the spatial variability of SOC was 143 mainly due to land uses and within them by a different land cover condition, since climatic and 144 pedologic conditions were the same. Specific soil sampling was carried out in 2007 in the selected 145 monitoring areas as described by Francaviglia et al. (2014) considering the land cover condition. 146 Briefly, the more heterogeneous land uses were sampled along and between the rows (TV and TG), 147 148 and in areas covered by trees and open areas (PA and HC). SN was sampled in different conditions 149 of vegetation cover due to the existence of heterogeneous natural vegetation. In the CO land use the 150 soil was sampled under trees and bushes. Since soil profiles showed a range of depths, mainly due to present or past tillage operations, data were normalized at 0-25, 25-50 and 50-75 cm calculating 151 152 the weighted average value for each variable in the three standard control sections to run the model. Soil input data of the three sections are shown in Tables 2-4. 153

Soil samples were air-dried, and the analyses were made on the <2mm soil fraction after sieving. The soil reaction (pH) was determined in 1:2.5 soil:water suspension by potentiometric method using a pH meter; cation exchange capacity (CEC) with the BaCl<sub>2</sub>-triethanolamine (pH 8.2) method; particle-size analysis with the wet sieving and sedimentation procedure; total N with the Kjeldahl method, SOC with the Walkley-Black method. Soil bulk density (BD), required to convert SOC concentrations to Mg ha<sup>-1</sup>, was calculated according to the method proposed by Rawls (1983) and Saxton et al (1986).

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#### 162 2.4 Baseline climate, climate change scenarios and model inputs

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The baseline climate was derived from the long-term data series (1985-2006) of Monti station (40° 48' N, 9° 19' E, 296 m a.s.l.), and the climate change scenarios using two Global Climate Models (GCMs): GISS (Hansen et al., 2002), and HadCM3 (Pope et al. 2000). Two emission scenarios based on the Intergovernmental Panel on Climate Change (IPCC, 2007) were chosen: A2, a marked climate change with global warming +3.4 °C by 2100 (uncertainty ranges 2.0-5.4 °C), and B2, a moderate scenario due to mitigation measures, with global warming +2.4 °C (uncertainty ranges 1.4-3.8 °C).

Three time horizons were chosen for climate change projections: 2020, mean climate change for the period 2010-2039; 2050 for the period 2040-2069; and 2080 for the period 2070-2099, providing

173 respectively a very close, an intermediate, and a fully realized climate change scenario (Table 5).

Mean air temperature during winter and summer and annual rainfall required to run CarboSOIL
(Muñoz-Rojas et al., 2013) are shown in (Table 6).

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177 2.5 Indicators of model performance

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The agreement of model predictions with the measured values of soil organic carbon stocks was tested using the correlation coefficient  $R^2$ , and two statistical indicators: the root mean square error (RMSE) and the modelling efficiency (EF):

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$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (O_i - S_i)^2} \qquad EF = 1 - \frac{\sum_{i=1}^{n} (S_i - O_i)^2}{\sum_{i=1}^{n} (O_i - \overline{O})^2}$$

183 where  $O_i$  and  $S_i$  are observed and simulated SOC at i<sup>th</sup> value,  $\bar{O}$  is the mean of the observed data and 184 n is the number of the paired values. The lowest possible value of RMSE is zero, indicating that 185 there is no difference between simulated and observed data. If the model accurately describes the 186 data the RMSE should have approximately the same order of magnitude of the standard deviation 187 (Smith and Smith, 2007). EF compares simulations and observations on an average level, and can 188 range from - $\infty$  to 1, with the best performance at EF=1. Negative values indicate that the simulated 189 values describe the data less well than the mean of the observations.

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#### 191 **3. Results and discussion**

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#### 193 *3.1 Model validation*

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With reference to the 0-25 cm soil section,  $R^2$ , RMSE and EF are 0.977, 8.42, and 0.63 respectively (Fig. 2). In this upper layer, the linear regression coefficients are significant at p<0.001 and the standard deviation of the measured values is 14.18, i.e. higher than RMSE.

In the 25-50 cm soil section,  $R^2$ , RMSE and EF are 0.990, 5.07, and 0.98 respectively (Fig. 3). The linear regression coefficients are significant at p<0.001 and the standard deviation of the measured values is 19.53, i.e. higher than RMSE.

Finally, in the 50-75 cm soil section,  $R^2$ , RMSE and EF are 0.762, 5.88, and 0.93 respectively (Fig. 4). In this soil layer, the linear regression coefficients are also significant at p<0.001 and the

standard deviation of the measured values is also higher than RMSE with a value of 11.09.

Based on the previous considerations, we can affirm that CarboSOIL predictions are fully acceptable for the purpose of this modelling exercise, and can therefore be used for SOC projections under climate change conditions.

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#### 208 *3.2 Prediction of SOC changes under climate change*

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CarboSOIL model predicted an overall increase of SOC stocks in the 2020 climate scenarios in all the soil sections (Fig. 5), with the higher percentage increases in the 50-75 cm section, e.g. 1.1-1.9% in the two vineyards, and 0.8-1.3% in the HC and the PA land use; the smaller increases are observed in the 25-50 cm soil section (0.1-0.8% in the two vineyards, 0-0.3% in HC and PA). Cumulated stocks for the total soil depth (0-75 cm) increased in the order GV (2.3-4.0%) > TV (1.9-3.1%) > PA (1.6-2.6%) > HC (1.2-2.0%) > SN with depth limited to 50 cm (0.4-1.1%) > CO with depth limited to 25 cm (0.3-0.5%).

- A SOC decrease is instead expected in the 2050 and 2080 scenarios in the 25-50 cm soil section, more marked in the vineyards in comparison with the other land uses (Fig. 6-7). In particular, SOC decreases in this section were higher in TV (0.2-0.5 and 0.5-1.2% in 2050 and 2080 respectively), and GV (0.4-1.0 and 1.1-2.7%), in comparison with HC (0.1-0.3 and 0.3-0.7%), PA (0.2-0.5 and 0.6-1.4%), and SN (0.1-0.3 and 0.3-0.7%).
- Oppositely, slight SOC increases are still expected in the 0-25 cm section (from 0.2 to 1.0% in the two vineyards, and from 0.1 to 0.6% in the other land uses), and to a more extent in the 50-75 cm section, particularly evident in the vineyards. In this section, increases in vineyards are less pronounced in 2050 (1.3-3.3 and 1.7-4.3 % in TV and GV respectively), in comparison with 2080 (3.2-5.5 in TV and 4.1-7.2% in GV). Lower SOC increases are found in HC (0.9-2.4 and 2.1-3.7% in 2050 and 2080) and PA (1.2-3.0 and 2.9-5.0%, again in 2050 and 2080).
- A shallow sampling depth is often chosen for reasons of efficiency in monitoring programs, as SOC predominantly accumulates at the surface and in the main rooting zone. Thus, most soils are sampled to a depth of 30 cm or less, and subsoil samplings are not very common (Jandl et al., 2014). However, it has been shown that the SOC pool in the upper mineral soil is not a useful estimator of the total soil C pool as a substantial fraction of this pool can be stored in the subsoil, and this has been shown also for Mediterranean ecosystems (Albaladejo et al., 2013; Chiti et al., 2012; Díaz-Hernández, 2010).
- In this context, this research has provided the first estimates of SOC stocks along the soil layers in agro-silvo-pastoral systems typical of a Mediterranean area in Sardinia (Italy) and their trends with

climate change. According to the results obtained in the validation process, CarboSOIL model hasproved to be consistent and measured values were well correlated with the simulated values.

The results suggest that future climatic scenarios can have a negative effect on SOC stocks in the 239 upper sections of the soil profile, mainly due to a very low increase in the 0-25 cm section and a 240 sharp decrease in the 25-50 cm soil section. The simulated decrease was particularly high by the 241 end of the century in the 2080 time horizon (covering the period 2070-2099), and particularly under 242 the emission scenario A2 with a marked climate change in comparison with the baseline. Moreover, 243 244 SOC depletion is more marked in the two vineyards and the HC and PA land uses, where soil 245 disturbance is higher in comparison with the cork oak forest (CO) and the semi-natural systems (SN). Also, differences found in the SOC contents along the soil profile and for different land uses 246 247 might be related to root allocation, which changes across plant species and vegetation types (Yang et al., 2012). 248

As a fact, increasing temperatures will accelerate SOC decomposition, and decrease photosynthesis rates and crop productivity, with a consequent lower return of crop residues to the soil; it has been reported that climate impacts on croplands and grasslands soils will tend to decrease SOC stocks all over Europe (Smith et al., 2005).

According to our findings, SOC stocks decrease in the top soil layers when rainfall decreases, opposite to the increases in deeper layers. This means that with increasing depth, the relative importance of climatic factors decreases and texture and lithology can become more important in controlling SOC regardless of the land use, in accordance with previous studies in Mediterranean areas of Spain (Albaladejo et al., 2013; Oyonarte at al., 2008).

A range of model projections is considered in this study. We obtained different results of SOC 258 contents associated to different climate predictions which highlight the uncertainty in future climate 259 scenarios. In climate projections, uncertainties can be related to emissions, climatic drivers (e.g., 260 261 carbon cycle), climate sensitivity and adaptive capacity, among others (Van Vuuren et al., 2011). In areas of complex topography like the Mediterranean region, application of GCMs might result in 262 considerable biases in the prediction of precipitation and temperature (Giorgi and Lionello, 2008). 263 264 In particular precipitation involves local processes of larger complexity than temperature and projections are usually less robust than those for temperature. 265

Due to climate change, impacts will be much greater in surface SOC, and the strategies for C sequestration should be focused on subsoil sequestration. In these conditions, carbon sequestration in cropland and managed grassland through appropriate management practices is recommended.

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**4. Conclusions** 

The model CarboSOIL has proved its ability to predict SOC stocks at different soil depths, and can be used as a tool for predicting SOC changes under different climate change scenarios in Mediterranean areas which are more vulnerable to temperature increases and rainfall decreases, such as the main islands (e.g. Sardinia) and the Southern Regions of Italy.

Climate change can have a negative impact on SOC stocks in the soil section 25-50 cm, in particular in a long term perspective (2080) and under the marked emission scenario A2, according to our results. Additionally, important decreases of SOC stocks were found in the upper soil sections of the vineyards due to the higher losses in the 25-50 cm soil section.

The methods undertaken in this research may be easily implemented to other Mediterranean areas with accessible information on climate, site, soil and land use. Combining CarboSOIL with spatial databases would allow to evaluate regional SOC stocks and sequestration potential to support land management strategies and policies.

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#### 293 **References**

- Albaladejo, J., Ortiz, R., Garcia-Franco, N., Ruiz Navarro, A., Almagro, M., Garcia Pintado, J.,
   Martínez-Mena, M., 2013. Land use and climate change impacts on soil organic carbon stocks
   in semi-arid Spain. J. Soils Sediments 13, 265–277.
- Álvaro-Fuentes, J., Easter, M., Paustian, K., 2012. Climate change effects on organic carbon storage
   in agricultural soils of northeastern Spain. Agr. Ecosyst. Environ. 155, 87–94.
- Bagella, S., Salis, L., Marrosu, G.M., Rossetti, I., Fanni, S., Caria, M.C., Roggero, P.P., 2013a.
  Effects of long-term management practices on grassland plant assemblages in Mediterranean
  cork oak silvo-pastoral systems. Plant Ecol. 214, 621-631.

- Bagella, S., Satta, A., Floris, I., Caria, M.C., Rossetti, I., Podani, J., 2013b. Effects of plant
  community composition and flowering phenology on honeybee foraging in Mediterranean
  sylvo-pastoral systems. Applied Vegetation Science 16, 688–697.
- Bernardoni, E., Acutis, M., Ventrella, D., 2012. Long-term durum wheat monoculture: modelling
  and future projection. Italian Journal of Agronomy 7, e13, 86–92.
- Cerdà, A., Lavee, H., Romero-Díaz, A., Hooke, J., Montanarella, L., 2010. Preface. Land Degrad.
  Dev. 21, 71–74.
- Chiti, T., Díaz-Pinés, E., Rubio., A., 2012. Soil organic carbon stocks of conifers, broadleaf and
  evergreen broadleaf forests of Spain. Biol. Fertil. Soils 48(7), 817–826.
- Coleman, K., Jenkinson, D.S., 1996. RothC-26.3 A model for the turnover of carbon in soil. In:
  Powlson, D.S., Smith, P., Smith, J.U. (Eds), Evaluation of Soil Organic Matter Models Using
  Existing Long-Term Datasets. Springer-Verlag, Heidelberg, pp. 237-246.
- Conant, R.T., Paustian, K, Elliott, E.T., 2001. Grassland management and conversion into
  grassland: effects on soil carbon. Ecol. Appl. 11, 343–355.
- De la Rosa, D., Mayol, F., Moreno, F., Cabrera, F., Diaz-Pereira, E., Fernández, M., 2004. A Land
  Evaluation Decision support System (MicroLEIS DSS) for Agricultural Soil Protection.
  Environ. Modell. Softw. 19, 929–942.
- De Sanctis, G., Roggero, P.P., Seddaiu, G., Orsini, R., Porter, C.H., Jones, J.W., 2012. Long-term
  no tillage increased soil organic carbon content of rain-fed cereal systems in a Mediterranean
  area. Eur. J. Agron. 40, 18–27.
- Díaz-Hernández, J.L., 2010. Is soil carbon storage underestimated? Chemosphere 80, 346–349.
- Don, A., Scumacher, J., Scherer-Lorenzen, M., Scholter, T., Schulze, E., 2007. Spatial and vertical
   variation of soil carbon at two grassland sites implications for measuring soil carbon stocks.
   Geoderma 141 (3–4), 272–283.
- Farina, R., Seddaiu, G., Orsini, R., Steglich, E., Roggero, P.P., Francaviglia, R., 2011. Soil carbon
  dynamics and crop productivity as influenced by climate change in a rainfed cereal system
  under contrasting tillage using EPIC. Soil Till. Res. 112, 36-46.
- Francaviglia, R., Coleman, K., Whitmore, A.P., Doro, L., Urracci, G., Rubino, M., Ledda, L., 2012.
  Changes in soil organic carbon and climate change Application of the RothC model in
  agrosilvo-pastoral Mediterranean systems. Agr. Syst. 112, 48–54.
- Francaviglia, R., Benedetti, A., Doro, L., Madrau, S., Ledda, L., 2014. Influence of land use on soil
- quality and stratification ratios under agro-silvo-pastoral Mediterranean management systems.
- 335 Agric. Ecosyst. Environ. 183, 86–92.

- Giorgi, F, Lionello, P., 2008. Climate change projections for the Mediterranean region. Global
  Planet. Change 63, 90–104
- Grüneburg, E., Schöning, I., Kalko, E.K.V., Weisser, W.W., 2010. Regional organic carbon stock
  variability: a comparison between depth increments and soil horizons. Geoderma 155, 426–433.
- Hansen, J., Sato, M., Nazarenko, L., Ruedy, R., Lacis, A., Koch, D., Tegen, I., Hall, T., Shindell,
  D., Santer, B., Stone, P., Novakov, T., Thomason, L., Wang, R., Wang, Y., Jacob, D.,
  Hollandsworth, S., Bishop, L., Logan, J., Thompson, A., Stolarski, R., Lean, J., Willson, R.,
- Levitus, S., Antonov, J., Rayner, N., Parker, D., Christy, J., 2002. Climate forcings in Goddard
- Institute for Space Studies SI2000 simulations. J. Geophys. Res-Atmos. 107 DOI:
  10.1029/2001jd001143.
- Huber, S., Syed, B., Freudenschuß, A., Ernstsen, V., Loveland P., 2001. Proposal for a European
  soil monitoring and assessment framework. European Environment Agency, Technical report
  61, Copenhagen, 58 pp.
- IPCC, 2006. Agriculture, forestry and other land use. In: Guidelines for National Greenhouse Gas
  Inventories. Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S.,
  Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan.
- IPCC, 2007. Technical summary. In: Climate Change 2007. Contribution of Working Group III to
   the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Available
   from: http://www.ipcc.ch/.
- Jandl, R., Rodeghiero, M., Martinez, C., M., Cotrufo, F., Bampa, F., vanWesemael, B., Harrison,
  R.B., Guerrini, I.A., Richter, D., Rustad. L., Lorenz, K., Chabbi, A., Miglietta, F., 2014. Current
  status, uncertainty and future needs in soil organic carbon monitoring. Sci. Total Environ. 468–
  469, 376–383.
- Jarecki, M.K., Lal, R., 2005. Soil organic carbon sequestration rates in two long-term no-till
  experiments in Ohio. Soil Sci. 170 (4), 280–291.
- Jones, M.B., Donnelly, A., 2004. Carbon sequestration in temperate grassland ecosystems and the
   influence of management, climate and elevated CO<sub>2</sub>. New Phytol. 164, 423-439.
- 363 Kirchmann, H., Andersson, R., 2001. The Swedish system for quality assessment of agricultural
  364 soils. Environ. Monit. Assess. 72, 129–139.
- Lagomarsino, A., Benedetti, A., Marinari, S., Pompili, L., Moscatelli, M.C., Roggero, P.P., Lai, R.,
  Ledda, L., Grego, S., 2011. Soil organic C variability and microbial functions in a
  Mediterranean agro-forest ecosystem. Biol. Fertil. Soils 47, 283–291.
- Li, Y., Zhang, Q.W., Reicosky, D.C., Lindstrom, M.J., Bai, L.Y., Li, L., 2007. Changes in soil organic carbon induced by tillage and water erosion on a steep cultivated hillslope in the

- 370 Chinese Loess Plateau from 1898–1954 and 1954–1998. J. Geophys. Res. 112 (G1), G01021.
  371 doi:10.1029/2005JG000107.
- Lozano-García, B., Parras-Alcántara, L., 2013. Land use and management effects on carbon and
   nitrogen in Mediterranean Cambisols. Agric. Ecosyst. Environ. 179, 208–214.
- Lugato, E., Berti, A., 2008. Potential carbon sequestration in a cultivated soil under different
  climate change scenarios: A modelling approach for evaluating promising management
  practices in north-east Italy. Agr. Ecosyst. Environ. 128, 97-103.
- Malmoud, K., McBratney, A.B., Minasny, B., Field, D.J., 2009. Modelling how carbon affects soil
  structure. Geoderma 149, 19–26.
- Mondini, C., Coleman, K., Whitmore, A.P., 2012. Spatially explicit modelling of changes in soil
  organic C in agricultural soils in Italy, 2001–2100: Potential for compost amendment. Agr.
  Ecosyst. Environ. 153, 24-32.
- Muñoz-Rojas, M., Jordán, A., Zavala, L.M., González-Peñaloza, F.A., De la Rosa, D., Pino-Mejias,
   R., Anaya-Romero, M., 2013. Modelling soil organic carbon stocks in global change scenarios:
   a CarboSOIL application. Biogeosciences 10, 8253–8268.
- Oyonarte, C., Aranda, V. & Durante, P., 2008. Soil surface properties in Mediterranean mountain
  ecosystems: Effects of environmental factors and implications of management, Forest Ecology
  and Management, 254, 156-165.
- Parton, W.J., Schime, D.S., Ojima, D.S., Cole, C.V., 1994. A general model for soil organic matter
  dynamics: sensitivity to litter chemistry, texture and management, in: Bryant, R.B., Arnold,
  R.W. (Eds), Quantitative Modeling of Soil Forming Processes. SSSA Special Publication 39,
  Madison, WI, pp. 147-167.
- Pope, V.D., Gallani, M.L., Rowntree, P.R., Stratton, R.A., 2000. The impact of new physical
  parametrizations in the Hadley Centre climate model: HadAM3. Clim. Dynam. 16, 123-146.
- Rawls, W.J., 1983. Estimating soil bulk density from particle size analyses and organic matter
  content. Soil Sci. 135, 123–125.
- Saxton, K.E., W.J. Rawls, J.S. Romberger, and R.I. Papendick., 1986. Estimating generalized soilwater characteristics from texture. Soil Sci. Soc. Am. J. 50(4), 1031-1036.
- Smith, P., 2005. An overview of the permanence of soil organic carbon stocks: influence of direct
  human-induced, indirect and natural effects. Eur. J. Soil Sci. 56, 673–680.
- 400 Smith, J., Smith, P., Wattenbach, M., Zaehle, S., Hiederer, R., Jones, R. J. A., Montanarella, L.,
- 401 Rounsevell, M. D. A., Reginster, I., Ewert, F., 2005. Projected changes in mineral soil carbon of
- European croplands and grasslands, 1990–2080. Glob. Change Biol.11, 2141–2152.

- Smith, J., Smith, P., 2007 Introduction to Environmental Modelling. Oxford University Press, New
  York, 180 pp.
- Van Vuuren, D, Kok, M, Girod, B, Lucas, P., 2012. Scenarios in Global Environmental
  Assessments: Key characteristics and lessons for future use. Global Environ. Change 22(4),
  884–895.
- WRB, 2014. World Reference Base for Soil Resources. International soil classification system for
  naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. FAO,
  Rome, 181 pp.
- Wright, A.L., Dou, F., Hons, F.M., 2007. Crop species and tillage effects on carbon sequestration in
  subsurface soil. Soil Sci. 172 (2), 124–131.
- 413 Yang, X., Yan, D., Zeng, L., Wu, M., 2012. Correlation of Root Structures and Soil Properties in the
- 414 Near-Surface Soil of Three Forest Types in the Southern Mountains of Henan Province, China,
  415 J. Agr. Sci. Appl., 1, 79–85.
- Yoo, K., Amundsen, R., Heimsath, A.M., Dietrich, W.E., 2006. Spatial patterns of soil organic
  carbon on hillslopes: integrating geomorphic processes and the biological C cycle. Geoderma
  130, 47–65.
- Young, R., Wilson, B.R., McLeod, M., Alston, C., 2005. Carbon storage in the soils and vegetation
  of contrasting land uses in northern New South Wales, Australia. Aust. J. Soil Res. 43, 21–31.

- 1 Table 1
- 2 CarboSOIL input variables, units, sources and references

Variable type	Variable name	Code	Unit	Source and reference
Dependent	Soil Organic C	SOCC	Mg/ha	University of Sassari
variable				Francaviglia et al. (2012;2014)
Climate	Total precipitation	PRPT	mm	CRA elaborations from baseline
				data and GCMs
	Winter Temperature	TDJF	°C	
	Summer Temperature	TJJA	°C	
Site	Elevation	ELEV	m	University of Sassari
	Slope	SLOP	%	
	Drainage	DRAI	-	
	Soil Erosion	SERO	-	
Soil	Nitrogen	NITRO	%	Field surveys and lab analyses
				Francaviglia et al. (2012 ;2014)
	рН	PHWA	-	
	Cation Exchange	CEXC	$\operatorname{cmol}_{(+)} \operatorname{kg}^{-1}$	
	Capacity			
	Sand	SAND	%	
	Clay	CLAY	%	
	Bulk density	BULK	g cm <sup>-3</sup>	
	Field capacity	FCAP	%	
Land use	Land use/land cover	LULC	-	Field surveys

Land	Sand	Silt	Clay		CEC	FC	Total N	SOC
use	%			рп	cmol <sub>(+)</sub> kg <sup>-1</sup>	%		
TV	82.5±3.5	5.9±4.3	11.6±1.1	5.1±0.1	12.6±2.6	9.1±1.2	$0.09 \pm 0.01$	1.18±0.14
GV	79.6±0.3	8.9±1.4	11.5±1.4	6.2±0.4	15.7±1.4	9.9±1.3	$0.09 \pm 0.00$	$1.20\pm0.38$
HC	73.5±0.3	13.7±0.4	12.8±0.7	5.6±0.4	15.4±2.1	13.3±1.7	0.13±0.01	$2.00\pm0.57$
PA	73.1±1.2	13.4±0.6	13.5±0.8	$5.5 \pm 0.4$	17.2±3.7	13.0±0.9	$0.20\pm0.02$	$1.84 \pm 0.30$
СО	78.1±2.9	10.5±2.6	11.4±0.3	5.6±0.2	16.6±3.2	12.1±1.3	$0.17 \pm 0.02$	2.06±0.34
SN	79.9±3.1	10.9±3.6	9.2±2.3	6.0±0.3	17.8±6.2	10.2±1.2	0.10±0.03	1.63±0.29

6 Input parameters of soil section 0-25 (mean  $\pm$ SD).

Land	Sand	Silt	Clay		CEC	FC	Total N	SOC
use	%			рн	$cmol_{(+)}  kg^{\text{-}1}$	%		
TV	84.3±3.4	4.6±3.6	11.1±0.6	5.3±0.3	14.6±4.1	8.9±1.3	$0.07 \pm 0.04$	0.99±0.59
GV	84.1±4.7	7.3±1.8	8.6±2.9	$6.2 \pm 0.8$	15.4±2.7	$7.4 \pm 2.9$	$0.05 \pm 0.03$	0.66±0.62
HC	73.7±7.9	14.4±7.5	11.9±0.9	5.8±0.3	15.2±1.3	11.6±1.8	$0.09 \pm 0.02$	1.43±0.36
PA	76.1±2.7	11.2±1.7	12.7±2.4	5.6±0.4	13.2±1.9	10.1±1.2	0.08±0.03	0.88±0.39
CO*	-	-	-	-	-	-	-	-
SN	82.7±2.5	8.0±1.8	9.3±1.9	6.2±0.3	18.7±8.0	9.5±1.1	$0.07 \pm 0.02$	1.48±0.35

10 Input parameters of soil section 25-50 (mean  $\pm$ SD).

11 \* depth limited by rock

12

15 Input parameters of soil section 50-75 (mean  $\pm$ SD).

Land	Sand	Silt	Clay		CEC	FC	Total N	SOC
use	%			рн	$cmol_{(+)}  kg^{\text{-}1}$	%		
TV	86.1±1.5	3.7±2.6	10.2±1.5	5.6±0.6	17.6±5.4	7.8±2.3	$0.07 \pm 0.04$	$0.79 \pm 0.77$
GV	89.5±2.0	4.1±2.9	$6.4\pm0.9$	6.3±0.5	15.5±3.0	5.0±0.4	$0.05 \pm 0.03$	$0.62 \pm 0.58$
HC	78.3±7.3	11.2±7.4	10.5±1.1	6.2±0.2	14.2±2.6	8.6±2.6	$0.04 \pm 0.02$	0.62±0.13
PA	77.8±4.1	9.1±3.5	13.1±5.0	5.6±0.3	12.5±2.9	9.3±2.9	$0.04 \pm 0.01$	0.53±0.25
CO*	-	-	-	-	-	-	-	-
SN*	-	-	-	-	-	-	-	-

16 \* depth limited by rock

19	Changes in the me	ean annual	temperat	ture and rainfall compared	with the baseline	climate.
		Emission	Time	Temperature $(+^{\circ}C)$	Rainfall (-mm)	-

Emission	Time	Tempera	ature (+°C)	Rainfall (-mm)	
scenario	horizon	GISS	HadCM3	GISS	HadCM3
	2020	0.5	0.7	39.9	43.3
A2	2050	1.4	1.9	70.1	28.6
	2080	3.1	3.5	108.9	129.4
	2020	0.6	0.7	75.0	39.0
B2	2050	1.0	1.4	108.6	65.4
	2080	2.0	2.2	131.2	52.7

# 23 Climate inputs for the model.

Emission	Time	Winter t	Winter temperature (C°)		temperature °C)	Rainfall (mm)	
scenario	ΠΟΓΙΖΟΠ	GISS	HadCM3	GISS	HadCM3	GISS	HadCM3
	2020	8.5	8.6	23.3	23.6	623.6	620.2
A2	2050	9.1	9.7	24.6	25.3	593.4	634.9
	2080	10.2	10.9	26.7	27.3	554.6	534.1
	2020	8.7	8.6	23.4	23.8	588.5	624.5
B2	2050	8.5	9.3	24.2	24.6	554.9	598.1
	2080	9.6	9.8	25.3	25.7	532.3	610.8
Baselin	e climate		7.8	2	3.0	6	63.5

24

Fig. 1. Location of the study area (Sardinia, Italy).

Fig. 2. Regression between predicted and measured SOC stocks for soil section 0-25 cm.

Fig. 3. Regression between predicted and measured SOC stocks for soil section 25-50 cm.

Fig. 4. Regression between predicted and measured SOC stocks for soil section 50-75 cm.

**Fig. 5.** Soil organic C stocks changes in 2020 under emission scenarios A2 and B2 for each land use at different soil depths (0–25, 25–50, 50–75 cm).

**Fig. 6.** Soil organic C stocks changes in 2050 under emission scenarios A2 and B2 for each land use at different soil depths (0–25, 25–50, 50–75 cm).

**Fig 7.** Soil organic C stocks changes in 2080 under emission scenarios A2 and B2 for each land use at different soil depths (0–25, 25–50, 50–75 cm).

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