Soil organic carbon dynamics in typical durum wheat-based crop rotations of Southern Italy

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Abstract

Mediterranean agricultural areas are dominated by cropping systems based on winter cereals crops, summer irrigated crops, forage-based systems, and mixed succession with bare fallow. Soil organic carbon (SOC) is widely used to assess the environmental performance of these cropping systems, since it is strongly influenced by management practices and environmental conditions. This study evaluates the sustainability of representative intensive cropping systems of Southern Italy, in terms of SOC stock changes and CO_2 emissions in the long-term perspective, using a process-based model (RothC10N) combined with a GIS-based spatialization procedure. On the basis of SOC modelling, results showed that crop management practices currently adopted by farmers did not guarantee SOC sequestration in all the rotations (–4.29 Mg C ha^{-1}). The sustainability of cropping systems can be improved through management practices such as the retention of crop residues into the field and/or the rational use of irrigation for the summer crop (6.73 Mg C ha^{-1}). This finding could help policy makers to provide suggestions for a more effective local implementation of agro-environmental measures.

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Introduction

In the last decades, Mediterranean cropping systems have undergone strong variations due to the intensification of agricultural activities in the most productive plains (Serra *et al*., 2008), and the extensification of land uses in less fertile zones (Bindi and Olesen, 2011; Nainggolan *et al*., 2012). Frequently, these changes may cause a simplification of agricultural production systems with significant consequences on environmental impacts and agroecosystem services. It is well-established that in conventional agronomic schemes, unsuitable agricultural practices, such as deep tillage, reduction in crop rotation length, and the removal of crop residues may have negative implications on soil organic carbon (SOC) pool (Le Gal *et al*., 2010; Álvaro-Fuentes *et al*., 2011; Martiniello, 2011; Pisante, 2013). So far, semi-arid areas of Southern Italy are dominated by cropping systems mostly oriented on winter cereals-based rotations, such as continuous durum wheat (*Triticum durum* Desf.), durum wheat-summer irrigated crops, forage-based systems, and mixed succession with bare fallow (Borrelli *et al*., 2011; Martiniello, 2011). In these agroecosystems, SOC level is quite low due to soil degradation processes. Thus, conservative farmlands can act as potential C sink, although the possibilities of SOC sequestration are quite site specific and strongly influenced by soil management and environmental factors (VandenBygaart *et al*., 2002; Rodríguez Martín *et al*., 2016). SOC is normally considered an indicator of soil quality, and soil can accumulate C for decades (Ruiz Sinoga *et al*., 2012). It is widely known the crucial role of SOC to maintain soil fertility, crop production potential, and prevent soil quality deterioration thanks to its filtering and buffering capacity (Kirchmann and Andersson, 2001). However, the studies of SOC dynamics based on field experiments and local surveys are costly and time consuming. Alternatively, many process-oriented models are available for predicting SOC dynamics on a temporal and spatial basis, with the most frequently adopted being Century (Parton *et al*., 1987), RothC (Jenkinson and Rayner, 1977; Jenkinson, 1990) and its recent modified version RothC10N (Farina *et al*., 2013).

The study aimed to propose a methodology to predict temporal SOC stock changes between 1994 and 2013 in representative intensive cropping systems of Southern Italy, using a process-based modelling approach and a GIS-based spatialization procedure. The purposes of the paper deal with: i) evaluating temporal and spatial SOC stock variations affected by current crop management using RothC10N model; and ii) understanding the factors influencing SOC maintenance in order to propose alternative management practices to improve soil C sequestration and reduce CO_2 emissions to be implemented in the local agro-environmental policies.

Materials and methods

Study area

The study was conducted in the Manfredonia Municipality, located in the Southeast part of the *Capitanata plain*, Apulia Region, Southern Italy (Figure 1). The area, with an elevation between 0 and 604 m a.s.l., was selected as pilot study because of its importance in the Italian agriculture context, mostly for the production of winter durum wheat and tomato. The utilised agricultural area (UAA) covers 282.25 km^2, almost 80% of the total area after the 2010 agricultural census (ISTAT, 2010). Land use is based on intensive agriculture, characterised by the cultivation of rainfed winter cereals (mainly durum wheat; 54.78%), irrigated summer horticultural crops (mostly tomato; 13.25%), forage and pasture systems (17.11%), olive trees and vineyards (5.48%). Livestock farms in Manfredonia accounts for less than 1% of the total in Apulia Region, and are mostly based on cattle and buffaloes (44%) and sheep and goats (38%). Climate is classified as Cfa (warm temperate, fully humid, hot summer) according to the updated Köppen-Geiger climate classification (Kottek *et al*., 2006). Long-term annual average temperature is 15°C, while average annual rainfall ranged from 684 to 730 mm, mostly concentrated in the autumn-winter months. Typically, soils are deep with a clay (86%), silty-clay (13%) or clay-loam (1%) texture, and are classified (WRB, 2014) as *Vertisols* (42%), *Phaenozems* (25%), *Luvisols* (21%), *Arenosols* (4%), *Calcisols* (4%), *Kastenozems* (4%), and *Leptosols* (4%).

Overall methodology

In this study, we propose a methodology to predict SOC stock changes in arable cropping systems and pastures across the Manfredonia Municipality, using a process-based modelling approach and a GIS-based spatialization procedure as follows: i) harmonise and combine weather, soil, and crop succession data, in a unique spatially explicit dataset in a GIS environment; ii) run the SOC model in batch mode that routinely takes inputs from the unique spatially explicit database and writes outputs to the same database; iii) analyse the predicted variation in SOC stock considering the current (baseline) and three alternative management scenarios for the main cropping systems studied.

Data sources

Weather database: For the 1989-2013 time period, mean monthly rainfall, temperature, and evapotranspiration data were extracted for the closest grid (20×20 km) from the AGRI4CAST archive (http://mars.jrc.ec.europa.eu/mars/About-us/AGRI4CAST), and validated with locally observed data. Weather data were downscaled at field level following the geographically weighted regression method as described in Fotheringham *et al*. (2003) and then formatted to be stacked into the GIS.

Soil database: A georeferenced soil database covering the entire Manfredonia Municipality (354.54 km^2) was obtained as a subset of the georeferenced soil database of Foggia Province by clipping the Manfredonia boundaries. The whole database includes 280 soil profiles from the CREA-RPS repository, described by the main soil physical (texture, bulk density, hydrological constants) and chemical properties (pH, CEC, soil organic carbon and total nitrogen concentrations). All soil data were normalised over the 0-30-cm layer for the modelling. Empirical Bayesian Kriging of the soil profiles was used as spatialization procedure to predict the value of SOC, clay and silt parameters in not sampled points (Figure 2).

Crop succession database: A georeferenced crop succession database for the 1994-2013 period was obtained by the collation and harmonisation of the following data sources: i) *AGRIT database*: is part of the sample survey project performed by Italian Ministry of Agricultural, Food and Forestry Policies (MIPAAF) since 1988, based on a point frame sampling land parcel cover survey, over all the Italian territory. The database was used to define the georeferenced crop succession in Manfredonia for 1994-2013 period (234 annual records) (Figure 1); ii) *FADN-RICA database*: Italian Farm Accountancy Data Network - *Rete di Informazione Contabile Agricola* (FADN-RICA, http://rica/public/it/index.php) concerning yearly economic information of farms, reporting UAA, utilised irrigated area, crop rotations and crop yields. The database was used to estimate crop yields and C inputs to the soil based on farms crop yield data. Sixteen most representative farms of the Manfredonia agricultural systems were monitored from 2001 to 2012 period; iii) *Corine Land Cover (CLC) datasets*: The land use and land cover of Manfredonia was defined considering the following agricultural area categories: arable land (non-irrigated and permanently irrigated) and pastures (source: http://uls.eionet.europa.eu/ CLC2006/CLC_Legeng.pdf).

Spatial interpolation database

Harmonised spatially explicit weather and soil database were intersected with crop succession database using a spatial overlapping procedure in a GIS environment. After this procedure, a specific and geo-

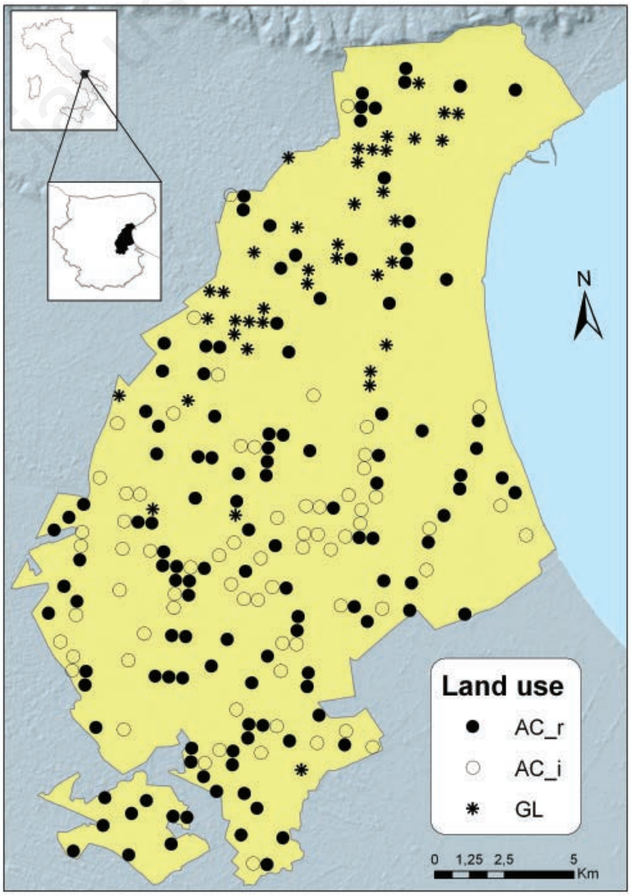

Figure 1. Study area (Manfredonia Municipality) located in Apulia Region, Southern Italy. The map of the study area shows the distribution of the 234 land use sites considered for the analysis. Black circles indicate rainfed arable crops succession (ACr); white circles represent irrigated arable crops succession (ACi), and black stars identify pasture systems (grassland; GL).

referenced value of weather and soil parameters was assigned to each crop succession record. This unique combined dataset was used to set-up all input files (*e.g.*, weather and land management) for running the model to an equilibrium state (initialisation), and in batch mode for the long-term SOC simulations (1994-2013) of all dataset crop succession records.

Crop management practices and estimation of carbon input to soil

As reported in previous studies carried out in the *Capitanata* plain, continuous rainfed winter cereals [mainly durum wheat (DW); *Triticum durum* Desf.] and durum wheat in rotation with irrigated summer crops [mainly processing tomato (T); *Solanum lycopersicum L.*] are the most common crop rotations. Cropping systems frequently include one year of fallow, and organic fertilisers are not applied to arable crops (Borrelli *et al*., 2011; Farina *et al*., 2013). Table 1 shows the main agronomic practices, currently used by farmers for durum wheat and tomato crops. Soil C input is mainly derived from crop materials. During bare fallow (BF), the soil cover biomass (composed by spontaneous species) is totally incorporated into the soil with tillage. Carbon inputs used for modelling were calculated from crop yield and from bibliographic sources as reported in Table 2. As detailed in Farina *et al*. (2013), plant C inputs were estimated as the sum of C inputs from crop residues (*Cr*), roots (*Crot*), root exudates (*Ce*), and weeds (*Cw*). In the study area, crop residues were commonly removed from the field. We estimated that C from *Cr* incorporated into the soil was 10-15% of the total aboveground biomass dry matter, and root C inputs as 10-15% of the harvested aboveground biomass according to Skjemstad *et al*. (2004). Rhizodeposits were calculated following Bolinder *et al*. (2007) procedure, and we assumed that root exudates were 9% of the total aboveground biomass dry matter as given by Kuzyakov and Domanski (2000). Carbon inputs from weeds were estimated to be 7-15% of total aboveground biomass dry matter. Biomass dry matter was converted to C assuming a carbon content of 45% (Johnson *et al*., 2006).

The C input values calculated for each crop were fitted with the average C input values estimated running the model in inverse at equilibrium for the 234 crop succession records considered. The model outputs also predict how much C should be returned to the soil to maintain the initial SOC stock.

Model description

In the present study, we used the RothC10N model, a modified version of the original RothC model (Coleman and Jenkinson, 1996; Jenkinson *et al*., 1999) by Farina *et al*. (2013), allowing to better simulating SOC dynamics under semi-arid and Mediterranean conditions (Figure 3). This is a process-based, multi-compartmental SOC turnover model, which simulates the effect of soil type, temperature, soil moisture content and plant cover on the turnover process. The model splits SOC inputs into one inert organic matter pool and four active compartments named: decomposable plant material (DPM), resistant plant material (RPM), microbial biomass (BIO) and humified organic matter (HUM). Each of the active pools decomposes by first order kinetics into CO_2, BIO and HUM. Decomposition of each pool is influenced by air temperature, soil moisture, and plant cover (Figure 3). The model uses a monthly time steps to calculate total SOC and its different pools on a years to centuries time scale. It requires few easily obtainable input parameters, and produces reliable and accurate simulations with a good general performance (Falloon and Smith, 2002; Guo *et al*., 2007; Ludwig *et al*., 2010; Francaviglia *et al*., 2012). At the end of the simulation, RothC10N predicts total SOC storage along with its different compartments and evolved CO_2. The data needed to run RothC10N were:

Climate data: Monthly rainfall (mm), monthly open pan evaporation (mm), average monthly mean air temperature (°C);

Soil data: Clay and silt content (%), initial SOC stock (Mg C ha^{-1}), bulk density (Mg cm^{-3}), depth of the soil layer considered (cm), field capacity (mm), wilting point (mm), hygroscopic water content (mm);

Land use and land management data: Soil cover, monthly input of plant residues (Mg C ha^{-1}), monthly input of farmyard manure or any other organic fertiliser (Mg C ha^{-1}), residue quality factor (DPM/RPM

Table 1. Current crop management of winter durum wheat and tomato.

	Wheat	Tomato
Tillage	Plowing	Plowing
Sowing/transplanting Mineral N fertilisation	2nd half of November	End of April
Pre-sowing/pre-transplanting*	60 kg ha^{-1}	100 kg ha^{-1}
Top-dressed°	60 kg ha^{-1}	100 kg ha^{-1}
Irrigation#	Rainfed	Automatic
Harvest	At maturity	At maturity
Crop residue§	Removed	Removed

*As diammonium phosphate; °as ammonium nitrate; #drip irrigation with water amount refilling 100% of soil water deficit; §in the current management crop residues were removed up to 85%.

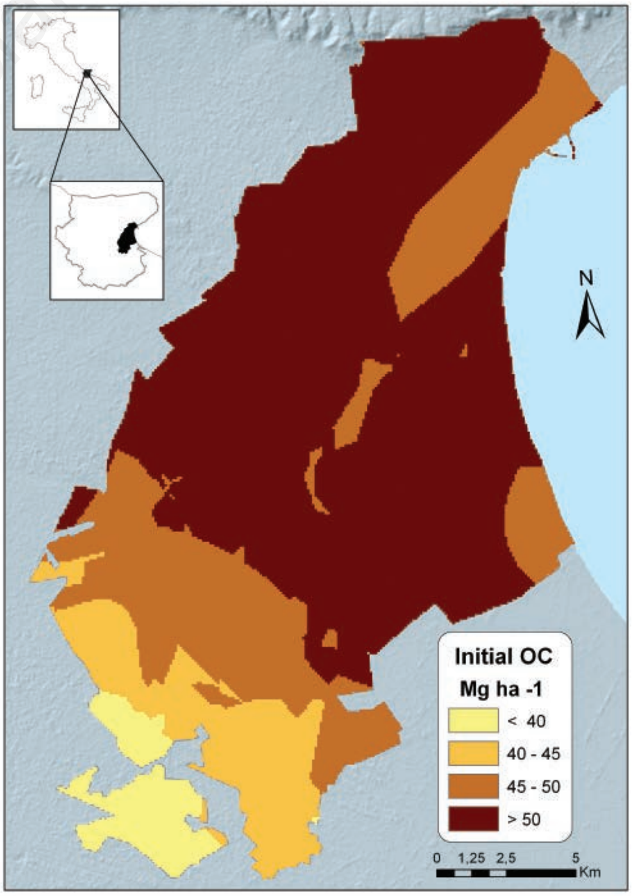

Figure 2. Map of initial soil organic carbon content of Manfredonia Municipality.

ratio, an estimate of residue decomposability according to the vegetation type). We set DPM/RPM ratio to 1.44 for all crops considered. Irrigation management is not a module of RothC model, thus, in irrigated systems, weather file must be modified by adding the irrigation water used for crops to the monthly rainfall amount (rainfall + irrigation) occurred during irrigated crop periods. Irrigation amount added to monthly rainfall was assumed equal to the soil water deficit (pan evaporation-rainfall).

Management scenarios

In the present study, SOC stock changes were predicted by RothC10N model for the 1994-2013 period, considering the commonly agronomic practices adopted by farmers. The current crop management was taken as the baseline (S_0) and three alternative scenarios where identified in order to increase C sequestration in soil. S_0 for arable crop (AC) land use category was run considering 15% of arable crop residues left in the field and irrigation refilling to 100% of soil water deficit. Alternative

Table 2. Formulas and values used to calculate plant C input (Mg ha^{-1}).

	Wheat	Tomato	Pasture	Fallow
Plant variables				
Yield (Y)	3.53	84.46	-	-
Dry total above-ground biomass	9.23	11.70	6.70	0.50
*Source of C**				
C from residues (Cr)=0.1×(Y/HI) ×0.45	0.38	0.22	0.30	0.23
C in roots (*Crot*)=(Y/(HI x S:R) ×0.45	1.25	1.58	0.90	0.07
C in root exudates (*Ce*)=0.09×(Y/HI)×0.45	0.38	0.47	0.27	0.02
C weeds (*Cw*)=0.07×(Y/HI) ×0.45	0.29	0.79	0.16	0.01
Total C input (*Ct*)°				
15% crop residue incorporation	2.29	3.06	1.64	0.33
100% crop residue incorporation	4.47	4.30	1.64	0.33

Y, yield (Mg ha^{-1} of dry matter); HI, harvest index; S:R, shoot to root ratio; C, content of plant material set to 0.45. *Formulas adapted from Skjemstad *et al.* (2004), Kong *et al.* (2005), Kuzyakov and Domanski (2000); °*Ct* is the sum of *Cr*, *Crot*, *Ce* and *Cw*. In the current management arable crop residues were removed up to 85%. In alternative S_1 and S_3 scenarios we proposed an incorporation of 100% of crop residues.

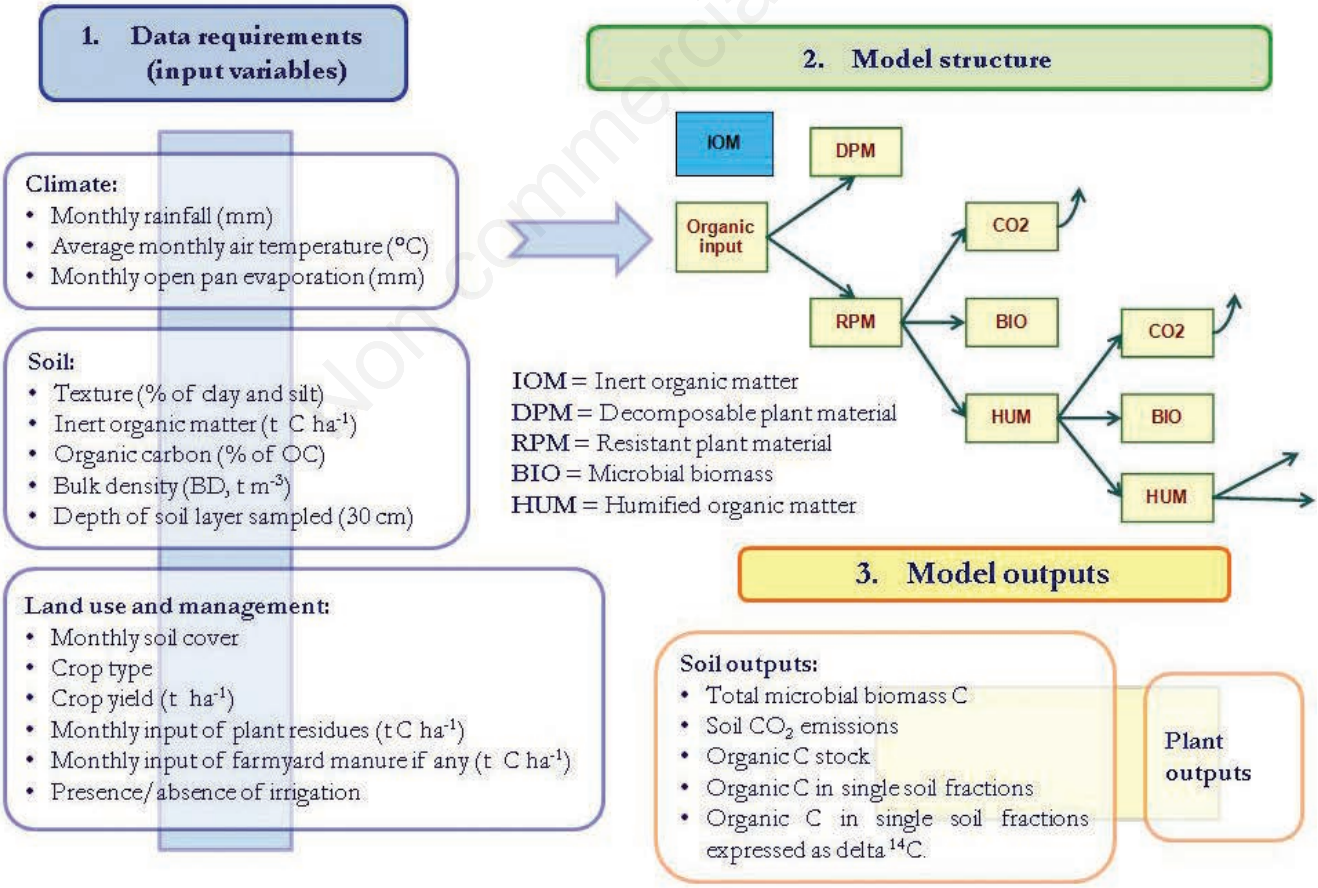

Figure 3. Overview of RothC10N model.

management options could either act to decrease C losses or to increase C inputs. The first scenario (S$_1$) was run considering management practices directly linked to the increase in C input in AC land use category by the incorporation of crop residues, and the improvement of semi-natural pasture in pasture (GL) land use category by overseeding leguminous as mixture and by a proper phosphorus fertilisation. The other two scenarios (S$_2$ and S$_3$) focused on irrigated crop sequences (ACi) and were run taking into account the management of crop residue and a more efficient and sustainable use of water in irrigation. Scenarios are defined as follows: i) S$_1$: In arable crops, 100% of residues are incorporated to soil and irrigation as in S$_0$; pastures are improved to increase plant cover and productivity; ii) S$_2$: Leave 15% of arable crop residues in the field and reduce summer crop irrigation volume to 50% of the soil water deficit, for irrigated-based cropping systems; iii) S$_3$: Leave 100% of arable crop residues in the field and reduce summer crop irrigation volume to 50% of the soil water deficit, for irrigated-based cropping systems.

These alternative practices could represent possible options for farmers for a more sustainable crop management, reducing the soil organic carbon loss.

Results and discussion

Description of the local cropping systems

According to the CORINE land cover classification, the 234 georeferenced 20-year crop successions were aggregated into two macro classes: AC and GL. AC rotation includes rainfed and irrigated cropping systems, mostly dominated by the rotation with DW. Based on AGRIT 1994-2013 database, in 41% of crop succession units, DW was cultivated in continuous, while in 43% was cultivated in rotation with BF (13%), or with processing T (18%) or with both BF and T (12%). GL covers 17% of total crop succession units and includes semi-natural pastures mostly based on spontaneous herbaceous vegetation and meadows. More details on crop sequences are reported in Table 3.

One of the main strength of this study is the use of the annual crop succession georeferenced database as model input. This permits to obtain good predictions of SOC dynamics for the different cropping systems, and to evaluate which crop rotations could favour C sequestration.

Initial soil organic carbon stock and stock variations, and CO$_2$ emissions (1994-2013)

Initial SOC stock associated to each crop succession unit was obtained by overlaying the crop succession database to the spatialized soil database. The majority of crop succession units were in Vertisols and Luvisols (90%) with a prevalent clay soil texture (85%). The estimated value of initial SOC stock was on average 45.97 Mg C ha^{-1}, ranging between 44.79 and 49.54 Mg C ha^{-1} in continuous DW and GL, respectively. Table 3 reports details on initial SOC stock for the land use categories studied. Final SOC stock in each crop succession units was predicted by RothC10N for the baseline (S$_0$) and the three alternative management scenarios (S$_1$, S$_2$, S$_3$) after 20 years of simulations. The model has been tested for the first time by Farina *et al.* in 2013 in similar cropping sequences and pedo-climatic conditions, using data from a long-term field experiment carried out at CREA-CER farm in Foggia Province. The authors reported that the difference between measured and modelled SOC was 0.11 Mg ha^{-1} yr^{-1} with a root mean standard error value of 3.4%. These results confirm that RothC10N model provided fair SOC stock simulations in these environments, especially for rotations that included BF. Irrespective of soil type, the values ranged from 40.25 Mg C ha^{-1} (in ACi land use category with BF in rotation) to 45.13 Mg C ha^{-1} (under continuous DW) in scenario S$_0$, and from 47.01 Mg C ha^{-1} (under ACi with BF) to 56.83 Mg C ha^{-1} (in continuous DW) in scenario S$_1$. S$_2$ and S$_3$ scenarios considered changes in management only for ACi land use category, namely a reduction in irrigation amount and an increase of C inputs coupled with irrigation reduction, respectively. On average, SOC stock increased by 4% in S$_2$ and 25% in S$_3$ with respect to the initial SOC stock. Maximum percentage of SOC increases with respect to S$_0$ was found for S$_1$ and S$_3$, with 20% and 40% respectively. Results allowed to derive the SOC sequestration rates of the four scenarios arising from the model predictions, and expressed in Mg C ha^{-1} yr^{-1}. Over the 20-yrs period, S$_0$ showed a negative SOC sequestration in all the rotations including bare fallow and/or tomato (–0.21 Mg C ha^{-1} yr^{-1}) and a positive value with continuous DW (0.02 Mg C ha^{-1} yr^{-1}) that can be considered in a steady-state condition. The highest loss of SOC was observed in GL and ACi land use categories with a mean decrease of 12% (Table 3). Final SOC predicted for the baseline in the GL land category suggests that poor management practices are important human-controlled factors that strongly influence pasture production and cause the depletion of soil carbon stocks (Ojima *et al*., 1993; Conant and Paustian, 2002). Our negative findings obtained for GL land category in the baseline are in contrast with the values reported in other Mediterranean systems (Francaviglia *et al*., 2014). However, improving grassland management can potentially reverse historical soil carbon losses and sequester substantial amounts of carbon in soils. Increasing production, maximize vegetative cover, carbon inputs or below-ground allocation, could increase SOC stocks (Conant *et al*., 2001; Follett *et al*., 2001). Moreover, final SOC predicted for the baseline management in the ACi land use category, showed that rotations including irrigated summer crops favour the degradation of soil C due to the combination of water availability and high temperatures. In

Table 3. Cropping systems, initial and final soil organic carbon stock (Mg ha^{-1}) predicted by RothC10N model under different scenarios, in the 234-georeferred crop succession units located in Manfredonia Municipality.

Land use categories	Numbers	Initial SOC	Final SOC (S$_0$)	Final SOC (S$_1$)	Final SOC (S$_2$)	Final SOC (S$_3$)
Arable crops						
Rainfed crop rotation						
DW in continuous	96	44.79±0.60*	45.13±0.44	56.83±0.44	-	-
3-yrs DW-BF	30	45.64±0.99	43.63±0.75	52.02±0.86	-	-
Irrigated crop rotation						
3-yrs DW-T	42	46.03±0.73	41.68±0.48	49.79±0.51	48.45±0.58	58.75±0.57
5-yrs DW-BF-T	27	45.26±0.77	40.25±0.56	47.01±0.61	46.73±0.55	55.57±0.56
Grassland						
Pasture	39	49.54±0.34	43.74±0.39	51.70±0.44	-	-

DW, durum wheat in continuous; BF, bare fallow; T, tomato. *Means±standard error.

Table 4. Cropping systems and 20-yrs cumulated CO_2 emissions (Mg CO_2 ha^{-1}) predicted by RothC10N model under different scenarios, in the 234 georeferenced crop succession units located in Manfredonia Municipality.

Land use categories	Numbers	S_0	S_1	S_2	S_3
Arable crops					
Rainfed crop rotation					
DW in continuous	96	174.60±0.60	306.07±0.62	-	-
DW-DW-BF	30	158.90±2.07	260.61±4.81	-	-
Irrigated crop rotation					
DW-DW-T	42	205.65±1.54	321.43±1.37	180.83±0.88	288.58±1.18
DW-DW-BF-DW-T	27	190.03±1.11	289.13±1.84	166.27±0.86	257.75±2.34
Grassland					
Pasture	39	123.09±4.86	155.46±11.52	-	-

the S_1, S_2 and S_3 alternative management scenarios, SOC sequestration rates were always positive, ranging from a maximum of 0.64 Mg C ha^{-1} yr^{-1} in S_3 for the 3-years durum wheat-tomato rotation, to a minimum of 0.07 Mg C ha^{-1} yr^{-1} in S_2 for the durum wheat in rotation with tomato and bare fallow. Predicted SOC in the different scenarios pointed out the patterns of potential SOC loss reduction due to the alternative crop management practices applied in all land use categories. In the present study, all alternative scenarios increased SOC stock compared to the baseline. As regards SOC stock predicted considering 100% of crop residue incorporation strategy for arable crops (S_1), our positive results are consistent with Bakht *et al*. (2009) study, reporting a mean annual increase in SOC value 1.04 times greater in the residues retained than removed treatment. Several study carried out worldwide confirm that leaving crop residues in the field after harvest is one way to stabilise soil fertility (Convertini *et al*., 1998; Franzluebbers, 2002; Lemke *et al*., 2010). However, the increase in SOC stock derived from this process is strongly affected by pedo-climactic features, type of crop residue, and agronomical practices adopted. As regards SOC stock in the improved pasture (S_1), our results are in good agreement with González and Candás (2004), and Francaviglia *et al*. (2014) reporting values of 54 Mg C ha^{-1}. The higher SOC stock predicted in S_1 for GL land use category with respect to the baseline (S_0) can be ascribed to the improvement of floristic composition, plant density obtained after overseeding pasture with leguminous mixture. In fact, sowing more productive species and/or supplying adequate nutrients, result in greater forage production (Nash *et al*., 2014) and carbon stocks (Conant *et al*., 2001).

Table 4 reports the twenty-years cumulated CO_2 emissions predicted by RothC10N model. CO_2 emissions were on average 171.45 Mg CO_2 ha^{-1} in the baseline. The highest emissions were predicted for ACi crop sequences (199.54 Mg CO_2 ha^{-1}) and the lowest for grasslands (123.09 Mg CO_2 ha^{-1}). The long-term predictions suggest that the most effective land use category considering both SOC sequestration and CO_2 emissions was ACi when incorporation of crop residues and a rational use of irrigation water were adopted. In details, S_2 and S_3 land management scenarios show that the tomato residues returning on the soil increased the biomass useful for humification processes. Also, these scenarios pointed out that in the semi-arid environments typical of southern Italy where evapotranspiration during summer is higher than rainfalls, the use of water resources for irrigation is a priority that should be managed considering a sustainable regulation of water deficit, which can contribute to save water with environmental and economic benefits (Zornoza *et al*., 2016), but without affecting crop productivity (Campi *et al*., 2014; Giuliani *et al*., 2016) so to maintain the profit for farmers. In fact, Leogrande *et al*. (2012) investigated the rational use of water resources and observed that the reduction of irrigation volume to 50% of crop water requirements did not significantly affect soil chemistry and tomato yield and quality in similar pedo-climatic conditions. Another important strategy to increase C inputs in intensive durum wheat-tomato rotation includes the use of cover crops during the winter season, after wheat and before tomato, that could be either used as green manure or flattened, with positive effect also on the weeds and in the build-up of C stocks (Canali *et al*., 2013).

Conclusions

The methodology proposed in this study to predict SOC stock changes has shown a good ability to characterise the existing cropping systems in the study area, and to understand the dynamics currently acting. RothC10N model is a suitable tool for assessing at regional level the sustainability of cropping systems in terms of SOC stock changes and CO_2 emissions in the long-term. Results showed that on the basis of SOC modelling, the sustainability of cropping systems could be improved through alternative management practices. In the most intensive cropping system, based on durum wheat-tomato crop rotation, the adoption of practices such as the retention of crop residues into the field and the rational use of irrigation can result in a substantial and positive change in SOC stock in comparison with the current management. Both practices are effective to improve SOC sequestration and maintain the profits for farmers. Results could also provide indications for policy makers to implement effective agro-environmental measures, and for valuing soil C sequestration in the carbon-credit market.

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