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Towards a Tier 3 approach to estimate SOC stocks at sub-regional scale in Southern Italy

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Abstract

A combined modeling - GIS platform was developed to estimate the long term soil organic carbon (SOC) stocks and CO_2 emissions with the IPCC Tier 3 approach, in relation to local soil properties and climate, land use (LU), and land use change (LUC). Arable rainfed (ACR) and irrigated crops (ACI), vines (VIN), olives (OLI), and grasslands (GL) were considered as LUs; the transition from arable to permanent crops (A2P) and from permanent to arable (P2A) as LUCs. Model simulations showed that OLI and VIN were able to store a considerable amount of C. Conversely, arable crops led to a reduction which was higher when the rotation included an irrigated summer crop. The transition A2P showed higher SOC stock increases compared to P2A. The CO_2-C released to the atmosphere was higher in ACI, P2A, and VIN, lower in OLI and GL. Main mitigation and adaptation strategies to prevent SOC decline in the study area are: conservation tillage, improvement of crop rotations with legume crops, retention of crop residues into the field, rational use of irrigation for the summer crop, use of cover crops during the winter season to replace fallow periods, and supply of organic fertilizers (compost or manure).

Keywords: CO_2 emissions, Land use; Land use change; Mediterranean systems, GIS, EBK spatialization; RothC10N model; Soil organic carbon.

Introduction, scope and main objectives

In Mediterranean cropping systems, agricultural practices were progressively intensified, with intense mechanization, high external inputs and monocropping with major environmental impacts and agro-ecosystem services reduction. To date, semi-arid areas of Southern Italy are dominated by arable rainfed cropping systems (winter cereals-based rotations, ACR), irrigated crops (winter cereals in rotation with irrigated tomato, ACI), forage-based systems (GL), woody crops (such as vines, VIN, and olives, OLI) (Di Bene et al. 2016). In agricultural soils intensive management practices, like deep ploughing, land use changes from both pasture to rotation or pasture to crop, crop residue removal, and erosion, causes SOC depletion. Thus, prediction of soil organic carbon (SOC) stocks has become a key issue over recent years, because of the potential contribution to climate change of soil carbon dioxide (CO_2) emissions. Soils, if well managed, represent a possible sink of C and a viable option to reduce the CO_2 concentration in atmosphere. Soil C stocks at regional or national level are influenced by many factors, such as climate, soil properties, land use (LU) and land use change (LUC) and agricultural management, that act and interact with complex relationship and exhibit a strong spatial variability. 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 (Farina et al., 2016). The Intergovernmental Panel on Climate Change (IPCC) in the Guidelines for National GHG (greenhouse gas emissions) inventories and reporting (IPCC, 2006), set up the methodologies for estimating soil C stock, considering three different levels of complexity or Tiers (1, 2, and 3). Tier 1 and 2 use the same methodological approach but with default or country-specific emission factors respectively. Tier 3 employs higher-order methods and resolutions, that include models and inventory measurement systems, repeated over-time, possibly disaggregated at the sub-national level (IPCC, 2006).

The study aimed to propose a methodology to predict the effect of LU and LUC in Southern Italy (province of Foggia) on the temporal and spatial variability of soil C and CO_2 emissions between 1994 and 2013, using

a process-based modelling approach and a GIS-based spatialization procedure. The main purposes was: i) evaluating temporal and spatial SOC stock variations affected by LU, LUC from permanent to arable crops (P2A) and vice versa (A2P), crop management, using RothC10N model (Farina et al., 2013), a RothC (Coleman et al., 1997) version modified to simulate SOC dynamics in Mediterranean regions; and ii) understanding the factors influencing SOC sequestration and CO_2 emissions to propose alternative effective management practices to be implemented in the agro-environmental policies.
The novelty of this study is represented by the interpolation at spatial scale of the RothC10N model predictions applied to annual crop rotations, using the Empirical Bayesian Kriging (EBK) procedure, that, to our knowledge, has not been used before for regional SOC stock assessments.

Methodology

To estimate the SOC stock and CO_2 emissions at regional level, a tool was developed to link the SOC dynamics simulation model with a soil, land use and climate spatially explicit database used with a GIS. The main steps were:

- Set-up of a harmonized spatially explicit database, obtained by assembling in a GIS environment soil, climate, and 20-yrs crop succession data.
- Run the RothC10N model to simulate 20-yrs SOC dynamics in batch mode that routinely takes inputs from the unique spatially explicit database and writes SOC and CO_2 outputs to the same database.
- Use of EBK to interpolate the RothC10N SOC stocks predicted variation and CO_2 emissions to estimate the potential to sequester C of the different land uses and soil types.

Results

EBK spatial interpolation of the SOC stock after 20-yrs (from RothC10N modeled crop successions) are presented in Fig. 1 and Table 1. The final EBK SOC stock was 19.0 Tg, 42.6 Mg C ha^{-1} (SD 5.9),. The SOC stock variation in 20 yrs was 0.3 Tg C. In detail, the arable crops stored 86.7% of the total SOC, of which 11.8 Tg in ACR and 5.6 by ACI. VIN and OLI stored 2.2 Tg C. Grassland and LUC stored 0.3 Tg C. The validation of modeled SOC with an independent set of data, showed a standardized error of -0.3 Mg C ha^{-1} and an standardized RMSE of 1.01 Mg C ha^{-1} .
CO_2 cumulated emissions in 20 years, were 16.95Tg CO_2-C and followed the ranking: ACR>ACI> VIN> OLI> GL > A2P> P2A> (Table 1).

Table 1. Empirical Bayesian Kriging (EBK) final spatialization of SOC stock and CO_2 emissions (2013) in the agricultural land use categories, in Foggia Province (Apulia Region, Italy).

	EBK spatialization						
Land use	Surface* (ha)	Mean SOC stock (Mg ha^{-1})	SD	Mean CO_2-C emissions (Mg ha^{-1})	SD	Amount of SOC (Tg)	Cumulated CO_2-C emissions (Tg)
Arable crops							
Rainfed rotations	261000	45.38	6.41	38.91	3.40	11.85	10.16
Irrigated rotations	105245	43.86	4.95	41.62	2.42	4.62	4.38
Woody crops							
Vines	31408	39.33	5.70	40.11	3.16	1.24	1.26
Olives	23365	42.27	7.51	38.25	3.14	0.99	0.89
Grasslands							
Pastures	6342	44.95	5.76	38.45	3.14	0.29	0.24
Land use change							
A2P	200	42.55	5.70	39.64	2.82	0.01	0.01
P2A	105	39.50	5.50	40.81	2.80	0.004	0.004
Total	427665	42.55	5.93	39.69	2.98	18.98	16.95

*Source: CORINE land cover 2012 map

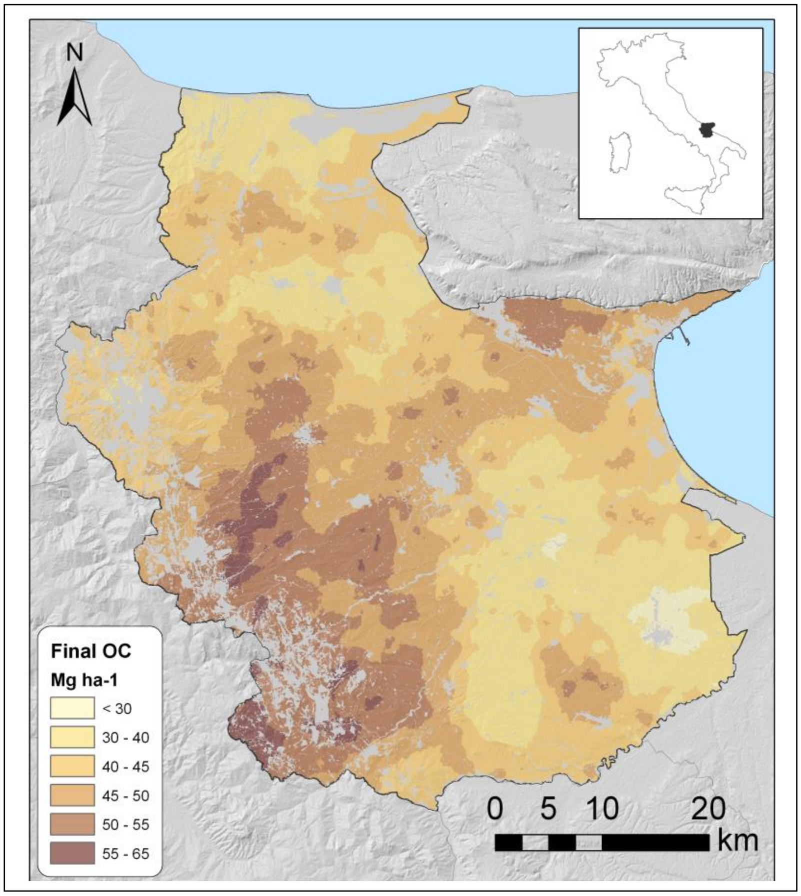

Fig. 1: Final regional SOC stock (Mg C ha^{-1}) obtained spatializing the RothC10N output by the EBK procedure in Foggia Province in 2013.

Discussion

Many authors agree on the importance of land use on soil C stocks level. The use of a detailed annual land-use history information allowed accurate simulations of SOC dynamics at regional scale. This approach provided information not only regarding the best land use in terms of C sequestration and CO_2 emissions and to predict the loss of C due to land use change, but also to evaluate which crop rotations, within the arable crops, could favor the C sequestration and reduce the soil CO_2 emissions. The different soil types showed a different value of C stock and a range of capacity in accumulating C in the period considered. The data obtained by overlaying the final EBK-SOC and CO_2-C maps with Corine Land Cover (CLC), allowed to predict the soil C stock and emissions for each land use category . All these information represent a valuable tool for the Kyoto Protocol accounting of soil C activities in cropland and grassland and as indicator for the effectiveness of the CAP (Common Agricultural Policies of European Union) measures to drive regional agricultural policies.

The long-term soil C assessment by modeling evidenced the following aspects: the soils C level in rainfed arable crops in the Foggia province, with the current practices, are almost at a steady state. The adoption of affordable practices like no-tillage (NT) or minimum tillage (MT), and the improvement of crop rotations with legume crops could increase the C sequestration. More complex is the management of rotations including summer crops, that are normally irrigated, and in this study showed important losses. As alternative management options MT and NT and reduction of irrigation volumes are feasible options.

Despite the inherent limitations, due to the algorithms used to simulate the C dynamics, RothC10N have proved to produce robust estimations. Uncertainties can be linked to data input quality, but the model validation with an independent set of data demonstrated that estimations were accurate and that the model was able to reproduce in average the dynamics of C in the study area.

Conclusions

This study is one of the first attempts to predict SOC stocks and changes at a regional scale in Italy, by using a Tier 3 approach, linking a biophysical model with an EBK spatial interpolation in a GIS environment. The methodology can be applied to other regional estimations, provided that the relevant data are available. The other peculiarity of our study is that the point data database included actual cropping sequences, and hence reproduced with a high degree of accuracy the farm management. The RothC10N model showed to predict accurately the C dynamics during the twenty years simulations, as confirmed by the comparison with a set of independent data used for validation. The spatial predictions allowed to identify the land use potential to sequester SOC, and to diversify this potential on the basis of the soil type and crops sequence. Such information represent an useful tool for policy makers to assess the past agricultural policies effects on SOC trends and to provide effective agro-environmental measures for implementing soil C sequestration in the carbon-credit market. The accuracy of the predictions could be improved through a more detailed dataset regarding farms management and yields obtained by local survey or remote sensing. Finally RothC10N model could be improved to take into account the effect of conservation tillage, that is a suggested practice to reduce SOC losses and CO_2 emissions in the Mediterranean systems. The proposed methodology can be applied if similar types of data can be retrieved either in all Italy or in other countries.

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