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Climate change impacts on soil organic carbon stocks of Mediterranean agricultural areas: A case study in Northern Egypt

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ABSTRACT

Mediterranean agricultural areas are characterised by low soil organic C (SOC) contents and as a consequence they are often degraded and highly vulnerable to environmental changes. Climate change is expected to have a large impact upon these areas but they may be key for mitigation of its effects given their potential for soil C sequestration. Several approaches have been proposed to evaluate climate change impacts on SOC stocks, being soil C models amongst the most effective tools to assess C stocks, dynamics and distribution and to predict trends under climate change scenarios. In this study, we applied the CarboSOIL model and global climate models to predict and analyse the effects of short- (2030), medium- (2050) and long-term (2100) climate changes on SOC contents at standard soil depths (0–25, 25–50 and 50–75 cm) in a Mediterranean arid area (El Fayoum, Northern Egypt) for different land use types. The validation of CarboSOIL with field data proved the consistency of the model. Overall decreases of SOC contents in the topsoil soil layer and increases in the subsoil layers are expected in the short, medium and long term. However, intensity of these changes will depend on the land use type and our results suggest that agricultural land uses relying on irrigation will be particularly vulnerable to losses of SOC stocks. This study demonstrates the importance of assessing SOC contents and dynamics along the soil profile and the potential for soil C sequestration particularly in the subsoil. The methods used in this research can be applied in other Mediterranean areas with available information on soil, land use and climate.

1. Introduction

Despite the on-going debate on climate change as a result of increased emission of greenhouse gases (GHG) into the atmosphere, there is scientific evidence that global climate is changing and that human activity contribution is significant (Princiotta and Loughlin, 2014; Smith et al., 2016). Carbon dioxide (CO_2) is the single most important GHG derived from human activity and responsible for 74% of global warming over the past decade (Canadell and Schulze, 2014). Soil organic C (SOC) plays a key role in the C cycle since it represents twice the amount of atmospheric C and 70–75% of the Earth's terrestrial pool (Lal, 2014; Brevik et al., 2015). Even minor changes in the SOC pool can have a critical effect in the global C cycle, influencing the atmospheric concentration of GHG in the atmosphere and therefore the global climate change (Smith, 2004a). At the same time, soils can act as sinks for atmospheric CO_2 by sequestration of organic C (Von Lützow and Kögel-Knabner, 2009) and are able to store C for long periods of time (Brevik and Homburg, 2004). It has been reported that 89% of mitigation potential by agricultural management depends on SOC sequestration (Smith et al., 2008). However, large uncertainty remains concerning the scope of these feedbacks and considerable differences exist among prediction models (Friedlingstein et al., 2006). A more accurate quantification of the response of terrestrial

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C, with a large proportion deriving from the soil C pool, is therefore crucial for understanding the Earth's response to global warming and climate change (Lal, 2014; Muñoz-Rojas et al., 2013).

In the last years, there has been a significant increase in the number of studies on SOC sequestration conducted in Mediterranean regions (Lugato et al., 2014a,b). Climate in these regions is characterised by seasonal dryness, and many subareas are classified as arid or semi-arid (Muñoz-Rojas et al., 2012; Albadalejo et al., 2013). In Mediterranean agricultural systems, levels of productivity are typically low and there is a largely dependency on irrigation (Aguilera et al., 2013a; Ouda et al., 2016). As a consequence of their low SOC contents, these areas are often degraded and vulnerable to environmental changes, and climate change is predicted to have a large impact upon them (Metz et al., 2007). Most of the prediction models suggest higher temperatures and decreases in rainfall in Mediterranean areas compared to other systems, which could promote higher decomposition rates of SOC (Davidson and Janssens, 2006). However, recent research underpins the key role of Mediterranean areas in mitigation of climate change given their potential for SOC sequestration by adopting adequate management practices (Smith, 2004b; Aguilera et al., 2013a). Besides its role in the C cycle, the presence of organic C in the soil is crucial to the quality and functionality of the soil ecosystem, improving physical, chemical and biological quality of the soil (Brevik et al., 2015; De Graaff et al., 2015; Keesstra et al., 2016; Smith et al., 2016). Thus, increasing SOC contents in these environments with appropriate land management techniques or land use changes could be also beneficial for soil erosion control, soil fertility and, ultimately, food production (Aguilera et al., 2013a; Hontoria et al., 2004; Lal, 2014). Biogeochemical cycles of N, P, S and other plant nutrients are driven by SOC dynamics (Alexander et al., 2015), and benefits can be obtained even after relatively short periods of time (Wasak and Drewnik, 2015).

Several approaches have been applied to evaluate climate change impacts on SOC stocks being soil carbon models amongst the most effective tools to assess SOC stocks, dynamics and distribution and to predict trends under climate change scenarios (Falloon and Smith, 2003; O'Leary et al., 2016). However, the absence of adequate models that are validated and calibrated with field data and monitoring challenges the development of appropriate integrated practices in response to climate change impacts (Stringer et al., 2012). Moreover, to predict future changes in SOC stocks, Global Climate Models (GCMs) are indispensable to simulate global climate since they provide simulations of atmospheric general circulation and project climate variables such as temperature and precipitation in future climate scenarios (Mitchell et al., 2004). These GCMs use available information on future GHG emissions generated by socioeconomic scenarios (Metz et al., 2007).

A number of soil carbon models have been used in the Mediterranean region in the last years, including CENTURY (Parton et al., 1987) or RothC (Coleman and Jenkinson, 1996). These models have been applied in different areas to assess the effects of management practices on SOC stocks (Álvaro-Fuentes et al., 2007) and also the impacts of climate change (Álvaro-Fuentes et al., 2012; Francaviglia et al., 2012; Mondini et al., 2012). But, despite the critical influence of soil depth on SOC stocks (Jobbágy and Jackson, 2000; Willaarts et al., 2016) most of the available research on soil carbon modelling focus on the upper soil layer (topsoil), and only few studies include deeper sections of soil in their analyses (Muñoz-Rojas et al., 2012, 2015a,b; Parras-Alcántara et al., 2015). Large amounts of SOC may be stored in subsoil layers, particularly in temperate grasslands where it has been estimated that 59% of the SOC stocks accumulates between 20 and 100 cm depth (Jobbágy and Jackson, 2000; Parras-Alcántara et al., 2015). Therefore, even minor alterations in these subsoil SOC stocks could have extensive impact on the balance of the entire SOC pool (Muñoz-Rojas et al., 2013). Moreover, several models assume that mechanisms and processes controlling SOC dynamics are similar in both topsoil and subsoil, but recent research has shown that driving factors of SOC differed across the vertical section of the soil profile (Muñoz-Rojas et al., 2013; Parras-Alcántara et al., 2015; Willaarts et al., 2016).

There is a strong relation between environmental conditions and C accumulation in the soil (Muñoz-Rojas et al., 2012; Ruiz Sinoga et al., 2012) although there are significant gaps in the knowledge of the effects that climate change will cause at different soil depths (Jobbágy and Jackson, 2000; Muñoz-Rojas et al., 2015a). Our main objective was to apply the CarboSOIL model (Muñoz-Rojas et al., 2013) and GCMs to predict and analyse the effects of short (2030), medium (2050) and long term (2100) climate changes on SOC contents at standard soil depths of 0–25, 25–50 and 50–75 cm in a Mediterranean arid area (El Fayoum, Northern Egypt) for different land use types. With that aim, the CarboSOIL

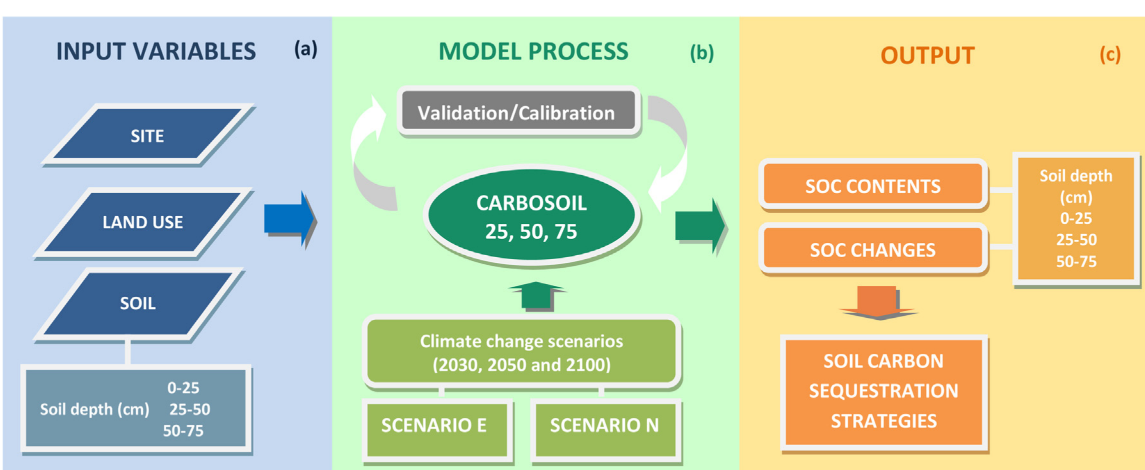

Fig. 1. Overall approach of the study describing: (a) input variables to the model, (b) validation and implementation of CarboSOIL model at 0–25 cm (CarboSOIL 25), 25–50 cm (CarboSOIL 50) and 50–75 cm (CarboSOIL 75) soil depth; climate scenarios implementation (Scenario E consider a progressive decrease in water inputs based on the GCM estimates of temperature and precipitation changes for Egypt; Scenario N consider a little increase in the source waters from the Nile river); (c) output of CarboSOIL model: SOC contents and changes.