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Can conservation tillage mitigate climate change impacts in Mediterranean cereal systems? A soil organic carbon assessment using long term experiments

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ABSTRACT

Simulation models, informed and validated with datasets from long term experiments (LTEs), are considered useful tools to explore the effects of different management strategies on soil organic carbon (SOC) dynamics and evaluate suitable mitigative options for climate change. But, while there are several studies which assessed a better prediction of crop yields using an ensemble of models, no studies are currently available on the evaluation of a model ensemble on SOC stocks. In this study we assessed the advantages of using an ensemble of crop models (APSIM-NWheat, DSSAT, EPIC, SALUS), calibrated and validated with datasets from LTEs, to estimate SOC dynamics. Then we used the mean of the model ensemble to assess the impacts of climate change on SOC stocks under conventional (CT) and conservation tillage practices (NT: No Till; RT: Reduced Tillage). The assessment was completed for two long-term experiment sites (Agugliano – AN and Pisa – PI2 sites) in Italy under rainfed conditions. A durum wheat (*Triticum turgidum* subsp. *durum* (Desf.) Husn.) – maize (*Zea mays* L.) rotation system was evaluated under two different climate scenarios over the periods 1971–2000 (CP: Present Climate) and 2021–2050 (CF: Future Climate), generated by setting up a statistical model based on canonical correlation analysis. Our study showed a decrease of SOC stocks in both sites and tillage systems over CF when compared with CP. At the AN site, CT lost −7.3% and NT −7.9% of SOC stock (0–40 cm) under CF. At the PI2 site, CT lost −4.4% and RT −5.3% of SOC stocks (0–40 cm). Even if conservation tillage systems were more impacted under future scenarios, they were still able to store more SOC than CT, so that these practices can be considered viable options to mitigate climate change. Furthermore, at the AN site, under CF, NT demonstrated an annual increase

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of 0.4%, the target value suggested by the 4 per thousand initiative launched at the 21st meeting of the Conference of the Parties in Paris. However, RT at the PI2 needs to be coupled with other management strategies, as the introduction of cover crops, to achieve such target.

1. Introduction

Soil organic carbon (SOC) is important to crop production because it mediates nutrient cycling, and affects soil fertility (Bolinder et al., 2010; Lal and Follett, 2009), and soil water-holding capacity (Huntington, 2007). Sequestration of carbon in soil by increasing SOC is also considered one way to mitigate climate change as SOC represents the main C sink in terrestrial ecosystems (Wang et al., 2015). Different tillage practices affect both sequestration capacity and the distribution of organic C in soil and can contribute to mitigative adaptation strategies to climate change in a variety of ways (Marraccini et al., 2012). In general, benefits associated with tillage include topsoil aeration, ease of seed emergence, effective weed control and incorporation of crop residue into the soil. However, conventional tillage (CT), characterized by traditional moldboard ploughing, can stimulate rapid mineralization of SOC, increase soil erosion, create a plough pan and increase the use of energy for mechanical operations (Bertolino et al., 2010; Rusu, 2014).

Less intensive tillage management, also referred to as conservation agriculture (i.e., Reduced tillage – RT and no till – NT), has been adopted to reduce these negative impacts although sometimes lower yields have been associated to these practices (Van den Putte et al., 2010). There is still uncertainty of the merit of conservation tillage to contribute to increasing the resilience of cropping systems to climate change (Powlson et al., 2016) and to increasing SOC compared with CT practices (González-Sánchez et al., 2012; Haddaway et al., 2016). In fact, SOC significantly increases in the layers closest to the soil surface under conservation tillage but does not always increase in the deeper soil profile where, conversely, SOC content tends to increase under conventional tillage, particularly near or at the bottom of the plowed layer (Alvarez, 2005; Angers and Eriksen-Hamel, 2008; De Sanctis et al., 2012). These results highlight the importance of evaluating the entire soil profile or, at least, the depth of the plowed layer to compare the effect of contrasting tillage practices on SOC stocks.

However, because changes in SOC can occur very slowly (Smith et al., 1997), the relationship between tillage practices and SOC sequestration should be evaluated over a sufficiently long period of time. Long-term experimental sites (LTEs) at research facilities thus represent the ideal setting to assess processes and factors that may affect SOC content over a long period of time because there are long-term datasets associated with these sites (Körschens, 1996; Ruisi et al., 2014). In fact, while short-term experiments can support research that focuses on the initial stages of a process, LTEs permit evaluation of the magnitude of change over a longer period of time and allows understanding the cause of these changes at the same time (Knapp et al., 2012). For this reason, data coming from LTEs play a key role in informing and validating crop simulation models. Furthermore, as LTEs permit understanding the relationship of short- and long-term processes, they are crucial to improving the ability of current crop simulation models to simulate future scenarios. Powerful tools can be developed from this process that permit researchers and policymakers to explore management strategies that increase SOC and define suitable adaptation and mitigation options to reduce the impact of climate change on cropping systems (Ewert et al., 2011; White et al., 2011). Models were successfully used to simulate contrasting tillage management in agroecosystems under current (Chang et al., 2013; De Sanctis et al., 2012; Franko and Spiegel, 2016; Leite et al., 2009; Tan et al., 2007) and future climates (Bhattarai et al., 2017; Farina et al., 2011).

Given the growing interest in assessing uncertainty, in particular under future scenarios (Wallach et al., 2016), both the climate and crop modeling communities have proposed the use of an ensemble of models to obtain a probability distribution of projections (Harris et al., 2010) rather than a single model. In fact, crop models can vary in structure and parameterization and formalize bio-physical and physiological processes differently. For this reason, they may respond in different way to future climate scenarios, thereby projecting different impacts of climate change on SOC and crop yield, even if they had been able to reproduce quite well the observed values under past conditions (Bassu et al., 2014). As a result, an assessment of climate change impacts based on an ensemble of outcomes from multiple model simulations is more reliable than one obtained from a single model (Rötter et al., 2011; Tao et al., 2009).

Furthermore, many studies of multi model ensembles (MME) under current climate conditions have shown that the mean or median of the ensemble's simulated values reproduce the measured crop yields better than any individual model (Asseng et al., 2014; Li et al., 2015; Martre et al., 2015; Palosuo et al., 2011; Rötter et al., 2012). Given the improved performance of crop model ensembles over single models under current conditions, Wallach et al. (2016) suggest that better predictions under future climate conditions can be obtained with the mean or median of the model ensemble, even without improving the present-day crop models. Nevertheless, while some research has assessed MME to predict crop yield, no MME studies are currently available that evaluate the ensemble mean or median to simulate SOC dynamics. Many studies have used biogeochemical models (Alvaro-Fuentes et al., 2012; Gottschalk et al., 2012; Lugato et al., 2007; Meersmans et al., 2016; Muñoz-Rojas et al., 2013; Tornquist et al., 2009) to assess the impact of climate change on SOC, but because these models have simplified processes for crop growth simulation, they could produce unreliable impacts on crop productivity and, consequently, on soil C-input. Most climate change impact studies using crop process based models have focused on the crop-atmosphere interaction of single crops alone (Asseng et al., 2014; Bassu et al., 2014; Long et al., 2006) while, more recently, studies emerge which consider the entire system of soil-crop-atmosphere interaction (Basso et al., 2015; Kollas et al., 2015; Nendel et al., 2014; Teixeira et al., 2015). This is particularly important under limited growing conditions such as in rainfed cropping systems with low SOC content. As a matter of fact, SOC can vary by year in response to agronomic management decisions and climate. These changes in SOC then affect soil water holding capacity and nitrogen and, at the same time, crop performance which, in turn, affects additional input of SOC.

Considering all of the issues mentioned above, we hypothesized that using an ensemble of models to estimate SOC in agricultural soils provides an advantage in terms of simulation accuracy, an approach that has not been used in previous studies. Moreover, we assumed that the use of process-based crop models for the dynamic estimation of plant C inputs to soil, varying year by year according to soil and climate variability and considered the main driver of SOC dynamic (Izaurralde et al., 2006), greatly improves the reliability of SOC simulations. We tested our hypothesis with four process-based crop models that were calibrated and evaluated with a set of data from selected Italian LTEs where different tillage options had been applied to cereal-based cropping systems in rainfed conditions. Thereafter we used MME to assess the long-term effects of contrasting tillage practices on changes in SOC stocks, considering both superficial (0–15 cm) and deeper layers (15–40 cm), in rainfed durum wheat (*Triticum turgidum* subsp. *durum* (Desf.) Husn.) – maize (*Zea mays* L.) rotations. These simulations were completed under both current and future climate scenarios. In this way we were able to assess the impact of future scenarios on both SOC and crop yield.