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Orchard and horticulture systems in Spanish Mediterranean coastal areas: Is there a real possibility to contribute to C sequestration?

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ABSTRACT

Agriculture in the Mediterranean basin is currently contributing to greenhouse gas emissions (GHG) and in the future is expected to be strongly affected by climate change. Increasing soil organic carbon (SOC) via soil organic matter (SOM) improvement is widely regarded as a way to both mitigate and adapt to climate change. Using as a case study the Mediterranean coastal area in Spain, which is regarded as one of the most intensively managed areas in Europe for orchards and horticultural cropping, we analyzed the potential for climate change mitigation of introducing different practices that are expected to increase SOC. We selected both as a single measure and in combination, cover cropping and application to the soil of the available underutilized exogenous organic matter (EOM), treated (e.g. composted or digested) or non-treated. These practices were compared against a baseline scenario that intended to reflect the current practices in the area (e.g. all livestock manure produced in the area is applied to the agricultural soil). We carried out a modelling exercise at the regional scale using the agricultural activity data and current climatic conditions as inputs. Modelling runs were performed coupling a widely used dynamic model of SOC turnover (RothC) with a model to simulate the GHG emissions from EOM processing or storage prior to soil application ($SIMS_{WASTE}$).

Results indicate that the most promising practice, considered as a single measure and with respect to the baseline, was introducing cover crops in woody cropping systems. This practice resulted in an increase of 0.44 Mg C ha^{-1} yr^{-1} during the first 20 years (range 0.41–0.52 Mg C ha^{-1} yr^{-1}) and led to a total SOC accumulation of about 30 Tg C after 100 years. Amendment of all agricultural land with available underutilized EOM resulted in an increase of up to 0.09 Mg C ha^{-1} yr^{-1} (range 0.07–0.16 Mg C ha^{-1} yr^{-1}) as a single measure (urban waste) and 0.13 Mg C ha^{-1} yr^{-1} (range 0.11–0.21 Mg C ha^{-1} yr^{-1}) as a combined measure (urban waste and composted agroindustry by-products), leading to a total SOC accumulation of about 7 Tg C (urban waste) and 10 Tg C (urban waste and composted agroindustry by-products) after 100 years. Manure anaerobic digestion or composting as a single measure did not result in significant SOC changes but, if GHG emissions and savings from manure storage and processing management stages are considered, they could help to reduce about 4.3 (anaerobic digestion) or 1.1 Tg CO_2eq yr^{-1} (composting) in the study area, which represents a significant amount compared with total agricultural emissions in Spain.

1. Introduction

Agriculture plays different roles in relation to climate change. On one hand, agriculture is particularly sensitive to the impact of climate change, and on the other hand, agriculture is responsible for about 10–12% of total man-made greenhouse gases emissions (Smith et al., 2014). Moreover, agriculture has also a climate change

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mitigating role as it can potentially act as a sink of atmospheric carbon (C) via, for example, soil organic carbon (SOC) sequestration. Anthropogenic activities, such as agricultural management, soil characteristics and climate are the main regulating factors affecting SOC changes (Farina et al., 2011).

One of the most important areas for agriculture in the world is the Mediterranean basin, where agriculture covers around 21 M ha located in the south of Europe and north of Africa. In general, Mediterranean agriculture is largely affected by a long summer drought and rainfall is, in most areas, confined to the autumn, winter and spring seasons. Unless field crops are irrigated they must either be sown in the autumn and harvested by early summer, or be capable of resisting drought. There are also comparatively mild winters and hot, sunny summers. Temperatures are such that a variety of temperate crops can be grown in the rainy season, and – with irrigation – sub-tropical crops in the summer (Grigg, 1974). In Spain, although subsistence agriculture occurs side by side with commercial farming, Mediterranean farming is generally intensive, highly specialised and varied in the kinds of crops raised. Many horticultural crops and orchards such as citrus, fruits, olives, and grapes are mainly for export and are largely grown in the Spanish Mediterranean coastal areas. Intensive agriculture negatively affects soil fertility mainly because of a loss in soil organic matter (SOM). Furthermore, the abundant use of fertilizers and pesticides used also increases the risk that nutrients and pesticides run-off into surface and leach into groundwater (Eurostat, 2015).

The specific conditions of this Spanish area (i.e. low water availability limiting crop growth, difficult land recovery after degradation, potentially high mineralization rates) make it especially sensitive to perturbations (e.g. those resulting from climate change). Although this particular setting can be a barrier for soil C sequestration, if measures to promote SOM are introduced, there are opportunities to largely increase soil C due to the high range of stocking capacity of these soils.

Several management options and farming practices have been proposed to enhance SOC accumulation by either increasing inputs (manure, compost and other recycled organic materials) or decreasing losses, e.g. stubble retention. Agricultural conservation practices (e.g. no-tillage and mulching, cover cropping, the introductions of crop rotations with high diversity, integrated nutrient management) or irrigation are amongst the practices that have been identified in order to sequester SOC in agricultural systems (Lal, 2004). These practices are, in fact, a reliable and effective way to improve soil structure and both chemical and biological fertility of soils.

In the Mediterranean area, in general, soil organic C stock is constrained by factors such as limited C input, long-term practices of intensive tillage combined with the use of long bare fallows and the removal of crop residues for animal feed (Álvaro-Fuentes and Paustian, 2011). However, there are still large amounts of exogenous organic matter (EOM), i.e. C inputs, which are underutilized as soil amendments.

In Mediterranean conditions, even though SOM models have already been used to predict SOC changes in agroecosystems (e.g. Álvaro-Fuentes et al., 2012a; Francaviglia et al., 2012; Liu et al., 2009; Mondini et al., 2012; Nieto et al., 2010) to our knowledge there is not such study that evaluates the effect on SOC accumulation of applying different EOM that are currently not used for agriculture, treated (e.g. compost or digestate) or non-treated (e.g. sewage sludge) in combination with other measures (cover cropping). Accordingly, here we present a modelling study in which the effects on SOC accumulation are investigated in a case study covering the Mediterranean costal area in Spain, which is a representative area of large horticulture and woody crops agricultural production within the Mediterranean climatic conditions.

2. Contextualisation of study area

2.1. Climate

The studied area covers the provinces that are situated along the entire Spanish Mediterranean coast, comprising mainly Meso-Mediterranean and Thermo-Mediterranean bioclimatic zones (Fig. 1) (Rivas-Martínez and Rivas-Sáenz, 2016). The thermo-Mediterranean zone is characterized by hot summers and mild winters with almost absence of frosts. It covers lowlands and littoral areas, and concentrates most of the citrus and horticultural production in the Iberian Peninsula. The Meso-Mediterranean zone, which is associated to inland areas, also involves hot summers but cool winters and frosts are likely.

Within the study area there is large variability in precipitation regimes, with annual rainfall ranges between 200 and 600 mm. Precipitation concentrates during the winter, autumn and spring seasons, often in the form of heavy storms. In contrast, droughts are frequent during hot summer months, involving water stress in plants and the need for irrigated agriculture (Mancinelli et al., 2013).In the coming decades, the Mediterranean basin is most likely to be strongly affected by the impacts of climate change (IPCC, 2013; Kushnir, 2015; Ludwig and Roson, 2016; Ozturk et al., 2015).

2.2. Soils

The soils in the studied area are mainly alkaline carbonated Aridisols (ranged from 40 to 70% depending region), Inceptisols and Entisols in accordance to USDA soil classification (Soil Survey Staff, 2014). These well-aerated soils, with light soil textures, produce high efficient conditions for OM oxidation, accelerated by tillage and irrigation in agricultural soils (Balesdent et al., 1990; Trost et al., 2013). The SOM content and natural humic pools for the studied area are very low, based on the study from Rodríguez Martín et al. (2016). In Fig. 2, SOC stock for the study area is shown. Soils with large clay concentration are associated with increased SOC stabilization potential (Sollins et al., 1996). In the study area the average content of clay is about 22%, although wide differences are observed depending on regions (Catalonia 19.1%; Valencian community 21.9%; Murcia 25.7%; Andalusia: Almeria 15.6%, Cadiz-Malaga 31.6%), which lead to different opportunities for the stabilization of SOC. Additionally, other soil characteristics found in these soils, e.g. enhanced physical protection of organic C by soil aggregates (microaggregates inside macroaggregates), in combination with physical and chemical mechanisms also increase the potential to sequester SOC in the study area (Álvaro-Fuentes et al., 2008; Garcia-Franco et al., 2015).

The Mediterranean agriculture in general and the study area in particular are very vulnerable to soil erosion, especially by water (Boix-Fayos et al., 2005; García-Ruiz, 2010), because of geo-ecological factors (lithology, topography, and climatology) and also the land use history and plant cover changes. Geographically, in the Andalusia region, about 20% of the surface is classified as "high erosion risk" with a mean annual soil loss of 23.2 Mg ha^{-1} (Rodríguez Martín et al., 2016). In other regions in the study area erosion losses have been estimated at 23.7 Mg ha^{-1} yr^{-1} in Catalonia, 16.8 Mg ha^{-1} yr^{-1} in Valencia and 17.6 Mg ha^{-1} yr^{-1}in Murcia (MAGRAMA, 2015). This soil loss has been found to represent soil C losses at rates ranging from 0.008 to 0.3 Mg C ha^{-1} yr^{-1} under orchard trees crops, for example, in the study area (Martínez-Mena et al., 2008; Nieto et al., 2012).