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Review

Orchard management, soil organic carbon and ecosystem services in Mediterranean fruit tree crops

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ABSTRACT

Agriculture is not only appointed to produce food but has the potential to provide a range of ecosystem services (ES) depending on the management options adopted at field scale. Information on the impact of management practices adopted in fruit tree crops on ES is fragmented and often not fully codified. This paper focuses on some Mediterranean fruit tree crops i.e. peach (*Prunus persica*), apricot (*Prunus armeniaca*), olive (*Olea europaea*) groves and vineyards (*Vitis vinifera*), and links mainly soil processes and functions to the provisioning, regulating and sociocultural ES. The effects of field practices (e.g., tillage/no-tillage, cover crops, retention/burning of pruning residues, mineral/organic fertilization) on manageable soil properties (e.g., porosity, organic carbon content, composition of microbial community) and related functions (e.g., supply of nutrients, water storage, soil stability, above-ground biodiversity) were examined.

The analysis draws the attention to the pivotal role of the soil organic carbon (SOC) stocks on soil aggregates and erodibility, soil water storage, use of fresh water for irrigation, plant nutrition, biodiversity, nutrient storage and absorption of pesticides. Sociocultural services delivered by tree crops are also discussed. This paper highlights the dependence of ES on the sustainable field practices adopted, particularly those aimed at increasing SOC stocks (e.g., no tillage, increased carbon input, recycling of pruning residuals, cover crops).

The outcomes presented may strengthen the significance of increasing SOC management practices for fruit tree crops and be supportive of the implementation of environmentally friendly policies assisting in the conservation or the improvement of the soil natural capital.

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1. Introduction

Soil represents a component of the natural capital containing approximately 1500 Pg of organic carbon (C) (1 m depth) which exceeds the amount of C stored in phytomass and atmosphere (Scharlemann et al., 2014). There is an increasing categorization of the various ecosystem services (ES) provided by the natural capital which includes also vegetation, aquatic ecosystems, biodiversity and climate variables (Costanza et al., 1997). Nowadays, the generally accepted framework of ES flowing from the natural capital embraces provisioning, regulating, cultural and supporting services. All these services are beneficial to humanity through the production of goods (food, fiber, biofuel), life-supporting (e.g., pollination, water purification, climate regulation) and fulfilling processes (e.g., recreational, spiritual) (see Adhikari and Hartemink, 2016 published for review).

Soil is a potential source of a large part of ES because of the several soil-based physicochemical and biological processes resulting in a number of functions (Jónsson and Davíðsdótt, 2016). These functions (e.g., supply of nutrients, water storage, soil stability, biodiversity) and the related ES are potentially subject to change. For example, the process of soil aggregates absorbing water allows the storage of water (function) and confers the ability to supply water (service). That process → function → service causal chain could be influenced by the soil management options adopted by farmers (e.g., tillage or cover crops) (Palese et al., 2014). This view is in line with the soil ES framework proposed by Dominati et al. (2010) who discriminates between "inherent" soil properties (slope, orientation, texture, soil coarse fraction, etc.) from the "manageable" ones including C content, land cover, size and structure of aggregates, etc.

The link between the structure and function of soil and the related ES has been recently reviewed by Adhikari and Hartemink, (2016). Soil organic carbon (SOC) may directly or indirectly provide a wide range of provisioning (e.g., yield, biomass production), regulating (e.g., reducing soil erosion, water regeneration, storage of atmospheric carbon dioxide (CO_2)), supporting (e.g., plant nutrients, water) and cultural ES (e.g., landscape conservation). These SOC-related ES have an increasing societal value to the extent that monetary valuations of these services are emerging (Costanza et al., 2014; Lal, 2014a, 2014b). Based on the evidence that soil interconnects the various C pools (i.e. atmosphere, hydrosphere, biosphere and geosphere) and that changes in SOC may significantly impact the overall global C cycle (Lal, 2016), it could be inferred that reductions in SOC stocks may negatively affect certain ES (e.g., regulation of atmospheric CO_2, supply of nutrients to plant). However, impairment of ES is often not clearly perceived as it is because masked by benefits derived from other compensating management practices. For example, soil tillage as combined with chemical fertilization may lead to the decline of SOC stocks and an increase in soil CO_2 emissions, whilst the yield may increase due to chemical inputs (e.g. fertilisers, pesticides) (West and Maraland, 2002).

There is increasing attention by policymakers to protecting the natural capital and to giving a proper value to the ES promoting investments in green infrastructures and soil remediation strategies. For example, since The Soil Thematic Strategy was issued by the European Commission (EC) (EC, 2006), there is a general consensus to identify specific targets for increasing the amount of SOC by 2020 while using the soil sustainably (EC, 2012a, 2012b). Therefore the assessment of ES provided by ecosystems is pivotal to recognising and boosting "the supply of" and "the demand for" ES and gaining as high priority as possible in the political agenda.

As fruit tree crops are functional systems able to sustain life that include all biological and non-biological variables, they conform to the ecosystem definition reported by Baumgärtner and Bieri (2006), whereby tree crops might be defined as fruit tree ecosystems. Within fruit tree ecosystems, soil organic carbon and tree biomass are relevant C pools that can be monitored and accounted for within annual national greenhouse gases (GHGs) reports (IPCC, 2006). International communities are aware of the evidence that perennial woody vegetation can capture atmospheric CO_2 through photosynthesis (see The Guidelines for National Greenhouse Gas Inventories – IPCC, 2006) however this process could be affected by the management practices adopted. For example, it has recently been documented that a Mediterranean commercial peach (*Prunus persica*) orchard may have a net ecosystem C balance ranging from ~0.9 up to ~7.3 Mg C m^{-2} yr^{-1} depending on management options adopted, in addition approx. 25 Mg C ha^{-1} are stored within above and below-ground tree biomass throughout the lifespan of the orchard (Montanaro et al., 2016).

Nowadays there is increasing attention to fruit tree ecosystems as sources of ES (Baumgärtner and Bieri, 2006; Clothier et al., 2013; Fagerholm et al., 2016), however to the best of our knowledge, information on the ES provided by these ecosystems remains fragmented and not extensively codified. In addition, it does not explore in detail the impact of different management options on ES. Improving knowledge about such ES might boost the release/improvement of policies and support the wide adoption of sustainable land use and management in fruit tree ecosystems. Therefore, this paper examines relevant ES that are provided by some Mediterranean fruit tree ecosystems mainly in relation to soil management options, and discusses their potential and constraints. As there are still gaps in identifying the causal link between specific soil properties and ES (Adhikari and Hartemink, 2016), this paper aims to link mainly the increased SOC stocks to improvements in soil-related ES.

The paper focuses on fruit tree orchards, olive (*Olea europaea*) groves and vineyards (*Vitis vinifera*) and discusses the effects of field practices (e.g., tillage/no-tillage, cover crops, retention/burning of pruning residues, mineral/organic fertilization) on manageable soil properties including SOC and related functions (e.g. supply of mineral nutrients, water storage, soil stability, pesticide degradation). Then the analysis draws attention to the ES provided by tree crops under sustainable practices (*sensu* Xiloyannis et al., 2016) in terms of ability to capture atmospheric CO_2, reduction of soil erosion, improvement of soil water reservoirs and use of fresh water for irrigation, plant nutrition and biodiversity. The social context of ES and delivery of cultural services by fruit tree ecosystems are also discussed.

2. Soil functions and regulating services

2.1. Organic carbon sequestration

There is a general consensus on the function of soil to potentially serve as a reservoir for atmospheric CO_2 contributing to partially offsetting continuing global anthropogenic CO_2 emissions (Lal, 2016). Despite fruit tree ecosystems having the potential to remove C at a rate similar to those of forests ranging from 240 to 1250 g C m^{-2} yr^{-1} (Montanaro et al., 2016 and references therein), the C sink function of fruit tree ecosystems and the regulating ES have received relatively little attention.

There are management options which could be designed to increase C stocks in tree biomass and soil within an orchard. Such an increase in C is relevant for environmental policy to the extent that orchards have been included within the "cropland" activity to account for and report changes in C pools within GHGs national inventory reports of European Member States (EC, 2013). In the meantime, analysis on carbon atmosphere-terrestrial ecosystems exchanges mainly focuses on forest, shrublands and savannah