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Agricultural land abandonment in Mediterranean environment provides ecosystem services via soil carbon sequestration

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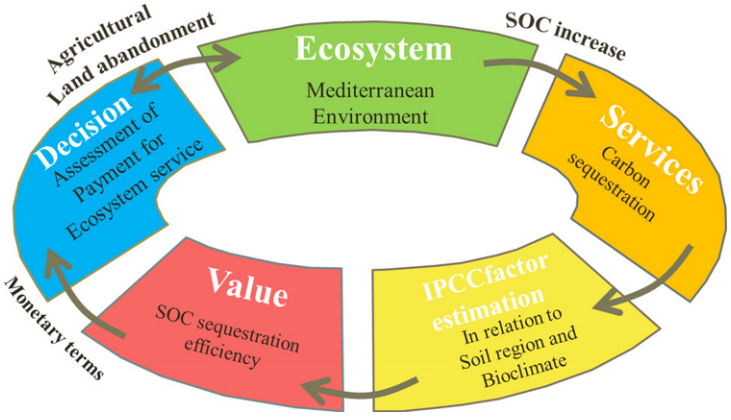
HIGHLIGHTS

- SOC after agricultural land abandonment was affected by Soil Region and Bioclimate.
- IPCC factors were calculated for Soil Region * Bioclimate interaction.
- C stored in abandoned soil would offset of 6% of the agriculture Sicilian emissions.
- Agro Environmental measures must be site specific to improve payments efficiency.

GRAPHICAL ABSTRACT



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ABSTRACT

Abandonment of agricultural land leads to several consequences for ecosystem functions. Agricultural abandonment may be a significant and low cost strategy for carbon sequestration and mitigation of anthropogenic CO_2 emissions due to the vegetation recovery and increase in soil organic matter. The aim of this study was to: (i) estimate the influence of different Soil Regions (areas characterized by a typical climate and parent material association) and Bioclimates (zones with homogeneous climatic regions and thermotype indices) on soil organic carbon (SOC) dynamics after agricultural land abandonment; and (ii) to analyse the efficiency of the agri-environment policy (agri-environment measures) suggested by the European Commission in relation to potential SOC stock ability in the Sicilian Region (Italy). In order to quantify the effects of agricultural abandonment on SOC, a dataset with original data that was sampled in Sicily and existing data from the literature were analysed according to the IPCC (Intergovernmental Panel on Climate Change) methodology. Results showed that abandonment of cropland soils increased SOC stock by 9.03 Mg C ha^{-1} on average, ranging from 5.4 Mg C ha^{-1} to 26.7 Mg C ha^{-1} in relation to the Soil Region and Bioclimate. The estimation of SOC change after agricultural use permitted calculation of the payments for ecosystem service (PES) of C sequestration after agricultural land abandonment in relation to environmental benefits, increasing in this way the efficiency of PES. Considering the 14,337 ha of abandoned lands in Sicily, the CO_2 emission as a whole was reduced by 887,745 Mg CO_2.

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Therefore, it could be concluded that abandoned agricultural fields represents a valid opportunity to mitigate agriculture sector emissions in Sicily.

1. Introduction

Worldwide land use changes are altering the fate of landscapes, and land abandonment is one of the processes responsible for these changes (Arnáez et al., 2015; García-Ruiz and Lana-Renault, 2011; Parras-Alcántara et al., 2013). Land abandonment has occurred mainly in developed countries as a consequence of the intensification of agriculture and the reduction of the agriculture land necessary to feed the population (Alonso-Sarría et al., 2016; Kou et al., 2016). This is mainly found in Europe, where numerous research studies have been published (Hatna and Bakker, 2011; MacDonald et al., 2000). This abandonment is most extensive and studied in the European Mediterranean belt (Plieninger et al., 2014; Romero-Díaz et al., 2016; Sheffer, 2012), and most of the research focuses on the mountainous regions that were abandoned as a consequence of the low income and loss of population (Lasanta et al., 2015a). The abandonment of land not only results in changes to the soil system, but also in the hydrological cycle and fauna and flora resources (Dixon-Coppage et al., 2005; de Araújo et al., 2015; Keesstra et al., 2016).

Agricultural land abandonment was the most important change in Mediterranean ecosystems over the last centuries and probably no other change in land use has been more important since the expansion of agriculture from the eastern to the western Mediterranean ten millennia ago (Petanidou et al., 2008; Rühl et al., 2005). Abandonment of agricultural land leads to several consequences for ecosystem functions and ecosystem service benefits (Cammeraat et al., 2010; Lasanta et al., 2015a; Parras-Alcántara et al., 2016; Rey Benayas et al., 2007). On the other hand, abandonment may be a significant and low cost strategy for C sequestration and mitigation of anthropogenic CO_2 emissions (Post and Kwon, 2000). Abandonment in Mediterranean ecosystems results in the recovery of vegetation (Lasanta et al., 2015b; Molinillo et al., 1997; Nadal-Romero et al., 2016), changes in water and sediment discharges (Keesstra, 2007; López-Vicente et al., 2016), soil erosion reduction (García-Ruiz and Lana-Renault, 2011), and increased biodiversity in the initial stages of plant succession (Suárez-Seoane et al., 2002; Zaravali et al., 2007).

Depletion of soil C occurs within the first few decades of agricultural practices (Fernández-Romero et al., 2014; Murty et al., 2002), but several years are necessary for soil C recovery after agriculture abandonment (Alberti et al., 2008; Rühl et al., 2015). Agricultural soils are a source of CO_2 emission around the world, and this is accompanied by mismanagement that results in high erosion rates, soil aggregate loss, low infiltration rates, and changes in the soil biota (Bruun et al., 2015; Choudhury et al., 2016; de Moraes Sá et al., 2015; de Oliveira et al., 2015; Frossard et al., 2016; Gelaw et al., 2015; Leifeld and Mayer, 2015). The impact of CO_2 on global warming has resulted in a growing interest in reducing emissions and increasing sequestration, and soil can be a good sequestration option under appropriate management (Carr et al., 2015; Ferreira et al., 2016; Hu et al., 2015; Hombegowda et al., 2016; Poeplau et al., 2016).

Rates of change in soil C following agricultural land abandonment have been estimated through chronosequence studies, comparing soil C in sites with long term agricultural land abandonment (SOC steady state) with adjacent agricultural fields (DeGryze et al., 2004; Del Galdo et al., 2003; La Mantia et al., 2013; McLauchlan, 2006; Novara et al., 2014, 2013; Rühl et al., 2015; Saiano et al., 2013). The chronosequence approach is frequently used to evaluate plant succession after disturbance, comparing sites that differ only in time since agricultural abandonment (Novara et al., 2014; Rühl et al., 2005). The climatological gradient approach is also applied in soil science, hydrology and geomorphology (Campos et al., 2014; Cerdà, 1998a; Lozano-García et al., 2016; Parras-Alcántara et al., 2015).

The potential and the rate of C sequestration due to agricultural land abandonment varies widely (Post and Kwon, 2000), depending on soil and climate characteristics of sites that result in differences in vegetation succession, ranging from the development of prairie to forests (Alberti et al., 2011; La Mantia et al., 2013; Rühl et al., 2015; Van Eerd et al., 2014). Soil C accumulation is strongly dependent on management strategies and therefore land use decisions can change the fate of SOC stocks (Novara et al., 2012; Teshome et al., 2014). Over the last few decades, substantial areas of the European Union, particularly the southern regions, have been affected by agricultural land abandonment (Renwick et al., 2013) due to the loss of productivity and/or to obtain payment for environmental purposes. In particular, the abandonment process was supported by the introduction, since the late 1980s, of agricultural policy measures designed to reduce crop production in a period of structural surpluses. According to these regulations, member states were obliged to implement a national program including a list of measures included in article 2, among which was the introduction of agricultural land abandonment for at least 20 years. Farmers who withdrew agricultural land from production received a subsidy over those twenty years to compensate them for the income loss. Very few empirical studies have assessed the impact of abandonment on the environmental side (Hodge et al., 2006), most of the research has focused on the socio-economic approach and on the farmer and stakeholder's perceptions (Pereira et al., 2016). The rationale used to promote abandonment was strongly based in environmental ideas to promote afforestation, reduce soil losses, and restore degraded soils (Cerdà, 1997). In this context, exploring the relationships between the implementation of agricultural land abandonment measures and their environmental benefits helps in assessing the efficiency of this political instrument. There are substantial limitations in knowledge of the effect of agricultural land abandonment on soil C sequestration and a long-term study is required to determine the pattern and rate of C sequestration across a full chronosequence after agricultural land abandonment.

According to a large chronosequence survey and the available bibliographic data, the aim of this study was: (i) to evaluate the effect of different Soil Regions and Bioclimates on soil C dynamics after agricultural land abandonment; and, (ii) to study the efficiency of the Agro Environmental Measures (AEM) in the Sicilian Region in relation to potential SOC stock.

2. Materials and methods

2.1. Study sites

In order to quantify the effects of agricultural land abandonment on SOC a dataset composed of original data sampled at different sites in Sicily (24 sites) and existing data collected from the literature (12 sites) was analysed. SOC dynamics in secondary succession areas (Alberti et al., 2011; La Mantia et al., 2013; Rühl et al., 2015) is strongly influenced by soil and climate, consequently the dataset was subdivided into: i) three bioclimatic groups (1. thermo-Mediterranean, 2. meso-Mediterranean, 3. supra-Mediterranean), representing the most typical bioclimatic belts occurring in Sicily; and, ii) four different Soil Regions (SR), named 1, 2, 3 and 4 (Fig. 1). The Soil Regions are areas characterized by a typical climate and parent material association (Costantini et al., 2004, 2013).

The classification proposed by Rivas-Martínez (Rivas-Martinez, 1994; Rivas-Martínez and Loidi Arregui, 1999) was used to designate