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Labile and stable soil organic carbon and physical improvements using groundcovers in vineyards from central Spain

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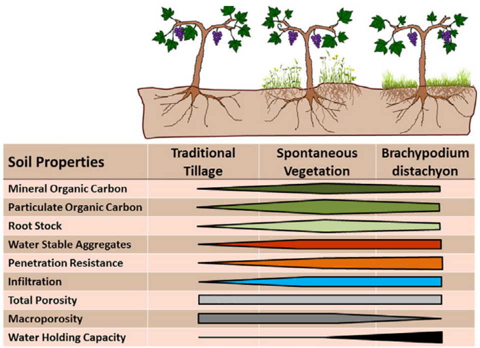
HIGHLIGHTS

- Groundcovers increased soil organic carbon at a maximum rate of 1.06 Mg per year.
- Despite higher compaction, pore connectivity improved considerably with spontaneous vegetation.
- Water holding capacity increased with *Brachypodium distachyon* groundcover.

GRAPHICAL ABSTRACT



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ABSTRACT

Mediterranean vineyards are usually managed with continuous tillage to maintain bare soils leading to low organic matter stocks and soil degradation. Vineyards are part of the Mediterranean culture, their management can be sustainable. We propose the setup of two types of groundcovers with the aim to assess their potential influence to improve soil properties. A field trial was performed to compare the effects of a seeded (*Brachypodium distachyon*) and spontaneous groundcovers, on a set of soil parameters, in comparison with the traditional tillage in four vineyards located in the center of Spain. Three years after the groundcovers establishment soil organic carbon stocks increased up to 1.62 and 3.18 Mg ha^{-1} for the seeded and the spontaneous groundcovers, respectively, compared to conventional tillage. Both labile and stable fractions improved their soil organic carbon content with the use of groundcovers, particularly the labile fraction. Moreover, soil structure and functional soil properties improved through better aggregate stability, pore connectivity and infiltration rates. The higher root biomass input of the spontaneous groundcovers derived in higher soil organic carbon increases and soil quality improvement. Consequently, under low rainfall conditions (<400 mm per year) spontaneous vegetation, properly managed according to site conditions, is an effective soil management strategy to revert soil degradation and increase soil quality in Mediterranean vineyards.

1. Introduction

Soil conservation is essential to supply goods, services and resources for the humankind (Keesstra et al., 2016). Agriculture causes several environmental impacts and particularly soil degradation (Bruun et al.,

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2015; Colazo and Buschiazzo, 2015). The severity and intensity of soil degradation can be determined by the methods and techniques to manage soil systems (Lorenz and Lal, 2016; Kabiri et al., 2016; Zhang and Ni, 2017) that can be exacerbated in vulnerable soils under harsh climatic conditions. In the context of agricultural land uses, Mediterranean vineyards are vulnerable to soil degradation processes: soil erosion, organic matter and nutrient loss and, thus, a decreasing fertility trend. Soil erosion rates are especially high in Mediterranean vineyards reaching figures up to 100 Mg ha^{-1} (Prosdocimi et al., 2016; Rodrigo Comino et al., 2016, 2017; Pacheco et al., 2014; García-Ruiz, 2010). This can be explained by the scarcity of soil cover throughout the year (Lasanta and Sobrón, 1988). In addition, other circumstances are triggering high erosion rates: (1) vineyards are frequently planted on slopes (Arnaez et al., 2007), (2) rainfall intensities in the studied region can be high (Panagos et al., 2015), (3) soils used for growing vineyards have low organic matter content and therefore weak structure, (4) soil management usually consists in continuous tillage (Novara et al., 2011) and (5) environmental land use conflicts as described by Valera et al. (2016). Soil degradation results in particle detachment and organic matter and nutrient loss (Bienes et al., 2010), which makes soil aggregates progressively more sensitive to the impact of rain drops and causes soil crusts (Issa et al., 2006). The crust creates an impermeable layer that slows down water infiltration (Bu et al., 2014). When infiltration rate is slower than rain intensity, runoff can cause nutrient loss and soil particle detachment (Gómez et al., 2009; Ramos and Martínez-Casasnovas, 2004). Farmers usually remove soil crusts by tilling after rains. Moreover, each time that the farmer ploughs a fraction of soil organic matter is mineralized, soil aggregates became more vulnerable to destruction and the crust formation will happen earlier during the forthcoming rainfalls.

Soil degradation causes on site and off site effects that can be underestimated by land users; on the one hand, it decreases soil fertility and reduces crop yields (Bakker et al., 2004) and even promotes land use changes and abandonment (Bakker et al., 2005). On the other hand, soil degradation contributes to worsen water quality in rivers and reservoirs (García-Díaz et al., 2017; Valle Junior et al., 2015). In the beginning, soil damages mean costs for the farmers but in the end, they turn into limitations and concerns for the socio-economic maintenance of the regions. Thus, it is critical to explore and encourage alternative soil managements to reduce soil degradation processes.

Soil organic matter (SOM) importantly influences physical, chemical and biological soil characteristics (Virto et al., 2012; Ramos et al., 2010; Fernández-Ugalde et al., 2009). SOM is related to aggregate stability, water infiltration and soil fertility by improving soil structure and nutrient availability (Balesdent et al., 2000; Reeves, 1997). Taking into account that soils in Mediterranean vineyards have low organic matter content (Panagos et al., 2013), shifting conventional soil management to other more sustainable alternatives will counterbalance mineralization and will increase or maintain SOM.

When a fresh plant residue falls on the soil, it becomes a particulate organic matter (POM) before humification processes (Gregorich and Janzen, 1996) thus, soil is enriched in SOM and nutrients and POM is considered as a good indicator of soil quality (Haynes, 2005). Besides, POM acts as a binding agent stabilizing macroaggregates (Six et al., 2002). Soil aggregation is affected by the different organic matter inputs, amendments, soil management and tillage methods (Wei et al., 2006; García-Orenes et al., 2005). Consequently, different soil management strategies will affect aggregate stability in different ways.

Different soil management strategies can have also an influence on the pore volume (Mulumba and Lal, 2008; Pituello et al., 2016) and its distribution (Ruiz-Colmenero et al., 2013). Tillage breaks natural porosity and destroys the biological macropores made by the macro and mesofauna (Léonard et al., 2004) and by roots (Gao et al., 2017).

In this study, we use the term groundcovers (GC) for perennial crops instead of cover crops as is recommended by Gonzalez-Sanchez et al. (2015). The use of GC in Mediterranean vineyards is well known for reducing erosion rates (Prosdocimi et al., 2016; Duran-Zuazo and Rodriguez-Pleguezuelo, 2009), increasing soil organic carbon (SOC) (Virto et al., 2012) or infiltration rates (Ruiz-Colmenero et al., 2013; Six et al., 2004). Temporal GC have proved to be a very effective tool for erosion control (Novara et al., 2011), but tillage, even if it is minimum, reduces the SOC threshold (García-Díaz et al., 2016). As mentioned, the physical-chemical effects of groundcovers on soil are site-specific, just like different local traditions to manage soils are.

Some Mediterranean regions have developed successful policies to promote the use of GC in vineyards. In Sicily, where the most of the rainfall is recorded in autumn and winter, the farmers are paid for using winter cover crops, which are mowed and tilled. This soil management practice is very effective controlling soil erosion and decreasing N loss (Novara et al., 2011, 2013). Similarly, in the Rioja Qualified Denomination of Origin's region (Spain), farmers receive different payments for using seeded or spontaneous GC (BOR, 2015). However, the majority of farmers in other Mediterranean regions, like in Central Spain, even having problems of soil degradation, decline using GC in vineyards because of social stigmatization, culture (Marqués et al., 2015) and grape harvest reduction (Ruiz-Colmenero et al., 2011). Only the 3.1% of the Madrid Region farmers use GC in vineyards (MAGRAMA, 2015a) which is one of the lowest percentages in Spain (MAGRAMA, 2015b). Moreover, in this region, the Common Agricultural Policy's agri-payments do not consider the use of GC in vineyards in any case (BOCM, 2009).

Thus, we argue that more knowledge of the advantages and disadvantages of different GC and their effect on soil properties is needed to develop an efficient soil protection policy in European viticulture areas in different environmental conditions. What is more, soil protection is being increasingly recognized as a long term strategy to sequester carbon and help to mitigate climate change (Poeplau and Don, 2015; Yagioka et al., 2015), therefore contributing to provide ecosystem goods and services not properly considered before. Recently, the 4 per mille initiative has emerged to promote better soil management with the goal to increase global SOM stocks by 0.4% per year in order to compensate anthropogenic sources of global emissions of greenhouse gases (Minasny et al., 2017).

Frequently, carbon sequestration rates are based on soil legacy data (Minasny et al., 2011; Akpa et al., 2016). Therefore a global effort on monitoring soil carbon “in situ” would be beneficial in obtaining the local soil conditions and SOC sequestration potential for particular environments as there is a critical limit to C sequestration which depends on soil texture and climatic conditions (Stockmann et al., 2015). In this regard, the SOC in 0.1 m depth in the vineyards of this study is going to be addressed as well.

The goal of this study was to assess the influence of two permanent GC (seeded and spontaneous) on a set of soil properties and C sequestration in semiarid Mediterranean vineyards in Central Spain. To provide evidences on the effects of different soil management strategies in different conditions, a field trial was performed in four vineyards with different edapho-climatic characteristics.

2. Materials and methods

2.1. Study area

The trial was performed in vineyards located in the Denomination of Origin “Wines of Madrid” (center of Spain). The annual rainfall is 365 mm and the average temperature is 15 °C (AEMET, 2017). Four vineyards were selected in the municipalities of Campo Real (40°21′8″ N, 03°22′30″ W), Belmonte de Tajo (two vineyards: 40°9′15″ N, 3°19′12″ W and 40°8′20″ N, 3°20′7″ W, respectively) and Navalcarnero (40°15′19″ N, 3°57′44″ W) (García-Díaz et al., 2017). All of them are haploxeralf soils, with predominantly loamy textures in a rolling landscape. In the beginning of the trial soils pits were performed and analyzed (Table 1). With the selection of these vineyards, we tried to