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The immediate effectiveness of barley straw mulch in reducing soil erodibility and surface runoff generation in Mediterranean vineyards

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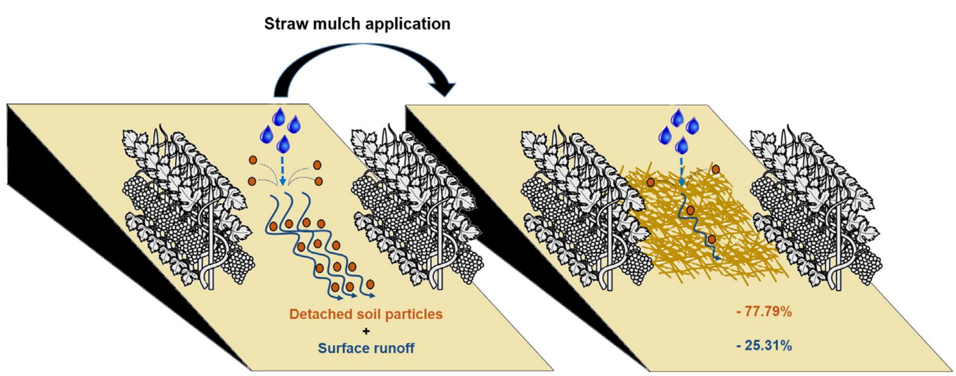
HIGHLIGHTS

- Mulching rate of 75 g m^{-2} has beneficial effects on soil and water losses.
- Straw mulch reduces the median water loss from 52.59 to 39.27%.
- Straw mulch reduces the median erosion rate from 2.81 to 0.63 Mg ha^{-1} h^{-1}.
- Straw mulch is a sustainable management strategy in Mediterranean vineyards.

GRAPHICAL ABSTRACT



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ABSTRACT

Soil and water loss in agriculture is a major problem throughout the world, and especially in Mediterranean areas. Non-conservation agricultural practices have further aggravated the situation, especially in vineyards, which are affected by one of the highest rates of soil loss among cultivated lands. Therefore, it is necessary to find the right soil practices for more sustainable viticulture. In this regard, straw mulching has proven to be effective in other crop and fire affected soils, but, nonetheless, little research has been carried out in vineyards. This research tests the effect of barley straw mulching on soil erosion and surface runoff on vineyards in Eastern Spain where the soil and water losses are non-sustainable. An experiment was setup using rainfall simulation tests at 55 mm h^{-1} over 1 h on forty paired plots of 0.24 m^2: twenty bare and twenty straw covered. Straw cover varied from 48 to 90% with a median value of 59% as a result of the application of 75 g of straw per m^2. The use of straw mulch resulted in delayed ponding and runoff generation and, as a consequence, the median water loss decreased from 52.59 to 39.27% of the total rainfall. The straw cover reduced the median sediment concentration in runoff from 9.8 to 3.0 g L^{-1} and the median total sediment detached from 70.34 to 15.62 g per experiment. The median soil erosion rate decreased from 2.81 to 0.63 Mg ha^{-1} h^{-1} due to the straw mulch protection. Straw mulch is very effective in reducing soil erodibility and surface runoff, and this benefit was achieved immediately after the application of the straw.

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1. Introduction

Soil erosion by water is considered one of the major threats to soil resources in Mediterranean areas due to their climatic, edaphic and geomorphologic conditions (Boardman et al., 1990; Cerdà and Doerr, 2007; Cerdà et al., 2009; Cerdan et al., 2010; Novara et al., 2011, 2015; Verheijen et al., 2009). Rainfall-induced soil erosion risk in the Mediterranean is especially high during summer storms or the early wet season, when plant cover is low (García-Orenes et al., 2009; Taguas et al., 2015). Soil loss is enhanced in cropped soils due to soil management and tillage practices (Blavet et al., 2009; Boardman et al., 1990; Boix-Fayos et al., 2005; Cerdan et al., 2010; Gómez et al., 1999; Vanwalleghem et al., 2011). Indeed, this is due to several reasons such as conventional plowing, removal of the original vegetation, use of pesticides and herbicides that damage biological activity in soils (Freemark and Boutin, 1995; Johnsen et al., 2001; Pelosi et al., 2013), low overall vegetation cover, soil compaction and sealing due to machinery traffic, depletion of organic matter and absence of soil erosion control measures (Arnáez et al., 2015; Bakker et al., 2005; Carr et al., 2015; Cerdà et al., 2009; Ciampalini et al., 2012; Cots-Folc et al., 2009; Laudicina et al., 2015; Raclot et al., 2009; Tarolli et al., 2014, 2015). The effect of intensive agricultural practices on soil erosion is now well known and is concerning given evidence that civilizations have collapsed throughout human history due to erosion (Brevik and Hartemink, 2010) and that erosion continues to negatively affect civilizations in all regions of the world (Brevik, 2009a; Brevik et al., 2015; Cerdà and Doerr, 2007; O'hara et al., 1993; Pimentel et al., 1987; Shi and Shao, 2000; Smith et al., 2015). Therefore, there is a need to find best management practices that will make agriculture sustainable. Among the cultivated lands, Mediterranean vineyards are recognized to be affected by high soil erosion rates because of a combination of natural and anthropogenic factors (Brillante et al., 2015; Cerdà and Doerr, 2007; Cerdan et al., 2002, 2010; Martínez-Casasnovas and Sánchez-Bosch, 2000; Raclot et al., 2009). The main reason for their high erodibility are practices that keep the soil between the vines bare during the entire year (Arnáez et al., 2007; Lasanta and Sobrón, 1988) and these bare surfaces are affected by intense storms that induce severe water erosion and runoff processes (Borga et al., 2011; Poesen and Hook 1997; Santos, 2000). Moreover, vineyards are often planted on steep-sloping soils (Arnáez et al., 2007; Wichereck, 1993) with poor nutrient and organic matter content (Cerdà, 1996; Corti et al., 2011; Novara et al., 2011, 2013). Changes in land use and farming practices or land abandonment have also negatively affected Mediterranean vineyards (Cerdà, 1994; Porta et al., 1994; Tarolli et al., 2014, 2015). Vineyards represent one of the most important crops in terms of income and employment, especially for three of the world's top ten grape-producing countries found in the Mediterranean region, namely Spain, Italy and France, where the total grape area in 2009 amounted to 11,000, 8020 and 8100 km^2 and thus 2.2, 2.6 and 1.5% of the respective national land areas (Anderson and Norman, 2011). For these reasons, adequate soil management practices are needed to contribute to a more sustainable viticulture, which includes evaluation to determine whether they are acceptable to the farmers who will have to utilize them (Galati et al., 2015; Marques et al., 2015). The most common soil management techniques in Mediterranean countries consist of tillage (mechanical weeding) and no-tillage (chemical weeding) operations (García-Orenes et al., 2009), and both of them generally result in bare soils during the entire year (Cerdà et al., 2009; Lasanta and Sobrón, 1988; Vaudour et al., 2015). However, alternative and more conservation-minded soil management practices have also been used like catch crops (Bonfante et al., 2015; García-Orenes et al., 2009), mulching (Jordán et al., 2011; Costantini et al., 2015), hydromulching (Prats et al., 2013), geotextiles (Giménez-Morera et al., 2010), natural grassing (Raclot et al., 2009) and rock fragments (Blavet et al., 2009). In particular, the use of catch crops, the implementation of no-tillage or reduced tillage systems, the addition of chipped pruned branches and the use of straw mulches are some of the soil management practices that have been applied on rain-fed experimental orchards in eastern Spain to reduce the high erosion rates (García-Orenes et al., 2009). Staff of the Soil Erosion and Degradation Research (SEDER) group have been studying soil erosion processes due to agriculture and cooperating with farmers to find possible solutions to soil erosion issues in vineyards, olive groves, and fruit and almond orchards. Among the soil conservation practices that have recently been implemented, mulching has proven to be effective in reducing water and soil loss rates and improving soil condition (Cerdà et al., 2015; Cook et al., 2006; García-Orenes et al. 2009; Jordán et al., 2010; Mwango et al., 2015; Mulumba and Lal, 2008; Sadeghi et al., 2015a; Tebrügge and Düring, 1999; Winteraeken and Spaan, 2010). According to Jordán et al. (2011), mulch is any material, other than soil, placed or left on the soil surface for soil and water management purposes. Mulching involves maintaining a permanent or semi-permanent protective cover on the soil surface that can be composed of different materials such as vegetative residues, biological geotextiles, gravel and crushed stones (Cerdà, 2001; Gilley et al., 1986; Jordán et al., 2010; Mandal and Sharda, 2013; Smets et al., 2008; Xu et al., 2012; Zhao et al., 2013). The beneficial effects of mulching can be summarized as follows: i) increased water intake and storage (Cook et al., 2006; Mulumba and Lal, 2008), ii) protection of soil against raindrop impact, reducing erosion rates (Blavet et al., 2009; Jordán et al., 2010; Sadeghi et al., 2015a), iii) decreased sediment and nutrient concentrations in runoff (Cerdà, 1998; Gholami et al., 2013; Poesen and Lavee, 1991), iv) decreased runoff generation rates and surface flow velocity by increasing roughness (Cerdà, 2001;Jordán et al., 2010), v) improved infiltration capacity (Jordán et al., 2010; Wang et al., 2014), vi) increased activity of some species of earthworms and crop performance (Wooldridge and Harris, 1991), vii) enhanced soil physical conditions such as soil structure and organic content (De Silva and Cook, 2003; Jordán et al., 2010; Karami et al., 2012), viii) reduced topsoil temperature for more optimum germination and root development (Dahiya et al., 2007; Riddle et al., 1996) and decreased evaporation (Uson and Cook, 1995), and xix) enhanced interactions with nutrients (Campiglia et al., 2014; Movahedi Naeni and Cook, 2000). Among the different types of mulching, straw mulch is considered one of the most effective in achieving the above-mentioned benefits (Blavet et al., 2009; Dahiya et al., 2007). In addition, it is easy to retrieve and transport and is relatively inexpensive if used at optimum application rates. Jordán et al. (2010) found that a mulching rate of 5 Mg ha^{-1} $yr.^{-1}$ was sufficient to make runoff flow and sediment concentration in runoff negligible in a no-tilled Fluvisol under semi-arid conditions in SW Spain. Similarly, Mulumba and Lal (2008) determined an optimum mulch rate of 4 Mg ha^{-1} for increasing porosity and 8 Mg ha^{-1} for enhancing available soil water capacity, moisture retention and aggregate stability. Although the beneficial effects of straw mulch are known, their quantification needs further research, especially within the context of rainfall-induced soil erosion in vineyards. Furthermore, the critical mulch rate needs to be established for site-specific soil and environment conditions (Mulumba and Lal, 2008). Jin et al. (2009) suggested that the relation between mulching rate and interrill soil detachment is not unique and can vary depending on rainfall intensity. They observed that sparse straw mulching on silt loam soils might favor soil loss compared to the bare soil under certain rainfall intensities (i.e. 65 mm h^{-1}). Given the importance of vineyards in the Mediterranean region, further research should be carried out to meet farmers' needs too. Indeed, it is also necessary to find the optimum mulch rate that entails reasonable expenses that farmers can afford.

Therefore, the objective of this paper is to assess the effect of barley straw mulch on soil water erosion and water losses in a vineyard in a Mediterranean area affected by intensive erosion rates under simulated rainfall.