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**Groundcover influence on physical and chemical
soil properties, runoff and nutrient loss and
grape yield and quality in semiarid
Mediterranean vineyards**

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Fdo. Ramón Arturo Bienes Allas

A mis padres,
a mi hermana,
a mi abuelo,
a mi compañera de vida.

And it came about that owners no longer worked on their farms. They farmed on paper; and they forgot the land, the smell, the feel of it, and remembered only that they owned it, remembered only what they gained and lost by it.

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ABBREVIATIONS

% Cov	Vegetation cover percentage
% Rf	Rock fragment percentage
% SI	Slope
AEM	Agro-environmental measures
ANOVA	Analysis of variance
BD	Bulk density
BEL-1	Belmonte de Tajo vineyard 1
BEL-2	Belmonte de Tajo vineyard 2
C	Carbon
CB	<i>Brachypodium distachyon</i> seeded groundcover
CEC	Cation exchange capacity
CND	Counting number drops
Cover	Vegetation cover
CR	Campo Real vineyard
CS	Spontaneous vegetation groundcover
CT	Conventional tillage
D	Sampling depth
DOC	Dissolved organic carbon
EC	Electrical conductivity
Er	Enrichment ratio
ET₀	Evapotranspiration
GC	Groundcover
Infil	Infiltration
MOC	Mineral-associated organic carbon
NAV	Navalcarnero vineyard
NAW	Not available water
NH₄	Nitrogen as ammonium lost in runoff
NH₄c	Nitrogen as ammonium concentration in runoff
NH₄soil	Nitrogen as ammonium in the soil
NO₃	Nitrogen as nitrates lost in runoff
NO₃c	Nitrogen as nitrates concentration in runoff
NO₃soil	Nitrogen as nitrates in the soil
NVZ	Nitrate vulnerable zone

OCloss_{AEM}	Organic carbon loss with agro-environmental measures
OCloss_{CT}	Organic carbon loss with conventional tillage
OM	Organic matter
P-Intra	Intrapedal porosity
P-Macro	Macroporosity
P-Meso	Mesoporosity
PA	Potential alcohol
PR	Penetration resistance
POC	Soil organic carbon of the particulate organic matter
POM	Particulate organic matter
R	Rainfall
SE	Soil erosion rate
SOC	Soil organic carbon
SOM	Soil organic matter
T	Conventional tillage
UAA	Utilized agricultural area
WHC	Water holding capacity
WSA	Water stable aggregates

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RESUMEN

La erosión es una de las principales formas de degradación del suelo que tiene lugar en ambientes Mediterráneos semiáridos. En este sentido, los viñedos son los cultivos que suelen alcanzar las tasas más elevadas de pérdida de suelo como consecuencia de permanecer desnudos o con una cubierta vegetal muy baja la mayor parte del año, un manejo convencional consistente en un laboreo continuo que degrada la estructura del suelo y favorece la mineralización de la materia orgánica, que ya de por sí suele registrar bajos niveles. Además, muchas zonas vitícolas están asentadas sobre laderas con fuertes pendientes. Como consecuencia, en numerosos emplazamientos las tasas de erosión llegan a ser muy superiores a la velocidad de formación del propio suelo, comprometiendo así la viabilidad de la producción y la calidad de los viñedos a medio y largo plazo.

En la literatura científica, la erosión en viñedos ha tenido un papel destacado en los últimos años. La pérdida de nutrientes está asociada también con la erosión. Este problema genera déficits en la nutrición de la planta y el agricultor se ve obligado a reponer esos nutrientes de forma artificial. Además, los nutrientes disueltos en la escorrentía, tales como el nitrógeno y el fósforo, pueden provocar un deterioro en las masas de aguas a las que escurran provocando eutrofización. Aunque algunos autores han medido pérdidas de nitrógeno mineral muy importantes en una sola lluvia, la pérdida de nutrientes en cultivos leñosos en ambientes semiáridos ha sido poco estudiada hasta el momento.

El incremento de la materia orgánica es un elemento imprescindible para la mejora de las propiedades físicas y químicas del suelo, mejorar la estructura y reducir las tasas de erosión y pérdida de nutrientes. Con el fin de revertir los procesos de degradación se propone el uso de cubiertas vegetales para potenciar la mejora en la calidad del suelo a través del incremento de materia orgánica y, por lo tanto, una disminución de la escorrentía y la pérdida de nutrientes. Sin embargo, este manejo alternativo supone un cambio en los paradigmas tradicionales de manejo del suelo y podrían afectar a la producción de uva y su calidad. Para evaluar esta problemática se realizaron dos estudios experimentales de campo.

El primero localizado en dos subzonas de la Denominación de Origen Vinos de Madrid, en la Comunidad de Madrid, España. A lo largo de tres campañas agrícolas en cuatro viñedos situados en pendiente, se ensayó con dos cubiertas vegetales permanentes en comparación con el laboreo convencional aplicando entre 2 y 3 pases de chisel al año. Las cubiertas utilizadas fueron: vegetación espontánea y sembrada con *Brachypodium distachyon*. Se analizó la materia orgánica

del suelo, la estabilidad de agregados, la macro, meso y microporosidad, la capacidad de retención de agua, la resistencia a la penetración y la capacidad de infiltración. Además, se diseñó, construyó y calibró un simulador de escorrentía con el que se realizaron experimentos en cadena para la determinación de escorrentía y pérdida de nitrógeno mineral disuelto.

En los cuatro viñedos del centro de España, el uso de cubiertas vegetales permanentes provocó una mejora de las propiedades y funcionalidad del suelo en cascada. El incremento en el input de materia orgánica dio lugar a un aumento en el stock de carbono del suelo, lo cual incrementó significativamente la estabilidad de los agregados del suelo. La falta de laboreo no alteró la porosidad del suelo; sin embargo, sí generó una redistribución de los poros y una mayor conexión que, junto con el efecto de los tallos y las raíces, provocó un aumento drástico de las tasas de infiltración en ambas cubiertas vegetales en comparación al laboreo. Estas mejoras se vieron reflejadas en las simulaciones de escorrentía en las que las cubiertas vegetales redujeron la escorrentía generada en el laboreo siendo la pérdida de nitrógeno mineral mayor. Debido a que la cubierta vegetal compuesta por vegetación espontánea fue la que mostró los mayores inputs de materia orgánica, mostró los incrementos más significativos. La cubierta vegetal sembrada obtuvo, por lo general, valores intermedios entre la vegetación espontánea y el laboreo.

El segundo experimento, llevado a cabo en el sur de Sicilia, consistió en el análisis de 50 pares de muestras provenientes de viñedos manejados con cubierta vegetal temporal de leguminosas y laboreo convencional. Se calculó la concentración de materia orgánica y se valoraron sus incrementos cinco años después del inicio del experimento. Los incrementos de materia orgánica que tienen lugar mediante el uso de cubierta vegetal temporal fueron significativos, si bien inferiores a los que tuvieron lugar en las cubiertas permanentes. Se comprobó que estos incrementos pueden, en suelos muy erosionables, dar lugar a la exportación de sedimentos muy enriquecidos en materia orgánica dando lugar a pérdidas de carbono superiores en viñedos manejados con cubierta vegetal.

SUMMARY

Erosion is one of the main forms of soil degradation in semiarid Mediterranean areas. The joint occurrence of several factors makes vineyards one of the land uses with highest erosion rates: bare soil the most of the year, continuous tillage promoting soil organic matter mineralization and soil structure degradation, low organic inputs and climate which promote organic matter mineralization, vine-producing regions are planted usually on hilly topography areas and high rainfall intensities. All together promotes erosion rates higher than soil formation rates. Thus, soil vineyards and grape quality sustainability at medium to long term is threatened.

Erosion in vineyards has been highlighted in scientific literature in the last years. Although several researchers reported high mineral nitrogen losses in single events, nutrient loss in semiarid vineyards have not been properly addressed. Nutrient loss results in on-site effects, with the loss of fertility that will have to be replaced by the farmer. Besides, there are off-site effects due to runoff dissolved nutrients such as nitrogen or phosphorous pollute groundwater, rivers and reservoirs.

Soil organic matter increase has a main role to improve physical and chemical soil properties and soil structure and to reduce erosion and nutrient loss. We propose the use of groundcovers to revert degradation processes and increase soil quality throughout the enhancement of soil organic matter. Nevertheless, alternative soil management strategies such as groundcovers are difficult to implement because are usually questioned by farmers and can have an impact on grape yields and quality.

Two field trials were performed. The first one was located in the Denomination of Origin Wines of Madrid, in Madrid Region, central Spain. The trial was performed along three agronomic seasons in four vineyards located in sloping areas, in which two permanent groundcovers were compared with conventional tillage. Groundcovers were: spontaneous vegetation groundcover and seeded *Brachypodium distachyon* groundcover. Soil organic matter stocks, aggregate stability, macro, meso and microporosity, water holding capacity, penetration resistance and infiltration rates were measured. Moreover, a runoff simulator was designed, built and calibrated to simulate runoff in field conditions and analyze runoff and mineral nitrogen loss. The second trial was performed in Sicily. Fifty paired samples were taken from temporary leguminous groundcovers and conventional tillage. A SOC threshold was calculated to assess in which conditions higher carbon loss with

temporary groundcovers than with conventional tillage can be found. Additionally the increase in soil organic matter 5 years of groundcover establishment was also addressed.

In central Spain, the use of groundcovers improved strongly soil properties. The increase in organic inputs promoted an increase in soil organic matter stocks, which enhanced significantly aggregate stability, and thus, soil structure. Tillage cessation did not affect soil porosity; however, soil pores had higher connection which increased infiltration rates. These improvements influenced decisively the reduction in runoff and mineral nitrogen loss. Runoff was reduced up to three times the runoff measured with tillage but the mineral nitrogen loss with groundcovers was up to six times lower than with tillage. Spontaneous vegetation groundcover resulted in the largest soil improvements as a consequence of higher organic inputs. Seeded groundcover showed generally intermediate values between spontaneous vegetation and conventional tillage.

The increases of organic matter with temporary groundcovers significant regarding tillage although were lower than those measured in permanent groundcovers. Erodible soils such as silty soils or those with poor soil structure under temporary groundcovers could result in higher carbon loss than with conventional tillage.

GENERAL INTRODUCTION

Soil is continually interacting with atmosphere, biosphere, hydrosphere and lithosphere (Porta et al., 2003; Tricart, 1969). As a key component of the Earth System, soil can control hydrological cycle because: texture, soil structure and organic matter determine infiltration, water storage and depuration; runoff and infiltration determines particle and nutrient loss. Furthermore, soil organisms strongly influence biological and biochemical cycles such as carbon, nitrogen and phosphorous cycles, with an essential role in regulating the emission or sequestration of carbon (Brevik et al., 2015; Decock et al., 2015; Porta et al., 2003). Thus, the way that human societies manage the soil affects food, water security, climate change and biodiversity (Baldwin et al., 1938; Dent and Young, 1981; Duchafour, 1987; Elbersen, 1991; Fitzpatrick, 1984), all of them being considered as key sustainable development goals for United Nations (Keesstra et al., 2016a).

Soil degradation is defined as a change in the soil health status resulting in the diminished capacity of an ecosystem to provide goods and services for its beneficiaries (FAO, 2017). In a global scale, agricultural practices are the main factor contributing to soil degradation. Agriculture can promote erosion, produce salinization or decrease soil fertility (Bruun et al., 2015; Colazo and Buschiazzo, 2015), consequently, determining the rates of the processes involved in soil degradation and soil quality (Calleja-Cervantes et al., 2015; Khaledian et al., 2017). Soil degradation decreases soil fertility, which reduces crop yields (Bakker et al., 2004) and can eventually promote land use changes (Bakker et al., 2005). Sustainable agricultural practices are needed to reach a sustainable land use ensuring the capacity of future generations to satisfy their basic requirements.

Vineyards, soil degradation and erosion

Mediterranean woody crops have been cultivated from centuries (Loumou and Giourga, 2003). As a consequence, vineyards and olive orchards are under the consideration of cultural landscapes by the United Nations, Educational, Scientific and Cultural Organization (ICOMOS, 2005; UNESCO–SCBD, 2014) because of its historical roots.

In Mediterranean basin, vineyards were traditionally planted in terraces or across the main slope (Cots-Folch et al., 2006). Tillage was shallow, performed with animal power and organic inputs were yearly applied. However, with the inclusion of machinery, vineyards started to be tilled more intensively (more passes each year) and deeply (Arnaez et al., 2007; Ferrero et al., 2005). Moreover, organic amendments were hardly applied because of a lack of animal manure. In the last decades, European Union paid farmers to introduce mechanization in the vineyards and,

consequently, old terraces and plantations were substituted by long rows along slopes (Arnaez et al., 2007). Nowadays, vineyards are still one of the most important woody crops in terms of incomes and employments (Anderson and Nelgen, 2011; Martínez-Casasnovas et al., 2010; Van Leeuwen et al., 2009).

Mediterranean vineyards have been relevant in scientific literature attending several problems related to soil erosion. Potential explanations can be:

- 1) Soil cover (leaf of the vines, spontaneous vegetation, etc.) is very low along the year. The cover is only significant during summers, when there is almost no rain. Soil cover of a typical vineyard consists eventually in rock fragments and vine's leafs (Fig. 0.1). Bare soil is widely recognized as prone to soil erosion in Mediterranean basin (Cerdeira, 1998; Novara et al., 2013).
- 2) Conventional soil management strategy in Mediterranean vineyards is the systematic elimination of weeds to eliminate competition with the vine plant through continuous tillage (Novara et al., 2011; Rodrigo Comino et al., 2016b). Tillage is known for resulting in high erosion rates (García-Orenes et al., 2009; Cerdeira et al., 2009). Moreover, in some regions, tillage has a cultural component and even "tillage contests" could be found. Farmers like to till, the soil color and even the smell (Fig. 0.2).
- 3) Low organic matter inputs and a climate which promotes high mineralization rates lead to low organic matter stocks in vineyard soils which otherwise could help reducing soil erodibility.
- 4) Vine-producing regions are often in hilly topography areas (Rodrigo Comino et al., 2016c; Rodrigo Comino et al., 2017; Tarolli et al., 2015).
- 5) Mediterranean region experience high rainfall intensities (Nadal-Romero et al., 2015; Ruiz Sinoga et al., 2010).

Figure 0.1. Image of a typical Mediterranean vineyard from November to April.

As a result, higher erosion rates than in other land uses can be found in Mediterranean vineyards, reaching to 100 Mg ha^{-1} (García-Ruiz, 2010; Kosmas et al., 1997; Prosdocimi et al., 2016a; Rodrigo Comino et al., 2016c). These high erosion rates lead not only to soil detachment but also to soil organic matter (SOM) and nutrient loss (Bienes et al., 2010), resulting in a decrease in soil fertility and threatening the sustainability of vineyards.

Figure 0.2. Farmer tilling the soil.

Organic matter importance: soil structure

SOM plays a central role in the soil fertility and quality because is related with biological, physical and chemical soil properties (Fernández-Ugalde et al., 2009; Ramos et al., 2010; Virto et al.,

2012a). SOM is highly correlated to porosity, water holding capacity, biodiversity, water infiltration and chemical fertility (Balesdent et al., 2000; Kay, 1998; Reeves, 1997; Salomé et al., 2016; Tisdall and Oades, 1982). Moreover, it acts as binding agent to aggregate soil elementary particles and consolidates soil structure (Kleber et al., 2007).

Soil structure concept indicates the way soil particles are related between them and aggregate stability is generally used as its indicator (Six et al., 2000a). Although SOM is the most important factor for aggregate stability (Six et al., 2004), there are other factors controlling soil aggregation such as microorganisms, clay particles, bivalent cations and ionic bridging. An improvement in soil structure is critical to reduce soil erosion because it means an increase in aggregate stability and a development in soil hydrological parameters (Barthès and Roose, 2002).

Labile organic matter

Physical fractioning of SOM can provide organic matter fractions correlated with SOM dynamics in natural and cultivated soils (Cambardella and Elliott, 1992). Particulate organic matter (POM) is generally defined as young organic matter fraction, composed by plant residues in which cell structure is still recognized. It can be considered as a transition between fresh plant residues and fully humified SOM (Gregorich and Janzen, 1996). Thus, POM reflects the organic matter labile pool, which responds relatively fast after soil management use changes. POM is related to microorganisms' activity, nutrient availability (Wander and Bidart, 2000) and contributes to aggregates formation and stability (Six et al., 2002). Consequently, its multiple functions make POM an indicator of soil quality (Haynes, 2005).

Soil tillage addiction

Decreasing SOM makes soil aggregates more sensitive to rain drop impacts as previously mentioned. Aggregate breakdown results in individual soil particles (Le Bissonnais and Arrouays, 1997) which are able to gradually fill soil surface pores sealing the soil (Issa et al., 2006). When a soil crust is formed, infiltration decreases and, thereby, runoff increases (Battany and Grismer, 2000; Castillo-Monroy et al., 2010; Seeger and Ries, 2008; Singer and Shainberg, 2004). In this heavy rainfall situation, the soil particle detachment and nutrient loss can be severe (Gómez et al., 2009; Ramos and Martínez-Casasnovas, 2004). To remove soil crusts, farmer till after each rainy period because of cultural reasons and because is recognized to increase in soil roughness (Wang et al., 2017). However, this increase is temporary and lasts until the next rain. With the tilling operations, aggregates are broken and soil temperature and aeration are most favorable for the microorganisms to mineralize SOM. Each time SOM is released as CO₂, soil aggregate become

weaker than before tilling and, consequently, soil crust occur more easily (Fig. 0.3). Therefore, this is a negative feedback caused by non-suitable soil management that has been repeated from decades ago decreasing soil fertility year after year.

Figure 0.3. Tillage and the negative feedback. Soil organic matter (SOM). Blue arrows reflect a feedback. Green arrow reflects positive outcomes. Red arrow reflects negative outcomes.

Nutrient loss

In Mediterranean vineyards, soil degradation processes have been a scientific concern in the last years (Prosdociimi et al., 2016a). For instance, several studies analyzed soil biodiversity and biology (Bruggisser et al., 2010; Burns et al., 2016; Steel et al., 2017; Carpio et al., 2017), soil quality (Salomé et al., 2016; Virto et al., 2015; Virto et al., 2012a), soil carbon sequestration (Eldon and Gershenson, 2015), water management (Brillante et al., 2015; Terrón et al., 2015), the use of alternative soil managements to revert soil degradation (Steenwerth and Belina, 2008a) and especially soil loss (Marques et al., 2010; Novara et al., 2011; Peregrina et al., 2014). However, there is a lack of knowledge regarding nutrient loss and how alternative soil management strategies can influence nitrate loss (Steenwerth and Belina, 2008a; Novara et al., 2013).

The effects of nutrient loss can be classified in on-site and off-site effects. On one hand, on-site effects consist in a fertility loss and reduction in crop yields caused by decreasing soil nutrients (Mekonnen et al., 2015; Tsozué et al., 2015). On the other hand, off-site effects are produced by an abnormally high nutrient concentration in water bodies such as rivers, reservoirs and groundwater, as well as reservoirs silting by eroded sediments (Hildebrandt et al., 2008).

Nitrate leaching became a serious concern due to a general misuse of nitrogen fertilizers (Flower et al., 2012). This occurs mostly in arable crops from central and northern Europe because of high percolating soil regime (Valkama et al., 2015), but also in semiarid Mediterranean drylands (Gabriel et al., 2013; Quemada et al., 2013). Currently, it is well understood that changing

traditional management to the use of cover crops as catch crops reduces leached and nitrogen loss (Zupanc et al., 2011).

In large areas of central Spain, vineyards are usually rainfed and not fertilized. However, European Union payments per mechanization and the willingness to reach higher yields promoted new intensive irrigated and fertilized vineyards. In Mediterranean vineyards, which can register high intensity rains, the loss of nitrogen could be up to 100 kg ha^{-1} in one single storm (Ramos and Martínez-Casasnovas, 2004). Nevertheless, few researches have been devoted to measure nutrient export by runoff (Novara et al., 2013) because its measurement in field conditions is costly and onerous.

Runoff simulations

Rainfall simulators have been widely used in order to investigate hydrological and erosional processes at watershed and vineyard scales or to compare soil management strategies (Grismer, 2016; Marques et al., 2007; Rodrigo Comino et al., 2016a). On the other hand, runoff simulators contributes to the understating of erosion processes because the effect of runoff in particle detachment, transport and nutrient loss is analyzed separately from the raindrops impacts, which makes the difference with rainfall simulators. Runoff simulations do not simulate actual rains and cannot be referred to certain return period. Nevertheless, it is a suitable methodology to compare between soil treatments. Runoff simulations have been performed to model nutrient and sediment losses (Little et al., 2005) and to assess the efficiency of buffer strips (Van Dijk et al., 1996). However, runoff simulators have never been used to assess runoff and nutrient loss in Mediterranean woody crops with different soil management strategies, which can provide valuable information about hydrological processes in vineyards and what is the effect of different soil management strategies because a significant part of the total nutrient loss is lost dissolved in runoff.

Alternative soil management strategy: Groundcovers

Due to the soil degradation condition in vineyards, there is a need to develop alternative soil management strategies to reduce soil erosion by water and increase SOM. The main technique is the use of groundcovers (GC). There are several types of GC that can be applied in woody crops.

Firstly, GC can be permanent, when it is mowed but is never tilled. Secondly, GC can be temporary, when the GC is tilled once or several times or for a certain time period. However, GC can be living or inert. Living GC consist in the development of a growing plant cover that can be seeded of a

particular species or mixture, or, simply, spontaneous. Inert GC is defined as the mulching of the inter-rows with a non-living material such as plastic or straw (Giménez-Morera et al., 2010; Hueso-Gonzalez et al., 2016). This doctoral dissertation is focused on the use of permanent (Fig. 0.4) and temporary living GC.

Figure 0.4. Detail of a living GC recently mowed.

Soil tillage influences in nutrient losses. Generally, nutrient concentrations in runoff are higher in soil conservation tillage, whereas the total nutrient losses are higher in conventional soil tillage (Guadagnin et al., 2005). GC have proved to be an effective soil management to reduce water erosion (Keesstra et al., 2016b; Marques et al., 2010; Novara et al., 2011) and increase SOC (Ruiz-Colmenero et al., 2013; Steenwerth and Belina, 2008a). Plant cover itself intercepts raindrops, reducing their kinetic energy and increasing soil tortuosity and roughness to decrease water flow velocity (Visser and Sterk, 2007). Consequently, the ability of water to detach soil particles and nutrients decreased. In addition, GC produces an augment of SOC that increase aggregate stability and improves soil structure (Virto et al., 2012a) and infiltration (Biddoccu et al., 2016).

Groundcovers: grape and wine

GC promote higher infiltration rates (Ruiz-Colmenero et al., 2013) and reduce runoff, which increase soil water storage. However, GC consume water and can produce yield reductions by water competition when water is a limiting factor (Hartwig and Ammon, 2002). Nevertheless, GC influences on grape yield is controversial as is affected by many factors (Ripoche et al., 2011). For instance, Ruiz-Colmenero et al. (2011) did not find statistical differences in one semiarid vineyard located in central Spain with approximately 400 mm of rainfall per year. GC are widely used to control plant vigor. At this regard, relative reduction in plant vigor could reduce stomatal

conductance in summer thought a total decrease in leaf area (Pou et al., 2011). Additionally increasing wine quality is often related to GC (Lopes et al., 2011; Guerra and Steenwerth, 2012; Lee and Steenwerth, 2013).

Most of the research based on the influence of GC on grape yield and quality has been performed on irrigated vineyards or with annual rainfall of 500 mm or more. Water scarcity is one of the most important limiting factors in agricultural semiarid regions. In central Spain, farmers relate the use of GC to water consumption and this, together with cultural reasons, generates a refuse to GC systematically (Marqués et al., 2015). Therefore, there is a need of research about the effects of GC on grape yield and must quality in representative vineyards of central Spain.

Relevance of this study

In vineyards, traditional management includes continuous tillage with bare soil that reduces SOC and produces higher erosion rates, runoff and nutrient loss. Alternative soil management strategies are necessary to break the “tillage negative feedback” (Fig. 0.5) and improve soil quality, meanwhile reducing runoff and nutrient loss. Although there are several studies showing the benefits of using GC in vineyards (Marques et al., 2010; Morvan et al., 2014; Ruiz-Colmenero et al., 2013; Virto et al., 2012a), GC are barely used mainly because of farmers cultural reasons. However, current soil degradation problems encourage developing further research to increase the knowledge on the advantages and disadvantages of using GC in semiarid Mediterranean vineyards and, thus, developing new policy according to sustainable land uses.

The present study is located in central Spain, in Madrid region, and was performed through a field trial in four vineyards of the Denomination of Origin “Wines of Madrid”. The GC use in Madrid region is reduced to 3.1 % of the vineyards (MAGRAMA, 2015b). Traditional vineyards management is becoming more intensive with irrigation, fertilization and training methods. Since in this region there is not legislation or policy to encourage sustainable soil management such as GC, this Thesis investigates in depth GC impacts on soil parameters, especially, SOC, mineral nitrogen losses by runoff and its influence on grape yield and quality (Fig. 0.5).

Figure 0.5. Tillage and the negative feedback and proposed alternative management strategy, hypothesis and objectives. Soil organic matter (SOM). Blue arrows reflect a feedback. Green arrow reflects positive outcomes. Red arrow reflects negative outcomes.

Thesis's structure

After introduction section, where the main researching topics will be addressed, this thesis will be structured in four chapters with the results of the field trial. A general discussion will be presented to assess a joint view of the findings and its interpretations. After that, conclusions and the attainment of the established objectives will be added. Finally, future lines for a new research proposal will be carried out.

Chapters:

Chapter 1. **Nitrogen losses in vineyards under different types of soil groundcover. A field runoff simulator approach in central Spain.** Published in 2017 in Agriculture, Ecosystems and Environment (García-Díaz et al., 2017) assessing runoff and nitrates loss with different soil management strategies throughout the use of a runoff simulator that was designed by the research team.

Citation:

García-Díaz A, Bienes R, Sastre B, Novara A, Gristina L, Cerdà A. 2017. Nitrogen losses in vineyards under different types of soil groundcover. A field runoff simulator approach in central Spain. Agric., Ecosyst. Environ. 236:256-267. doi: <http://dx.doi.org/10.1016/j.agee.2016.12.013>.

Chapter 2 **Labile and stable soil organic carbon and physical improvements using GC in vineyards in central Spain.** Submitted to Agriculture for Sustainable Development. The chapter evaluates the GC influence on labile and stable organic matter as well as physical parameters three years after the GC establishment.

Chapter 3. **Carbon input threshold for soil carbon budget optimization in eroding vineyards.** Published in 2016 in Geoderma (García-Díaz et al., 2016). Exploring if the SOC increases when GC are performed could suppose environmental problem through higher carbon loss than with conventional tillage.

Citation:

García-Díaz A, Bienes R, Gristina L, Cerdà A, Pereira P, Novara A. 2016. Carbon input threshold for soil carbon budget optimization in eroding vineyards. Geoderma 271:144-149. doi: <http://dx.doi.org/10.1016/j.geoderma.2016.02.020>.

Chapter 4. **Grape yield and quality and soil organic carbon sequestration value in Mediterranean semiarid vineyards using groundcovers.** Submitted to Agricultural Systems. This chapter assesses the influence of GC in grape yield and quality in three vineyards during three agronomy seasons and it was related to the carbon sequestration rates to explore the economic value of the sequestered carbon.

GENERAL OBJECTIVES

The general aim of this doctoral dissertation was to assess the influence of GC in semiarid vineyards on soil physical and chemical properties, runoff and mineral nitrogen loss.

Specific objectives were:

- i. To quantify runoff and mineral nitrogen loss with the use of GC and traditional tillage, to determine the main factors that affect them throughout runoff simulations.
- ii. To assess the influence of GC on labile and stable organic carbon, on a set of physical properties and the relationships between variables three years after the GC establishment.
- iii. To answer the following questions: With the use of GC, It is possible to increase SOC without resulting in higher carbon loss due to erosion? Is there any SOC threshold where carbon loss was higher than with traditional tillage? It is possible to measure SOC threshold?
- iv. To evaluate grape yield and quality with the use of GC. To assess the economic impact of GC on grape yield and quality and relate economic income/loss to carbon sequestration rates.

CHAPTER 1. NITROGEN LOSSES IN VINEYARDS UNDER
DIFFERENT TYPES OF SOIL GROUNDCOVER. A FIELD RUNOFF
SIMULATOR APPROACH IN CENTRAL SPAIN

ABSTRACT

The soils of Mediterranean vineyards are usually managed with continuous tillage, resulting in bare soil, low infiltration and high soil erosion rates. Soil nutrients, such as nitrogen, could be lost dissolved in the runoff, causing a decrease in soil fertility on such degraded soils and producing eutrophication downstream. The influences of groundcover on the soil erosion processes and sediment yields in Mediterranean vineyards have been widely addressed. However, the runoff process itself, excluding the effect of raindrop impacts, has barely been studied. Thus, a field runoff simulator was built to assess runoff and nutrient losses under different soil management strategies in Central Spain. In the winter of the 2012-2013, four vineyards were selected, and two types of groundcover were established to compare with conventional tillage (T): spontaneous vegetation (CS) and seeded *Brachypodium distachyon* (CB). In 2014 and 2015, 72 runoff simulations were performed to assess the influence of the two different types of groundcover on the dissolved mineral nitrogen losses in runoff. The results showed that spontaneous vegetation cover was the most effective management choice to reduce runoff and nitrogen loss by producing 3 times less runoff than conventional tillage and 6 times less nitrate loss. Conventional tillage resulted in higher mineral nitrogen loss because it produced more runoff and higher runoff nitrate concentrations. The vegetation cover had a strong influence on runoff and nitrogen losses, while the slope angle and rock fragment cover showed a negligible impact.

1.1. INTRODUCTION

The Soil System is a key component of the Earth System because it controls the hydrological cycle via infiltration, evaporation and transpiration, the biological cycle due to photosynthesis, the erosional cycle, which determines the portioning of the rainfall and sediment delivery, and the geochemical cycles, such as the carbon cycle, which regulates the emission and sequestration of carbon via the decomposition of the organic matter (Brevik et al., 2015; Decock et al., 2015; Smith et al., 2015). The soil system is also relevant to achieve the sustainability of human societies and to supply goods, services and resources for the humankind (Keesstra et al., 2016a). Agriculture management can determine the fate of soils and thus the sustainability of human society as well as the Earth System because agriculture determines the rates of the processes involved in soil degradation (Bruun et al., 2015; Cerdà, 2000; Colazo and Buschiazio, 2015; Novara et al., 2015b; de Oliveira et al., 2015).

The joint occurrence of hilly topography (Tarolli et al., 2015), low organic matter inputs, high rainfall intensities (Panagos et al., 2015) and continuous tillage on bare soils (Arnaez et al., 2007; Cerdà et al., 2009) enhances the soil water erosion processes. All of the processes take place in most Mediterranean vineyards, which is the reason why this has been an important topic in the scientific literature (Prosdocimi et al., 2016a).

The typical soil management in Mediterranean vineyards includes several tillage operations per year to maintain the soil bare and avoid the competition between weeds and the crop for nutrients and water. Alternative forms of management, such as reduced tillage and the use of groundcover (GC), have been developed to reduce soil water erosion and increase soil organic carbon (Ruiz-Colmenero et al., 2013). Controlling water erosion with plant covers is widely accepted (Cerdà et al., 2016; Keesstra et al., 2016b). The plant cover intercepts raindrops, reducing their energy and acting as physical barriers to the overland flow of water and sediment, which reduces the runoff discharge and the sediment delivery (Buendia et al., 2016; Marchamalo et al., 2016; Masselink et al., 2016). GC enhances soil organic carbon (Castro et al., 2008; Steenwerth and Belina, 2008b), increasing aggregate stability and improving soil structure (Cerdà, 2000; Virto et al., 2012b), which causes higher infiltration rates (Biddoccu et al., 2016; Ruiz-Colmenero et al., 2013).

Most of the soil erosion research carried out in vineyards focuses on soil erosion processes: the detachment and the transport of sediments (Novara et al., 2011; Lieskovský and Kenderessy, 2014; Rodrigo Comino et al., 2015; Martínez-Casasnovas et al., 2016; Prosdocimi et al., 2016a;

Prosdocimi et al., 2016c; Rodrigo Comino et al., 2016b; Rodrigo Comino et al., 2016c). Another growing topic in vineyard research is the impact of management on the carbon cycle and the potential of the degraded soils in the vineyards to act as a net carbon sink (Galati et al., 2015; Galati et al., 2016; García-Díaz et al., 2016). Other studies performed recently are related to water management in vineyards (Brillante et al., 2015; Terrón et al., 2015), pollution (Marín et al., 2016) and soil biology (Costantini et al., 2015; Gagnarli et al., 2015). However, there is much less research devoted to nutrient losses in vineyards with different soil management strategies for nitrates (Steenwerth and Belina, 2008a; Steenwerth and Belina, 2010; Novara et al., 2013).

Soil erosion processes and the loss of nutrients cause on-site and off-site effects. On-site impacts are the decrease in available soil nutrients. Thus, a loss of soil fertility occurs and as a consequence, a reduction in crop yields (Mekonnen, M., Keesstra, S., Baartman, J., Ritsema, C., Melesse, A., 2015; Tsozué et al., 2015). Off-site effects result in polluted rivers, reservoirs and groundwater (Hildebrandt et al., 2008; Kalkhoff et al., 2016). Nitrate leaching is a source of water pollution and has been a concern within the scientific community, but it is also a management concern. As a result, there has been a reduction in nitrate leaching in arable crops through cover crops used as catch crops (Valkama et al., 2015; Quemada et al., 2013). However, orchards and vineyards avoid the use of cover crops, and the bare surfaces results in high erosion rates (Atucha et al., 2013; Sang-Arun et al., 2006; Cerdà et al., 2009; Bravo-Espinosa et al., 2014; Li et al., 2014; Taguas et al., 2015).

It is understood that under extreme Mediterranean meteorological events, fertilized vineyards can register high nutrient losses. In fact, Ramos and Martínez-Casasnovas, (2006) measured a loss of 100 kg of nitrogen per hectare in one single storm. Although the problem is relevant due to the on-site and off-site impacts of the soil and nutrients losses, there is no information available about the transport of dissolved nutrients, such as nitrogen from Mediterranean vineyards. This is because measuring nutrient losses in runoff is more difficult and costly than measuring the sediment yield (Ramos and Martínez-Casasnovas, 2004). Few studies have surveyed the nutrient export by runoff (Wang et al., 2016; Novara et al., 2013), and only few of them researched the nutrient discharge by the runoff (Molina-Navarro et al., 2014).

Water erosion is a function of both the detachment and transport of particles (Defersha and Melesse, 2012). As the slope increases, the surface wash becomes the dominant factor, and the sediment transport is very efficient (Battany and Grismer, 2000). In agricultural land under semiarid conditions, due to the compaction of the soils and the lack of organic material, the rainfall intensity exceeds the infiltration rate, and then surface runoff takes place (Esteves and

Lapetite, 2003). Rainfall simulation is a useful methodology to measure the loss of water, sediments and nutrients because it allows repetitions of the experiments and the accurate control of the rainfall intensity and distribution (Iserloh et al., 2013; Lassu et al., 2015; Grismer, 2016). Some of the research developed by means of rainfall simulation focuses on the effects of soil management and tillage systems (Franklin et al., 2007). However, runoff simulators have scarcely been used to measure and model nutrient and sediment losses (Little et al., 2005), and buffer strips efficiency (Van Dijk et al., 1996). Since some authors, such as Gómez et al. (2009), found that a significant fraction of the nutrient loss is dissolved in runoff, runoff simulations can be a useful apparatus to compare nitrogen losses under different soil management strategies.

In Central Spain, the vineyard management is changing from rainfed, low plant density vineyards to irrigated and chemically fertilized vineyards with a higher plant density (MAGRAMA 2009, 2010, 2011, 2012, 2013, 2015, 2015a). In addition, nearly 50 % of the Denomination of Origin “Wines of Madrid” area was declared a Nitrate Vulnerable Zone (NVZ) according to the Nitrates Directive (BOCM, 2009). Directive defined NVZs as the areas that drain into waters affected by nitrate pollution (Council of the European Communities, 1991). Moreover, in the study area, nitrogen pollution problems have been addressed (Arauzo and Jose Martinez-Bastida, 2015). Consequently, the reduction of nitrogen loss should be a central issue to develop sustainable management strategies.

Despite the advantages of GC for reducing erosion and improving soil quality, the use of GC in Spanish vineyards is found only in 5.0 % of vineyards (MAGRAMA, 2015a). In the Madrid region, it is even lower: 3.1 % (MAGRAMA, 2015c). This is mostly due to cultural reasons and the reduction in grape yields (Marqués et al., 2015). Ruiz-Colmenero et al. (2011) found that in two out of three trials, GC in rainfed vineyards reduced grape yields significantly. Nevertheless, this type of economic analysis tends to ignore the cost of erosion and nutrient loss. We hypothesized lower runoff rates and nitrogen losses with the adoption of GC, which can strengthen these practices from the farmers’ point of view. There is a gap between scientific and farmer knowledge, and the exchange of information with policy makers is poor (Marqués et al., 2015). Then, agro-environmental payments and agricultural managements were mainly encouraged in the context of the Common Agricultural Policy, without any adaptation to local conditions. In the Madrid region, there are no agro-payments designed to promote the use of GC in vineyards (BOCM, 2009) to reduce erosion or to avoid the economic impact of yield reduction.

The main objectives of this research are: i) to quantify the runoff and nitrogen losses under different management soil treatments; ii) to determine the main factors affecting runoff and nitrogen losses; and iii) to measure the trends of nitrogen losses throughout the simulations.

1.2. MATERIALS AND METHODS

1.2.1. Study area

The study was carried out on four sites located in the Denomination of Origin “Wines of Madrid”, Central Spain. The average annual temperature is 14.8 °C, and the average annual rainfall is approximately 400 mm. The selected municipalities were Belmonte de Tajo, Campo Real and Navalcarnero (Fig.1.1).

Figure 1.1. Location of the studied vineyards, Madrid region, Nitrate Vulnerable Zones and Denomination of Origin “Wines of Madrid” area.

All of the studied vineyards are located on sloping terrain, making them prone to water erosion. They represent the main soil types of the study area. The two Belmonte de Tajo vineyards (BEL-1 and BEL-2) are planted on a plateau composed of Miocene limestone parent material. The Campo Real vineyard (CR) is on alluvial deposits made of quartzite in a clayey matrix. Navalcarnero (NAV) is on arkoses deposits resulting from the erosion of the Central Spanish Mountain Range. One pit was excavated in each vineyard in the winter of the 2012-2013 to study the soils and their profiles. Soil samples from every horizon were collected to analyze the soil properties. The soil type, altitude, location and selected soil properties of the Ap horizon are shown in Table 1.1. The

variables were obtained as follows: altitude and location using a GPS device; slope using a manual inclinometer; pH using the potentiometric method, texture using the Robinson pipette method; and organic matter (OM) using the Walkley and I.A.Black (1934) method.

Table 1.1. Soil Classification (Soil Survey Staff, 2015), altitude, location, slope (%) of the experimental vineyards: Belmonte de Tajo (BEL-1 and BEL-2), Campo Real (CR) and Navacarnero (NAV). The pH, texture class and soil organic matter % (SOM) correspond to the Ap horizon.

Site	Soil Classification	Altitude (m)	Slope (%)	pH (1:2.5)	Texture class (USDA)	SOM (%)
BEL-1	Calcic Haploxeralf	754	7.2	8.5	Loam	1.38
BEL-2	Typic Haploxeralf	743	7.0	8.6	Clay-Loam	0.90
CR	Calcic Haploxeralf	783	13.4	8.6	Sandy Clay Loam	1.24
NAV	Typic Haploxeralf	586	13.5	7.7	Sandy Loam	1.21

1.2.2. Experimental design

The study was composed of 3 treatments that were performed in all 4 sites in 3 repetitions over two years ($3 \times 4 \times 3 \times 2 = 72$ tests) (Figure 1.2).

Figure 1.2. Runoff simulations layout. T: conventional tillage; CB: *Brachypodium distachyon*; CS: spontaneous vegetation.

The treatments were: i) conventional tillage (T), which consisted of 2-3 tillage operations per year, with the chisel at a depth of 20 cm, following the conventional soil management of farmers in the area; ii) *Brachypodium distachyon* (CB) cover, which was seeded in the central 2 m of the inter-

rows in December 2012; and (iii) spontaneous vegetation (CS). To keep the rows with bare soil for the easier management of the vines and to limit the competition effect of the cover, a row chisel pass was carried out every year. The vegetation cover treatments (CB and CS) were mowed at the height of 10 cm one or two times every spring depending on the cover development. This height allowed to CB cover to auto-seed year after year. The litter was left on the soil surface. One Gerlach type plot (Gerlach, 1967) was installed on each row: 3 per treatment and 3 repetitions per site. The plots were metal sheet-bounded and were 2 m long and 0.5 m wide (Fig. 1.3). To collect the simulated runoff, each plot had a trough.

Figure 1.3. View of the runoff simulation plots in the field. a) Lower view of a *Brachypodium distachyon* microplot with a trough to collect the runoff. b) Upper view of a spontaneous vegetation microplot with the drilled pipe to generate homogenous sheet flow.

1.2.3. Runoff simulator and experimental design

A runoff simulator was designed and built with the following objectives: (i) to produce sheet flow; (ii) to simulate runoff at different controlled discharge flows; (iii) to be portable and easy to move and manage; and (iv) to have a high water storage capacity to be independent of water sources. The runoff flow was controlled by a previously calibrated pressure gauge. Water runs off through 49 holes, which were drilled in a 16 mm pipe. Each hole was 1 mm in diameter, and the distance between holes was 1 cm. The water of the runoff simulations was taken from a 120 L deposit, which was fed from a 1000 L tank to be transported with a trailer. Therefore, the 120 L tank could be filled both by gravity or pumped. The 120 L tank was on a wheelbarrow, where the flow was controlled by a 12 v pump and a pressure gauge, and it was connected to the drilled pipe by a hose (Fig. 1.2).

The runoff simulations were carried out during the summer to avoid changes in soil moisture, and the plots were wetted before the experiments to reach similar soil moisture in all the plots prior to

the application of runoff sheet flow. The runoff simulations lasted 24 minutes. The goal of the runoff simulations was to create sheet flow in the plots to compare the hydrological behavior and nutrient losses between different soil management strategies. Thus, the applied flow was 192 L h^{-1} to ensure sheet flow in the four different studied locations and allow the comparison between them and with the findings of other researchers. Although we can simulate runoff at different flow discharges, in this set of experiments, we only used 192 L h^{-1} to make these plots comparable with the high magnitude low frequency rainfall events in the study area, which are the ones that generate overland flow (Gonzalez-Hidalgo et al., 2012). Every 2 minutes the total runoff was measured, and a sample was filtered, collected and stored in a portable refrigerator. Runoff simulations were performed in every plot in the summers of 2014 and 2015 for a total of 72 experiments.

1.2.4. Soil and runoff measurements

The soil cover of each plot (1 m^2) was determined every year immediately before the runoff simulations using $25 \times 25 \text{ cm}^2$ quadrats. Measurements of the percentages of vegetation and rock fragments were taken by 6 trained observers, and the average of the 6 observations was used. Each plot was divided in 3 sections (upper, middle and lower sections) and the average value of the three sections was taken. The results of this methodology are similar to those from that employ digital image analysis (García-Estríngana et al., 2005). Simultaneously to the simulations, soil samples were taken to analyze the nitrogen content as nitrates and as ammonium in the soil. Both were analyzed by extracting the soil with KCl 2 M in a 1:10 relationship (soil: solution) and shaken for 30 min. The extracts were analyzed with a FIAstarTM 5000 (Foss Tecator) analyzer. The same method was performed for the runoff samples. The runoff percentage was calculated as the relationship between the applied volume of water and the collected runoff.

1.2.5. Data analysis

The data were analyzed using a variance analysis (Factorial ANOVA) in the STATISTICA 10 software (StatSoft Inc., 2011). In the case of lack of normality, the variables were transformed. Treatment (T, CB and CS), Site (BEL1, BEL2, NAV and CR) and Year (2014 and 2015) were considered the factors, while runoff, nitrogen as nitrates lost in runoff (NO_3), nitrogen as ammonium lost in runoff (NH_4), nitrogen as nitrates concentration in runoff (NO_3c), nitrogen as ammonium concentration in runoff (NH_4c), nitrogen as nitrates in the soil (NO_3soil), nitrogen as ammonium in the soil (NH_4soil); vegetation cover percentage (%Cov), rock fragment cover (%Rf), and slope angle (%Sl) were dependent variables. The differences between means were evaluated with the post hoc

Bonferroni Test. Canonical analyses were used to assess relationships between Treatments, Sites, and Years with mineral nitrogen loss, runoff and soil variables. Three analyses were performed. The first analysis including T and CB as treatments. The second analysis including CB and CS as treatments, while the third analysis was performed grouping treatments as GC (CB and CS) and T.

1.3. RESULTS

1.3.1. Analysis of variance

Analyses of variance of the obtained data from 72 runoff simulations were performed. Runoff, NO_3 , NO_3soil , NH_4soil and %Cov were affected significantly by the soil treatment (Table 2). All the variables presented a significant effect with the Site. The interaction Treatment x Site was highly significant on Runoff, NO_3 , NH_4c , NO_3soil , NH_4soil , %Cov and %SI, while Site x Year showed a strong influence on all variables, with the exception of %Cov, %Rf and %SI. The Year had a significant effect on almost all variables, but as expected, %Rf and %SI were not affected. %Rf and %SI were determined exclusively by the Site. Table 1.2 shows that even with the variance included in different sites and field campaigns (Year), the use of GC significantly affects the runoff discharge and the loss of nitrogen as nitrates.

Table 1.2. Analysis of variance for nitrogen as nitrates lost in the runoff (NO_3), nitrogen as ammonium lost in the runoff (NH_4), nitrogen as nitrates concentration in the runoff NO_3c , nitrogen as ammonium concentration in the runoff NH_4c , nitrogen as nitrates in the soil (NO_3soil), nitrogen as ammonium in the soil (NH_4soil), vegetation cover percentage (%Cov), rock fragments cover (%Rf) and slope percentage (%SI). Treatments (Treat) were CB (*Brachypodium distachyon*), CS (Spontaneous Vegetation) and T (Conventional Tillage). Sites were vineyards in Belmonte de Tajo, Campo Real and Navalcarnero. Years were 2014 and 2015. Terms with p value >0.1 were not reported (NR). N=24.

Factor	Runoff	NO_3	NH_4	NO_3c	NH_4c	NO_3 soil	NH_4 soil	%Cov	%Rf	%SI
Treat	0.0019	0.0041	NR	NR	NR	0.0001	0.0022	<0.0001	NR	NR
Site	0.0001	0.0265	0.0003	0.0161	0.0009	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Year	<0.0001	<0.0001	0.0012	<0.0001	NR	0.0001	0.0020	0.02701	NR	NR
Treat x Site	0.0814	0.0009	NR	NR	0.0011	0.0011	0.0080	<0.0001	NR	0.0030
Treat x Year	NR	0.0044	NR	NR	NR	0.0061	0.0177	<0.0001	NR	NR
Site x Year	0.0401	0.0212	0.0004	0.0061	<0.0001	<0.0001	0.0013	NR	NR	NR
Treat x Site x Year	NR	0.0009	NR	NR	0.0031	0.0185	0.0015	NR	NR	NR

1.3.2. Groundcover influence

The first aim of this work was to study the effect of soil management on runoff and nitrogen loss, and hence, differences between treatments were analyzed. Because of different cover development and site characteristics, runoff was highly variable, ranging between 0 % and 69 %. Both GC showed lower runoff rates than the T plots, but only CS was statistically significant (Table 1.3). After analyzing the total nitrogen losses in runoff, we observe that CS generated 6 times less nitrates and 5 times less total mineral nitrogen in the runoff than T. CB showed a tendency to differ from T in these variables, but was not statistically significant. The NO_3 loss represents the main form of mineral nitrogen in the runoff. CS was the most effective treatment to reduce runoff and nitrogen losses. However, the nitrate concentration on the soil was higher in the T treatment than in the GC treatments. However, relative to NH_4soil , CS did not show differences with T, and only CB was significantly lower.

Table 1.3. Mean and standard deviation of the statistically significant results of the analysis of variance (factorial ANOVA) for the treatment factor. Runoff; nitrogen as nitrates lost in the runoff (NO_3); nitrogen as nitrates in the soil (NO_3soil); and nitrogen as ammonium in the soil (NH_4soil) and vegetation cover percentage. Values followed by different letters show significant differences ($p < 0.05$). $N=24$.

Treat	Runoff (%)	NO_3 (mg)	NO_3soil ($\text{mg}\cdot\text{kg}^{-1}$)	NH_4soil ($\text{mg}\cdot\text{kg}^{-1}$)	Vegetation cover (%)
T	22.73 $\pm$ 25.32 a	36.27 $\pm$ 74.74 a	0.76 $\pm$ 0.67 a	0.79 $\pm$ 0.44 a	6,95 $\pm$ 5,91 b
CB	13.65 $\pm$ 19.45 ab	16.05 $\pm$ 28.53 ab	0.50 $\pm$ 0.68 b	0.39 $\pm$ 0.36 b	38,39 $\pm$ 33,09 a
CS	7.09 $\pm$ 12.39 b	6.11 $\pm$ 12.78 b	0.44 $\pm$ 0.35 b	0.67 $\pm$ 0.84 a	35,81 $\pm$ 25.44 a

T: Conventional Tillage. CB: Vegetation cover of *Brachypodium distachyon*. CS: Vegetation cover of spontaneous vegetation.

1.3.3. Temporal runoff trends

The runoff discharge increased with time in all the experiments. The steady-state runoff discharge was not reached in any case (Fig. 1.4). The temporal increase of the runoff rates in GC was not as pronounced as in T. In all treatments, runoff was adjusted to a logarithmic model with high R^2 values, particularly in T and CB. In the last time interval (22-24 minutes after runoff initiation) the average runoff rates were 28.0 %, 15.8 % and 9.2 % of the applied discharge for T, CB and CS, respectively.

Figure 1.4. Evolution of runoff along the simulations for the three treatments (T: conventional tillage; CB: *Brachypodium distachyon*; CS: spontaneous vegetation) in time intervals of 2 minutes.

The concentration of nitrogen in the runoff has been analyzed to determine trends and different patterns between treatments (Figures 5 and 6). NO_3c was one order of magnitude higher than NH_4c , and both forms had differences in runoff loss. Thus, both forms were analyzed separately. As shown in Table 1.2, the influence of the Treatment was more remarkable for nitrates (Fig. 1.5) than for ammonium (Fig. 6). The concentration of nitrates in T decreased and followed logarithmic behavior, while CB and CS did not show any trends. In T, the concentration of nitrates in the first time interval was up to 4 times the concentration at the end of the experiment. An analysis of variance (Table 1.2) did not find differences in the NO_3c between treatments, but Figure 5 demonstrated that in the first time interval, the difference was considerable. In the first time interval, the NO_3c in T was up to two times higher than in CB and 18 times higher than in CS. The concentration of nitrates in CB followed a similar trend to that of T but with a low R^2 (0.34). CS showed no trends. The average values of NH_4c were always below 1 mg L^{-1} (Fig. 1.6). NH_4c showed an erratic evolution for all treatments, with no certain patterns and low values of R^2 . Figure 1.7 shows the accumulated runoff and mineral nitrogen loss simultaneously throughout the simulations. It was clear that from the beginning of the experiment, but especially from the 6th (10-12 minutes) to the 8th time intervals (12-14 minutes), that T had much higher values of runoff and mineral nitrogen loss than CB and CS. CS was revealed as the more effective treatment when the goal is reducing runoff and mineral nitrogen loss.

Figure 1.5. Evolution of the mean concentration of nitrogen as nitrates NO_3c (bars) in time intervals of 2 minutes with best fit equations (lines) for the three treatments (T: conventional tillage; CB: *Brachypodium distachyon*; CS: spontaneous vegetation).

Figure 1.6. Evolution of the mean concentration of nitrogen as ammonium NH_4c (bars) in time intervals of 2 minutes with best fit equations (lines) for the three treatments (T: conventional tillage; CB: *Brachypodium distachyon*; CS: spontaneous vegetation).

Figure 1.7. Evolution of the mean accumulated mineral nitrogen loss (the sum of nitrogen as nitrates and nitrogen as ammonium) in time intervals of 2 minutes on the Y-left axis (bars) and accumulated runoff on the Y-right axis (lines) for the three treatments (T: conventional tillage; CB: *Brachypodium distachyon*; CS: spontaneous vegetation).

1.3.4. Relationships between variables

The relationships between factors with dependent variables and their interactions have been analyzed with a canonical analysis (Fig. 1.8). First, we performed a canonical analysis with CB and CS as treatments. The scores of CB were -0.40 and 0.30 (Roots 1 and 2, respectively), and the CS scores were -0.52 and 0.36. Since these scores were similar and to facilitate interpretations, we performed a canonical analysis with CB and CS grouped as GC. As expected, the rock fragments and the slope were strongly influenced by the Site (Table 1.2). Consequently, Site was not included in the canonical analysis to avoid statistical problems with dependence. The canonical analysis extracted 27 and 19 % of the variability of the independent variables (Roots 1 and 2, respectively) and 15 and 11 % of the variability of the dependent variables. The ordination of variables (Figure 8) showed two main groups of variables (Group 1 and Group 2). Group 1 one included NO_3 , NH_4 , NO_3soil , NO_3c and Runoff and had a relatively high influence on the model. Group 1 was positively correlated, in Root 1, with T and negatively correlated with GC and the vegetation cover percentage. The analysis of variance did not show differences in nitrates or ammonium concentrations in the runoff (Table 1.2), but the canonical analysis found that more runoff meant a higher concentration of nitrates. As a consequence, T produces a higher loss of nitrates not only through higher runoff discharge, but because of a higher concentration of nitrates in the runoff. Group 2 included %Rf, %Sl and NH_4c , and had very low impact on the results. Thus, rock fragments cover and slope had a much lower influence on runoff and nitrates and ammonium loss than the vegetation cover. The Year had an effect on the results, correlating negatively in both roots with

the first group. As shown previously, the Year had a strong influence on most of the studied variables (Table 1.2). Ammonium measurements were less influenced by the Year. The relatively low extracted variability was attributed to the large number of variables included in the analysis. The canonical analysis showed that the GC generated less runoff and had lower mineral nitrogen concentration than T.

Figure 1.8. Ordination resulting from canonical analysis. Runoff, Years, GC: groundcover; T: conventional tillage; NO₃: total nitrogen as nitrates lost in the runoff; NH₄: total nitrogen as ammonium lost in the runoff; %Cov: vegetation cover; % Rf: rock fragment cover; NO₃soil: nitrogen as nitrates in the soil; NH₄soil: nitrogen as ammonium in the soil; NO₃c: nitrogen as the nitrates concentration in runoff; NH₄c: nitrogen as the ammonium concentration in runoff.

1.4. DISCUSSION

The typical soil management in Mediterranean vineyards consists of several tillage operations per year to maintain bare soil, which promotes erosion and soil degradation. Soil erosion and the loss of soil organic carbon and nutrients should be reduced because it can result in environmental problems, such of eutrophication (Quilbe et al., 2005; Bienes et al., 2010), the loss of soil fertility (García-Díaz et al., 2016) and economic concerns for the farmer (Martínez-Casasnovas and Ramos, 2006; Galati et al., 2015; Galati et al., 2016). This study was conducted to simulate sheet erosion and to measure runoff and dissolved inorganic nitrogen under different soil management strategies. The present experiment is the first to analyze nutrient losses caused by sheet flow in Mediterranean vineyards using a runoff simulator. In our experiments, the soil cover was low in comparison to vineyards in other regions of Europe (Novara et al., 2011; Rodrigo Comino et al.,

2015; 2016b; 2016c) because the farmers of the region near Madrid avoid any cover that can reduce the water available for their crops. Despite this difference, our results demonstrate that the use of GC in vineyards is not only a method to reduce water runoff, which has already been found by other researchers in orchards and vineyards (Cerdà et al., 2016; Keesstra et al., 2016b), but it is also an instrument to reduce mineral nitrogen losses via runoff, which has positive consequences for environmental pollution, soil fertility and the farmer's income.

This paper demonstrates that the impacts of raindrops are not the only key factor to control the runoff discharges. The low runoff rates in the covered plots in comparison to T demonstrate that the plants reduce the velocity and erosivity of overland flow. The litter layer mainly causes a delay and ponding of the runoff, which increased the infiltration rates, as has been described under rainfall simulation experiments (Cerdà, 1998; Wang et al., 2016), and the vegetation stems reduce the sheet flow velocity and prevents the development of rills (Ghahramani and Ishikawa, 2013; Sun et al., 2016; Zhao et al., 2016). On the other hand, the plants of the GC contribute root macropores, which improve water infiltration and produce more vertical connections than in the soils under tillage. The use of plant cover increases the biological macropores that increase the infiltration rates but also increases the amount of soil organic matter (Léonard et al., 2004; Cammeraat et al., 2010; Mekonnen et al., 2015). There is also an increase in fauna when GC are present. This increase in burrowing animals can increase the sediment available and the soil erosion at a patchy scale (Cerdà et al., 2009). However, the fauna activity results in an increase in infiltration and a reduction in soil losses, as organic farming has shown in comparison to the bare, chemically managed soils (Cerdà and Jurgensen, 2011).

The use of GC increases the spatial variability of the runoff responses as shown by the data that range from 0 to 69% in the vineyards studied in Madrid. This variability is reasonable and was due to the different covers between treatments and plots. The increase of vegetation cover results in a higher diversity and then in higher variability, such as that which occurs in the patchy distribution of vegetation in soils that are stressed by the lack of water or/and nutrients (Cerdà, 1997; Bochet, 2015; Certini et al., 2015).

The results of our experiments in the vineyards of Central Spain showed that CS reduced the nitrate loss produced in the T plots. Jiao et al. (2012) produced a similar finding, but our results disagree with Zhang et al. (2010), who did not find significant differences in mineral nitrogen losses between bare soil and two levels of covered soil. As expected, T was the treatment with the higher nitrate loss, since it was the soil management with significantly higher NO_3 soil. The nitrate was caught by the GC in the organic biomass (Gabriel et al., 2013; Gabriel and Quemada, 2011).

reducing the nitrate loss by runoff. The analysis of variance did not find differences in $\text{NO}_3\text{-c}$ and $\text{NH}_4\text{-c}$ between GC and T, which agrees with Guadagnin et al. (2005) and was in contrast with Zhang et al. (2010). CS produced 3 times less runoff and 6 times less nitrate loss. However, in the first time intervals of the simulations, T produced higher concentration of nitrates than both GC, but the concentrations were especially higher than CS. Consequently, in the studied vineyards, CS reduced mineral nitrogen losses by reducing the runoff rates but also because the concentration of nitrates in the runoff was lower during the first minutes of the simulations. Our results showed that cover correlates negatively with $\text{NO}_3\text{-c}$ and runoff rates, which are strongly correlated with each other and are linked to tillage (Figure 1.8).

The CB cover reduced the ammonium content of the soil compared with T and CS. In contrast to nitrate, the differences in ammonium concentration in the soil did not have influence on its loss through the runoff. The most of the ammonium ion is adsorbed in the clay-humic complex and, thus, when erosion take place it is lost attached to clay and organic matter particles. In this study, we focused on dissolved nitrogen forms in runoff. As a consequence, the amount of ammonium in the runoff is much lower than the amount of nitrates, and significant differences were not found. Furthermore, because of the low recorded values, the ammonium concentrations in the runoff followed no trends at any treatment. Regarding runoff and nitrate loss, CB tends to differ from T, but the differences were not statistically significant. This could be due to problems in the CB cover because of herbivory by rabbits, which are a plague in three out of the four vineyards. Soil macrofauna can disturb the soil runoff and erosion due to burrowing (de Araújo et al., 2015; Arnold and Williams, 2016). CS was barely affected. However, the cover % of CB and CS were almost the same (Table 1.3). Therefore, the larger size of stems and root systems of the different species of spontaneous vegetation had a decisive effect on reducing the runoff and nitrate loss, as found by other authors recently (Ni et al., 2015; Ola et al., 2015; Shaw et al., 2016).

The use of GC increase aggregate stability, which affects the infiltration rates and hence, the runoff (Holifield Collins et al., 2015). Moreover, GC blocked the sheet movement of water, making it remain longer at the same point and reducing the runoff. The runoff increased quickly in the first minutes, tended to stabilize, but did not reach a steady state after 24 minutes of the simulations. Our results agree with those of Little et al. (2005), who did not find a steady-state discharge after 30 minutes of runoff simulations. The evolution of nitrates and ammonium loss in the runoff showed that only the nitrates followed a good fit with a decreasing logarithmic equation, in contrast to the findings of Zhang et al. (2010). Nitrates were lost in greater amounts in the first 6-8 minutes of the simulated runoff. This trend is mainly caused by the high solubility of the nitrate ion

and because it is dissolved in the soil solution (Barger et al., 2006; Baptista et al., 2015). After 10 minutes, the differences between treatments were small.

The Year had the strongest influence on the measured parameters. We performed runoff simulations in equal conditions both years: during the summer and after more than two weeks without any rain and with strong evapotranspiration. Nevertheless, the rainfall and the temperatures were different every season, affecting the antecedent soil moisture, soil sealing and cover development. This could indicate that one year of field experiments are not enough to verify trends and findings when the goal is analyzing the influence of GC on runoff and mineral nitrogen loss. Moreover, we must highlight the high seasonal and temporal variability of the soils in the Mediterranean due to the effect of the droughts and the high interannual variability of the climate, which results in contrasting results (Keesstra et al., 2016b; Novara et al., 2016; Nunes et al., 2016; Van Eck et al., 2016).

Arnaez et al. (2007) found that slope had an influence on soil loss and runoff. However, our data showed little influence from the slope on runoff and mineral nitrogen loss. This could be due to the low range of slopes of the studied vineyards, which range from 6 to 15 %. On the other hand, many researchers have addressed the importance of rock fragments to reduce runoff and soil erosion processes (Nachtergaele et al., 1998; Poesen and Lavee, 1994; Ruiz Sinoga and Martinez Murillo, 2009). In this case, the rock fragment percentage ranged from 1.9 to 78.9 %, and its impact on runoff or nutrient loss was minor. Based on our research, we attributed this to two factors: i) the lack of raindrop impacts in our experiment could indicate that the main effect of rock fragments on reducing runoff and nutrient loss is the protection of the soil against raindrops; and ii) vegetation cover is more effective at reducing runoff and mineral nitrogen loss than rock fragments in Mediterranean vineyards under sheet flow.

1.5 CONCLUSION

The use of GC in vineyards is not only a method to reduce sediment and water losses, as shown by the scientific literature, but it is also an instrument to reduce nitrogen loss via runoff, which has positive consequences, such as reducing environmental pollution, increasing soil fertility and improving farmer income. In this regard, spontaneous plant cover (weeds) is more efficient than a GC such as *Brachypodium dystachyon*. Tillage is the form of management that results in the highest losses of nitrogen and water. The vegetation cover is the key factor in the runoff and nitrogen yield, while the slope and rock fragment cover have less impact. Tillage is the form of

management that yields more nitrogen because more runoff is generated in ploughed soils and because the concentration of nitrates in the runoff is higher.

CHAPTER 2. LABILE AND STABLE SOIL ORGANIC CARBON
AND PHYSICAL IMPROVEMENTS USING GC IN VINEYARDS
FROM CENTRAL SPAIN

ABSTRACT

Mediterranean vineyards are usually managed with continuous tillage to maintain bare soils leading to low organic matter stocks and soil degradation processes. The vineyards are part of the Mediterranean culture and in order to make vineyards a sustainable land use we propose the use of two types of groundcover (GC). Therefore, a field trial was performed to compare the effects of a seeded (*Brachypodium distachyon*) and spontaneous GC 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 the soil organic carbon stocks increased in 1.62 and 3.18 Mg ha⁻¹ for the seeded and the spontaneous GC, respectively, regarding to conventional tillage. Both labile and stable soil organic carbon increased with the use of GC, but the labile fraction increase was higher. Moreover, the soil structure and functional soil properties improved through an increase in the aggregate stability, the pore connectivity and infiltration rates. The higher root biomass input of the spontaneous groundcover derived in higher soil organic carbon increases and soil quality improvement.

2.1. INTRODUCTION

Soil conservation is essential to supply goods, services and resources for the humankind (Keesstra et al., 2016a). Agriculture causes several environmental impacts and particularly soil degradation processes (Bruun et al., 2015; Colazo and Buschiazzo, 2015). The severity and intensity of soil degradation is determined by the methods and techniques of managing soil systems (Lorenz and Lal, 2016; Kabiri et al., 2016; Zhang and Ni, 2017). In the context of agricultural land uses, Mediterranean vineyards undergo a sort of soil degradation processes: soil erosion, organic matter loss; nutrient loss and, thus, a decreasing fertility. Soil erosion rates are especially high in Mediterranean vineyards reaching figures up to 100 Mg ha⁻¹ (Prosdocimi et al., 2016a; Rodrigo Comino et al., 2016b; 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 this region can be high (Panagos et al., 2015), 3) soils used for growing vineyards have low organic matter content and therefore weak structure and (4) soil management usually consists in continuous tillage (Novara et al., 2011). Soil degradation results in particle detachment and organic matter loss (Bienes et al., 2010), which makes the 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, the water runs off over the soil surface causing nutrient loss and soil particle detachment (Gómez et al., 2009; Ramos and Martínez-Casasnovas, 2004). Farmers usually remove these crusts by tilling after rains. As a consequence, each time that the farmer ploughs, fraction of soil organic matter is mineralized, soil aggregates became more easily destroyed and the crust formation will happen earlier during the forthcoming rainfalls. This way, Mediterranean vineyards experience continuous negative feedbacks caused by soil management practices.

The importance of soil degradation and erosion processes is usually underestimated. Not only because it causes on site and off site effects, but because decreases soil fertility, reducing crop yields (Bakker et al., 2004), and promoting land use changes (Bakker et al., 2005). In the beginning, soil damages mean costs for the farmers but in the end they turn on 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) is one of the most important soil parameters because it enhances the global soil quality by improving physical, chemical and biological soil characteristics (Virto et al., 2012a; Ramos et al., 2010; Fernández-Ugalde et al., 2009). SOM is related to aggregate stability,

soil structure, water infiltration and chemical fertility (Balesdent et al., 2000; Reeves, 1997). At this regard, climate change models agree that in the next decade the temperatures will increase in Mediterranean Basin, and this will increase organic matter mineralization rates (Pachauri et al., 2014). Taking into account that soils in Mediterranean vineyards have low organic matter contents (Panagos et al., 2013), changing the conventional soil management practices to other more sustainable alternatives will counterbalance mineralization and increase or maintain SOM. When a fresh plant residue falls in the soil, it becomes a particulate organic matter (POM) for a while, before humification processes (Gregorich and Janzen, 1996). Because of that, soil is enriched in SOM and nutrients and POM is considered as a good indicator of soil quality (Haynes, 2005). Besides, POM acts as binding agents stabilizing macroaggregates (Six et al., 2002) which makes it an important variable to be considered to study soil management strategies in Mediterranean soils.

The soil structure concept reflects how soil particles are aggregated. As a physical soil characteristic, the soil structure is a key factor to explain soil functioning (Bronick and Lal, 2005) and aggregate stability is commonly used as its indicator (Six et al., 2000a). SOM, microorganisms, clay, bivalent cations and ionic bridging are the main factors controlling soil aggregation. SOM has a main role as a binding agent between soil particles and its importance in aggregate stability is critical (Six et al., 2004). 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 the aggregate stability differently.

Pore volume and pore size distribution are important factors in the soil-water relationships and soil aeration. Moreover, the biochemical processes take place in the soil pores (Jigău, 2012). Different soil management strategies can have an influence on the pore volume (Mulumba and Lal, 2008; Pituello et al., 2016) and 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). On the other hand, the roots of the vegetation cover create continuous pores enhancing infiltration (Glinski and Lipiec, 1990).

In this study, we use the term groundcover (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., 2016a; Duran Zuazo and Rodriguez Pleguezuelo, 2009), increasing SOM (Virto et al., 2012b) or infiltration rates (Ruiz-Colmenero et al., 2013; Six et al., 2004). Temporal GC has been probed as very effective tool to erosion control (Novara et al., 2011), but the tillage, even if it is minimum, reduces the SOC increase threshold

(García-Díaz et al., 2016). Consequently, the use of permanent GC is advisable in order to get significant and long term SOM increases.

Although vineyards in central Spain suffer all previously described degradation processes, the majority of farmers 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, 2015c). Moreover, in the study area, the Common Agricultural Policy's agri-payments do not consider the use of GC in vineyards in any case (BOCM, 2009). In Europe, each country and region have the autonomy to develop their own agri-payments in the context of the Common Agricultural Policy to encourage sustainable soil management and, in this context, seeded and spontaneous GC use to have different considerations. 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. This management consists in seeded GC with leguminous species from October to April. In April, the GC are mowed and tilled. This soil management is very effective controlling soil erosion and decreasing N loss (Novara et al., 2011; Novara et al., 2013). In Rioja Protected Denomination of Origin the farmers receive different payments by using seeded or spontaneous GC (BOR, 2015). 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.

Soils enriched in SOM are also carbon sinks to fight against global warming (Poeplau and Don, 2015; Yagioka et al., 2015). In this regard, the soil carbon content (SOC) in 0.1 m depth in the vineyards of this study is going to be addressed as well considering the composition of SOM as 58 per cent carbon. The 4 per mille initiative is a new strategy for climate change mitigation through a good soil management promotion. The goal is to increase global soil organic matter stocks by 0.4% per year in order to compensate anthropogenic sources of global emissions of greenhouse gases (Minasny et al., 2017). Sequestration rates may be high during initial years following sustainable management practices but they can decline as time progresses due to the achievement of soil equilibrium in C stock.

Frequently C 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 condition (Stockmann et al., 2015).

With the main goal of studying the effect of two permanent GC (seeded and spontaneous) on soil properties and C sequestration in comparison with conventional tillage, we performed a trial including 4 different vineyards in the south of Madrid, with different soil characteristics which are representative of a large area of central Spain. We studied a set of soil parameters three years after the GC establishment: SOC and the carbon of two fractions of the organic matter (particulate organic matter and organic matter associated to the mineral fraction); the aggregate stability with two different methods; the root content, the pore volume and pore size distribution; bulk density; intrapedal porosity; penetration resistance and infiltration rates. By including four different vineyards with different soils, slopes, orientations, vine varieties, prune systems, cultivation methods and microclimates we want to assess the effects of soil management strategy. Finally, the set of parameters was analyzed by multivariate analysis to improve the understanding of the relationships between soil variables.

2.2. MATERIALS AND METHODS

2.2.1. Study area

The trial was performed on four vineyards located in the Denomination of Origin “Wines of Madrid”, in the center of Spain. The annual rainfall is approximately 400 mm and the average temperature is 14.8 °C. We selected four vineyards located on sloping terrain in the municipalities of Campo Real, Belmonte de Tajo (two vineyards) and Navalcarnero. With the selection of these vineyards, we tried to represent the main soil types of the study area. The vineyards and the rows of the trials were also selected for having at least 9 consecutives inter-rows with the same soil and terrain characteristics. The Belmonte de Tajo vineyards are planted on a plateau on Miocene limestone parent material. Campo Real vineyard is located on ancient alluvial deposits with quartzite stones and clayey matrix. Navalcarnero vines are growing on soils over arkoses deposits resulted from the Central Spanish Mountain Range erosion. Pits for soil classification and analyses were performed before the GC establishment. All soils were classified as Haploxeralfs (Soil Survey Staff, 2015) with an altitude ranging from 586 and 783 meters above the sea level (Table 2.1). Slopes were moderate (7 to 13.5 %) and the SOC contents and electric conductivity values were low (less than 200 $\mu\text{S}/\text{cm}$). On the one hand, the soils of Belmonte de Tajo and Campo Real vineyards are carbonated, which pH ranges from 8.5 to 8.6 and have active lime presence. On the

other hand, Navalcarnero vineyard does not have carbonates nor active lime and its pH is 7.7. The cation exchange capacity is medium to low and textures were similar with the exception of the high sand percentage in Navalcarnero vineyard.

Table 2.1. Soil Classification (Soil Survey Staff, 2015) and main soil characteristics of the vineyards. The trial had vineyards located in Belmonte de Tajo municipality (Bel-1 and Bel-2), Campo Real (CR) and Navalcarnero (Naval). The soil organic carbon (SOC), pH, electrical conductivity (EC), carbonates, active lime, texture class and cation exchange capacity (CEC) correspond to the Ap horizon.

Site	Soil Classification (USDA)	Altitude (m)	Slope (%)	SOC (gr kg ⁻¹)	pH (1:2.5)	EC (μS cm ⁻¹)	Carbonates (%)	Active lime (%)	Clay (%)	Silt (%)	Sand (%)	CEC (meq 100 g ⁻¹)
Bel-1	Calcic Haploxeralf	754	7.2	8.1	8.5	162	27.8	8.7	24.0	31.5	44.5	14.9
Bel-2	Typic Haploxeralf	743	7.0	5.2	8.6	144	20.0	4.4	27.5	38.5	34.0	18.8
CR	Calcic Haploxeralf	783	13.4	7.2	8.6	160	16.1	6.2	31.5	18	50.5	12.2
Naval	Typic Haploxeralf	586	13.5	7.0	7.7	145	0.1	<0.1	24.5	8.5	67.0	14.0

2.2.2. Experimental design

The trial started in the winter of 2012/2013 with the selection of the four studied vineyards. The treatments were: i) conventional tillage (T) consisted in 2-3 tillage operations with chisel (20 cm depth) per year following the typical soil management practice of the farmers of this area; ii) *Brachypodium distachyon* groundcover (hereafter CB), seeded in the central 2 m of the inter-rows in December 2012 being the seeding rate 20 kg ha⁻¹; and, iii) spontaneous vegetation cover (hereafter CS). A row chisel pass was carried out every year to maintain bare soil for easing the vines operations (prune and harvesting). Both vegetation cover treatments (CB and CS) were mowed every spring once or twice a year, depending on the rainfall regime, at the height of 10 cm. The resulted straw residue or litter was left on the soil surface. This height allowed the CB treatment to auto-seed. We performed the 3 treatments in all 4 sites with 3 repetitions according to (García-Díaz et al., 2017).

2.2.3. Soil sampling and laboratory methods

In the summer of 2015, 9 soil samples per treatment were collected from the 4 vineyards at 0 to 5 cm and 5 to 10 cm depth. Soil samples were air-dried and sieved to obtain various sized fractions to carry out soil tests as described below. Texture was determined with Robinson pipette method.

Soil organic carbon can be found in different forms and potentials to be stable or recycled, thus the need to identify stable and labile fractions.

The organic matter content associated to the soil mineral fraction is considered as the stable fraction of organic carbon as it can be found at water stable aggregates. The mineral fraction was separated from the total organic matter by dispersing 10 g of the 2 mm sieved fraction in 30 mL of sodium hexamethaphosphate (5 g L^{-1}) and further shaking for 15 h. Then, the dispersed soils were wet sieved at $50 \mu\text{m}$ and the different fractions were oven-dried at 50°C (Cambardella and Elliott, 1992). SOC and mineral-associated organic carbon (MOC) were determined by Walkley and I.A.Black (1934) method. Soil organic carbon of the particulate organic matter (POC) was obtained as the difference between SOC and MOC. POC fraction is considered as the labile organic matter mainly composed of litter, roots and animal remains, i.e. readily available material for decomposition by microbial attack.

SOC, MOC and POC stocks were obtained based in Equation 2.1.

$$\text{C Stock (Mg ha}^{-1}\text{)} = [\text{SOC, MOC or POC}] \times \text{BD} \times \text{D} \times 10 \quad (\text{Eq.2.1})$$

where: SOC is soil organic carbon (fraction $< 2 \text{ mm}$) (g kg^{-1}); MOC is the mineral-associated organic carbon (g kg^{-1}); POC is particulate organic carbon (g kg^{-1}); BD is the bulk density (Mg m^{-3}); and D is the sampling depth (m).

The plant roots percentage was determined in undisturbed soil samples obtained by drill sampling ($\varnothing=2.18 \text{ cm}$) at 0-5 and 5-10 cm depth taking 9 samples per treatment. The samples were air dried, weighed and wet sieved at 0.2 mm . Then, water and roots were vacuum filtered with a Büchner funnel and Kitasato flask over a tared paper filter. The obtained filters with roots were oven-dried at 105°C for 24 h and weighed. The root stock was calculated with Eq. 1 but C was substituted by the root content.

There are several methodologies to assess aggregate stability (Hernanz et al., 2002; Imeson and Vis, 1984) and a number of researches have addressed the increase in the aggregate stability with organic amendments (Hontoria et al., 2016; Peng et al., 2016; Rahman et al., 2017) or the use of cover crops (Ruiz-Colmenero et al., 2011; Salomé et al., 2016). But most of them include only one aggregate stability test. Knowing that the results can be different by using different methodologies, we propose including two aggregate stability tests to assess the effects of different soil management strategies on aggregate stability and, thus, soil structure.

The first method was performed by counting the number of drops (CND) needed to break aggregates. An aliquot of soil samples was dry sieved to obtain macro-aggregates with diameter size between 4 to 4.75 cm (Boix-Fayos et al., 2001) to perform the CND test. Thirty macro-aggregates of each soil sample (9 samples per treatment) were used to perform resistance to drop

impact test (Imeson and Vis, 1984) by the CND method. The second method was the water stable aggregates WSA method, that was expressed as the percentage of the <2 mm aggregates resistant to wet sieving (Kemper and Rosenau, 1986). Aggregate samples were submerged and emerged over a 0.25 mm sieve at 30 oscillations per minute during 3 minutes. These calculations were corrected for sand content. Three subsamples of 5 g were evaluated (9 samples per treatment).

2.2.4. Soil cores: macro, meso, microporosity, water holding capacity and bulk density

To obtain the macro, meso and microporosity, total porosity, water holding capacity (WHC) and bulk density, 9 undisturbed soil cores per treatment were taken in the 4 vineyards. The cores have 5 cm of diameter and 5.1 cm of height (100 cm³). The cores were taken with the objective of sampling the first 5 cm of depth, however, to ensure that 100 cm³ were exactly sampled, the first 2 to 3 cm of the surface soil were removed to avoid irregularities mainly caused by the vegetation. Consequently, the final sampled depth was between 2-3 and 7-8 cm deep.

The cores were water saturated by capillarity in a sandbox. Then, increasing suctions from pF 0 to pF 4.2 were applied. In the sandbox pF ranged from 0 to 2, and in the pressure plates system (Richards, 1941; Richards, 1965) pF ranged from 2.54 to 4.2. As the last step, the samples were completely oven dried (24 h at 105°C) to calculate the bulk density. We define the different pore size groups following the classification suggested by (Taboada et al., 2004) which separates macropores (those pores > 60 µm; pF from 0 to 1.8), mesopores (those pores between 60 and 10 µm; pF from 1.8 to 2.54) and micropores (those pores ≤ 10 µm; pF>2.54). Water holding capacity (WHC) was calculated as the difference between the moisture held in soil microporosity and that of the permanent wilting point (pF = 4.2). Not available water (NAW) was calculated as water content below the permanent wilting point. pF data were also used to determine water retention curves. We used RETC software (van Genuchten et al., 1991) to calculate the parameters of the empirical equation Eq.2.2 modified by van Genuchten and Nielsen (1985).

$$\theta_h = \theta_r + (\theta_s - \theta_r) [1 + (\alpha h)^n]^{-m} \quad (\text{Eq 2.2})$$

Where θ_h is the water content at tension h (m³ water m⁻³ soil); θ_r is the residual water content (m³ water m⁻³ soil); θ_s is the saturated water content (m³ water m⁻³ soil); α is the inverse of the air entry suction (m⁻³); n is a dimensionless value related with the pore size distribution; m is $1 - (1/n)$ and h is the suction pressure.

Intrapedal porosity was assessed using the petroleum method (Mursec, 2011). Aggregates were weighed, submerged in petroleum oil during 24 h to allow pores to infill. The mass difference was used to calculate the intrapedal porosity.

2.2.5. Field tests and determinations

Infiltration rates were obtained with a simple-ring infiltrometer of 12.5 cm of diameter (USDA, 1998) by recording the time necessary to infiltrate 25 mm of water and repeating it for 10 times. Nine infiltration tests were performed on each treatment of each vineyard (3 treatments x 4 vineyards x 9 infiltration test).

Penetration resistance was assessed using an Eijkelkamp® penetrometer. It was carried out 27 times per treatment for the four vineyards at the depths of 2.5, 5, 10, 15, 20, 25, 30, 35, 40 and 45 cm.

The vegetation cover percentage was determined in three random spots along each row of each treatment (3 spots x 3 rows x 3 treatments x 4 vineyards) at the beginning of the summer using 25 x 25 cm² quadrats. At each spot, the average of 6 observations from 6 trained observers was used to determine the percentage of vegetation cover. This methodology results in similar values than those obtained employing digital image analysis (García-Estríngana et al., 2005).

2.2.6. Data analysis

Before the data analyses, the variables were checked and transformed to ensure normal distribution of data if needed. The analyses were developed in different stages using Statistica 10 software (StatSoft Inc., 2011). First, we conducted a variance analysis (Factorial ANOVA). Factors were the soil treatment (CB, CS and T), site (the four studied vineyards) and depth (0-5 cm and 5-10 cm). The dependent variables were SOC, MOC, POC, CND, WSA, roots, BD, intrapedal porosity and vegetation cover. After that, the variables were analyzed by separating depths, except BD and intrapedal porosity as they have been studied for the same depth. Considering that penetration resistance was measured for many depths we performed simple ANOVA at each depth with soil treatment as the only factor. Further, macro, meso, microporosity, WHC, NAW and infiltrations were analyzed with simple ANOVA with soil treatment as a factor. Canonical analyses were used to assess the relationships between soil treatments (CB, CS and T) and dependent variables. Soil treatments were previously codified as dummy variables to include them in canonical analysis.

2.3. RESULTS

2.3.1. Soil organic carbon and fractions

The factorial ANOVA showed that SOC, MOC and POC were strongly affected by the soil treatment and the site (Table 2.2). The depth had influence in SOC and MOC but not in POC. The interaction [Treat x Site] was strongly significant on SOC and lower on MOC. [Treat x Depth] and [Site x Depth] had overall low significance and only [Site x Depth] for POC had a big influence. Again, POC was the only organic carbon fraction with a big influence of the interaction [Treat x Site x Depth].

Table 2.2. Results from the analysis of variance for soil organic carbon (SOC), mineral-associated organic carbon (MOC), soil carbon of the particulate organic matter fraction (POC). The treatments were CB (*Brachypodium distachyon*), CS (Spontaneous Vegetation) and T (Conventional Tillage). Sites were vineyards in Belmonte de Tajo (two vineyards), Campo Real and Navalcarnero. Depth were 0-5 and 5-10 cm. Different letters mean differences between treatments for the 0-10 depth at $p < 0.05$. Terms with p value > 0.1 were not reported (NR).

	Treat	Site	Depth	Treat* Site	Treat* Depth	Site* Depth	Treat* Site*Depth
SOC	<0.001	<0.001	<0.001	0.001	0.091	0.014	0.051
MOC	<0.001	<0.001	<0.001	0.011	NR	NR	0.040
POC	0.004	<0.001	0.083	NR	0.047	0.003	0.001

For both studied depths the differences between treatments were the same for SOC, MOC and POC: with CS showing significantly higher carbon values than T, while CB did not differ from CS and T (Fig. 2.1). The MOC stocks for the different treatments were 8.85, 9.72 and 8.03 Mg ha^{-1} for CB, CS and T, respectively, which mean a relative increase of 10 % for CB and 21 % for CS compared to T. POC contents were 4.06, 4.75 and 3.75 Mg ha^{-1} for CB, CS and T, respectively. The relative increase caused by GC was 25 % for CB and 46 % for CS. Three years after introducing groundcovers CB increased SOC in 1.62 $\text{Mg ha}^{-1} \text{ year}^{-1}$ and CS did it in 3.18 $\text{Mg ha}^{-1} \text{ year}^{-1}$ regarding T.

Figure 2.1. Mean of soil organic carbon (SOC), mineral-associated organic carbon (MOC) and soil organic carbon of the particulate organic matter fraction (POC) for the different treatments for the 0-10 cm depth. CB (*Brachypodium distachyon*), CS (spontaneous vegetation) and T (conventional tillage). Different letters mean significant differences between treatments at $p < 0.05$. Surrounded letters refer just to SOC statistical differences. $N=36$.

2.3.2. Soil parameters and its relations to management strategies

After three years of GC establishment all variables were significantly affected by the soil treatment at $p < 0.05$ and strongly affected by the site at $p < 0.001$ (Table 2.3). The depth had influence in WSA and roots. The interaction [Treat x Site] was strongly significant on CND and vegetation cover but had lower significance on WSA and roots. [Site x Depth] was significant for the roots while [Treat x Site x Depth] did not influence any variable. CS increased strongly the CND doubling the average of T while CB scored similar values than T. However, both GC treatments increased the WSA significantly. The roots content was increased in CS by more than 3 Mg ha^{-1} while CB also showed higher values than T but not statistically significant. CB showed the higher values of bulk density and CS did not differ from T. CB increased significantly intrapetal porosity in soil while CS did not.

Table 2.3. Mean and standard deviation for the different treatments and results from the analysis of variance for counting number drops aggregate stability test (CND), water stable aggregates test (WSA), roots stock and bulk density for the different treatments. The treatments were CB (Brachypodium distachyon), CS (Spontaneous Vegetation) and T (Conventional Tillage). Sites were vineyards in Belmonte de Tajo, Campo Real and Navalcarnero. Depths were 0-5 and 5-10 cm. Different letters mean differences between treatments for the 0-10 cm depth at $p < 0.05$. Terms with p value > 0.1 were not reported (NR).

	Treatment			Effect						
	CB	CS	T	Treat	Site	Depth	Treat* Site	Treat* Depth	Site* Depth	Treat* Site*Depth
CND	10.41 $\pm$ 0.76 a	20.14 $\pm$ 2.67 b	9.14 $\pm$ 0.85 a	<0.001	<0.001	NR	0.001	NR	NR	NR
WSA (%)	41.63 $\pm$ 1.56 b	43.01 $\pm$ 1.81 b	37.11 $\pm$ 1.46 a	<0.001	<0.001	<0.001	0.023	NR	NR	NR
Roots (Mg ha⁻¹)	7.39 $\pm$ 8.04 ab	9.55 $\pm$ 11.58 b	6.04 $\pm$ 6.02 a	<0.001	<0.001	<0.001	0.019	NR	<0.001	0.036
Bulk density (Mg m⁻³)	1.42 $\pm$ 0.02 b	1.37 $\pm$ 0.03 ab	1.34 $\pm$ 0.02 a	0.049	<0.001	-	NR	-	-	-
Intrapedal porosity (%)	36.61 $\pm$ 0.76 b	34.61 $\pm$ 0.90 a	34.14 $\pm$ 0.84 a	0.011	<0.001	-	0.096	-	-	-

2.3.3. Depth and soil management

Both GC showed higher SOC values at 0-5 cm depth than at 5-10 cm (Fig. 2.2) meaning that a stratification of SOC is taking place. Regarding MOC only CS showed statistically different values between depths. POC values did not differ between depths. SOC, MOC and POC showed the same trend of differences between treatments at the studied depths: CS had significantly higher values than T with CB showing no differences with any treatment at 0-5 cm depth. The aggregate stability tests did not show differences between depths for any treatments with the exception of WSA in T. No statistical differences were found for WSA when separating between depths. The CND test had significantly higher values for CS than CB and T in the two selected depths. At 5-10 cm depth, no statistical differences between treatments were recorded for any variables. Regarding roots content, only CB showed statistically significant higher values at 0-5 cm depth than at 5-10 cm depth. Again, at 0-5 cm depth only CS differs from T.

Figure 2.2. Mean and standard error of soil organic carbon (SOC), mineral-associated organic carbon (MOC), soil organic carbon of the particulate organic matter fraction (POC), counting number drops aggregate stability test (CND), water stable aggregates test (WSA) and roots stock for the different treatments and depths after three agronomy seasons. CB (*Brachypodium distachyon*), CS (Spontaneous Vegetation) and T (Conventional Tillage). Different uppercase letters mean differences between treatments at the same depth at $p < 0.05$. Different lowercase letters mean differences between depths at the same treatment at $p < 0.05$. N=36.

2.3.4. Penetration resistance

The results after analyzing the penetration resistance data were separated in two sections (Fig. 2.3): from 0 to 20 cm depth, with significant differences, and from 25 to 45 cm depth where no statistical differences were observed. Section 1 showed that T scored the lower penetration resistance than both GC treatments. From 0 to 15 cm depth, the penetration resistance of groundcovers doubled the values of the tilled soils. At the depth of 20 cm T and CS had no

differences. CB scored the highest values along the most of the profile. In section 2, the values were erratic along different depths and had very high variability which resulted in a lack of statistical differences.

Figure 2.3. Mean and standard error of penetration resistance for the different treatments after three agronomy seasons at different depths. CB (*Brachypodium distachyon*), CS (spontaneous vegetation) and T (conventional tillage). Different letters mean differences between treatments at $p < 0.05$. Section 1: with statistically significant differences. Section 2: without statistically significant differences.

2.3.5. Porosity and infiltration

Total porosity of sampled cores after three years of soil treatments did not change significantly (Fig. 2.4). CS scored the highest average with 47.3 % followed by CB (46.2%) and T (45.8%). CS and T had significantly higher macroporosity than CB. However, CB had higher micro-porosity than CS and T, which was reflected in a higher WHC. The analysis of Fig. 4 shows that three years of GC development have been enough to reorganize the soil pore structure , although total porosity does not change.

Figure 2.4. Upper part: water retention curve for the three treatments three years after the start of the trial. θ = volumetric water content. Lower part: mean values volumetric water content for the tree treatments. Total porosity is divided in macroporosity, mesoporosity and microporosity. Micro porosity was divided in water holding capacity (WHC) and not available water (NAW). CB (*Brachypodium distachyon*), CS (spontaneous vegetation) and T (conventional tillage). Different letters mean significant differences between treatments at $p < 0.05$. Letters surrounded by a square refer to micro-porosity differences. Letters surrounded by a circle refer to total porosity differences. N=36.

With regard to infiltration rates, during the first minutes of the experiments all the treatments showed similar rates starting with 80 cm h^{-1} . However, CS and CB maintained higher values by 0.15 hours after the beginning (Fig. 2.5). The steady state values of CS and CB were 28.1 and 23.3 cm h^{-1} , respectively, which were statistically higher than T, with 13.1 cm h^{-1} . Thus, in three years, groundcovers improved infiltration rates by increasing them ca. 2 times.

Figure 2.5. Infiltration curves for the three treatments three years after the start of the trial fitted to potential equations. CB (*Brachypodium distachyon*), CS (spontaneous vegetation) and T (conventional tillage). Different letters mean significant differences between treatments at $p < 0.05$. $N = 36$.

2.3.6. Relationships between parameters

The relationship between SOC and aggregate stability is especially important in Mediterranean vineyards as explained in the Introduction section and deserves further analysis. A first exploration of the variables correlation matrix (Table A1.1, Appendix 1) showed that the aggregate stability tests scored the highest correlation indexes with SOC instead of POC and MOC. Thus, correlation analyses were performed with SOC and aggregate stability tests.

CND and WSA showed a positive and significant correlation with SOC ($p < 0.05$) (Fig. 2.6) with and adjusted R^2 of 19.5 and 38.6 %, respectively. These figures indicated that with low SOC values, a small increase strongly improves the aggregate stability. On the contrary, with higher SOC, a bigger increase is needed to promote aggregate stability. This is particularly marked in the correlation between WSA and SOC (Fig. 2.6b), in which an asymptotic equation could be observed. On the contrary CND showed an almost lineal relationship with SOC.

Figure 2.6. Relationships between soil organic carbon (SOC) at 0-10 cm depth and (a) counting number drops CND; and (b) water stable aggregates (WSA) with the best fitting equations, which are statistically significant at $p < 0.05$.

Due to the multiple correlations found between variables a multivariate canonical analysis was performed with selected variables that minimize co-variation, site-dependence relationship and redundancy. The model included: the treatments CB, CS and T, and the variables; POC, MOC, CND, WSA, roots, PR, Infil, P-Intra, P-total, P-Macro, P-Meso, WHC, BD and Cover. The canonical analysis extracted 61 and 38 % (roots 1 and 2, respectively) of the variability of the independent variables and 14 and 10 % (roots 1 and 2, respectively) of the dependent variables. This relatively low explained variability is due to the large number of variables that were included in the canonical analysis. To facilitate interpretations, two graphs were made with the ordination resulting from canonical analysis (Fig. 2.7a and b). The first one was focused on organic matter and aggregate stability and the second one on variables related to the water in the soil. Roots and vegetation cover were included in both graphs because they had big influence in the two sets of variables.

Vegetation cover scored positive in Root 1 as well as both GC treatments. Fig. 7a showed similar scores for the organic matter fractions, aggregate stability and roots in Root 1, which explain the most of the variability and is linked to the GC. All dependent variables but particularly CND scored positives values in Root 2, which positioned them closer to CS than to CB. Figure 7b showed that soil treatments had very low influence on mesoporosity. The macroporosity was negatively correlated with CB. Total porosity was slightly affected by soil treatments but scored more similar

to groundcovers than to T. WHC and intrapedal porosity were highly related and scored close to BD. These variables scored positive in Root 1 as well as groundcovers but negative in Root 2. Vegetation cover was related to penetration resistance, infiltration rates and roots content in the soil. Higher vegetation cover meant higher penetration resistance or compaction. However, contrary to expectations, this did not lead to infiltration problems, instead, the infiltration rates were higher as the vegetation cover and penetration resistance values went higher. Taking into account that groundcover did not increase the pore volume (Figs 2.4 and 2.7b) we can conclude that the pores connection is more important than the pore volume to explain infiltration rates and that soil compaction is not directly related to water infiltration in this study. GC, and especially CS, increase the vegetation cover percentage, which increases the soil roots content. This higher root biomass input increases the organic carbon (both fractions) and improves the aggregate stability.

Figure 2.7. Ordination resulted from canonical analysis. Brachypodium distachyon groundcover (CB), spontaneous vegetation groundcover (CS), conventional tillage (T), soil organic carbon of the particulate organic matter fraction (POC), mineral-associated organic carbon (MOC), counting number drops aggregate stability test (CND), water stable aggregates test (WSA), roots, penetration resistance (PR), infiltration (Infil), intrapedal porosity (P-Intra), total porosity (P-total), macroporosity (P-Macro), mesoporosity (P-Meso), water holding capacity (WHC), bulk density (BD) and vegetation cover (Cover).

2.4. DISCUSSION

As it was expected, the site had the strongest influence on the studied variables. However, this study aimed to include soil and location variability to contrast it with the soil management practice and to prove whether a soil management strategy can improve soil quality, no matter the type of soil. Three years after the beginning of the GC establishment the studied soil properties experienced some changes. Soils with CS had significantly more SOC, MOC and POC than T, with CB scoring intermediate values. The most important increase corresponds to the 0 to 5 cm depth. At 5 to 10 cm depth there were just tendencies but not statistically significant changes. Usually, at deeper layers there are no significant differences between conventional tillage and other sustainable soil management practices (Piccoli et al., 2016; Powlson et al., 2011).

Our results showed that CS increased soil carbon in both the stable and the labile fractions. The importance of this result is that the performing GC promotes atmospheric CO₂ sequestration in the soil via increasing MOC stocks (Stockmann et al., 2013). At the same time its quality and fertility are improved (Gregorich et al., 1997) and erodibility is reduced (Parras-Alcántara et al., 2016) via increasing POC stocks.

CS and CB had 1.06 and 0.54 Mg SOC ha⁻¹ year⁻¹ sequestration rates, respectively. These results agree with those from Vicente-Vicente et al. (2016) who performed a meta-analysis including 16 publications on vineyards and found an average of 0.78 Mg SOC ha⁻¹ year⁻¹ while for olive orchards the rates were 1.1 Mg SOC ha⁻¹ year⁻¹. Peregrina et al. (2010; 2014) observed SOC sequestration rates of 0.47 and 1.19, and 1.34, 1.52, Mg SOC ha⁻¹ year⁻¹ in different trials for different types of permanent GC. More importantly, these stocks demonstrate that the 4 per mille objective can be accomplished. The relatively low values from CB could be attributed to the lower biomass input that we have proved in the case of the root biomass. Moreover, it is difficult to compare the SOC sequestration rates because sometimes the soil management strategy is called cover crops or groundcovers but these strategies include an annual tillage for seeding operations or to limit water competition obviating that tillage is one of the major driving forces of carbon mineralization (Kabiri et al., 2016). Additionally, there is not a standard of soil sampling depth to calculate SOC stocks or sequestration rates. CB increased POC stocks in 0.8 Mg ha⁻¹ and CS did in 1.5 Mg ha⁻¹ in relation to T. The increase in POC has been widely addressed in the literature as an improvement in soil quality (Duval et al., 2013). Moreover, though most of the soil organic carbon belongs to the stable fraction (MOC) GC increased relatively more POC stocks than MOC with a maximum of 46 % for CS.

The aggregate stability tests showed different results. Regarding the CND only CS averaged significantly higher than T while both GC had higher values of WSA. T showed the lower values of

any soil treatment in both test. As tillage destroys the natural structure of the soil, it produces more unstable macroaggregates because of lower SOC contents (Six et al., 2000b). Therefore, the increase in aggregate stability is related to higher SOC contents (Blavet et al., 2009) and especially to the POC content (Imaz et al., 2010). This labile organic matter content is more sensitive to management changes than SOC (Bayer et al., 2004). In this study, the WSA was similarly influenced by MOC and POC in the canonical analyses, while the CND was closer to MOC. Higher POC is related with a continuous replacement of fresh organic matter that inputs in the soil (Sá and Lal, 2009). Besides, POC acts as a binding agent to stabilize macroaggregates (Denef et al., 2004; Six et al., 2002). This could suggest that, in Mediterranean conditions, stable organic carbon increases the resistance of aggregates against the raindrops and thus, decrease soil erodibility.

Both aggregate stability tests were positively correlated with SOC, which was observed by several researchers (Bronick and Lal, 2005; Six et al., 2004), but the correlations were different. CND followed a nearly linear distribution while the one of WSA was asymptotic. This could be explained by the fact that the WSA had higher sensitivity to a SOC increase when the initial SOC content was low. In fact, Minasny et al. (2017) have established in more than 20 countries that there is a tendency of a higher C sequestration potential on croplands with low initial SOC stock. In this study with soils having low SOC, WSA is more suitable to assess soil quality changes, hence it is recommended in the majority of Mediterranean vineyards.

The cessation of the tillage and the mowing operations are often related with soil compaction (Lagacherie et al., 2006). Accordingly, our data showed that GC had significantly higher penetration resistance than T in the tilling depth. Nevertheless, this compaction had no consequences on the soil-water and soil-air relationships. As the soil water retention curves and multivariate analysis showed, GC did not have a strong impact on soil porosity. Total porosity was statistically the same for all treatments, in fact CS tended to be even higher. GC developed a new pore distribution with similar pore volume but a higher connectivity. BD was higher in the GC than in T showing an increasing soil compaction that was also proved by the penetration resistance field tests. Nevertheless, even with higher soil compaction and similar porosity, GC doubled the infiltration rates of T. The vegetation cover, penetration resistance and infiltration scored similarly in the canonical analysis indicated that the soil compaction itself is not enough to explain the water movement in the soil. Our results agree with those from Pires et al. (2017) and Gao et al. (2017) which observed small differences in macroporosity, but a better pore connectivity under no tillage treatment. Thus, despite soil compaction, GC improves the water movement while not threatening the soil aeration.

In this regard, CB had behaved slightly different than CS: macroporosity was lower and microporosity and WHC were higher in CB. The intrapedal porosity was also higher in CB which explained the higher proportion of small pores and the enhancement of WHC. It is well known that different patterns in soil roots result in different soil structure and pore size distribution (Krebs et al., 1993) and that traditionally tilled plots usually show less intrapedal porosity (Aguilar et al., 1990).

The most of the studied variables were not affected by soil treatments at 5 to 10 cm depth, which is mainly due to the slow evolution of soil parameters in semiarid Mediterranean soils (Bienes et al., 2016). Nevertheless, changes in the 0 to 5 cm depth have been enough for an improvement in hydrologic characteristics as infiltration and runoff (García-Díaz et al., 2017). The use of GC is a useful management strategy to increase soil quality in Mediterranean climate (Salomé et al., 2016). Our results showed that the GC promotes an increase in soil quality and, as a result, in the soil functioning (Salomé et al., 2014). Permanent covers have increased the organic inputs in the soil system, increasing the SOC stock which has improved the aggregate stability and soil structure. The two GC had a different development. The spontaneous vegetation GC produced higher carbon input through the roots than CB (González-Sánchez et al., 2012), and this produced larger increases of SOC and, as a consequence, bigger improvements in aggregate stability and infiltration rates.

A seeded GC requires an investment in seeds and the use of machinery for soil conditioning. The spontaneous GC does not require this kind of costs as it can be established directly by stop tilling operations. Moreover, along the trial we noticed herbivore problems with rabbits that showed much higher predilection for the *Brachypodium distachyon* GC. There are researches who have addressed water competition between the plants of GC and the vines in rainfed Mediterranean vineyards producing grape production decreases (Ruiz-Colmenero et al., 2011; Guerra and Steenwerth, 2012; Muscas et al., 2017). Nevertheless, these types of studies tend to ignore the costs of increasing SOC and erosion reductions on degraded soils.

2.5. CONCLUSIONS

Alternative soil management strategies such as the use of GC on degraded soils of Mediterranean vineyards improve the soil quality in comparison with the conventional tillage. GC reduce the mineralization rates and increase organic carbon input in the soil. The increase in organic carbon stocks take place in both stable and labile fractions, but these increases are relatively higher in the labile fraction which immediately improves soil fertility. Besides, this indicates that a pool of fresh

organic matter will be further humified, increasing the stable fractions and contributing to atmospheric CO₂ fixation. SOC stocks increase promotes an improvement of aggregate stability and soil structure making soil more resilient to water erosion. The pore volume and pore size distribution remains similar while the pore connectivity increases dramatically. Spontaneous GC is the most effective soil management strategy to improve the global soil functioning.

The most effective soil management strategy to improve soil quality is the use of spontaneous vegetation GC. However, in the context of Mediterranean vineyards, the competition between the vine plants and the GC could affect the performance of the vines. Thus, further research is needed to assess at the same time the influence of alternative soil managements to improve soil quality and its influence on grape harvest and wine quality.

WSA reveals as the best choice to assess soil quality changes in Mediterranean vineyards.

CHAPTER 3. CARBON INPUT THRESHOLD FOR SOIL CARBON BUDGET OPTIMIZATION IN ERODING VINEYARDS

ABSTRACT

Previous studies have documented that, relative to conventional tillage (CT), alternative soil management (reduced tillage, mulching, or cover crops) decreases soil erosion and increases soil organic matter (SOM) in vineyards. These previous studies, however, failed to consider the loss of soil organic carbon (SOC) with erosion that could occur with the adoption of agro-environmental measures (AEM) in a semiarid environment. Accordingly, the aims of this study were to determine whether changes in SOC content under AEM management are always positive and to develop a conceptual model for estimating the “SOC threshold”. The SOC threshold was defined as that level of SOC in an AEM-managed vineyard above which erosion will result in greater loss of C than occur in a comparable vineyard with CT management. SOC was analyzed at a 100 paired sites (vineyards with AEM management vs. CT). The results showed that in some cases the loss of C was higher with AEM than with CT. Overall, the results indicate that the SOC threshold may be a key parameter in determining the best AEM measures for vineyards that are on slopes and therefore vulnerable to erosion.

3.1. INTRODUCTION

Soil erosion is a problem in vineyards because it reduces soil fertility, damages nearby roads, and causes floods, (Costantini et al., 2015; Lieskovský and Kenderessy, 2014; Martínez-Casasnovas et al., 2016; Vaudour et al., 2015). Higher erosion rates have been recorded in vineyards than in other land use areas (Cerdan et al., 2010) in the Mediterranean region (Vanmaercke et al., 2011) because of several characteristics of the soil, climate, topography, soil management and the vines are planted and cultivated along the slope (Novara et al., 2011; Tarolli et al., 2015). First, the soil in traditional Mediterranean vineyards is bare for most of the year; the cover is only significant during the summer, when there is almost no rain other than sparse and irregular storms. Bare soils result in high erosion rates, and a recovery of the vegetation contributes to an important reduction of soil and nutrient losses in the Mediterranean region (Cerdà, 1998; Novara et al., 2013; Novara et al., 2015a) and Africa (Mekonnen et al., 2015). Second, traditional soil management in Mediterranean vineyards includes continuous tillage with the goal of eliminating competition between vines and other plants for water and nutrients. Although tillage also reduces evaporation in the Mediterranean region, it results in high erosion rates (García-Orenes et al., 2009). Third, a high soil organic matter content can help reduce erosion, but soils of the Mediterranean vineyards have low organic matter content because of the low inputs of organic matter and because the climate promotes high mineralization rates. The organic matter content is further reduced by the tillage. Fourth, vineyard soils in many regions are shallow and with low infiltration rate, which increases their vulnerability to soil erosion. Finally, the large vine-producing regions in the Mediterranean region are hilly and experience high intensity rainfall events, both of which will obviously increase the potential for erosion (Cerdà et al., 2016). Within this context, alternative management, such as reduced tillage, the application of mulch, or the planting of cover crops, has been developed to protect soil from erosion. These alternative management methods generally increase the input of soil organic matter (SOM) (Prosdocimi et al., 2016b; Brevik, 2013). The importance of SOM in reducing soil erosion is well known, i.e., SOM reduces erosion by improving soil structure, hydrological characteristics, aggregate stability and resistance (Balesdent et al., 2000; Barthès and Roose, 2002; Six et al., 2004). Erosion rates are lower and SOM contents are higher in vineyards that are planted with cover crops and are not tilled than in vineyards that are managed with bare soil and traditional tillage (Biddoccu et al., 2015; Ruiz-Colmenero et al., 2013; Virto et al., 2012b). Hence, the adoption of soil-conservation practices is encouraged both to prevent erosion and to sequester atmospheric carbon dioxide (CO₂) in the soils. As a consequence of the 1992 reforms of the Common Agricultural Policy in Europe, agro-environmental policies

have been developed through payments to farmers in order to improve environmental protection. In Mediterranean countries, the payments are especially desirable because some agro-environmental measures (AEM) could reduce agricultural production and therefore farmer profit (Ruiz-Colmenero et al., 2011).

A main objective of the second axis of the Rural Development Program of the European Union (Council Regulation EC No 1698/2005) is the improvement of the environment and the countryside, and the program encourages soil management with cover crops to reduce erosion (Article 4, EC No 1698/2005). This can be done through the previously mentioned AEM payments, which will be provided to growers whose management results in positive environmental outcomes. Although agricultural conservation practices, including the planting of cover crops, are included in the AEM, few studies have analyzed the carbon (C) cycle under erosion processes with alternative soil management. The apparently positive effect of higher soil C content on soil properties and climate change mitigation could lead to C loss in the system in terms of higher CO₂ emissions or higher amounts of C in soil sediments that are transported from the field by erosion. Gao et al. (2013) introduced the C health threshold theory, which indicates that increases in soil C levels could lead to ecosystem degradation. Gao et al. also determined that if C storage exceeds nutrient and water supply limits, an ecosystem will fall into a sub-health state of fitness; after that, C will be lost through soil erosion or other pathways. In the current study, the SOC threshold is defined as that level of SOC in an AEM managed vineyard above which erosion will result in a greater loss of C than occur in a comparable vineyard that is managed with conventional tillage (CT). Several authors have studied the C health threshold theory with respect to afforested and natural soils (Gao et al., 2012; Wang and Cao, 2011), but the theory has not been investigated in a semiarid cultivated soil.

This paper attempts to answer three questions with respect to vineyards located on hillsides in the semi-arid environment of the Mediterranean region: i) given that substantial C may be lost via erosion, is it always desirable to increase the SOC content of the soil?; ii) can the SOC stock be increased under AEM without resulting in high C loss due to erosion? and iii) is the SOC threshold measurable?

3.1.2. The SOC threshold concept

Erosion results in C loss via three major pathways: (i) C contained in soil that is transported and deposited elsewhere as sediment; (ii) dissolved organic carbon (DOC) contained in runoff; and (iii) CO₂ emission (Jacinthe and Lal, 2001). Among these pathways, the first is most important, because

the most C is lost as SOC in sediment. The other two pathways, although relevant for the global C budget and for ecological properties, are dependent on sediment transport and C content. Using data for SOC stocks and dynamics from long-term experiments (more than 7 years) in different regions (Jacinthe and Lal, 2001) found that erosion-induced CO₂ emission rates ranged from 6 to 52 g C m⁻² yr⁻¹. Similarly, in a short-term experiment (98 days), (Van Hemelryck et al. (2010) estimated that soil redistribution processes resulted in an additional loss of 2 to 12% of C from eroded sediment via CO₂ emission. Both studies showed that erosion induced-CO₂ emission depends on the C content of the soil and sediment. Similarly, the DOC in runoff represents a low percentage of the total C loss (Mchunu and Chaplot, 2012). It follows that the quantity of C lost during erosion can be reasonably estimated from the quantity of SOC that is transported with eroded soil and that is deposited elsewhere as sediment.

The loss of C in soil sediments ($OCloss_{sediment}$) can be described by the following linear relationship (Starr et al., 2000):

$$OCloss_{sediment} = SE \times SOC \times E_r \quad (3.1)$$

where SOC is the content of organic C in soil (%), E_r is the enrichment ratio of eroded sediment relative to the original soil (dimensionless), and SE is soil erosion rate (Mg ha⁻¹ y⁻¹). According to Eq. (3.1), C loss increases with the erosion rate and SOC content. SOC and SE are both functions of organic matter input into the soil, i.e., increases in soil organic matter increase SOC and reduce SE because organic matter increases soil aggregate stability (Loveland and Webb, 2003).

In sloping vineyards, alternative soil management (AEM management, i.e., management without tillage and with a cover crop) reduces erosion relative to conventional tillage (CT) because the cover crop reduces the impact of rain drops on the soil, increase infiltration and dissipation of flow energy, produces biomass that contributes to increases in SOC (Novara et al., 2011) and therefore to aggregate stability (Blavet et al., 2009). The higher SOC level resulting from continuous AEM management, however, produces C-enriched sediments and consequently could lead to higher C losses than with CT, despite the lower SE (Fig. 3.1). Considering that possibility and as noted earlier, we define the SOC threshold as the level of SOC under AEM management that results in a C loss with AEM management that is equal to the C loss under CT management ($OCloss_{CT}$) (Fig. 3.1).

Figure 3.1. Conceptual diagram of dynamic changes in OC loss in a sloping area with different soil management systems. The soil erosion is lower under AEM management (green line) than CT management (red line). The increase of SOC in AEM management (green circle) can entail an higher OC loss in AEM than CT. The cross point between the dotted red line (OC loss under CT) and dotted green line (OC loss under AEM) is described as the SOC threshold in the sloping area

If the soil C saturation level (the maximum, steady state level of C that can accumulate in a specific soil) is higher than the SOC threshold, the SOC threshold will correspond to a C_{AEM} value; if the soil C saturation level is lower than the SOC threshold, the SOC threshold will be equivalent to the C saturation value. We indicated C saturation level (or C steady state) as the maximum level of C accumulated in a certain soil, despite the C input increasing.

Considering constant environmental conditions for both soil managements, the SOC threshold is calculated with the following Eqs. (3.2) and (3.3):

$$Closs_{AEM} = Closs_{CT} \quad (3.2)$$

and according to Eq. (1), it follows that:

$$SE_{AEM} \times SOC_{AEM} \times E_{rAEM} = SE_{CT} \times SOC_{CT} \times E_{rCT} \quad (3.3)$$

Based on Eq. (3.3), the C losses relative to SOC content with AEM and CT management are presented in Fig. 3.2. (green and red lines). Considering the same value of SOC (C_1) for CT and AEM, OCloss will be higher for CT ($OCloss_{CT}$) than AEM ($OCloss_{AEM}$), given that the erosion rate SE will be higher in CT than in AEM because of differences in soil cover.

Figure 3.2. C loss under two different soil managements. The black circle indicates the SOC threshold

If no change in soil management occurs, the SOC content in CT can be considered constant over many years. Given a value of SOC under CT (SOC_1) with OC_{lossCT} , the $OC_{lossAEM}$ will be reached with a SOC content equal to SOC_2 . Values higher to SOC_2 will result in a higher OC_{loss} in AEM than in CT. The SOC_2 value can, therefore, be considered the SOC threshold for a given soil that, if managed under CT, will contain a steady state level of SOC equal to SOC_1 (Fig. 3.2).

3.2. MATERIALS AND METHODS

3.2.1. Study area and soil sampling

The study area is located in southern Sicily and is one of the 18 vineyard Controlled Denomination of Origin areas on the island (Fig. 3.3). In the “utilized agricultural area” (UAA) of 11,588 ha, 35.5% is devoted to vineyard cultivation, 32.2% is arable land, and 11.1% is planted with olive trees. The mean annual precipitation is 516 mm. Rainfall is highest in October (monthly mean rainfall of 81 mm) and lowest in July (monthly mean rainfall of 2 mm). On average, 3% of the mean annual rainfall occurs during summer (June, July, and August) while 42% occurs during November, December, and January. The mean annual temperature is 18 °C; the hottest months are July and August (monthly means of 25 °C), and the coldest months are January and February (monthly means of 11 °C). Vineyards in Sicily are commonly managed with CT (at least five shallow tillages per year) to control weeds and reduce water competition. Recently, alternative soil management in vineyards is spreading thanks to AEM. In particular, AEM management in Sicilian vineyards involves annual cover cropping using legumes like faba bean (*Vicia faba*) and vetch (*Vicia sativa*). The cover crop is seeded in autumn and disked into the soil in spring. In summer the vineyard is subjected to two shallow tillages.

Figure 3.3. The studied Santa Margherita Controlled Denomination of Origin area (controlled denomination of origin) in Sicily, the selected paired sites (red bullets), in green vineyards of the studied area, and an example of paired site.

In the study area, 100 paired sites were chosen (Fig. 3.3). The paired-site approach was used to compare SOC stocks after 5 years of management with AEM vs. CT (Novara et al., 2012). The plots at each pair of sites (one plot per site) were similar with respect to soil type, slope, elevation, exposure, and drainage. *V. faba* was used as a cover crop in the AEM plots. Three soil samples were collected from the 0–15 cm depth in each plot. The soil was dried and passed through a 2-mm sieve before SOC was quantified according to Walkley and I.A.Black, (1934). Data for soil

texture were obtained from the regional government of Sicily (Banca dati geografica dei suoli della Sicilia del Dipartimento Agricoltura dell'Assessorato Agricoltura, Sviluppo rurale e Pesca mediterranea — Regione Siciliana).

3.2.2. SOC threshold calculation

The SOC threshold for each pair of sites was calculated according to Eq. (3.3). SE_{AEM} and SE_{CT} were estimated using the USLE equation (Wischmeier and Smith, 1978):

$$SE (Mg\ ha^{-1}) = K \times R \times C \times LS \times P \quad (3.4)$$

where K is the soil erodibility, C is C_{factor} , R is the rainfall erosivity, LS is a topographic factor, and P is support practice.

Because R, LS, and P factors were the same for the two plots of each pair of sites, the calculation of SE was simplified by their exclusion.

Soil erodibility (K) for each plot of paired sites was calculated based on texture, organic matter content, and permeability according to equations presented by (Wischmeier et al., 1971) and (Renard et al., 1997); these equations are recommended when the organic matter content is known and when the silt content is < 70%. Values for the C_{factor} were 0.65 in CT plots and 0.22 in AEM plots (Novara et al., 2011). The same value was used for E_{rAEM} and E_{rCT} . (Ruiz-Colmenero et al., 2013) found different values of SOC in sediment and soil but similar ratios for vineyards managed with conventional tillage ($E_r = 1.4$) and with a *Secale cereale* cover crop ($E_r = 1.5$).

Eq. (3.3) was arranged as follows:

$$K_{AEM} \times SOC_{AEM} = \frac{K_{CT} \times SOC_{CT} \times E_{rCT}}{E_{rAEM}} \quad (3.5)$$

as:

$$K = f(SOC_{AEM}) \quad (3.6)$$

It follows:

$$SOC_{threshold} = SOC_{AEM} = \frac{K_{CT} \times SOC_{CT} \times E_{rCT}}{E_{rAEM} \times f^{-1}} \quad (3.7)$$

The mean and standard deviation of the SOC values were calculated for each plot

3.3. RESULTS AND DISCUSSION

3.3.1. SOC as affected by CT and AEM soil management

Five years after AEM management was initiated, the SOC did not greatly increase (Fig. 3.4). The C increase after AEM adoption was moderate relative to that reported in other studies (Batjes, 2014; Debasish-Saha et al., 2014; Jaiarree et al., 2014; Li et al., 2014; Lozano-García and Parras-Alcántara, 2014).

Figure 3.4. Soil organic carbon (SOC%) in each paired site for the two soil managements. The dotted blue line represents SOC under Conventional tillage (CT). The crossing point between the logarithmic curve (black line) and linear equation (dotted line) describes the C saturation level. The distance between linear line and logarithmic curve represents the SOC change after AEM adoption.

Among the 100 AEM plots, the highest SOC gain was 0.24%, and the average was 0.046%. The higher C sequestration rates in AEM plots occurred in those pairs with low SOC values in CT plots; the sequestration rate dropped as the SOC in CT plots approached 0.66%. With this high SOC value in CT plots, the C sequestration rate was 0, and 0.66% SOC content was therefore assumed to be the C saturation level for vineyard soils given the environmental conditions of the study area and the soil management performed. However, others have reported no increase in SOC following a conversion from CT to management that reduced tillage and increased surface cover in semi-arid environments (Carr et al., 2015).

3.3.2. SOC threshold

The SOC threshold, which was calculated for each paired site according to Eq. (3.7), showed an exponential trend both for soil with high silt content and low silt content (Fig. 3.5a and b). In the absence of limiting factors, which reduce the capacity of soil to sequester C, the increase in organic C exponentially improves soil structure and soil chemical properties, leading to a lower erosion rate and soil C sink ability. Soil erodibility and consequently OCloss increased with the silt content of soil (Pérez-Rodríguez et al., 2007). Soils with high silt are more susceptible to erosion and have a reduced ability to retain C, leading to lower SOC threshold values (Fig. 3.5). After 5 years of AEM adoption, SOC_{AEM} exceeded the SOC threshold in soils in which the CT plots had a high silt content and low SOC content. For values of SOC under CT ranging from 0.2% to 0.45%, the SOC_{AEM} reached the SOC threshold, and in these cases the values for OCloss were higher with AEM than with CT. Similar results were found by Ruiz-Colmenero et al. (2013), who compared SOC in a vineyard managed with a cover crop vs. CT. The latter researchers reported that less sediment was generated with a cover crop than with CT but that the sediment from the cover crop soil contained about 1.4-times more SOC than the sediment from the CT soil. For values of SOC ranging from 0.45% to 0.66% (the saturation level) with CT management in the current study, the SOC threshold was higher than SOC_{AEM} . In these cases, the adoption of AEM should be encouraged up to the SOC threshold. Further studies should be carried out to evaluate the potential annual carbon sequestration and the relative C input through cover crop soil management in order to maintain the reached C steady state.

Figure 3.5. SOC threshold and measured SOC after 5 years of AEM adoption in soil with high silt (a) and low silt (b) content.

Although the difference between the SOC threshold and SOC_{AEM} increases exponentially with SOC_{CT} content, the maximum value that can be reached is the saturation level, and it is considered therefore the maximum level of the SOC threshold in the vineyards of the study area. Unlike the soils with high silt content, the soils with low silt content that were managed with AEM did not reach the SOC threshold (Fig. 3.5b). In all of these cases, the SOC threshold corresponded to the saturation level.

Like organic matter content, soil texture greatly affects a soil's erodibility and also affects a soil's capacity to serve as a sink for C. Information on a soil's potential to retain C is therefore essential for the efficient adoption of AEM and for preserving agrosystem health. This paper presents a method to evaluate the effects of AEM management on both the increase in SOC and the risk of C loss. As a consequence, this paper suggests a tool for payment diversification in relation to agro-ecosystem services provided by AEM management.

3.4. CONCLUSION

AEM management using cover crops in vineyards increases SOC. In sloping areas, however, selecting the best AEM depends on an understanding of C loss resulting from erosion. Our results showed that in some cases the loss of C is greater with AEM management than with CT management. In these cases, the difference between SOC_{AEM} and the SOC threshold indicates the increase in C loss resulting from AEM adoption (green area, Fig. 3.6); the difference between the SOC threshold and SOC_{CT} , on the other hand, indicates the potential of the soil to increase its SOC stock while maintaining the same C losses with AEM management. In other cases, the SOC threshold was higher than AEM; in these cases, the difference between the SOC threshold and SOC_{AEM} represents the potential quantity of C that could be sequestered by soil (Fig. 3.6). Although the SOC stock can reach the saturation level after several years of AEM management (Pachauri et al., 2014), our results showed that the risk of C loss can increase after only 5 years. Consequently, to maximize the effectiveness of AEM management both for the environment and for the optimization of SOC input, European policies should consider many factors such as the pedoclimate, cover crop management, plant species, and the quality and quantity of cover crop biomass.

Figure 3.6. Scenarios of OC loss and potential C sequestration in relation to different AEMs (AEM₁ and AEM₂).

CHAPTER 4. GRAPE YIELD AND QUALITY AND SOIL CARBON
SEQUESTRATION ECONOMIC VALUE IN MEDITERRANEAN
SEMIARID VINEYARDS USING GROUNDCOVERS

ABSTRACT

In the last decades, unsustainable management practices such as continuous tillage are promoting severe soil degradation. In Mediterranean basin, woody crops are particularly degraded mostly because soil is bare the most of the year producing high erosion rates. The use of alternatives soil management strategies such as groundcovers (GC) are well known to reduce erosion and increase soil organic carbon (SOC) but few research have been devoted to analyze its effects on grape yields and quality in Mediterranean semiarid vineyards. Over three agronomy seasons, grape yield and quality in three different vineyards were analyzed to assess the influence of a seeded *Brachypodium distachyon* groundcover (CB) and spontaneous vegetation groundcover (CS) compared to conventional tillage (T). Additionally, SOC was measured to calculate the SOC value in terms of euros per megagram of sequestered SOC. Results showed a general decrease of grape yield while grape quality had high dependence on grape variety. The loss of income caused by GC were between 690 and 1048 € ha⁻¹ year⁻¹ for CB and CS and SOC sequestration values were 375 and 758 € Mg⁻¹ for CB and CS, respectively.

4.1. INTRODUCTION

Mediterranean woody crops landscapes and particularly olive orchards and vineyards are considered cultural landscapes with deep historical roots (ICOMOS, 2005; UNESCO–SCBD, 2014). These soils have been cultivated from many centuries ago (Loumou and Giourga, 2003). In Spain, woody crops were traditionally planted and tilled contrary to slopes or in terraces (Cots-Folch et al., 2006), with animal power, were tilled with animal power and organic amendments were applied every year. From the half of the XX Century, Spanish woody crops started to be tilled with machinery, the organic matter amendments started decrease because of a lack of animals manure and many vineyards were planted along high (Arnaez et al., 2007). Consequently, vineyard soils are tilled continuously with bare the most of the year (Lasanta and Sobrón, 1988) and had low organic matter inputs. The previous, together with high rainfall intensities (Panagos et al., 2015) make soil vineyards prone to soil erosion processes (Prosdocimi et al., 2016a) leading to soil and nutrient loss but also to decreasing soil fertility and the sustainability of Mediterranean vineyards in medium to long term. Climate change threatens the sustainability of these agro-ecosystems. First, along the XXI Century the average temperatures will increase (Pachauri et al., 2014) promoting higher soil organic matter (SOM) mineralization rates (Conant et al., 2011) and making soils more prone to erosion (Bronick and Lal, 2005). Besides, climate projections agree with a reduction in the number but an increase in the magnitude of extreme rainfall events (Rodríguez-Lloveras et al., 2016; Christensen et al., 2007; Gibelin and Deque, 2003), which are responsible of the most of soil erosion in Mediterranean basin (Rodrigo Comino et al., 2016b; Martínez-Casasnovas et al., 2002).

SOM plays a central role in soil quality and resilience (Six et al., 2004). The main soil management strategy to reduce erosion and increase SOM in vineyards is the use of groundcovers (GC) (Prosdocimi et al., 2016a; Virto et al., 2012b). GC could be performed as temporary or permanent GC. Temporary GC increased SOM limitedly (García-Díaz et al., 2016) because tillage is one of the major driving forces of SOM mineralization. Nevertheless, temporary GC increase SOM in degraded vineyards and reduces erosion and nutrient loss (Novara et al., 2012; Novara et al., 2011; Novara et al., 2013) especially when the main erosive rains take place from October to April. On the other hand, permanent GC allow higher increase in SOM (Ruiz-Colmenero et al., 2013; Vicente-Vicente et al., 2016) and protect soils throughout all year. Thus, vineyards can be used as carbon sinks (Brunori et al., 2016) while improving its soil sustainability.

Though, in Mediterranean climate, soil water resources are limited and water stress in the vine plants is one of farmer's main concerns (Marqués et al., 2015) and it is becoming critical in the

new context of climate change. The effect of GC in grape yields is controversial since it is affected by many factors (Ripoche et al., 2011). Generally, GC are related with a decrease in yield because of water competition in areas with scarce rainfall (Hartwig and Ammon, 2002). Excessive water competition during spring and summer could severely affect plant vigor promoting early defoliations which influences grape yield and quality (Medrano et al., 2015). On the other hand, an early and limited competition between the plant vines and the GC could reduce vegetative vigor, which reduces the leaf area and thus, reducing stomatal conductance during the summer (Pou et al., 2011). Besides, vine plants are proved to change its root system distribution and size with GC to explore water resources otherwise misused, which counterbalance water uptake (Celette et al., 2008). Moreover, there are several researches relating increasing wine quality with GC (Lopes et al., 2011; Guerra and Steenwerth, 2012; Lee and Steenwerth, 2013)

Through agri-payments, European Union legislated promoting the use of sustainable agronomic practices, but every region has autonomy to develop its own legislation. Because of that, certain soil protection regulation inequalities can be found along Mediterranean Basin. Sicilian farmers (Italy) are paid 450 € ha⁻¹ year⁻¹ to perform temporary *Vicia faba* GC from October to April (Regione Siciliana, 2016). On the other hand, farmers from Madrid Region (Spain) are not paid for any soil protection management strategy (BOCM, 2009). At this regard, the efficiency of incentives for agri-environmental payments is being researched in the last years (Galati et al., 2015) showing that many variables such as the loss of farmers income and C sequestration rates are involved. Consequently, more knowledge of the loss of income and the influence of sustainable agronomic practices such as GC is needed to develop suitable legislation, favoring soil protection and C sequestration while guaranteeing farmers' incomes.

The goals of this study were: (1) to assess the influence of two different permanent GC in grape yield and quality in rainfed vineyards, (2) to analyze the economic impact of grape yield and quality variations and (3) to link economic impact with carbon sequestration rates. For those purposes we established seeded, spontaneous and conventional tillage in three different vineyards in South Madrid (central Spain) and data from grape yield and quality were analyzed along three agronomy seasons.

4.2. MATERIALS AND METHODS

4.2.1. Study area

The trial was set up in three commercial vineyards sited in South Madrid belonging to Denomination of Origin “Wines of Madrid”, in the center of Spain. Annual rainfall is approximately 400 mm and average temperature 14.8 °C. The three vineyards are representatives of different viticulture types. Belmonte de Tajo vineyard is an old low density vineyard of cv. Airén (Table 4.1). It represents the traditional viticulture model, with low inputs and goblet training method. Campo Real is an organic farmed 18 years old vineyard of cv. Tempranillo with 2222 plants ha⁻¹. Navalcarnero vineyard represents a more intensive viticulture, managed conventionally with 3570 plants ha⁻¹ of cv. Merlot. The vineyards and the rows of the trials were also selected for having at least 9 consecutives inter-rows with the same soil and terrain characteristics. Pits for soil classification and analyses were performed before the beginning of the trial. Soils were classified as Haploxeralfs (Soil Survey Staff, 2015) with an altitude ranging from 586 and 783 meters above the sea level (Table 4.1). Slopes were moderate (7 to 13.5 %) and the SOC contents were low. Root depths were low, ranging between 0.2 and 0.6 m with strong physical limitations underneath.

Table 4.1. Soil Classification (Soil Survey Staff, 2015) and main characteristics of the vineyards. Altitude (meters above the sea level) slope, soil organic carbon (SOC), pH, USDA texture, rooting depth, cultivar, plant density and training method. SOC, pH and texture correspond to the Ap horizon.

Site	Soil Classification (USDA)	Altitude (m)	Slope (%)	SOC (gr kg ⁻¹)	pH (1:2.5)	Texture	Root Depth* (m)	Cultivar	Age	Plan density (Plants ha ⁻¹)	Training method
Belmonte de Tajo	Calcic Haploxeralf	754	7.2	8.1	8.5	Loam	0.2	Airén	>90	1200	Ancient goblet transformed to vertical trellis
Campo Real	Calcic Haploxeralf	783	13.4	7.2	8.6	Sandy Clay Loam	0.4	Tempranillo	18	2222	Vertical trellis (double cordon)
Navalcarnero	Typic Haploxeralf	586	13.5	7.0	7.7	Sandy Clay Loam	0.4	Merlot	16	3570	Vertical trellis (single Cordon)

* Root depth does not include horizons with very few or no roots

4.2.2. Experimental design

The trial started in the winter of 2012/2013 with the GC establishment in the selected vineyards. Treatments were: i) conventional tillage (T) consisted in 2-3 tillage operations with chisel (20 cm depth) per year following the typical soil management practice of the farmers of this area; ii) *Brachypodium distachyon* groundcover (CB), seeded in the central 2 m of the inter-rows in December 2012 being the seeding rate 20 kg ha⁻¹; and, iii) spontaneous vegetation cover (hereafter CS). GC were mowed every spring one or two times depending of the vegetation

growth, at the height of 10 cm. Litter was left on the soil surface as mulch and it was never incorporated into the soil. The three treatments were performed in the three vineyards with 3 repetitions as was explained in García-Díaz et al. (2017).

4.2.3. Grape sampling and laboratory measurements

Samples were taken in the grape harvests of 2013, 2014 and 2015. Grape samples were taken the day before farmer's harvest in each vineyard. For grape yield, the harvest from 12 vines per treatment was measured individually with a dynamometer. Four clusters from 12 vines per treatment were weighted to get the average cluster weight. The number of grapes per cluster was also noted. Average grape size (g) was calculated as the relation between the number of grapes per cluster and the average cluster weight. The grapes from 6 out of the 12 sampled vines were randomly sampled from the central and lower part of the clusters according to Jordan and Crosser, (1983). These samples were crushed and analyses of the juice were performed immediately. Total soluble solids were measured by refractometry with Atago refractometer PR-100 and expressed in potential alcohol (PA). Total acidity was measured by titration with NaOH 0.1 N. Every winter, the pruning wood from 18 vines per treatment at each vineyard was weighted with a dynamometer. Prune was performed according owners guidelines. In 2013, data to calculate grape size was not recorded. Juice parameters of Navalcarnero vineyard in 2013 were discarded because of logistic concerns. In 2014, Navalcarnero vineyard harvest was not sampled because of owner personal reasons.

4.2.4. Soil organic carbon and vegetation cover

In the summer of 2015, 9 soil samples per treatment were collected at 0-10 cm depth. Soil organic carbon (SOC) was determined by wet oxidation (Walkley and I.A.Black, 1934). Additionally 9 undisturbed soil cores per treatment were taken at 2.5-7.5 cm dept. To calculate the bulk density cores were completely oven dried (24 h at 105°C). SOC stocks were calculated by multiplying SOC (gr kg^{-1}) by bulk density (kg m^{-3}) and soil depth (m).

Vegetation cover percentage was determined selecting randomly three spots in each row of each treatment using 25 x 25 cm² quadrats. For each quadrat, the average of 6 observations from 6 trained observers was used to determine vegetation cover percentage. This methodology was chosen for being time efficient and resulting in similar values than those obtained by digital image analysis (García-Estríngana et al., 2005).

4.2.5 Meteorological data

Rainfall and reference evapotranspiration calculated with FAO Penman-Monteith method (ET_0) data were taken from Spanish Agroclimatic Service for Irrigation (SIAR, 2017). For Belmonte de Tajo and Campo Real vineyards Arganda del Rey meteorological station was chosen. The distance between the station and vineyards is 9 and 16 km for Campo Real and Belmonte de Tajo respectively. The closest station from Navalcarnero vineyard was Villa del Prado (22 km). Bulk data is shown in Tables A2.1 and A2.2 in Appendix 2.

4.2.6 Data analysis

Variables were checked before data analysis to ensure normal distribution and were transformed if needed. For each vineyard and year, simple variance analysis (ANOVA) was performed with soil treatment (CB, CS and T) as factor with Statistica 10 software (StatSoft Inc., 2011). Dependent variables were grape harvest, grape weight, PA, total acidity, wood pruning weight and vegetation cover. Canonical analysis were used to assess relationships between independent (Rainfall, ET_0 and vegetation cover) and dependent (grape harvest, grape weight, PA, total acidity, wood pruning weight and vegetation cover) variables. Resulting canonical scores were represented in a 2D graph. Independent variables were marked with arrows to facilitate interpretations.

4.3. RESULTS AND DISCUSSION

4.3.1. Rainfall and ET_0

In Belmonte de Tajo and Campo Real vineyards, the total rainfall decreased slightly year after year (Fig. 4.1). In contrast, in 2014, Navalcarnero showed higher values than 2013 and 2015. Regarding the period from bud break to the harvest, the rainfall decreased from 2013 in all vineyards. ET_0 increased along the years in all vineyards and similarly in the whole season and from bud break to harvest. The joint occurrence of lower rainfall and much higher ET_0 values strongly decreased the water availability from 2013 to 2015. Although Mediterranean climate is recognized by its variability, both models (Anaya-Romero et al., 2015) and measurements (Laget et al., 2008) agree with increasing temperatures and decreasing rainfall in Mediterranean basin, which will increase water scarcity threatening crops.

Figure 4.1. Total rainfall (mm) and ET_0 (mm) (a) and rainfall (mm) and ET_0 (mm) from the bud break to the harvest (b) in the three agronomy seasons in the closest weather stations from Belmonte (Bel) and Campo Real (CR) vineyards and for Navalcarnero (Nav).

4.3.2. Harvest and quality variables

Soil treatments had low influence on Belmonte de Tajo vineyard. Vegetation cover percentages were lower than in the other vineyards because rabbit herbivory and by the degraded previous condition of the soil. The highest values were scored by CS in the last two years of the experiment. Nevertheless, the averages of CS vegetation cover percentage were always below 20 % (Fig. 4.2b). Moreover, the low plant density and the root system of the old vine plant resulted in similar yield values with GC (Miller, 1986). These results agree with (Ruiz-Colmenero et al., 2011) who did not find grape yield differences in an old low density vineyard in the same area and similar soil and climate conditions. In 2013, CS had significantly lower PA than CB and T while the grape harvest was similar. Total acidity was slightly higher in CS but without statistical differences.

In Campo Real vineyard, grape harvest of T was higher than GC in all years being statistically significant in 2013 and 2015 (Fig. 4.2a), the driest years of the study period. In 2013, CB did not differ from T and the harvest was nearly 7500 kg ha^{-1} . Grape weight showed neither trends nor statistical differences. PA of the GC was higher than T in all years and statistically significant in 2014 for CS and in 2015 for both GC which can be explained by moderate water competition

between vine plants and GC (Muscas et al., 2017; Spayd et al., 2002). Total acidity was similar between soil treatments with slightly lower values of CS in 2015 but not statistically significant. No statistical differences or trends were observed regarding the pruning wood weight.

Figure 4.2a. Mean and confidence interval (95%) of grape yield, grape weight and potential alcohol for the three studied vineyards in during the three agronomy seasons. Soil treatments were: conventional tillage (T), Brachypodium distachyon groundcover (CB) and spontaneous vegetation groundcover (CS). All values correspond to an average year. Different letters mean difference between treatments at p < 0.05.

The biggest influence of soil treatments was observed in the Navalcarnero vineyard. In 2013, Navalcarnero vineyard was irrigated 4 times during July and August at 100 m³ ha⁻¹. Grape yields were extremely high with 14131, 11602 and 8181 kg ha⁻¹ for T, CB and CS, respectively, which are above the Denomination of Origin limit (7500 kg ha⁻¹) (BOCM, 2014). No statistical differences were observed at this regard. In 2015, without irrigation, the harvest was much lower for all treatments and significantly lower for both GC. CS had significantly lower grape weight than T while CB did not differ statistically. PA was similar in 2013, but in 2015 the CS scored much lower values than CB and T with an average of 8.5 %. Total acidity was higher for both GC but only CS was statistically higher than T. CB had statistically lower pruning wood than T in all years while CS did it in 2014 and 2015. Pruning wood in CS had a decreased trend along the studied years. Vegetation cover percentage of both GC was significantly higher than T in all years scoring the

highest percentages of the studied vineyards. In 2015, soil vegetation cover of the CS inter-rows was nearly 100 %. Thus, the high vegetation cover development and particularly CS, promoted strong water competition and ripening problems were noticed during 2015. An early defoliation took place promoting sugar synthesis limitations (Lopes et al., 2011), thus, PA of CS was abnormally low. Nevertheless, in this vineyard, we noticed lower PA values than the usual for this region for all treatments and years.

Figure 4.2b. Mean and confidence interval (95%) of total acidity, pruning weight and vegetation cover, for the three studied vineyards in during the three agronomy seasons. Soil treatments were: conventional tillage (T), Brachypodium distachyon groundcover (CB) and spontaneous vegetation groundcover (CS). All values correspond to an average year. Different letters mean difference between treatments at p < 0.05.

4.3.3. General trends

Along the three studied years for the three vineyards, GC grape yields decreased gradually and particularly with CS (Fig. 4.3). Celette et al. (2008) found that GC plant vines can develop new root systems to adapt and explore the soil to find water resources, but this is only applicable to deep soils, which are not common in Mediterranean vineyards. Our results suggest an accumulated water stress effect of the GC as other researchers found (Ruiz-Colmenero et al., 2011). Nevertheless, this could not be attained exclusively to an accumulated water competition caused

by GC as it was explained in 4.3.1 section. Pruning wood was similar for all treatments showing low water competition in the first stages of vine development. The joint occurrence of similar pruning wood and lower grape yields with GC suggest late water competition. This could be caused because before mowing a strong water competition has already happened.

Figure 4.3. Average grape yields for all vineyards and treatments in 2013, 2014 and 2015. Conventional tillage (T), *Brachypodium distachyon* groundcover (CB) and spontaneous vegetation groundcover (CS). All values correspond to an average year.

In the case of CB and T in 2013 and T in 2015 in Campo Real vineyard and all treatments in 2013 in Navalcarnero we noticed grape yields above the maximum allowed in “Wines of Madrid” denomination of origin, which is 7000 kg ha⁻¹ for Merlot and Tempranillo varieties (BOCM, 2014). This high yields compromises the quality of the wines (Chapman et al., 2005) and suggest that farmers focused their vineyards to quantity and not quality, and that makes difficult the use of alternatives soil management strategies that reduces grape yields and direct grape incomes as proposed in this study. This is mainly because farmers do not recognize soil degradation as an actual threat (Marqués et al., 2015).

4.3.4. Relationships between variables

Using the data from all soil treatments, vineyards and years, a canonical analysis was performed to assess the relationships between the two sets of variables (independents and dependents). The canonical analyses extracted 45 and 34 % (roots 1 and 2, respectively) of the variability of the independent variables (total rainfall, cumulative ET₀ and vegetation cover percentage) and 21 and

20 % (roots 1 and 2, respectively) of the dependent variables (grape yield, grape weight, PA, pruning wood weight and total acidity). Vegetation cover correlated strongly negatively with grape weight and slightly with grape harvest, PA and pruning wood. The vegetation cover had similar relative influence than rainfall and ET_0 regarding the magnitude of scores (Fig. 4.4). The low effect by independent variables on grape yield could be explained because grape yield is not only affected by vegetation cover and climate conditions of the current agronomy season but also by the previous. Furthermore, this result strengthens our hypothesis that decreasing yields were caused by both vegetation cover and climate cumulative effect. Vegetation cover scored similar than total acidity which is in contrast with Monteiro and Lopes (2007), but their vineyard location had the double average annual rainfall than central Spain. Generally, GC have low influence on acidity (Medrano et al., 2015). Contrary to expectations, while slightly, PA was negatively correlated with vegetation cover. This could be explained by two extraordinary low PA occurred in 2013 with Belmonte de Tajo and in 2015 in Navalcarnero, both cases with CS. In the first case, we attribute this to a very early harvest and in the second case to a lack of grape maturity caused by an early defoliation.

Figure 4.4. Ordination resulting from canonical analysis. Vegetation cover percentage (V. Cover), ET_0 , total rainfall (R), grape weight, pruning wood (Wood), potential alcohol (PA), grape yield (GY) and total acidity (Acidity).

4.3.5. Yield and GC costs

The average value of grapes between 2013 and 2015 were 0.0217 € kg⁻¹ alcohol⁻¹ for Airén, 0.0266 for Tempranillo and 0.0267 for Merlot (Table 4.2). These prices are very similar than those perceived for the local farmers of the study area (personal communications), while they refused to say the prices publicly.

Table 4.2. Grape prizes in the biggest wineries from Castilla La Mancha region from 2013, 2014, 2015 and the average for Airén, Tempranillo and Merlot varieties.

Variety	2013 (€ kg ⁻¹ % alcohol ⁻¹)	2014 (€ kg ⁻¹ % alcohol ⁻¹)	2015 (€ kg ⁻¹ % alcohol ⁻¹)	Average (€ kg ⁻¹ % alcohol ⁻¹)
<i>Vitis vinifera</i> , L. Airén	0.0241	0.0204	0.0207	0.0217
<i>Vitis vinifera</i> , L. Tempranillo	0.0266	0.0249	0.0284	0.0266
<i>Vitis vinifera</i> , L. Merlot	0.0278	0.0228	0.0296	0.0267

CB on Campo Real was not included in the calculations because its carbon sequestration rate was nearly zero. The biggest loss of income was CS in the three vineyards and was between 210 in Belmonte de Tajo vineyard (cv. Airén) and 1809 € ha⁻¹ in Navalcarnero vineyard (cv. Merlot). The loss of income in Belmonte de Tajo was always smaller because of the lower grape prices and low relative grape yields for all treatments as is usual in old vineyards in the region. The higher PA with GC in Campo Real vineyard buffered the loss of income even when the grape harvest was much lower for the GC (Table 4.3).

Table 4.3. Sequestered soil organic carbon (SOC), grape yield (yield), probable alcohol, income, loss of income and SOC value from the different vineyards and soil management strategies. Conventional tillage (T), *Brachypodium distachyon* groundcover (CB) and spontaneous vegetation groundcover (CS). All values correspond to an average year.

	Sequestered SOC (Mg ha ⁻¹)	Yield (Kg ha ⁻¹)	Probable Alcohol (%)	Income (€ ha ⁻¹)	Loss of income (€ ha ⁻¹)	SOC value (€ Mg ⁻¹)
Belmonte						
T		3310.8	10.6	759.5		
CB	0.8	3055.3	9.6	635.0	124.4	156.2
CS	0.5	2566.4	9.8	549.2	210.3	420.9
Campo Real						
T		8332.5	14.4	3191.9		
CB	0.1	5088.4	15.6	2108.5	1083.4	
CS	1.2	4910.6	15.8	2066.8	1125.1	953.1
Navalcarnero						
T		8282.4	12.5	2774.1		
CB	1.5	5997.6	11.9	1909.1	864.9	594.5
CS	2.0	3391.5	10.6	964.7	1809.4	901.4

Average income loss was 690.9 and 1048.3 € ha⁻¹ for CB and CS, respectively. Regarding the SOC value in relative term to the loss of income the CS showed the highest value with an average of 758.5 € Mg⁻¹ as a consequence of recording the highest SOC sequestration rates. Using CB, the cost of the sequestered SOC was 375.4 € Mg⁻¹. These values are slightly lower than the obtained by Galati et al. (2016), but they relate the SOC value to the actual payment that Sicilian farmers are perceiving already. In their research, they assumed same income by grape sales by using

temporary GC. In the study area, with permanent GC, the agri-payment that Sicilian farmers perceived, 450 € ha⁻¹ year⁻¹, (Regione Siciliana, 2016) would not cover the loss of income. That said, we have not analyzed ecosystem benefits of using GC instead of T or the replacement costs of nutrients and soil erosion. The average income loss of using GC is similar than the ecosystem benefits calculated by Galati et al. (2015). Consequently, for permanent GC in rainfed central Spanish vineyards, the agri-payments needed to counterbalance the loss of income could be between 690 and 1048 € ha⁻¹ year⁻¹ for CB and CS, respectively, which correspond to SOC sequestration values of 375 and 758 € Mg⁻¹ (Table 4.4). These values are far above the actual payments in the European Union to encourage sustainable soil management strategies. Since these agri-payments are far from actual viability in the context of European Union, we propose further field trials performing different GC species, early mowing dates and alternatives GC strategies as alternating inter-rows with GC and moderate T.

Table 4.4. Average income loss and SOC value averages for the performed groundcovers. Conventional tillage (T), *Brachypodium distachyon* groundcover (CB) and spontaneous vegetation groundcover (CS). Values correspond to an average year.

Groundcover	Average income loss (€ ha ⁻¹)	SOC value (€ Mg ⁻¹)
CB	690.9	375.4
CS	1048.3	758.5

4.4. CONCLUSIONS AND FURTHER RESEARCH

In semiarid Mediterranean agricultural soils, tillage cessation or seeding GC does not ensure GC success in terms of high cover percentage or increasing biomass input significantly (Bienes et al., 2016). With three commercial vineyards located in different degraded soils the most typical vineyards in central Spain are represented. This study provides an evaluation of GC in semiarid degraded Mediterranean soils showing GC performance, its effects on grape yield and quality and an assessment of economic loss in terms of SOC sequestration for different types of viticulture practices in Central Spain. To our knowledge, this is the GC field trial in vineyards performed with the lower average rainfall.

Although GC are recognized to promote soil benefits, control vine vigor and increase wine quality, the results of this study suggest a general decrease in grape yields and variety-dependent influence in grape quality.

According to its different variety, plant density and vegetation cover development, the three vineyards behaved differently. Belmonte de Tajo, with low cover percentage, low plant density

and strong all root system, had non to slight water competition and it was slightly influenced by the soil treatment in grape yield and quality. Campo Real vineyard, with 2222 plant ha⁻¹ and relevant cover development experienced moderate influence. GC reduced grape yield while increased grape quality. On the other hand, Navalcarnero vineyard, with high plant density and high vegetation cover was strongly influenced in 2015, when an early defoliation caused ripening problems

The loss of income caused by the use of GC makes unadvisable the development of new policy to promote permanent GC in rainfed vineyards in central Spain as a unique agri-payment to all types of vineyards. However, the use of permanent GC in old low density vineyards of Airén could be encouraged with agri-payments of 200 € ha⁻¹ year⁻¹, that counterbalance the loss of income. An accurate selection of GC species is critical to avoid competition in mid-spring. In the study area, the low temperatures during the winter and early spring complicate the GC mowed before May. Thus, in this trial, strong competition between the plant vines and the GC took place. Before its recommendation to farmers and policy development in central Spain more research is needed addressing the following matters: suitable GC species, alternative and rotating tillage in consecutive inter-rows, temporary GC and GC suitability depending of the plant density and irrigation status.

GENERAL DISCUSSION

Conventional soil management in Mediterranean vineyards has led to high erosion rates and nutrient, SOC and fertility losses. These processes are becoming not just environmental concerns (Quilbe et al., 2005; Pimentel, 2006), but also producing economical losses for farmers (Martínez-Casasnovas and Ramos, 2006; Galati et al., 2015). This doctoral dissertation addressed the influence of GC to revert soil degradation processes paying special attention to SOC.

GC influence on soil parameters

In central Spain, conventional soil management generally ignores the need of organic amendments and, thus, organic matter inputs are scarce and limited to vine leafs and few weeds that grow between tillage operations. With continuous tillage, it resulted in very low organic matter contents (Panagos et al., 2013), poor soil structure and soils prone to erosion (Pérez-Rodríguez et al., 2007).

Degraded soils of this area can hardly improve its properties (Bienes et al., 2016). However, three years after the GC establishment, significant improvements in global soil quality have been observed. GC increased the main deficiency of soil in traditionally managed vineyards of this area which is organic matter inputs. In the present research, the total biomass data of each soil treatment are not available, but increasing root biomass and plant cover development showed increasing organic matter input in GC. As a consequence, a cascade of soil improvements was happened. In three years, SOC stocks increased in 3.18 and 1.62 Mg ha⁻¹ for CS and CB, respectively, regarding T. These increases correspond to 1.06 and 0.54 Mg SOC ha⁻¹ year⁻¹ for CS and CB, which are in the same range than those recorded by Peregrina et al. (2010; 2014). The fact that positive carbon sequestration rates were recorded even with very low vegetation cover and root biomass inputs strengthen the notion that tillage is one of the major driving forces of SOC mineralization (Kabiri et al., 2016) and that tillage cessation could be as decisive as plant cover development to increase SOC and reduce soil degradation.

As it was explained in Chapter 2, POC is often related to soil quality and particle aggregation (Duval et al., 2013; Six et al., 2002) and to a higher sensitivity to management changes than SOC (Blavet et al., 2009). Nevertheless, in this study, POC responded similarly to MOC and SOC which could be explained because the measurements included in Chapter 2 were taken 3 years after the GC establishment and a fraction of POC was naturally humified becoming more stable organic carbon (MOC). However, after three years, POC stocks increased 1.5 Mg ha⁻¹ in CS regarding T and 0.8 Mg ha⁻¹ in the case of CB.

The increase in both organic carbon fractions promoted increasing aggregate stability as it was expected and have been widely addressed in the literature (Blavet et al., 2009; Bronick and Lal, 2005; Hernanz et al., 2002; Peng et al., 2016; Six et al., 2000b; Wander and Bidart, 2000). Significant improvements were recorded for both performed aggregate stability test (CND and WSA), but WSA showed higher suitability for Mediterranean vineyards for its quick response to SOC and soil management changes.

Although GC promoted soil compaction, soil-water relationships of GC were also positively affected. GC showed low impact on soil porosity. Slight differences were observed for WHC, macro, meso, micro and total porosity and only WHC and microporosity had significant differences between CB and T. Nevertheless, GC infiltration rates doubled T. Therefore, the improvement in soil structure of GC created a new pore system with a better connectivity as other researchers found (Gao et al., 2017; Pires et al., 2017). This improvement represents a greater use of rainwater and, therefore, of water economy. Additionally, canonical analyses supported the understanding that soil compaction are not the main factors explaining soil-water relationships.

GC influence on runoff and mineral nitrogen loss

A runoff simulator was designed, built, calibrated and used to simulate sheet flow in field trials. Additional images of the runoff simulator and how the measurements were done can be found in Appendix 3. The performed experiments were the first to analyze runoff and mineral nitrogen losses caused by sheet flow and separating this effect from raindrop impacts in Mediterranean vineyards.

GC reduced runoff in two forms. First, the increase of aggregate stability and, thus, soil structure improvement affected infiltration rates (Holifield Collins et al., 2015). Moreover, plant stems and litter reduced sheet flow speed, making water remain more time in the same point to infiltrate (Cerdeira, 1998; Wang et al., 2016).

The most effective soil treatment reducing runoff and mineral nitrogen loss was CS. Runoff produced with CS was 3 times less than with T and the nitrate loss was 6 times lower. GC acted as catch crops in arable cover crops and caught the soil nitrate creating organic biomass (Gabriel and Quemada, 2011; Gabriel et al., 2013; Gabriel et al., 2012). Consequently, T induced higher runoff rates, and runoff mineral nitrogen concentration was higher (Jiao et al., 2012). These concentrations were especially higher during the first minutes of the experiments, which encourage the need of increase infiltration rates and avoid runoff events.

Yield and grape quality and soil sequestration economic value

To our knowledge, only Ruiz-Colmenero et al. (2011) performed a comparative trial with GC with similar annual rainfall and study area. This is the first field trial analyzing grape yield and quality in three different vineyards in central Spain including three agronomy seasons and two permanent GC.

GC encouraged water deficit and generally reduced yields. Grape yield reductions and quality influence were higher as vine plant density and vegetation cover were higher. Thus, Belmonte de Tajo vineyard, with low plant density and vegetation cover, was not statistically influenced by GC, while Navalcarnero, an intensive 3500 plant ha⁻¹ vineyard with more than 90 % of vegetation cover was strongly influenced the last year of the trial. However, data from rainfall, ET₀ and canonical analysis showed that the increase in water deficit and yield reductions cannot be fully attributed to GC. In Campo Real vineyard, moderate water deficit allowed an increase in PA with GC as other researchers found (Muscas et al., 2017; Spayd et al., 2002).

On the other hand, strong decreases in PA caused by high water deficit produced that globally, independent variables such as rainfall or vegetation cover showed low influence on PA. Regarding all vineyards and years, GC reduced grape average weight and increased juice acidity, which is related to grape quality (Hidalgo, 2003) and is interesting for enological point of view because local vine varieties lack acidity and aromas (Cabello et al., 2012; Crespo et. al., 2014).

The loss of income caused by using GC was similar than the economic value of ecosystem benefits calculated by Galati et al. (2015). However, a question arises. Is European society willing to pay for this ecosystem benefits to counterbalance the loss of farmers income? In Madrid region, there is not any payment for this matter currently. Moreover, the average income loss (690.9 and 1048.3 € ha⁻¹ for CB and CS, respectively) is significantly higher than actual agri-payments in Spain or Europe. For instance, farmers from La Rioja obtain a maximum of 250 € ha⁻¹ year⁻¹ to establish permanent GC (BOR, 2015) in vineyards or in Sicily, where farmers perceive 450 € ha⁻¹ year⁻¹ for temporary leguminous GC (Regione Siciliana, 2016). In this sense, each ton of sequestered SOC had an economic value of 375 and 758 € for CB and CS, respectively, in terms of the loss of income produced by decreasing grape yield and PA changes. However, production costs were not included in this study and could reduce the loss of income by decreasing machinery costs and reducing soil and nutrient loss.

GC performance

Vegetation cover percentages were low compared with similar works about GC in Mediterranean woody crops (Novara et al., 2011; Ruiz-Colmenero et al., 2011). Only Navalcarnero vineyard was composed by vegetation covers above 80 % during the last two years. The low covers could be attributed to several factors:

- Soils had low organic matter content, were shallow and were under the consideration of degraded soils.
- Rainfall was scarce along the entire trial.
- Strong herbivory caused mainly by rabbits.

One of the reasons of *Brachypodium distachyon* selection for a seeded GC was its well adaptation resulting in high vegetation cover in degraded soils that could be found in other trials (Sastre et al., 2017). Nevertheless, rabbit herbivory affected especially CB in Belmonte de Tajo and Campo Real vineyards where rabbits are a plague. This concern reached its maximum in Belmonte de Tajo. The reader will notice that the experiments were performed in four vineyards and Chapter 4 is referred to just 3 vineyards. The second vineyard in Belmonte de Tajo (Bel II) was removed from grape yield and quality measurements because rabbits ate nearly the whole yield of that vineyard and, besides, stems and buds were damaged. Images are shown in Appendix 4.

Despite the fact that vegetation cover percentages were similar in both permanent GC, CS had larger impact in the most of studied variables than CB: in runoff, nitrate loss, POC, MOC and SOC sequestration, aggregate stability, infiltration rates and grape yield and quality. CB generally showed intermediate values between CS and T and statistically significant differences were few. This could be caused by a higher biomass input provided by the spontaneous vegetation at same vegetation cover. CS had more than 2 Mg ha⁻¹ root biomass stock, at 0 to 10 cm depth, than CB. The most important soil improvements occurred with CS because its bigger organic matter inputs promoted higher soil structure improvements and, consequently, increased infiltration and reduced runoff and mineral nitrogen loss.

The 4 per mille initiative proposes climate change mitigation through appropriate soil management (Minasny et al., 2017), which has been widely discussed in literature (Chambers et al., 2016; Li et al., 2017; Stockmann et al., 2013). SOC sequestration rates detailed in this document show that initiatives such as The 4 per mille should be carrying out diversely in the different world regions. The increase of 0.4 % in SOM stocks is achievable even in woody crops in semiarid climate as was shown in the trial with permanent GC. However, its effects on agronomic

productivity and farmers' incomes make it unfeasible from farmers' point of view. Sustainable soil management strategies must be encouraged in order to increase soil fertility, reduce erodibility and total erosion, ensure sustainability and guarantee soil fertility for future generations.

Generally, GC increased SOC, improved soil quality and reduced runoff and mineral nitrogen loss, which has positive outcomes from many points of view: climate change mitigation, environmental pollution, soil fertility, land use long term sustainability and farmer's income. However, water competition took place. Grape yield reductions were significant and produced remarkable losses of economic incomes. In certain circumstances, water competition promoted early defoliations and ripening problems. Thus, permanent GC are unadvisable in young and high plant density rainfed vineyards. However, it can be considered a very efficient soil management strategy in old low plant density vineyards of cultivars with high resistance to drought as Airén cultivar.

Furthermore, pruning wood was similar in all years for the most of the vineyards, showing that water competition occurred from middle spring (Medrano et al., 2015). This suggests that mowing date was too late and water competition already happened. Other researches addressed mowing dates starting in February (Lopes et al., 2011) but in regions with relatively warm winters. In our study area, average temperatures remain under 10 °C from November to April and average minimum temperatures are often under 0 °C. These circumstances make difficult GC development, especially for CB. Thus, mowing date was in the first week of May, when GC reached a reasonable growth and CB was ripened. It is necessary performing new trials with well adapted species to cold winters.

It was proved that permanent GC reduce grape yield and compromises its quality when strong water competition happens in central Spain rainfed vineyards. Consequently, new scientific and agronomic management concerns arise about:

- Mow timing
- Temporary or permanent GC?
- Species selection for a seeded GC
- Economical compensation for farmers using GC

Temporary GC and SOC threshold

Temporary GC are effective soil management to reduce erosion and reducing nitrate loss (Novara et al., 2011; Novara et al., 2013) in Mediterranean areas where the most of the rain falls in winter (Nadal-Romero et al., 2015; Rodrigo Comino et al., 2017). In April, inter rows are tilled to eliminate water competition with vine plants.

The 50 paired sites from southern Sicily showed an increase in SOC with the adoption of AEM but relatively lower than the reported by other researchers (Batjes, 2014; Debasish-Saha et al., 2014). This was caused by the tillage operations from April that mineralizes SOC (Kabiri et al., 2016) and because the GC species was leguminous, which has a low C/N relationship and increases mineralization rates (Plaza-Bonilla et al., 2015).

This chapter questioned the possibility of increase SOC loss via erosion as a consequence of SOC enriched sediments under AEM. The SOC content that produces the same SOC loss than T under temporary GC was named SOC threshold. As calculations were based on USLE equation, results were separated in high silt content soils and low silt content soils. Results showed that SOC threshold can be reached in 5 years of AEM in high silt soils due to its high erodibility. In the case of low content silt soils, SOC threshold is higher than SOC saturation level and will never be reached. As a consequence, European policies that encourage the use of sustainable management practices effectiveness should be maximized through the consideration of factors such as particular GC species and management, initial SOC stocks and SOC and soil loss.

Further research

In semiarid environments, long-term field trials are scarce and are usually arable crops field trials (Hernanz et al., 2002; Moreno et al., 2011). For our knowledge, there is not any long-term vineyard trial devoted to assess the comparative influence of GC in soil, erosion, nutrient loss, SOC sequestration or grape yield and quality with semiarid climate. Moreover, the fertility loss that takes place with continuous tillage and which have consequences on grape yield and quality need to be monitored in long term trials, because continuous degradation caused by tillage is systematically ignored due to the short term of field trials.

Runoff simulations generated valuable information about runoff and dissolved mineral nitrogen loss. Nevertheless, phosphorous, potassium and dissolved organic carbon data will be also interesting to complete the full picture of runoff impact on nutrient and fertility loss. Additionally,

the simulation of rainfall and runoff in the same plots could complete the information about the relative importance of splash and runoff in soil particle detachment and nutrient losses.

The trial was composed by four vineyards with three repeated treatments. Our knowledge about GC impact on soil properties and GC influence on yield and grape quality increased. However, more vineyards with different plant densities and varieties are needed to increase our scientific knowledge about the GC use possibilities in semiarid vineyards, where water competition is a critical issue. At this regard, the inclusion of a mixed treatment such as alternant inter-rows with GC and tillage could reduce soil degradation while maintaining grape yields. In our trial, that was impossible because the number of farmers willing to provide vineyards for trials was a limiting factor. Additionally, the influence of the rootstock on yields regarding GC competition with water should provide valuable information. In the present work, that was not possible giving that in two out of four vineyards rootstocks were unknown.

In this thesis, grape yield and quality results showed high dependence on each vineyard, which had different vine variety, training method, plant density and even rootstock. Consequently, more research is needed to adapt these factors to GC in steep semiarid vineyards, where alternative soil management strategies are mandatory to ensure long-term sustainability.

More field trials in semiarid vineyards are needed to increase the knowledge about the influence of the mowing timing and the water competition threshold for permanent GC and areas with different annual rainfalls.

GC species selection seems critical for a well water competition management and ensures correct mowing dates.

The importance of soil degradation processes obligates human societies to develop new agronomic paradigms and sustainable land uses. For that purpose, Inter-disciplinary studies including soil science, economics and social points of view are urgently demanded.

GENERAL CONCLUSIONS

The use of permanent groundcovers increases soil organic carbon stocks with higher efficiency than temporary groundcovers. Three years after the establishment of permanent groundcovers in Mediterranean vineyards soil organic carbon of the particulate organic matter, mineral-associated organic carbon and soil organic carbon stocks increased throughout higher organic inputs. This increase influenced strongly aggregate stability by improving soil structure.

Although soil compaction was higher with groundcovers than with conventional tillage, porosity volume was not affected. A new pore connection system was created allowing a high increase of infiltration rates and thus, reducing runoff.

Runoff simulations are an efficient methodology to compare runoff and nutrient loss with different soil management strategies. Runoff simulations helped with the understanding of the fact that raindrops impacts are not the unique factor to explain runoff and mineral nitrogen loss. Even with low vegetation cover percentages, vegetation cover is the key factor for reducing runoff and mineral nitrogen loss. Groundcovers in vineyards reduced mineral nitrogen loss by means of lower runoff and much lower mineral nitrogen concentration dissolved in runoff.

Although average vegetation cover percentages were similar, spontaneous vegetation groundcover promoted the biggest soil improvements and, consequently, the most important reductions in runoff and mineral nitrogen loss.

Soil organic carbon threshold can be reached in high erodibility soil with temporary groundcovers. This management protects the soil from the most erosive rainfalls but remains bare from April to November. When temporary groundcovers are performed in erodible soils such as silty soils or those with poor structure the increase in soil organic carbon could result in higher carbon loss through highly carbon enriched sediments.

Groundcovers promoted important improvements in soil quality but generally resulted in lower grape yields. Lower yields and quality changes caused significant decreases in economic incomes which were much higher than other agri-payments that farmers from other European regions perceive currently. An old Airén variety vineyard was barely affected by groundcovers.

REFERENCES

- Aguilar, J., Fernáandez, J., Ortega, E., de Haro, S., Rodríguez, T. 1990. Micromorphological Characteristics of Soils Producing Olives under Nonploughing Compared with Traditional Tillage Methods. *Dev. Soil Sci.* 19:25-32. doi: [http://dx.doi.org/10.1016/S0166-2481\(08\)70312-X](http://dx.doi.org/10.1016/S0166-2481(08)70312-X).
- Akpa, S.I.C., Odeh, I.O.A., Bishop, T.F.A., Hartemink, A.E., Amapu, I.Y. 2016. Total soil organic carbon and carbon sequestration potential in Nigeria. *Geoderma* 271:202-215. doi: <http://dx.doi.org/10.1016/j.geoderma.2016.02.021>.
- Anaya-Romero, M., Abd-Elmabod, S.K., Munoz-Rojas, M., Castellano, G., Juan Ceacero, C., Alvarez, S., Mendez, M., De la Rosa, D. 2015. Evaluating Soil Threats Under Climate Change Scenarios in the Andalusia Region, Southern Spain. *Land Degrad. Dev.* 26:441-449. doi: <http://dx.doi.org/10.1002/ldr.2363>.
- Anderson K, Nelgen S (2011) *Global Wine Markets, 1961 to 2009: A statistical compendium*. University of Adelaide Press.
- Arauzo, M., Jose Martinez-Bastida, J. 2015. Environmental factors affecting diffuse nitrate pollution in the major aquifers of central Spain: groundwater vulnerability vs. groundwater pollution. *Environ. Earth Sci.* 73:8271-8286. doi: <http://dx.doi.org/10.1007/s12665-014-3989-8>.
- Arnaez, J., Lasanta, T., Ruiz-Flaño, P., Ortigosa, L. 2007a. Factors affecting runoff and erosion under simulated rainfall in Mediterranean vineyards. *Soil Tillage Res.* 93:324-334. doi: <http://dx.doi.org/10.1016/j.still.2006.05.013>.
- Arnold, S., Williams, E.R. 2016. Quantification of the inevitable: the influence of soil macrofauna on soil water movement in rehabilitated open-cut mined lands. *SOIL* 2:41-48. doi: <http://dx.doi.org/10.5194/soil-2-41-2016>.
- Atucha, A., Merwin, I.A., Brown, M.G., Gardiazabal, F., Mena, F., Adriazola, C., Lehmann, J. 2013. Soil erosion, runoff and nutrient losses in an avocado (*Persea americana* Mill) hillside orchard under different groundcover management systems. *Plant Soil* 368:393-406. doi: <http://dx.doi.org/10.1007/s11104-012-1520-0>.
- Bakker, M.M., Govers, G., Kosmas, C., Vanacker, V., Oost, K.v., Rounsevell, M. 2005. Soil erosion as a driver of land-use change. *Agric. , Ecosyst. Environ.* 105:467-481. doi: <http://dx.doi.org/10.1016/j.agee.2004.07.009>.
- Bakker, M.M., Govers, G., Rounsevell, M.D.A. 2004. The crop productivity–erosion relationship: an analysis based on experimental work. *Catena* 57:55-76. doi: <http://dx.doi.org/10.1016/j.catena.2003.07.002>.
- Baldwin M, Kellogg CE, Thorp.J (1938) *Soil Classification, Soils and Men: Yearbook of Agriculture*. U.S. Government Printing Office, Washington D.C.

- Balesdent, J., Chenu, C., Balabane, M. 2000. Relationship of soil organic matter dynamics to physical protection and tillage. *Soil Tillage Res.* 53:215-230. doi: [http://dx.doi.org/10.1016/S0167-1987\(99\)00107-5](http://dx.doi.org/10.1016/S0167-1987(99)00107-5).
- Baptista, I., Ritsema, C., Geissen, V. 2015. Effect of Integrated Water-Nutrient Management Strategies on Soil Erosion Mediated Nutrient Loss and Crop Productivity in Cabo Verde Drylands. *PLoS One* 10:e0134244. doi: <http://dx.doi.org/10.1371/journal.pone.0134244>.
- Barger, N.N., Herrick, J.E., Van Zee, J., Belnap, J. 2006. Impacts of biological soil crust disturbance and composition on C and N loss from water erosion. *Biogeochemistry* 77:247-263. doi: <http://dx.doi.org/10.1007/s10533-005-1424-7>.
- Barthès, B., Roose, E. 2002. Aggregate stability as an indicator of soil susceptibility to runoff and erosion; validation at several levels. *Catena* 47:133-149. doi: [http://dx.doi.org/10.1016/S0341-8162\(01\)00180-1](http://dx.doi.org/10.1016/S0341-8162(01)00180-1).
- Batjes, N. 2014. Projected changes in soil organic carbon stocks upon adoption of recommended soil and water conservation practices in the upper Tana River Catchment, Kenya. *Land Degrad. Dev.* 25:278-287. doi: <http://dx.doi.org/10.1002/ldr.2141>.
- Battany, M.C., Grismer, M.E. 2000. Rainfall runoff and erosion in Napa Valley vineyards: effects of slope, cover and surface roughness. *Hydrol. Process.* 14:1289-1304. doi: [http://dx.doi.org/10.1002/\(SICI\)1099-1085\(200005\)14:73.0.CO;2-R](http://dx.doi.org/10.1002/(SICI)1099-1085(200005)14:73.0.CO;2-R).
- Bayer, C., Martín-Nieto, L., Mielniczuk, J., Pavinato, A. 2004. Armazenamento de carbono em frações lábeis da matéria orgânica de um Latossolo Vermelho sob plantio direto. *Pesquisa Agropecuária Brasileira* 39:677-683. doi: <http://dx.doi.org/10.1590/S0100-204X2004000700009>.
- Biddoccu, M., Ferraris, S., Opsi, F., Cavallo, E. 2016. Long-term monitoring of soil management effects on runoff and soil erosion in sloping vineyards in Alto Monferrato (North-West Italy). *Soil Tillage Res.* 155:176-189. doi: <http://dx.doi.org/10.1016/j.still.2015.07.005>.
- Biddoccu, M., Ferraris, S., Opsi, F., Cavallo, E. 2015. Effects of Soil Management on Long-Term Runoff and Soil Erosion Rates in Sloping Vineyards. In: Lollino G, Manconi A, Clague J, Shan W, Chiarle M (eds) *Engineering Geology for Society and Territory - Volume 1: Climate Change and Engineering Geology* Springer International Publishing, Cham, pp 159-163.
- Bienes, R., Marques, M.J., Sastre, B., García-Díaz, A., Ruiz-Colmenero, M. 2016. Eleven years after shrub revegetation in semiarid eroded soils. Influence in soil properties. *Geoderma* 273:106-114. doi: <http://dx.doi.org/10.1016/j.geoderma.2016.03.023>.
- Bienes, R., Ruiz, M., Marques, M.J. 2010. Pérdida de suelo, fósforo y materia orgánica por erosión hídrica en parcelas revegetadas con matorral autóctono bajo clima semiárido. *Revista de Ciências Agrárias* 33:58-69.
- Blavet, D., De Noni, G., Le Bissonnais, Y., Leonard, M., Maillo, L., Laurent, J.Y., Asseline, J., Leprun, J.C., Arshad, M.A., Roose, E. 2009. Effect of land use and management on the early stages of soil water erosion in French Mediterranean vineyards. *Soil Tillage Res.* 106:124-136. doi: <http://dx.doi.org/10.1016/j.still.2009.04.010>.

- Bochet, E. 2015. The fate of seeds in the soil: a review of the influence of overland flow on seed removal and its consequences for the vegetation of arid and semiarid patchy ecosystems. SOIL 1:131-146. doi: <http://dx.doi.org/10.5194/soil-1-131-2015>.
- BOCM. 2014. ORDEN 2047/2014, de 20 de octubre, de la Consejería de Medio Ambiente y Ordenación del Territorio, por la que se adecua a la normativa vigente el Reglamento de la Denominación de Origen "Vinos de Madrid". B.O.C.M. Num. 259. Viernes 31 de octubre de 2014.
- BOCM. 2009. Boletín Oficial de la Comunidad de Madrid no 170, del 20 de Julio de 2009.
- Boix-Fayos, C., Calvo-Cases, A., Imeson, A.C., Soriano-Soto, M.D. 2001. Influence of soil properties on the aggregation of some Mediterranean soils and the use of aggregate size and stability as land degradation indicators. Catena 44:47-67. doi: [http://dx.doi.org/10.1016/S0341-8162\(00\)00176-4](http://dx.doi.org/10.1016/S0341-8162(00)00176-4).
- BOR. 2015. Boletín Oficial de La Rioja no 74 del 8 de junio de 2015.
- Bravo-Espinosa, M., Mendoza, M.E., Carlón Allende, T., Medina, L., Sáenz-Reyes, J.T., Páez, R. 2014. Effects of converting forest to avocado orchards on topsoil properties in the Trans-Mexican Volcanic System, Mexico. Land Degrad. Dev. 25:452-467. doi: <http://dx.doi.org/10.1002/ldr.2163>.
- Brevik, .E.C. 2013. The Potential Impact of Climate Change on Soil Properties and Processes and Corresponding Influence on Food Security. Agriculture 3 doi: <http://dx.doi.org/10.3390/agriculture3030398>.
- Brevik, E.C., Cerdà , A., Mataix-Solera, J., Pereg, L., Quinton, J.N., Six, J., Van Oost, K. 2015. The interdisciplinary nature of SOIL. SOIL 1:117-129. doi: <http://dx.doi.org/10.5194/soil-1-117-2015>.
- Brillante, L., Mathieu, O., Bois, B., van Leeuwen, C., Lévêque, J. 2015. The use of soil electrical resistivity to monitor plant and soil water relationships in vineyards. SOIL 1:273-286. doi: <http://dx.doi.org/10.5194/soil-1-273-2015>.
- Bronick, C.J., Lal, R. 2005. Soil structure and management: a review. Geoderma 124:3-22. doi: <http://dx.doi.org/10.1016/j.geoderma.2004.03.005>.
- Bruggisser, O.T., Schmidt-Entling, M.H., Bacher, S. 2010. Effects of vineyard management on biodiversity at three trophic levels. Biol. Conserv. 143:1521-1528. doi: <http://dx.doi.org/10.1016/j.biocon.2010.03.034>.
- Brunori, E., Farina, R., Biasi, R. 2016. Sustainable viticulture: The carbon-sink function of the vineyard agro-ecosystem. Agric. , Ecosyst. Environ. 223:10-21. doi: <http://dx.doi.org/10.1016/j.agee.2016.02.012>.
- Bruun, T.B., Elberling, B., de Neergaard, A., Magid, J. 2015. Organic Carbon Dynamics in Different Soil Types After Conversion of Forest to Agriculture. Land Degrad. Dev. 26:272-283. doi: <http://dx.doi.org/10.1002/ldr.2205>.

- Bu, C., Wu, S., Yang, K. 2014. Effects of physical soil crusts on infiltration and splash erosion in three typical Chinese soils. *International Journal of Sediment Research* 29:491-501. doi: [http://dx.doi.org/10.1016/S1001-6279\(14\)60062-7](http://dx.doi.org/10.1016/S1001-6279(14)60062-7).
- Buendia, C., Vericat, D., Batalla, R.J., Gibbins, C.N. 2016. Temporal Dynamics of Sediment Transport and Transient In-channel Storage in a Highly Erodible Catchment. *Land Degrad. Dev.* 27:1045-1063. doi: 10.1002/ldr.2348.
- Burns, K.N., Bokulich, N.A., Cantu, D., Greenhut, R.F., Kluepfel, D.A., O'Geen, A.T., Strauss, S.L., Steenwerth, K.L. 2016. Vineyard soil bacterial diversity and composition revealed by 16S rRNA genes: Differentiation by vineyard management. *Soil Biol. Biochem.* 103:337-348. doi: <http://dx.doi.org/10.1016/j.soilbio.2016.09.007>.
- Cabello, F., Ortiz, J.M., Muñoz, G., Rodríguez, I., Benito, A., Rubio, C., García, S., Sáiz, R. 2012. *Variedades de Vid en España*. Editorial Agrícola Española, S.A. ISBN: 9788492928132.
- Calleja-Cervantes, M.E., Fernández-González, A.J., Irigoyen, I., Fernández-López, M., Aparicio-Tejo, P.M., Menéndez, S. 2015. Thirteen years of continued application of composted organic wastes in a vineyard modify soil quality characteristics. *Soil Biol. Biochem.* 90:241-254. doi: <http://dx.doi.org/10.1016/j.soilbio.2015.07.002>.
- Cambardella, C.A., Elliott, E.T. 1992. Particulate Soil Organic-Matter Changes across a Grassland Cultivation Sequence 56:777-783. doi: <http://dx.doi.org/10.2136/sssaj1992.03615995005600030017x>.
- Cammeraat, E.L.H., Cerda, A., Imeson, A.C. 2010. Ecohydrological adaptation of soils following land abandonment in a semi-arid environment. *Ecohydrology* 3:421-430. doi: <http://dx.doi.org/10.1002/eco.161>.
- Carpio, A.J., Castro, J., Mingo, V., Tortosa, F.S. 2017. Herbaceous cover enhances the squamate reptile community in woody crops. *Journal for Nature Conservation* doi: <http://dx.doi.org/10.1016/j.jnc.2017.02.009>.
- Carr, P.M., Brevik, E.C., Horsley, R.D., Martin, G.B. 2015. Long-Term No-Tillage Sequesters Soil Organic Carbon in Cool Semiarid Regions 56 doi: <http://dx.doi.org/10.2136/sh15-07-0016>.
- Castillo-Monroy, A., Maestre, F.T., Delgado-Baquerizo, M., Gallardo, A. 2010. Biological soil crusts modulate nitrogen availability in semi-arid ecosystems: insights from a Mediterranean grassland. *Plant Soil* 333:21-34. doi: <http://dx.doi.org/10.1007/s11104-009-0276-7>.
- Castro, J., Fernández-Ondoño, E., Rodríguez, C., Lallena, A.M., Sierra, M., Aguilar, J. 2008. Effects of different olive-grove management systems on the organic carbon and nitrogen content of the soil in Jaén (Spain). *Soil Tillage Res.* 98:56-67. doi: <http://dx.doi.org/10.1016/j.still.2007.10.002>.
- Celette, F., Gaudin, R., Gary, C. 2008. Spatial and temporal changes to the water regime of a Mediterranean vineyard due to the adoption of cover cropping. *Eur. J. Agron.* 29:153-162. doi: <http://dx.doi.org/10.1016/j.eja.2008.04.007>.
- Cerda, A. 1998. The influence of aspect and vegetation on seasonal changes in erosion under rainfall simulation on a clay soil in Spain. *Can. J. Soil Sci.* 78:321-330.

- Cerdà, A. 2000. Aggregate stability against water forces under different climates on agriculture land and scrubland in southern Bolivia. *Soil Tillage Res.* 57:159-166. doi: [http://dx.doi.org/10.1016/S0167-1987\(00\)00155-0](http://dx.doi.org/10.1016/S0167-1987(00)00155-0).
- Cerdà, A., 1997. The effect of patchy distribution of *Stipa tenacissima* L. on runoff and erosion. *Journal of Arid Environments* 36:37-51. doi: <http://dx.doi.org/10.1006/jare.1995.0198>.
- Cerdà, A., Gonzalez-Pelayo, O., Gimenez-Morera, A., Jordan, A., Pereira, P., Novara, A., Brevik, E.C., Prosdocimi, M., Mahmoodabadi, M., Keesstra, S., Garcia Orenes, F., Ritsema, C.J. 2016. Use of barley straw residues to avoid high erosion and runoff rates on persimmon plantations in Eastern Spain under low frequency-high magnitude simulated rainfall events. *Soil Res.* 54:154-165. doi: <http://dx.doi.org/10.1071/SR15092>.
- Cerdà, A., Jurgensen, M.F. 2011. Ant mounds as a source of sediment on citrus orchard plantations in eastern Spain. A three-scale rainfall simulation approach. *Catena* 85:231-236. doi: <http://dx.doi.org/10.1016/j.catena.2011.01.008>.
- Cerdà, A., Jurgensen, M.F., Bodí, M.B. 2009. Effects of ants on water and soil losses from organically-managed citrus orchards in eastern Spain. *Biologia* 64:527-531. doi: <http://dx.doi.org/10.2478/s11756-009-0114-7>.
- Cerdà, A., Morera, A.G., Bodí, M.B. 2009. Soil and water losses from new citrus orchards growing on sloped soils in the western Mediterranean basin. *Earth Surf. Process. Landforms* 34:1822-1830. doi: <http://dx.doi.org/10.1002/esp.1889>.
- Cerdan, O., Govers, G., Le Bissonnais, Y., Van Oost, K., Poesen, J., Saby, N., Gobin, A., Vacca, A., Quinton, J., Auerswald, K., Klik, A., Kwaad, F.J.P.M., Raclot, D., Ionita, I., Rejman, J., Rousseva, S., Muxart, T., Roxo, M.J., Dostal, T. 2010. Rates and spatial variations of soil erosion in Europe: A study based on erosion plot data. *Geomorphology* 122:167-177. doi: <http://dx.doi.org/10.1016/j.geomorph.2010.06.011>.
- Certini, G., Vestgarden, L.S., Forte, C., Tau Strand, L. 2015. Litter decomposition rate and soil organic matter quality in a patchwork heathland of southern Norway. *SOIL* 1:207-216. doi: <http://dx.doi.org/10.5194/soil-1-207-2015>.
- Chambers, A., Lal, R., Paustian, K. 2016. Soil carbon sequestration potential of US croplands and grasslands: Implementing the 4 per Thousand Initiative. *J. Soil Water Conserv.* 71:68A-74A. doi: <http://dx.doi.org/10.2489/jswc.71.3.68A>.
- Chapman, D., M., Roby, G., Ebeler, S., E., Guinard, J., Matthews, M., A. 2005. Sensory attributes of Cabernet Sauvignon wines made from vines with different water status. *Australian Journal of Grape and Wine Research* 11:339-347. doi: <http://dx.doi.org/10.1111/j.1755-0238.2005.tb00033.x>.
- Christensen, J.H., Hewitson, B., Busuioc, A., Chen, A., Gao, X., Held, I., Jones, R., Kolli, R.K., Kwon, W.-, Laprise, R., Rueda, V.M., Mearns, L., Menéndez, C.G., Räisänen, J., Rinke, A., Sarr, A., Whetton, P. 2007. Regional climate projections. *Climate change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. :897-940.

- Colazo, J.C., Buschiazio, D. 2015. The Impact of Agriculture on Soil Texture Due to Wind Erosion. *Land Degrad. Dev.* 26:62-70. doi: <http://dx.doi.org/10.1002/ldr.2297>.
- Conant, R.T., Ryan, M.G., Ågren, G.I., Birge, H.E., Davidson, E.A., Eliasson, P.E., Evans, S.E., Frey, S.D., Giardina, C.P., Hopkins, F.M., Hyvönen, R., Kirschbaum, M.U.F., Lavelle, J.M., Leifeld, J., Parton, W.J., Megan Steinweg, J., Wallenstein, M.D., Martin Wetterstedt, J.Å., Bradford, M.A. 2011. Temperature and soil organic matter decomposition rates – synthesis of current knowledge and a way forward. *Global Change Biol.* 17:3392-3404. doi: <http://dx.doi.org/10.1111/j.1365-2486.2011.02496.x>.
- Costantini, E.A.C., Agnelli, A.E., Fabiani, A., Gagnarli, E., Mocali, S., Priori, S., Simoni, S., Valboa, G. 2015. Short-term recovery of soil physical, chemical, micro- and mesobiological functions in a new vineyard under organic farming. *SOIL* 1:443-457. doi: <http://dx.doi.org/10.5194/soil-1-443-2015>.
- Cots-Folch, R., Martínez-Casasnovas, J.A., Ramos, M.C. 2006. Land terracing for new vineyard plantations in the north-eastern Spanish Mediterranean region: Landscape effects of the EU Council Regulation policy for vineyards' restructuring. *Agric. , Ecosyst. Environ.* 115:88-96. doi: <http://dx.doi.org/10.1016/j.agee.2005.11.030>.
- Council of the European Communities,.1991. Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources. Brussels, 12 Dec 1991.
- Crespo, J., Romero, V., García, M., Arroyo, T., Cabellos, J.M. 2014. Influencia de los distintos métodos de elaboración en el perfil aromático y sensorial de los vinos Malvasía, D.O. Vinos de Madrid. XXXVI Jornadas de Viticultura y Enología Tierra de Barros. C.U.S., Ed. Almendralejo, España. 153-177.
- de Araújo, A.S.F., Eisenhauer, N., Nunes, L.A.P.L., Leite, L.F.C., Cesarz, S. 2015. Soil Surface-Active Fauna in Degraded and Restored Lands of Northeast Brazil. *Land Degrad. Dev.* 26:1-8. doi: <http://dx.doi.org/10.1002/ldr.2247>.
- de Oliveira, S.P., de Lacerda, N.B., Blum, S.C., Escobar, M.E.O., de Oliveira, T.S. 2015. Organic Carbon and Nitrogen Stocks in Soils of Northeastern Brazil Converted to Irrigated Agriculture. *Land Degrad. Dev.* 26:9-21. doi: <http://dx.doi.org/10.1002/ldr.2264>.
- Debasish-Saha, Kukal, S.S., Bawa, S.S. 2014. Soil organic carbon stock and fractions in relation to land use and soil depth in the degraded shiwaliks hills of lower Himalayas. *Land Degrad. Dev.* 25:407-416. doi: <http://dx.doi.org/10.1002/ldr.2151>.
- Decock, C., Lee, J., Necpalova, M., Pereira, E.I.P., Tendall, D.M., Six, J. 2015. Mitigating N2O emissions from soil: from patching leaks to transformative action. *SOIL* 1:687-694. doi: <http://dx.doi.org/10.5194/soil-1-687-2015>.
- Defersha, M.B., Melesse, A.M. 2012. Effect of rainfall intensity, slope and antecedent moisture content on sediment concentration and sediment enrichment ratio. *Catena* 90:47-52. doi: <http://dx.doi.org/10.1016/j.catena.2011.11.002>.
- Denef, K., Six, J., Merckx, R., Paustian, K. 2004. Carbon Sequestration in Microaggregates of No-Tillage Soils with Different Clay Mineralogy 68:1935-1944. doi: <http://dx.doi.org/10.2136/sssaj2004.1935>.

- Dent D, Young A (1981) Soil Survey and Land Evaluation. Allen and Unwin. 278 pp, London.
- Duchafour P (1987) Edafología, edafogénesis y clasificación. Masson SA, Barcelona.
- Duran Zuazo VH, Rodriguez Pleguezuelo CR (2009) Soil-Erosion and Runoff Prevention by Plant Covers: A Review. In: Lichtfouse, E Navarrete, M Debaeke, P Souchere, V Alberola, C. (ed) Springer-Verlag Berlin, Heidelberg Platz 3, D-14197, Berlin, Germany, pp 785-811.
- Duval, M.E., Galantini, J.A., Iglesias, J.O., Canelo, S., Martinez, J.M., Wall, L. 2013. Analysis of organic fractions as indicators of soil quality under natural and cultivated systems. Soil Tillage Res. 131:11-19. doi: <http://dx.doi.org/10.1016/j.still.2013.03.001>.
- Elbersen, G.W.W. 1991. Syllabus Soil Survey Methodology . FAO, Roma.
- Eldon, J., Gershenson, A. 2015. Effects of Cultivation and Alternative Vineyard Management Practices on Soil Carbon Storage in Diverse Mediterranean Landscapes: A Review of the Literature. Agroecology and Sustainable Food Systems 39:516-550. doi: <http://dx.doi.org/10.1080/21683565.2015.1007407>.
- Esteves, M., Lapetite, J.M. 2003. A multi-scale approach of runoff generation in a Sahelian gully catchment: a case study in Niger. Catena 50:255-271. doi: [http://dx.doi.org/10.1016/S0341-8162\(02\)00136-4](http://dx.doi.org/10.1016/S0341-8162(02)00136-4).
- FAO. 2017. Food and Agriculture Organization of the United Nations. <http://www.fao.org/soils-portal/soil-degradation-restoration/en/>. Accessed 3/1 2017.
- Fernández-Ugalde, O., Virto, I., Bescansa, P., Imaz, M.J., Enrique, A., Karlen, D.L. 2009. No-tillage improvement of soil physical quality in calcareous, degradation-prone, semiarid soils. Soil Tillage Res. 106:29-35. doi: <http://dx.doi.org/10.1016/j.still.2009.09.012>.
- Ferrero, A., Usowicz, B., Lipiec, J. 2005. Effects of tractor traffic on spatial variability of soil strength and water content in grass covered and cultivated sloping vineyard. Soil Tillage Res. 84:127-138. doi: <http://dx.doi.org/10.1016/j.still.2004.10.003>.
- Fitzpatrick, E.A. 1984. Suelos. Su formación, clasificación y distribución. Compañía Editorial Continental, México.
- Flower, K.C., Cordingley, N., Ward, P.R., Weeks, C. 2012. Nitrogen, weed management and economics with cover crops in conservation agriculture in a Mediterranean climate. Field Crops Res. 132:63-75. doi: <http://dx.doi.org/10.1016/j.fcr.2011.09.011>.
- Franklin, D., Truman, C., Potter, T., Bosch, D., Strickland, T., Bednarz, C. 2007. Nitrogen and phosphorus runoff losses from variable and constant intensity rainfall simulations on loamy sand under conventional and strip tillage systems. J. Environ. Qual. 36:846-854. doi: <http://dx.doi.org/10.2134/jeq2005.0359>.
- Gabriel, J.L., Muñoz-Carpena, R., Quemada, M. 2012. The role of cover crops in irrigated systems: Water balance, nitrate leaching and soil mineral nitrogen accumulation. Agric. , Ecosyst. Environ. 155:50-61. doi: <http://dx.doi.org/10.1016/j.agee.2012.03.021>.

- Gabriel, J.L., Quemada, M. 2011. Replacing bare fallow with cover crops in a maize cropping system: Yield, N uptake and fertiliser fate. *Eur. J. Agron.* 34:133-143. doi: <http://dx.doi.org/10.1016/j.eja.2010.11.006>.
- Gabriel, J.L., Garrido, A., Quemada, M. 2013. Cover crops effect on farm benefits and nitrate leaching: Linking economic and environmental analysis. *Agricultural Systems* 121:23-32. doi: <http://dx.doi.org/10.1016/j.agsy.2013.06.004>.
- Gagnarli, E., Goggioli, D., Tarchi, F., Guidi, S., Nannelli, R., Vignozzi, N., Valboa, G., Lottero, M.R., Corino, L., Simoni, S. 2015. Case study of microarthropod communities to assess soil quality in different managed vineyards. *SOIL* 1:527-536. doi: <http://dx.doi.org/10.5194/soil-1-527-2015>.
- Galati, A., Crescimanno, M., Gristina, L., Keesstra, S., Novara, A. 2016. Actual provision as an alternative criterion to improve the efficiency of payments for ecosystem services for C sequestration in semiarid vineyards. *Agricultural Systems* 144:58-64. doi: <http://dx.doi.org/10.1016/j.agsy.2016.02.004>.
- Galati, A., Gristina, L., Crescimanno, M., Barone, E., Novara, A. 2015. Towards More Efficient Incentives for Agri-environment Measures in Degraded and Eroded Vineyards. *Land Degrad. Dev.* 26:557-564. doi: <http://dx.doi.org/10.1002/ldr.2389>.
- Gao, L., Becker, E., Liang, G., Houssou, A.A., Wu, H., Wu, X., Cai, D., Degré, A. 2017. Effect of different tillage systems on aggregate structure and inner distribution of organic carbon. *Geoderma* 288:97-104. doi: <http://dx.doi.org/10.1016/j.geoderma.2016.11.005>.
- Gao, Y., Yu, G., He, N. 2013. Equilibration of the terrestrial water, nitrogen, and carbon cycles: Advocating a health threshold for carbon storage. *Ecol. Eng.* 57:366-374. doi: <http://dx.doi.org/10.1016/j.ecoleng.2013.04.011>.
- García-Díaz, A., Bienes, R., Gristina, L., Cerdà, A., Pereira, P., Novara, A. 2016. Carbon input threshold for soil carbon budget optimization in eroding vineyards. *Geoderma* 271:144-149. doi: <http://dx.doi.org/10.1016/j.geoderma.2016.02.020>.
- García-Díaz, A., Bienes, R., Sastre, B., Novara, A., Gristina, L., Cerdà, A. 2017. Nitrogen losses in vineyards under different types of soil groundcover. A field runoff simulator approach in central Spain. *Agric. , Ecosyst. Environ.* 236:256-267. doi: <http://dx.doi.org/10.1016/j.agee.2016.12.013>.
- García-Estríngana, P., Alegre Álvaro, J., Guerrero, E. 2005. Determinación de la cobertura del suelo en ensayos de pequeña parcela una comparación de métodos. In: *Control de la degradación de suelos*, Madrid. (ed), pp 275-279.
- García-Orenes, F., Cerdà, A., Mataix-Solera, J., Guerrero, C., Bodí, M.B., Arcenegui, V., Zornoza, R., Sempere, J.G. 2009. Effects of agricultural management on surface soil properties and soil-water losses in eastern Spain. *Soil Tillage Res.* 106:117-123. doi: <http://dx.doi.org/10.1016/j.still.2009.06.002>.
- García-Orenes, F., Guerrero, C., Mataix-Solera, J., Navarro-Pedreño, J., Gómez, I., Mataix-Beneyto, J. 2005. Factors controlling the aggregate stability and bulk density in two different

- degraded soils amended with biosolids. *Soil Tillage Res.* 82:65-76. doi: <http://dx.doi.org/10.1016/j.still.2004.06.004>.
- García-Ruiz, J.M. 2010. The effects of land uses on soil erosion in Spain: A review. *Catena* 81:1-11. doi: <http://dx.doi.org/10.1016/j.catena.2010.01.001>.
- Ghahramani, A., Ishikawa, Y. 2013. Water flux and sediment transport within a forested landscape: the role of connectivity, subsurface flow, and slope length scale on transport mechanism. *Hydrol. Process.* 27:4091-4102. doi: <http://dx.doi.org/10.1002/hyp.9791>.
- Gibelin, A.L., Deque, M. 2003. Anthropogenic climate change over the Mediterranean region simulated by a global variable resolution model. *Clim. Dyn.* 20:327-339. doi: <http://dx.doi.org/10.1007/s00382-002-0277-1>.
- Giménez-Morera, A., Sinoga, J.D.R., Cerdà, A. 2010. The impact of cotton geotextiles on soil and water losses from Mediterranean rainfed agricultural land. *Land Degrad. Dev.* 21:210-217. doi: <http://dx.doi.org/10.1002/ldr.971>.
- Glinski, J., Lipiec, J. 1990. Soil physical conditions and plant roots. CRC Press.
- Gómez, J.A., Guzmán, M.G., Giráldez, J.V., Fereres, E. 2009. The influence of cover crops and tillage on water and sediment yield, and on nutrient, and organic matter losses in an olive orchard on a sandy loam soil. *Soil Tillage Res.* 106:137-144. doi: <http://dx.doi.org/10.1016/j.still.2009.04.008>.
- Gonzalez-Hidalgo, J.C., Batalla, R.J., Cerdà, A., de Luis, M. 2012. A regional analysis of the effects of largest events on soil erosion. *Catena* 95:85-90. doi: <http://dx.doi.org/10.1016/j.catena.2012.03.006>.
- González-Sánchez, E.J., Ordóñez-Fernández, R., Carbonell-Bojollo, R., Veroz-González, O., Gil-Ribes, J.A. 2012. Meta-analysis on atmospheric carbon capture in Spain through the use of conservation agriculture. *Soil Tillage Res.* 122:52-60. doi: <http://dx.doi.org/10.1016/j.still.2012.03.001>.
- Gonzalez-Sanchez, E.J., Veroz-Gonzalez, O., Blanco-Roldan, G.L., Marquez-Garcia, F., Carbonell-Bojollo, R. 2015. A renewed view of conservation agriculture and its evolution over the last decade in Spain. *Soil Tillage Res.* 146, Part B:204-212. doi: <http://dx.doi.org/10.1016/j.still.2014.10.016>.
- Gregorich, E.G., Carter, M.R., Doran, J.W., Pankhurst, C.E., Dwyer, L.M. 1997. Chapter 4 Biological attributes of soil quality. *Dev. Soil Sci.* 25:81-113. doi: [http://dx.doi.org/10.1016/S0166-2481\(97\)80031-1](http://dx.doi.org/10.1016/S0166-2481(97)80031-1).
- Gregorich, E.G., Janzen, H.H. 1996. Storage of soil carbon in the light fraction and macro-organic matter. In "Structure and Soil Organic Matter Storage in Agricultural Soils" (M. R. Carter and B. A. Steward, Eds.):167-193-CRC Press, Boca Raton, FL.
- Grismer, E.M., 2016. Determination of Watershed Infiltration and Erosion Parameters from Field Rainfall Simulation Analyses. *Hydrology* 3 doi: <http://dx.doi.org/10.3390/hydrology3030023>.

- Guadagnin, J., Bertol, I., Cassol, P., do Amaral, A. 2005a. Soil, water and nitrogen losses through erosion under different tillage systems. *Rev. Bras. Cienc. Solo* 29:277-286. doi: <http://dx.doi.org/10.1590/S0100-06832005000200013>.
- Guerra, B., Steenwerth, K. 2012. Influence of Floor Management Technique on Grapevine Growth, Disease Pressure, and Juice and Wine Composition: A Review. *Am. J. Enol. Vitic.* 63:149-164. doi: <http://dx.doi.org/10.5344/ajev.2011.10001>.
- Hartwig, N.L., Ammon, H.U. 2002. Cover crops and living mulches. *Weed Sci.* 50:688-699. doi: [http://dx.doi.org/10.1614/0043-1745\(2002\)050\[0688:AIACCA\]2.0.CO;2](http://dx.doi.org/10.1614/0043-1745(2002)050[0688:AIACCA]2.0.CO;2).
- Haynes, R.J. 2005. Labile Organic Matter Fractions as Central Components of the Quality of Agricultural Soils: An Overview. *Adv. Agron.* 85:221-268. doi: [http://dx.doi.org/10.1016/S0065-2113\(04\)85005-3](http://dx.doi.org/10.1016/S0065-2113(04)85005-3).
- Hernanz, J.L., López, R., Navarrete, L., Sánchez-Girón, V. 2002. Long-term effects of tillage systems and rotations on soil structural stability and organic carbon stratification in semiarid central Spain. *Soil Tillage Res.* 66:129-141. doi: [http://dx.doi.org/10.1016/S0167-1987\(02\)00021-1](http://dx.doi.org/10.1016/S0167-1987(02)00021-1).
- Hidalgo, J. 2003. *Tratado de Enología*. Ed. Mundi-Prensa. Barcelona. ISBN: 84-8476-119-3.
- Hildebrandt, A., Guillaumon, M., Lacorte, S., Tauler, R., Barceló, D. 2008. Impact of pesticides used in agriculture and vineyards to surface and groundwater quality (North Spain). *Water Res.* 42:3315-3326. doi: <http://dx.doi.org/10.1016/j.watres.2008.04.009>.
- Holifield Collins, C.D., Stone, J.J., Cratic III, L. 2015. Runoff and sediment yield relationships with soil aggregate stability for a state-and-transition model in southeastern Arizona. *J. Arid Environ.* 117:96-103. doi: <http://dx.doi.org/10.1016/j.jaridenv.2015.02.016>.
- Hontoria, C., Gómez-Paccard, C., Mariscal-Sancho, I., Benito, M., Pérez, J., Espejo, R. 2016. Aggregate size distribution and associated organic C and N under different tillage systems and Ca-amendment in a degraded Ultisol. *Soil Tillage Res.* 160:42-52. doi: <http://dx.doi.org/10.1016/j.still.2016.01.003>.
- Hueso-Gonzalez, P., Francisco Martinez-Murillo, J., Damian Ruiz-Sinoga, J. 2016. Effects of topsoil treatments on afforestation in a dry Mediterranean climate (southern Spain). *Solid Earth* 7:1479-1489. doi: <http://dx.doi.org/10.5194/se-7-1479-2016>.
- ICOMOS. 2005. International Council on Monuments and Sites. Monuments and sites in their setting: conserving cultural heritage in changing townscapes and landscapes ICOMOS 15th General Assembly and Scientific Symposium, ICOMOS, Charenton-le-Pont (France).
- Imaz, M.J., Virto, I., Bescansa, P., Enrique, A., Fernandez-Ugalde, O., Karlen, D.L. 2010. Soil quality indicator response to tillage and residue management on semi-arid Mediterranean cropland. *Soil Tillage Res.* 107:17-25. doi: <http://dx.doi.org/10.1016/j.still.2010.02.003>.
- Imeson, A. C., Vis M., 1984. Assessing soil aggregate stability by water-drop impact and ultrasonic dispersion. *Geoderma* 34:185-200. doi: [http://dx.doi.org/10.1016/0016-7061\(84\)90038-7](http://dx.doi.org/10.1016/0016-7061(84)90038-7).
- Iserloh, T., Ries, J.B., Arnáez, J., Boix-Fayos, C., Butzen, V., Cerdà, A., Echeverría, M.T., Fernández-Gálvez, J., Fister, W., Geißler, C., Gómez, J.A., Gómez-Macpherson, H., Kuhn, N.J., Lázaro, R.,

- León, F.J., Martínez-Mena, M., Martínez-Murillo, J.F., Marzen, M., Mingorance, M.D., Ortigosa, L., Peters, P., Regüés, D., Ruiz-Sinoga, J.D., Scholten, T., Seeger, M., Solé-Benet, A., Wengel, R., Wirtz, S. 2013. European small portable rainfall simulators: A comparison of rainfall characteristics. *Catena* 110:100-112. doi: <http://dx.doi.org/10.1016/j.catena.2013.05.013>.
- Issa, O.M., Le Bissonnais, Y., Planchon, O., Favis-Mortlock, D., Silvera, N., Wainwright, J. 2006. Soil detachment and transport on field- and laboratory-scale interrill areas: erosion processes and the size-selectivity of eroded sediment. *Earth Surf. Process. Landforms* 31:929-939. doi: <http://dx.doi.org/10.1002/esp.1303>.
- Jacinthe, P.A., Lal, R. 2001. A mass balance approach to assess carbon dioxide evolution during erosional events. *Land Degrad. Dev.* 12:329-339. doi: <http://dx.doi.org/10.1002/ldr.454>.
- Jaiarree, S., Chidthaisong, A., Tangtham, N., Polprasert, C., Sarobol, E., Tyler, S.C. 2014. Carbon budget and sequestration potential in a sandy soil treated with compost. *Land Degrad. Dev.* 25:120-129. doi: <http://dx.doi.org/10.1002/ldr.1152>.
- Jiao, P., Xu, D., Wang, S., Wang, Y., Liu, K., Tang, G. 2012. Nitrogen loss by surface runoff from different cropping systems. *Soil Research* 50:58-66.
- Jigău, G. 2012. Processes and factors of porosity evolution. *Soil Forming Factors and Processes from the Temperate Zone 9* doi: <http://dx.doi.org/10.15551/fppzt.v9i1.146>.
- Jordan, A.D., Crosser, B.J. 1983. Determination of grape maturity by aroma/flavour assessment. In: Lee, T.H., Somers, T.C. (Eds.), *Proceedings of the Fifth Australian Wine Industry Technical Conference* Australian Wine Research Institute, Glen Osmond.:261-274.
- Kabiri, V., Raiesi, F., Ghazavi, M.A. 2016. Tillage effects on soil microbial biomass, SOM mineralization and enzyme activity in a semi-arid Calcixerepts. *Agric. , Ecosyst. Environ.* 232:73-84. doi: <http://dx.doi.org/10.1016/j.agee.2016.07.022>.
- Kalkhoff, S.J., Hubbard, L.E., Tomer, M.D., James, D.E. 2016. Effect of variable annual precipitation and nutrient input on nitrogen and phosphorus transport from two Midwestern agricultural watersheds. *Sci. Total Environ.* 559:53-62. doi: <http://dx.doi.org/10.1016/j.scitotenv.2016.03.127>.
- Kay, B. D., 1998. Soil structure and organic carbon: a review. <http://www.nal.usda.gov/>
- Keesstra, S.D., Bouma, J., Wallinga, J., Tittonell, P., Smith, P., Cerdà, A., Montanarella, L., Quinton, J.N., Pachepsky, Y., van der Putten, W.H., Bardgett, R.D., Moolenaar, S., Mol, G., Jansen, B., Fresco, L.O. 2016a. The significance of soils and soil science towards realization of the United Nations Sustainable Development Goals. *SOIL* 2:111-128. doi: <http://dx.doi.org/10.5194/soil-2-111-2016>.
- Keesstra, S., Pereira, P., Novara, A., Brevik, E.C., Azorin-Molina, C., Parras-Alcántara, L., Jordán, A., Cerdà, A. 2016b. Effects of soil management techniques on soil water erosion in apricot orchards. *Sci. Total Environ.* 551–552:357-366. doi: <http://dx.doi.org/10.1016/j.scitotenv.2016.01.182>.

- Khaledian, Y., Kiani, F., Ebrahimi, S., Brevik, E.C., Aitkenhead-Peterson, J. 2017. Assessment and Monitoring of Soil Degradation during Land Use Change Using Multivariate Analysis. *Land Degrad. Dev.* 28:128-141. doi: <http://dx.doi.org/10.1002/ldr.2541>.
- Kleber, M., Sollins, P., Sutton, R. 2007. A conceptual model of organo-mineral interactions in soils: self-assembly of organic molecular fragments into zonal structures on mineral surfaces. *Biogeochemistry* 85:9-24. doi: <http://dx.doi.org/10.1007/s10533-007-9103-5>.
- Kosmas, C., Danalatos, N., Cammeraat, L.H., Chabart, M., Diamantopoulos, J., Farand, R., Gutierrez, L., Jacob, A., Marques, H., Martinez-Fernandez, J., Mizara, A., Moustakas, N., Nicolau, J.M., Oliveros, C., Pinna, G., Puddu, R., Puigdefabregas, J., Roxo, M., Simao, A., Stamou, G., Tomasi, N., Usai, D., Vacca, A. 1997. The effect of land use on runoff and soil erosion rates under Mediterranean conditions. *Catena* 29:45-59. doi: [http://dx.doi.org/10.1016/S0341-8162\(96\)00062-8](http://dx.doi.org/10.1016/S0341-8162(96)00062-8).
- Krebs, M., kretschmar, A., Chadoeuf, J., Goulard, M. 1993. Investigations on distribution patterns in soil: basic and relative distributions of roots, channels and cracks. *Dev. Soil Sci.* 22:437-449. doi: [http://dx.doi.org/10.1016/S0166-2481\(08\)70432-X](http://dx.doi.org/10.1016/S0166-2481(08)70432-X).
- Lagacherie, P., Coulouma, G., Ariagno, P., Virat, P., Boizard, H., Richard, G. 2006. Spatial variability of soil compaction over a vineyard region in relation with soils and cultivation operations. *Geoderma* 134:207-216. doi: <http://dx.doi.org/10.1016/j.geoderma.2005.10.006>.
- Laget, F., Tondut, J.-., Deloire, A., Kelly, M.T. 2008. Climate trends in a specific Mediterranean viticultural area between 1950 and 2006. *J. Int. Sci. Vigne Vin.* 42:113-123.
- Lasanta, T., Sobrón, L. 1988. Influencia de las prácticas de laboreo en la evolución hidromorfológica de suelos cultivados con viñedo. *Cuadernos de Investigación Geográfica* 14:81-97.
- Lassu, T., Seeger, M., Peters, P., Keesstra, S.D. 2015. The Wageningen Rainfall Simulator: Set-up and Calibration of an Indoor Nozzle-Type Rainfall Simulator for Soil Erosion Studies. *Land Degrad. Dev.* 26:604-612. doi: <http://dx.doi.org/10.1002/ldr.2360>.
- Le Bissonnais, Y., Arrouays, D. 1997. Aggregate stability and assessment of soil crustability and erodibility: II. Application to humic loamy soils with various organic carbon contents; Stabilité structurale et évaluation de la sensibilité des sols à la battance et à l'érosion hydrique: II. Application à une série de sols limoneux à teneur en carbone organique variée. *Eur. J. Soil Sci.* 48:39-48. doi: <http://dx.doi.org/10.1111/j.1365-2389.1997.tb00183.x>.
- Lee, J., Steenwerth, K.L. 2013. 'Cabernet Sauvignon' grape anthocyanin increased by soil conservation practices. *Scientia Horticulturae* 159:128-133. doi: <http://dx.doi.org/10.1016/j.scienta.2013.05.025>.
- Léonard, J., Perrier, E., Rajot, J.L. 2004. Biological macropores effect on runoff and infiltration: a combined experimental and modelling approach. *Agric. , Ecosyst. Environ.* 104:277-285. doi: <http://dx.doi.org/10.1016/j.agee.2003.11.015>.
- Li, C., Fultz, L.M., Moore-Kucera, J., Acosta-Martínez, V., Horita, J., Strauss, R., Zak, J., Calderón, F., Weindorf, D. 2017. Soil carbon sequestration potential in semi-arid grasslands in the

- Conservation Reserve Program. *Geoderma* 294:80-90. doi: <http://dx.doi.org/10.1016/j.geoderma.2017.01.032>.
- Li, Q.Y., Fang, H.Y., Sun, L.Y., Cai, Q.G. 2014. Using the ¹³⁷Cs technique to study the effect of soil redistribution on soil organic carbon and total nitrogen stocks in an agricultural catchment of northeast China. *Land Degrad. Dev.* 25:350-359. doi: <http://dx.doi.org/10.1002/ldr.2144>.
- Li, X. , Yang, J., Zhao, C. , Wang, B. 2014. Runoff and sediment from orchard terraces in southeastern China. *Land Degrad. Dev.* 25:184-192. doi: <http://dx.doi.org/10.1002/ldr.1160>.
- Lieskovský, J., Kenderessy, P. 2014. Modelling the effect of vegetation cover and different tillage practices on soil erosion in vineyards; a case study in Vráble (Slovakia) using WATEM/SEDEM. *Land Degrad. Dev.* 25:288-296. doi: <http://dx.doi.org/10.1002/ldr.2162>.
- Little, J., Bennett, D., Miller, J. 2005. Nutrient and sediment losses under simulated rainfall following manure incorporation by different methods. *J. Environ. Qual.* 34:1883-1895. doi: <http://dx.doi.org/10.2134/jeq2005.0056>.
- Lopes, C.M., Santos, T.P., Monteiro, A., Rodrigues, M.L., Costa, J.M., Chaves, M.M. 2011. Combining cover cropping with deficit irrigation in a Mediterranean low vigor vineyard. *Scientia Horticulturae* 129:603-612. doi: <http://dx.doi.org/10.1016/j.scienta.2011.04.033>.
- Lorenz, K., Lal, R. 2016. Chapter Three - Environmental Impact of Organic Agriculture. *Adv. Agron.* 139:99-152. doi: <http://dx.doi.org/10.1016/bs.agron.2016.05.003>.
- Loumou, A., Giourga, C. 2003. Olive groves: "The life and identity of the Mediterranean". *Agriculture and Human Values* 20:87-95. doi: <http://dx.doi.org/10.1023/A:1022444005336>.
- Loveland, P., Webb, J. 2003. Is there a critical level of organic matter in the agricultural soils of temperate regions: a review. *Soil Tillage Res.* 70:1-18. doi: [http://dx.doi.org/10.1016/S0167-1987\(02\)00139-3](http://dx.doi.org/10.1016/S0167-1987(02)00139-3).
- Lozano-García, B., Parras-Alcántara, L. 2014. Variation in soil organic carbon and nitrogen stocks along a toposequence in a traditional Mediterranean olive grove. *Land Degrad. Dev.* 25:297-304. doi: <http://dx.doi.org/10.1002/ldr.2284>.
- MAGRAMA, 2015a. Encuesta sobre superficies y rendimiento de cultivos (ESYRCE). Resultados Nacionales y Autonómicos.
- MAGRAMA. 2015b. Encuesta sobre superficies y rendimientos (ESYRCE). Análisis de las Técnicas de Mantenimiento de los Suelos y de los Métodos de Siembra de España. MAGRAMA, Madrid.
- MAGRAM. 2015c. Encuesta sobre superficies y rendimientos (ESYRCE). Análisis de las Técnicas de Mantenimiento de los Suelos y de los Métodos de Siembra de España. Subdirección General de Estadística MAGRAMA .
- Marchamalo, M., Hooke, J.M., Sandercock, P.J. 2016. Flow and Sediment Connectivity in Semi-arid Landscapes in SE Spain: Patterns and Controls. *Land Degrad. Dev.* 27:1032-1044. doi: <http://dx.doi.org/10.1002/ldr.2352>.

- Marín, A., Andrades, M., Iñigo, V., Jiménez-Ballesta, R. 2016. Lead and Cadmium in Soils of La Rioja Vineyards, Spain. *Land Degrad. Dev.* 27:1286-1294. doi: <http://dx.doi.org/10.1002/ldr.2471>.
- Marques, M.J., García-Muñoz, S., Muñoz-Organero, G., Bienes, R. 2010. Soil conservation beneath grass cover in hillside vineyards under Mediterranean Climatic conditions (Madrid, Spain). *Land Degrad. Dev.* 21:122-131. doi: <http://dx.doi.org/10.1002/ldr.915>.
- Marqués, M.J., Bienes, R., Cuadrado, J., Ruiz-Colmenero, M., Barbero-Sierra, C., Velasco, A. 2015. Analysing Perceptions Attitudes and Responses of Winegrowers about Sustainable Land Management in Central Spain. *Land Degrad. Dev.* 26:458-467. doi: <http://dx.doi.org/10.1002/ldr.2355>.
- Marques, M.J., Bienes, R., Jiménez, L., Pérez-Rodríguez, R. 2007. Effect of vegetal cover on runoff and soil erosion under light intensity events. Rainfall simulation over USLE plots. *Sci. Total Environ.* 378:161-165. doi: <http://dx.doi.org/10.1016/j.scitotenv.2007.01.043>.
- Martínez-Casasnovas, J.A., Ramos, M.C. 2006. The cost of soil erosion in vineyard fields in the Penedès–Anoia Region (NE Spain). *Catena* 68:194-199. doi: <http://dx.doi.org/10.1016/j.catena.2006.04.007>.
- Martínez-Casasnovas, J.A., Ramos, M.C., Cots-Folch, R. 2010. Influence of the EU CAP on terrain morphology and vineyard cultivation in the Priorat region of NE Spain. *Land Use Policy* 27:11-21. doi: <http://dx.doi.org/10.1016/j.landusepol.2008.01.009>.
- Martínez-Casasnovas, J.A., Ramos, M.C., Benites, G. 2016. Soil and Water Assessment Tool Soil Loss Simulation at the Sub-Basin Scale in the Alt Penedès–Anoia Vineyard Region (Ne Spain) in the 2000s. *Land Degrad. Dev.* 27:160-170. doi: <http://dx.doi.org/10.1002/ldr.2240>.
- Martínez-Casasnovas, J.A., Ramos, M.C., Ribes-Dasi, M. 2002. Soil erosion caused by extreme rainfall events: mapping and quantification in agricultural plots from very detailed digital elevation models. *Geoderma* 105:125-140. doi: [http://dx.doi.org/10.1016/S0016-7061\(01\)00096-9](http://dx.doi.org/10.1016/S0016-7061(01)00096-9).
- Masselink, R.J.H., Keesstra, S.D., Temme, A.J.A.M., Seeger, M., Giménez, R., Casalí, J. 2016. Modelling Discharge and Sediment Yield at Catchment Scale Using Connectivity Components. *Land Degrad. Dev.* 27:933-945. doi: <http://dx.doi.org/10.1002/ldr.2512>.
- Mchunu, C., Chaplot, V. 2012. Land degradation impact on soil carbon losses through water erosion and CO₂ emissions. *Geoderma* 177–178:72-79. doi: <http://dx.doi.org/10.1016/j.geoderma.2012.01.038>.
- Medrano, H., Tomas, M., Martorell, S., Escalona, J., Pou, A., Fuentes, S., Flexas, J., Bota, J. 2015. Improving water use efficiency of vineyards in semi-arid regions. A review. *Agron. Sustain. Dev.* 35:499-517. doi: <http://dx.doi.org/10.1007/s13593-014-0280-z>.
- Mekonnen, M., Keesstra, S., Baartman, J., Ritsema, C., Melesse, A. 2015. Evaluating sediment storage dams: structural off-site sediment trapping measures in northwest Ethiopia. *Cuadernos de Investigación Geográfica* 41 doi: <http://dx.doi.org/10.18172/cig.2643>.

- Mekonnen, M., Keesstra, S.D., Stroosnijder, L., Baartman, J.E.M., Maroulis, J. 2015. Soil Conservation Through Sediment Trapping: A Review. *Land Degrad. Dev.* 26:544-556. doi: <http://dx.doi.org/10.1002/ldr.2308>.
- Miller, D. 1986. Root Systems in Relation to Stress Tolerance. *Hort Science* 21:963-970.
- Minasny, B., Malone, B.P., McBratney, A.B., Angers, D.A., Arrouays, D., Chambers, A., Chaplot, V., Chen, Z., Cheng, K., Das, B.S., Field, D.J., Gimona, A., Hedley, C.B., Hong, S.Y., Mandal, B., Marchant, B.P., Martin, M., McConkey, B.G., Mulder, V.L., O'Rourke, S., Richer-de-Forges, A.C., Odeh, I., Padarian, J., Paustian, K., Pan, G., Poggio, L., Savin, I., Stolbovoy, V., Stockmann, U., Sulaeman, Y., Tsui, C., Vågen, T., van Wesemael, B., Winowiecki, L. 2017. Soil carbon 4 per mille. *Geoderma* 292:59-86. doi: <http://dx.doi.org/10.1016/j.geoderma.2017.01.002>.
- Minasny, B., Sulaeman, Y., Tney, A.B. 2011. Is soil carbon disappearing? The dynamics of soil organic carbon in Java. *Global Change Biol.* 17:1917-1924. doi: <http://dx.doi.org/10.1111/j.1365-2486.2010.02324.x>.
- Molina-Navarro, E., Trolle, D., Martínez-Pérez, S., Sastre-Merlín, A., Jeppesen, E. 2014. Hydrological and water quality impact assessment of a Mediterranean limno-reservoir under climate change and land use management scenarios. *Journal of Hydrology* 509:354-366. doi: <http://dx.doi.org/10.1016/j.jhydrol.2013.11.053>.
- Monteiro, A., Lopes, C.M. 2007. Influence of cover crop on water use and performance of vineyard in Mediterranean Portugal. *Agric. , Ecosyst. Environ.* 121:336-342. doi: <http://dx.doi.org/10.1016/j.agee.2006.11.016>.
- Moreno, M.M., Lacasta, C., Meco, R., Moreno, C. 2011. Rainfed crop energy balance of different farming systems and crop rotations in a semi-arid environment: Results of a long-term trial. *Soil Tillage Res.* 114:18-27. doi: <http://dx.doi.org/10.1016/j.still.2011.03.006>.
- Morvan, X., Naisse, C., Malam Issa, O., Desprats, J.F., Combaud, A., Cerdan, O. 2014. Effect of ground-cover type on surface runoff and subsequent soil erosion in Champagne vineyards in France. *Soil Use Manage.* 30:372-381. doi: <http://dx.doi.org/10.1111/sum.12129>.
- Mulumba, L.N., Lal, R. 2008. Mulching effects on selected soil physical properties. *Soil Tillage Res.* 98:106-111. doi: <http://dx.doi.org/10.1016/j.still.2007.10.011>.
- Mursec, M. 2011. Agricultural practices impact on soil quality and health. Case studies of Slovenian irrigated or organic orchards. Dissertation, Université de Bourgogne; University of Maribor-SLOVENIA.
- Muscas, E., Cocco, A., Mercenaro, L., Cabras, M., Lentini, A., Porqueddu, C., Nieddu, G. 2017. Effects of vineyard floor cover crops on grapevine vigor, yield, and fruit quality, and the development of the vine mealybug under a Mediterranean climate. *Agric. , Ecosyst. Environ.* 237:203-212. doi: <http://dx.doi.org/10.1016/j.agee.2016.12.035>.
- Nachtergaele, J., Poesen, J., van Wesemael, B. 1998. Gravel mulching in vineyards of Southern Switzerland. *Soil Tillage Res.* 46:51-59. doi: [http://dx.doi.org/10.1016/S0167-1987\(98\)80107-4](http://dx.doi.org/10.1016/S0167-1987(98)80107-4).

- Nadal-Romero, E., González-Hidalgo, J.C., Cortesi, N., Desir, G., Gómez, J.A., Lasanta, T., Lucía, A., Marín, C., Martínez-Murillo, J.F., Pacheco, E., Rodríguez-Blanco, M.L., Romero Díaz, A., Ruiz-Sinoga, J.D., Taguas, E.V., Taboada-Castro, M.M., Taboada-Castro, M.T., Úbeda, X., Zabaleta, A. 2015. Relationship of runoff, erosion and sediment yield to weather types in the Iberian Peninsula. *Geomorphology* 228:372-381. doi: <http://dx.doi.org/10.1016/j.geomorph.2014.09.011>.
- Ni, J., Luo, D.H., Xia, J., Zhang, Z.H., Hu, G. 2015. Vegetation in karst terrain of southwestern China allocates more biomass to roots. *Solid Earth* 6:799-810. doi: <http://dx.doi.org/10.5194/se-6-799-2015>.
- Novara, A., Gristina, L., Guitoli, F., Santoro, A., Cerda, A. 2013. Managing soil nitrate with cover crops and buffer strips in Sicilian vineyards. *Solid Earth* 4:255-262. doi: <http://dx.doi.org/10.5194/se-4-255-2013>.
- Novara, A., Gristina, L., Saladino, S.S., Santoro, A., Cerdà, A. 2011. Soil erosion assessment on tillage and alternative soil managements in a Sicilian vineyard. *Soil Tillage Res.* 117:140-147. doi: <http://dx.doi.org/10.1016/j.still.2011.09.007>.
- Novara, A., Rühl, J., La Mantia, T., Gristina, L., La Bella, S., Tuttolomondo, T. 2015a. Litter contribution to soil organic carbon in the processes of agriculture abandon. *Solid Earth* 6:425-432. doi: <http://dx.doi.org/10.5194/se-6-425-2015>.
- Novara, A., Cerdà, A., Dazzi, C., Lo Papa, G., Santoro, A., Gristina, L. 2015b. Effectiveness of carbon isotopic signature for estimating soil erosion and deposition rates in Sicilian vineyards. *Soil Tillage Res.* 152:1-7. doi: <http://dx.doi.org/10.1016/j.still.2015.03.010>.
- Novara, A., Keesstra, S., Cerdà, A., Pereira, P., Gristina, L. 2016. Understanding the role of soil erosion on CO₂-C loss using ¹³C isotopic signatures in abandoned Mediterranean agricultural land. *Sci. Total Environ.* 550:330-336. doi: <http://dx.doi.org/10.1016/j.scitotenv.2016.01.095>.
- Novara, A., La Mantia, T., Barbera, V., Gristina, L. 2012. Paired-site approach for studying soil organic carbon dynamics in a Mediterranean semiarid environment. *Catena* 89:1-7. doi: <http://dx.doi.org/10.1016/j.catena.2011.09.008>.
- Nunes, A.N., Lourenço, L., Vieira, A., Bento-Gonçalves, A. 2016. Precipitation and Erosivity in Southern Portugal: Seasonal Variability and Trends (1950–2008). *Land Degrad. Dev.* 27:211-222. doi: <http://dx.doi.org/10.1002/ldr.2265>.
- Ola, A., Dodd, I.C., Quinton, J.N. 2015. Can we manipulate root system architecture to control soil erosion?. *SOIL* 1:603-612. doi: <http://dx.doi.org/10.5194/soil-1-603-2015>.
- Pachauri RK, Allen MR, Barros VR, Broome J, Cramer W, Christ R, Church JA, Clarke L, Dahe Q, Dasgupta P, Dubash NK, Edenhofer O, Elgizouli I, Field CB, Forster P, Friedlingstein P, Fuglestad J, Gomez-Echeverri L, Hallegatte S, Hegerl G, Howden M, Jiang K, Cissneroz BJ, Kattsov V, Lee H, Mach KJ, Marotzke J, Mastrandrea MD, Meyer L, Minx J, Mulugetta Y, O'Brien K, Oppenheimer M, Pereira JJ, Pichs-Madruga R, Plattner G-, Portner H, Power SB, Preston B, Ravindranath NH, Reisinger A, Riahi K, Rusticucci M, Scholes R, Seyboth K, Sokona Y, Stavins R, Stocker TF, Tschakert P, Vuuren Dv, Ypserle J-v. 2014. *Climate Change 2014:*

- Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland.
- Panagos, P., Ballabio, C., Borrelli, P., Meusburger, K., Klik, A., Rousseva, S., Tadić, M.P., Michaelides, S., Hrabalíková, M., Olsen, P., Aalto, J., Lakatos, M., Rymaszewicz, A., Dumitrescu, A., Beguería, S., Alewell, C. 2015. Rainfall erosivity in Europe. *Sci. Total Environ.* 511:801-814. doi: <http://dx.doi.org/10.1016/j.scitotenv.2015.01.008>.
- Panagos, P., Ballabio, C., Yigini, Y., Dunbar, M.B. 2013. Estimating the soil organic carbon content for European NUTS2 regions based on LUCAS data collection. *Sci. Total Environ.* 442:235-246. doi: <http://dx.doi.org/10.1016/j.scitotenv.2012.10.017>.
- Parras-Alcántara, L., Lozano-García, B., Keesstra, S., Cerdà, A., Brevik, E.C. 2016. Long-term effects of soil management on ecosystem services and soil loss estimation in olive grove top soils. *Sci. Total Environ.* doi: <http://dx.doi.org/10.1016/j.scitotenv.2016.07.016>.
- Peng, X., Zhu, Q.H., Xie, Z.B., Darboux, F., Holden, N.M. 2016. The impact of manure, straw and biochar amendments on aggregation and erosion in a hillslope Ultisol. *Catena* 138:30-37. doi: <http://dx.doi.org/10.1016/j.catena.2015.11.008>.
- Peregrina, F., Pérez-Álvarez, E., García-Escudero, E. 2014. The short term influence of aboveground biomass cover crops on C sequestration and β -glucosidase in a vineyard ground under semiarid conditions. *Spanish Journal of Agricultural Research* 12 doi: <http://dx.doi.org/10.5424/sjar/2014124-5818>.
- Peregrina, F., Larrieta, C., Ibanez, S., Garcia-Escudero, E. 2010. Labile Organic Matter, Aggregates, and Stratification Ratios in a Semiarid Vineyard with Cover Crops. *Soil Sci. Soc. Am. J.* 74:2120-2130. doi: <http://dx.doi.org/10.2136/sssaj2010.0081>.
- Pérez-Rodríguez, R., Marques, M.J., Bienes, R. 2007. Spatial variability of the soil erodibility parameters and their relation with the soil map at subgroup level. *Sci. Total Environ.* 378:166-173. doi: <http://dx.doi.org/10.1016/j.scitotenv.2007.01.044>.
- Piccoli, I., Chiarini, F., Carletti, P., Furlan, L., Lazzaro, B., Nardi, S., Berti, A., Sartori, L., Dalconi, M.C., Morari, F. 2016. Disentangling the effects of conservation agriculture practices on the vertical distribution of soil organic carbon. Evidence of poor carbon sequestration in North-Eastern Italy. *Agric. , Ecosyst. Environ.* 230:68-78. doi: <http://dx.doi.org/10.1016/j.agee.2016.05.035>.
- Pimentel, D. 2006. Soil Erosion: A Food and Environmental Threat. *Environ. Dev. Sustainability* 8:119-137. doi: <http://dx.doi.org/10.1007/s10668-005-1262-8>.
- Pires, L.F., Borges, J.A.R., Rosa, J.A., Cooper, M., Heck, R.J., Passoni, S., Roque, W.L. 2017. Soil structure changes induced by tillage systems. *Soil Tillage Res.* 165:66-79. doi: <http://dx.doi.org/10.1016/j.still.2016.07.010>.
- Pituello, C., Dal Ferro, N., Simonetti, G., Berti, A., Morari, F. 2016. Nano to macro pore structure changes induced by long-term residue management in three different soils. *Agric. , Ecosyst. Environ.* 217:49-58. doi: <http://dx.doi.org/10.1016/j.agee.2015.10.029>.

- Plaza-Bonilla, D., Arrúe, J.L., Cantero-Martínez, C., Fanlo, R., Iglesias, A., Álvaro-Fuentes, J. 2015. Carbon management in dryland agricultural systems. A review. *Agronomy for Sustainable Development* 35:1319-1334. doi: <http://dx.doi.org/10.1007/s13593-015-0326-x>.
- Poeplau, C., Don, A. 2015. Carbon sequestration in agricultural soils via cultivation of cover crops – A meta-analysis. *Agric. , Ecosyst. Environ.* 200:33-41. doi: <http://dx.doi.org/10.1016/j.agee.2014.10.024>.
- Poesen, J., Lavee, H. 1994. Rock Fragments in Soil: Surface Dynamics Rock fragments in top soils: significance and processes. *Catena* 23:1-28. doi: [http://dx.doi.org/10.1016/0341-8162\(94\)90050-7](http://dx.doi.org/10.1016/0341-8162(94)90050-7).
- Porta, J, López-Acevedo, M., Roquero, C. 2003. *Edafología para la agricultura y el medio ambiente*, Madrid.
- Pou, A., Gulias, J., Moreno, M., Tomas, M., Medrano, H., Cifre, J. 2011. Cover Cropping in Vitis Vinifera L. Cv. Manto Negro Vineyards Under Mediterranean Conditions: Effects on Plant Vigour, Yield and Grape Quality. *J. Int. Sci. Vigne Vin.* 45:223-234.
- Powlson, D.S., Whitmore, A.P., Goulding, K.W.T. 2011. Soil carbon sequestration to mitigate climate change: a critical re-examination to identify the true and the false. *Eur. J. Soil Sci.* 62:42-55. doi: <http://dx.doi.org/10.1111/j.1365-2389.2010.01342.x>.
- Prosdocimi, M., Cerdà, A., Tarolli, P. 2016a. Soil water erosion on Mediterranean vineyards: A review. *Catena* 141:1-21. doi: <http://dx.doi.org/10.1016/j.catena.2016.02.010>.
- Prosdocimi, M., Jordán, A., Tarolli, P., Keesstra, S., Novara, A., Cerdà, A. 2016b. The immediate effectiveness of barley straw mulch in reducing soil erodibility and surface runoff generation in Mediterranean vineyards. *Sci. Total Environ.* 547:323-330. doi: <http://dx.doi.org/10.1016/j.scitotenv.2015.12.076>.
- Prosdocimi, M., Tarolli, P., Cerdà, A. 2016c. Mulching practices for reducing soil water erosion: A review. *Earth-Sci. Rev.* 161:191-203. doi: <http://dx.doi.org/10.1016/j.earscirev.2016.08.006>.
- Quemada, M., Baranski, M., Nobel-de Lange, M.N.J., Vallejo, A., Cooper, J.M. 2013. Meta-analysis of strategies to control nitrate leaching in irrigated agricultural systems and their effects on crop yield. *Agric. , Ecosyst. Environ.* 174:1-10. doi: <http://dx.doi.org/10.1016/j.agee.2013.04.018>.
- Quilbe, R., Serreau, C., Wicherek, S., Bernard, C., Thomas, Y., Oudinet, J. 2005a. Nutrient transfer by runoff from sewage sludge amended soil under simulated rainfall. *Environ. Monit. Assess.* 100:177-190. doi: <http://dx.doi.org/10.1007/s10661-005-4773-8>.
- Rahman, M.T., Zhu, Q.H., Zhang, Z.B., Zhou, H., Peng, X. 2017. The roles of organic amendments and microbial community in the improvement of soil structure of a Vertisol. *Applied Soil Ecology* 111:84-93. doi: <http://dx.doi.org/10.1016/j.apsoil.2016.11.018>.
- Ramos, M.C., Martínez-Casasnovas, J.A. 2006. Erosion rates and nutrient losses affected by composted cattle manure application in vineyard soils of NE Spain. *Catena* 68:177-185. doi: <http://dx.doi.org/10.1016/j.catena.2006.04.004>.

- Ramos, M.C., Martínez-Casasnovas, J.A. 2004. Nutrient losses from a vineyard soil in Northeastern Spain caused by an extraordinary rainfall event. *Catena* 55:79-90. doi: [http://dx.doi.org/10.1016/S0341-8162\(03\)00074-2](http://dx.doi.org/10.1016/S0341-8162(03)00074-2).
- Ramos, M.E., Benítez, E., García, P.A., Robles, A.B. 2010. Cover crops under different managements vs. frequent tillage in almond orchards in semiarid conditions: Effects on soil quality. *Applied Soil Ecology* 44:6-14. doi: <http://dx.doi.org/10.1016/j.apsoil.2009.08.005>.
- Reeves, D.W. 1997. The role of soil organic matter in maintaining soil quality in continuous cropping systems. *Soil Tillage Res.* 43:131-167. doi: [http://dx.doi.org/10.1016/S0167-1987\(97\)00038-X](http://dx.doi.org/10.1016/S0167-1987(97)00038-X).
- Regione Siciliana, 2016. Assessorato Regionale Risorse Agricole ed Alimentari, Dipartimento Interventi Strutturali. PSR SICILIA 2007- 2013 Misura 214 “ Pagamenti agroambientali”- Sottomisura 214/1 – Azioni 214/1A 214/1B 214/1D.
- Renard, K.G., Foster, G.R., Weessies, G.A., McCool, D.K. 1997. Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). U.S. Department of Agriculture.
- Richards, L.A. 1965. Physical condition of water in soil. *Methods of soil analysis. Part 1. Agronomy Monogr.* 9. ASA and SSSA, Madison, WI. :128-152.
- Richards, L.A. 1941. A pressure-membrana extraction apparatus for soil solution. *Soil Science* 51:377-386.
- Ripoche, A., Metay, A., Celette, F., Gary, C. 2011a. Changing the soil surface management in vineyards: immediate and delayed effects on the growth and yield of grapevine. *Plant Soil* 339:259-271. doi: <http://dx.doi.org/10.1007/s11104-010-0573-1>.
- Rodrigo Comino, J., Brings, C., Lassu, T., Iserloh, T., Senciales, J.M., MartÁñez Murillo, J.F., Ruiz Sinoga, J.D., Seeger, M., Ries, J.B. 2015. Rainfall and human activity impacts on soil losses and rill erosion in vineyards (Ruwer Valley, Germany). *Solid Earth* 6:823-837. doi: <http://dx.doi.org/10.5194/se-6-823-2015>.
- Rodrigo Comino, J., Iserloh, T., Morvan, X., Malam Issa, O., Naisse, C., Keesstra, D.S., Cerdà, A., Prosdoci, M., Arnáez, J., Lasanta, T., Ramos, C.M., Marqués, J.M., Ruiz Colmenero, M., Bienes, R., Ruiz Sinoga, D.J., Seeger, M., Ries, B.J. 2016a. Soil Erosion Processes in European Vineyards: A Qualitative Comparison of Rainfall Simulation Measurements in Germany, Spain and France. *Hydrology* 3 doi: <http://dx.doi.org/10.3390/hydrology3010006>.
- Rodrigo Comino, J., Quiquerez, A., Follain, S., Raclot, D., Le Bissonnais, Y., Casalí, J., Giménez, R., Cerdà, A., Keesstra, S.D., Brevik, E.C., Pereira, P., Senciales, J.M., Seeger, M., Ruiz Sinoga, J.D., Ries, J.B. 2016b. Soil erosion in sloping vineyards assessed by using botanical indicators and sediment collectors in the Ruwer-Mosel valley. *Agric. , Ecosyst. Environ.* 233:158-170. doi: <http://dx.doi.org/10.1016/j.agee.2016.09.009>.
- Rodrigo Comino, J., Ruiz Sinoga, J.D., Senciales González, J.M., Guerra-Merchán, A., Seeger, M., Ries, J.B. 2016c. High variability of soil erosion and hydrological processes in Mediterranean hillslope vineyards (Montes de Málaga, Spain). *Catena* 145:274-284. doi: <http://dx.doi.org/10.1016/j.catena.2016.06.012>.

- Rodrigo Comino, J., Senciales, J.M., Ramos, M.C., Martínez-Casasnovas, J.A., Lasanta, T., Brevik, E.C., Ries, J.B., Ruiz Sinoga, J.D. 2017. Understanding soil erosion processes in Mediterranean sloping vineyards (Montes de Málaga, Spain). *Geoderma* 296:47-59. doi: <http://dx.doi.org/10.1016/j.geoderma.2017.02.021>.
- Rodriguez-Lloveras, X., Buytaert, W., Benito, G. 2016. Land use can offset climate change induced increases in erosion in Mediterranean watersheds. *Catena* 143:244-255. doi: <http://dx.doi.org/10.1016/j.catena.2016.04.012>.
- Ruiz Sinoga, J.D., Garcia Marín, R., Martínez-Murillo, J.F., Gabarrón Galeote, M.A. 2010. Pluviometric gradient incidence and the hydrological behaviour of soil surface components (southern Spain). *Land Degrad. Dev.* 21:484-495. doi: <http://dx.doi.org/10.1002/ldr.994>.
- Ruiz Sinoga, J.D., Martinez Murillo, J.F. 2009. Effects of soil surface components on soil hydrological behaviour in a dry Mediterranean environment (Southern Spain). *Geomorphology* 108:234-245. doi: <http://dx.doi.org/10.1016/j.geomorph.2009.01.012>.
- Ruiz-Colmenero, M., Bienes, R., Eldridge, D.J., Marques, M.J. 2013. Vegetation cover reduces erosion and enhances soil organic carbon in a vineyard in the central Spain. *Catena* 104:153-160. doi: <http://dx.doi.org/10.1016/j.catena.2012.11.007>.
- Ruiz-Colmenero, M., Bienes, R., Marques, M.J. 2011. Soil and water conservation dilemmas associated with the use of green cover in steep vineyards. *Soil Tillage Res.* 117:211-223. doi: <http://dx.doi.org/10.1016/j.still.2011.10.004>.
- Sá, J.C.d.M., Lal, R. 2009. Stratification ratio of soil organic matter pools as an indicator of carbon sequestration in a tillage chronosequence on a Brazilian Oxisol. *Soil Tillage Res.* 103:46-56. doi: <http://dx.doi.org/10.1016/j.still.2008.09.003>.
- Salomé, C., Coll, P., Lardo, E., Metay, A., Villenave, C., Marsden, C., Blanchart, E., Hinsinger, P., Le Cadre, E. 2016. The soil quality concept as a framework to assess management practices in vulnerable agroecosystems: A case study in Mediterranean vineyards. *Ecol. Ind.* 61, Part 2:456-465. doi: <http://dx.doi.org/10.1016/j.ecolind.2015.09.047>.
- Salomé, C., Coll, P., Lardo, E., Villenave, C., Blanchart, E., Hinsinger, P., Marsden, C., Le Cadre, E. 2014. Relevance of use-invariant soil properties to assess soil quality of vulnerable ecosystems: The case of Mediterranean vineyards. *Ecol. Ind.* 43:83-93. doi: <http://dx.doi.org/10.1016/j.ecolind.2014.02.016>.
- Sang-Arun, J., Mihara, M., Horaguchi, Y., Yamaji, E. 2006. Soil erosion and participatory remediation strategy for bench terraces in northern Thailand. *Catena* 65:258-264. doi: <http://dx.doi.org/10.1016/j.catena.2005.11.010>.
- Sastre, B., Barbero-Sierra, C., Bienes, R., Marqués, M.J., García-Díaz, A. 2017. Soil loss in an olive grove in Central Spain under cover crops and tillage treatments, and farmer perceptions. *Journal of Soils and Sediments* 17:873-888. doi: <http://dx.doi.org/10.1007/s11368-016-1589-9>.
- Seeger, M., Ries, J.B. 2008. Soil degradation and soil surface process intensities on abandoned fields in Mediterranean mountain environments. *Land Degrad. Dev.* 19:488-501. doi: <http://dx.doi.org/10.1002/ldr.854>.

- Shaw, E.A., Denef, K., Milano, d.T., Cotrufo, M.F., Wall, D.H. 2016. Fire affects root decomposition, soil food web structure, and carbon flow in tallgrass prairie. *SOIL* 2:199-210. doi: <http://dx.doi.org/10.5194/soil-2-199-2016>.
- SIAR. 2017. Sistema de Información Agroclimática para el Regadío. Ministerio de Agricultura y Pesca, Alimentación y Medio Ambiente. <http://eportal.magrama.gob.es/websiar/Inicio.aspx>. Accessed 1/2 2017.
- Singer, M.J., Shainberg, I. 2004. Mineral soil surface crusts and wind and water erosion. *Earth Surf. Process. Landforms* 29:1065-1075. doi: <http://dx.doi.org/10.1002/esp.1102>.
- Six, J., Bossuyt, H., Degryze, S., Denef, K. 2004. A history of research on the link between (micro)aggregates, soil biota, and soil organic matter dynamics. *Soil Tillage Res.* 79:7-31. doi: <http://dx.doi.org/10.1016/j.still.2004.03.008>.
- Six, J., Elliott, E.T., Paustian, K. 2000a. Soil macroaggregate turnover and microaggregate formation: a mechanism for C sequestration under no-tillage agriculture. *Soil Biol. Biochem.* 32:2099-2103. doi: [http://dx.doi.org/10.1016/S0038-0717\(00\)00179-6](http://dx.doi.org/10.1016/S0038-0717(00)00179-6).
- Six, J., Feller, C., Denef, K., Ogle, S., Sa, J., Albrecht, A. 2002. Soil organic matter, biota and aggregation in temperate and tropical soils - Effects of no-tillage. *Agronomie* 22:755-775. doi: <http://dx.doi.org/10.1051/agro:2002043>.
- Six, J., Paustian, K., Elliott, E., Combrink, C. 2000b. Soil structure and organic matter: I. Distribution of aggregate-size classes and aggregate-associated carbon. *Soil Sci. Soc. Am. J.* 64:681-689.
- Smith, P., Cotrufo, M.F., Rumpel, C., Paustian, K., Kuikman, P.J., Elliott, J.A., McDowell, R., Griffiths, R.I., Asakawa, S., Bustamante, M., House, J.I., Sobocki, J., Harper, R., Pan, G., West, P.C., Gerber, J.S., Clark, J.M., Adhya, T., Scholes, R.J., Scholes, M.C. 2015. Biogeochemical cycles and biodiversity as key drivers of ecosystem services provided by soils. *SOIL* 1:665-685. doi: <http://dx.doi.org/10.5194/soil-1-665-2015>.
- Spayd, S., Tarara, J., Mee, D., Ferguson, J. 2002. Separation of sunlight and temperature effects on the composition of *Vitis vinifera* cv. Merlot berries. *Am. J. Enol. Vitic.* 53:171-182.
- Starr, G.C., Lal, R., Malone, R., Hothem, D., Owens, L., Kimble, J. 2000. Modeling soil carbon transported by water erosion processes. *Land Degrad. Dev.* 11:83-91. doi: [http://dx.doi.org/10.1002/\(SICI\)1099-145X\(200001/02\)11:13.0.CO;2-W](http://dx.doi.org/10.1002/(SICI)1099-145X(200001/02)11:13.0.CO;2-W).
- StatSoft Inc., 2011. STATISTICA (data analysis software system) version 10.
- Steel, Z.L., Steel, A.E., Williams, J.N., Viers, J.H., Marquet, P.A., Barbosa, O. 2017. Patterns of bird diversity and habitat use in mixed vineyard-matorral landscapes of Central Chile. *Ecol. Ind.* 73:345-357. doi: <http://dx.doi.org/10.1016/j.ecolind.2016.09.039>.
- Steenwerth, K.L., Belina, K.M. 2010. Vineyard weed management practices influence nitrate leaching and nitrous oxide emissions. *Agric. , Ecosyst. Environ.* 138:127-131. doi: <http://dx.doi.org/10.1016/j.agee.2010.03.016>.

- Steenwerth, K., Belina, K.M. 2008a. Cover crops and cultivation: Impacts on soil N dynamics and microbiological function in a Mediterranean vineyard agroecosystem. *Applied Soil Ecology* 40:370-380. doi: <http://dx.doi.org/10.1016/j.apsoil.2008.06.004>.
- Steenwerth, K., Belina, K.M. 2008b. Cover crops enhance soil organic matter, carbon dynamics and microbiological function in a vineyard agroecosystem. *Applied Soil Ecology* 40:359-369. doi: <http://dx.doi.org/10.1016/j.apsoil.2008.06.006>.
- Stockmann, U., Adams, M.A., Crawford, J.W., Field, D.J., Henakaarchchi, N., Jenkins, M., Minasny, B., McBratney, A.B., Courcelles, V.d.R.d., Singh, K., Wheeler, I., Abbott, L., Angers, D.A., Baldock, J., Bird, M., Brookes, P.C., Chenu, C., Jastrow, J.D., Lal, R., Lehmann, J., O'Donnell, A.G., Parton, W.J., Whitehead, D., Zimmermann, M. 2013. The knowns, known unknowns and unknowns of sequestration of soil organic carbon. *Agric. , Ecosyst. Environ.* 164:80-99. doi: <http://dx.doi.org/10.1016/j.agee.2012.10.001>.
- Stockmann, U., Padarian, J., McBratney, A., Minasny, B., de Brogniez, D., Montanarella, L., Hong, S.Y., Rawlins, B.G., Field, D.J. 2015. Global soil organic carbon assessment. *Global Food Security* 6:9-16. doi: <http://dx.doi.org/10.1016/j.gfs.2015.07.001>.
- Sun, J., Yu, X., Li, H., Chang, Y., Wang, H., Tu, Z., Liang, H. 2016. Simulated erosion using soils from vegetated slopes in the Jiufeng Mountains, China. *Catena* 136:128-134. doi: <http://dx.doi.org/10.1016/j.catena.2015.02.019>.
- Taboada, M.A., Barbosa, O.A., Rodríguez, M.B., Cosentino, D.J. 2004. Mechanisms of aggregation in a silty loam under different simulated management regimes. *Geoderma* 123:233-244. doi: <http://dx.doi.org/10.1016/j.geoderma.2004.02.009>.
- Taguas, E.V., Arroyo, C., Lora, A., Guzmán, G., Vanderlinden, K., Gómez, J.A. 2015. Exploring the linkage between spontaneous grass cover biodiversity and soil degradation in two olive orchard microcatchments with contrasting environmental and management conditions. *SOIL* 1:651-664. doi: <http://dx.doi.org/10.5194/soil-1-651-2015>.
- Tarolli, P., Sofia, G., Calligaro, S., Prosdocimi, M., Preti, F., Dalla Fontana, G. 2015a. Vineyards in Terraced Landscapes: New Opportunities from Lidar Data. *Land Degrad. Dev.* 26:92-102. doi: <http://dx.doi.org/10.1002/ldr.2311>.
- Terrón, J.M., Blanco, J., Moral, F.J., Mancha, L.A., Uriarte, D., Marques, d.S. 2015. Evaluation of vineyard growth under four irrigation regimes using vegetation and soil on-the-go sensors. *SOIL* 1:459-473. doi: <http://dx.doi.org/10.5194/soil-1-459-2015>.
- Tisdall, J.M., Oades, J.M. 1982. Organic matter and water-stable aggregates in soils. *J. Soil Sci.* 33:141-163. doi: <http://dx.doi.org/10.1111/j.1365-2389.1982.tb01755.x>.
- Tricart, J. 1969. *La epidermis de la tierra*. Edit. Labor S.A., Barcelona.
- Tsozué, D., Nghonda, J.P., Mekem, D.L. 2015. Impact of land management system on crop yields and soil fertility in Cameroon. *Solid Earth* 6:1087-1101. doi: <http://dx.doi.org/10.5194/se-6-1087-2015>.
- UNESCO–SCBD. 2014. Florence Declaration on the Links Between Biological and Cultural Diversity.

- Valkama, E., Lemola, R., Känkänen, H., Turtola, E. 2015. Meta-analysis of the effects of undersown catch crops on nitrogen leaching loss and grain yields in the Nordic countries. *Agric. , Ecosyst. Environ.* 203:93-101. doi: <http://dx.doi.org/10.1016/j.agee.2015.01.023>.
- Van Dijk, P.M., Kwaad, F.J.P.M., Klapwijk, M. 1996. Retention of water and sediment by grass strips. *Hydrol. Process.* 10:1069-1080. doi: [http://dx.doi.org/10.1002/\(SICI\)1099-1085\(199608\)10:83.O.CO;2-4](http://dx.doi.org/10.1002/(SICI)1099-1085(199608)10:83.O.CO;2-4).
- Van Eck, C.M., Nunes, J.P., Vieira, D.C.S., Keesstra, S., Keizer, J.J. 2016. Physically-Based Modelling of the Post-Fire Runoff Response of a Forest Catchment in Central Portugal: Using Field versus Remote Sensing Based Estimates of Vegetation Recovery. *Land Degrad. Dev.* 27:1535-1544. doi: <http://dx.doi.org/10.1002/ldr.2507>.
- van Genuchten MT, Leij FJ, Yates SR (1991) The RETC code for quantifying the hydraulic functions of unsaturated soils. EPA/600/2-91/065. 85pp, USA.
- Van Hemelryck, H., Fiener, P., Van Oost, K., Govers, G., Merckx, R. 2010. The effect of soil redistribution on soil organic carbon: an experimental study. *Biogeosciences* 7:3971-3986. doi: <http://dx.doi.org/10.5194/bg-7-3971-2010>.
- Van Leeuwen, C., Tregoat, O., Chone, X., Bois, B., Pernet, D., Gaudillere, J.-. 2009. Vine Water Status is a Key Factor in Grape Ripening and Vintage Quality for Red Bordeaux Wine. how can it be Assessed for Vineyard Management Purposes?. *J. Int. Sci. Vigne Vin.* 43:121-134.
- Vanmaercke, M., Poesen, J., Verstraeten, G., de Vente, J., Ocakoglu, F. 2011. Sediment yield in Europe: Spatial patterns and scale dependency. *Geomorphology* 130:142-161. doi: <http://dx.doi.org/10.1016/j.geomorph.2011.03.010>.
- Vaudour, E., Costantini, E., Jones, G.V., Mocali, S. 2015. An overview of the recent approaches to terroir functional modelling, footprinting and zoning. *SOIL* 1:287-312. doi: <http://dx.doi.org/10.5194/soil-1-287-2015>.
- Vicente-Vicente, J.L., García-Ruiz, R., Francaviglia, R., Aguilera, E., Smith, P. 2016. Soil carbon sequestration rates under Mediterranean woody crops using recommended management practices: A meta-analysis. *Agric. , Ecosyst. Environ.* 235:204-214. doi: <http://dx.doi.org/10.1016/j.agee.2016.10.024>.
- Virto, I., Imaz, M.J., Fernandez-Ugalde, O., Urrutia, I., Enrique, A., Bescansa, P. 2012a. Soil quality evaluation following the implementation of permanent cover crops in semi-arid vineyards. Organic matter, physical and biological soil properties. *Span. J. Agric. Res.* 10:1121-1132. doi: <http://dx.doi.org/10.5424/sjar/2012104-613-11>.
- Virto, I., Imaz, M.J., Fernandez-Ugalde, O., Urrutia, I., Enrique, A., Bescansa, P. 2012b. Soil quality evaluation following the implementation of permanent cover crops in semi-arid vineyards. Organic matter, physical and biological soil properties. *Span. J. Agric. Res.* 10:1121-1132. doi: <http://dx.doi.org/10.5424/sjar/2012104-613-11>.
- Virto, I., Jose Imaz, M., Fernandez-Ugalde, O., Gartzia-Bengoetxea, N., Enrique, A., Bescansa, P. 2015. Soil Degradation and Soil Quality in Western Europe: Current Situation and Future Perspectives. *Sustainability* 7:313-365. doi: <http://dx.doi.org/10.3390/su7010313>.

- Visser, S.M., Sterk, G. 2007. Nutrient dynamics—wind and water erosion at the village scale in the Sahel. *Land Degrad. Dev.* 18:578-588. doi: <http://dx.doi.org/10.1002/ldr.800>.
- Walkley, A., I.A.Black. 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* 37:29-38.
- Wander, M.M., Bidart, M.G. 2000. Tillage practice influences on the physical protection, bioavailability and composition of particulate organic matter. *Biol. Fertility Soils* 32:360-367. doi: <http://dx.doi.org/10.1007/s003740000260>.
- Wang, L., Dalabay, N., Lu, P., Wu, F. 2017. Effects of tillage practices and slope on runoff and erosion of soil from the Loess Plateau, China, subjected to simulated rainfall. *Soil Tillage Res.* 166:147-156. doi: <http://dx.doi.org/10.1016/j.still.2016.09.007>.
- Wang, Y., Fan, J., Cao, L., Liang, Y. 2016. Infiltration and Runoff Generation Under Various Cropping Patterns in the Red Soil Region of China. *Land Degrad. Dev.* 27:83-91. doi: <http://dx.doi.org/10.1002/ldr.2460>.
- Wei, C., Gao, M., Shao, J., Xie, D., Pan, G. 2006. Soil aggregate and its response to land management practices. *China Particuology* 4:211-219. doi: [http://dx.doi.org/10.1016/S1672-2515\(07\)60263-2](http://dx.doi.org/10.1016/S1672-2515(07)60263-2).
- Wischmeier, W.H., Johnson, C.B., Cross, B.V. 1971. A soil credibility nomograph for farmland and construction sites. *Journal of Soil and Water Conservation* 26:189-193.
- Wischmeier, W.H., Smith, D. 1978. Predicting Rainfall Erosion Losses: a Guide to Conservation Planning. Agricultural Handbook No 537. U.S. Department of Agriculture, Washington DC. USA.
- Yagioka, A., Komatsuzaki, M., Kaneko, N., Ueno, H. 2015. Effect of no-tillage with weed cover mulching versus conventional tillage on global warming potential and nitrate leaching. *Agric. , Ecosyst. Environ.* 200:42-53. doi: <http://dx.doi.org/10.1016/j.agee.2014.09.011>.
- Zhang, G.S., Ni, Z.W. 2017. Winter tillage impacts on soil organic carbon, aggregation and CO2 emission in a rainfed vegetable cropping system of the mid-Yunnan plateau, China. *Soil Tillage Res.* 165:294-301. doi: <http://dx.doi.org/10.1016/j.still.2016.09.008>.
- Zhang, G., Liu, G., Wang, G. 2010. Effects of Caragana Korshinskii Kom. cover on runoff, sediment yield and nitrogen loss. *International Journal of Sediment Research* 25:245-257. doi: [http://dx.doi.org/10.1016/S1001-6279\(10\)60042-X](http://dx.doi.org/10.1016/S1001-6279(10)60042-X).
- Zhao, C., Gao, J., Huang, Y., Wang, G., Zhang, M. 2016. Effects of Vegetation Stems on Hydraulics of Overland Flow Under Varying Water Discharges. *Land Degrad. Dev.* 27:748-757. doi: <http://dx.doi.org/10.1002/ldr.2423>.
- Zupanc, V., Šturm, M., Lojen, S., Maršič-Kacjan, N., Adu-Gyamfi, J., Bračič-Železnik, B., Urbanc, J., Pintar, M. 2011. Nitrate leaching under vegetable field above a shallow aquifer in Slovenia. *Agric. , Ecosyst. Environ.* 144:167-174. doi: <http://dx.doi.org/10.1016/j.agee.2011.08.014>.

APPENDICES

APPENDIX 1

Table A1.1. Correlation matrix of soil organic carbon (SOC), soil carbon of the particulate organic matter fraction (POC), soil carbon of the mineral-associated organic matter fraction (FM), counting number drops aggregate stability test (CND), water stable aggregates test (WSA), roots, penetration resistance (PR), infiltration (Infil), intrapedal porosity (P-Intra), total porosity (P-total), macro porosity (P-Macro), meso porosity (P-Meso), micro porosity (Micro), water holding capacity (WHC) and bulk density (BD).

	COV	SOC	POC	FM	CND	WSA	Roots	PR	Infil	Pintr	Ptotal	Macro	Meso	Micro	WHC	BD
COV		0.46*	0.50*	0.18	0.09	0.38*	0.65*	0.57*	0.73*	-0.33*	-0.17	0.33*	-0.36*	-0.24*	-0.45*	0.28*
SOC	0.46*		0.90*	0.70*	0.28*	0.67*	0.53*	0.51*	0.47*	-0.25*	-0.01	0.35*	-0.45*	-0.05	-0.27*	0.17
POC	0.50*	0.90*		0.31*	0.25*	0.53*	0.49*	0.50*	0.48*	-0.27*	-0.07	0.40*	-0.41*	-0.17	-0.37*	0.12
FM	0.18	0.70*	0.31*		0.21*	0.59*	0.36*	0.28*	0.23*	-0.10	0.07	0.11	-0.31*	0.17	0.03	0.16
CND	0.09	0.28*	0.25*	0.21*		0.12	0.10	0.01	0.08	0.03	0.15	0.14	-0.17	0.14	0.08	-0.22*
WSA	0.38*	0.67*	0.53*	0.59*	0.12		0.58*	0.50*	0.42*	-0.43*	-0.20*	0.40*	-0.53*	-0.23*	-0.49*	0.39*
Roots	0.65*	0.53*	0.49*	0.36*	0.10	0.58*		0.43*	0.64*	-0.47*	-0.20*	0.53*	-0.64*	-0.28*	-0.49*	0.33*
PR	0.57*	0.51*	0.50*	0.28*	0.01	0.50*	0.43*		0.56*	-0.33*	-0.28*	0.25*	-0.41*	-0.24*	-0.36*	0.28*
Inf	0.73*	0.47*	0.48*	0.23*	0.08	0.42*	0.64*	0.56*		-0.46*	-0.35*	0.43*	-0.47*	-0.44*	-0.53*	0.31*
Pintr	-0.33*	-0.25*	-0.27*	-0.10	0.03	-0.43*	-0.47*	-0.33*	-0.46*		0.41*	-0.52*	0.49*	0.57*	0.70*	-0.44*
Ptotal	-0.17	-0.01	-0.07	0.07	0.15	-0.20*	-0.20*	-0.28*	-0.35*	0.41*		0.01	0.48*	0.70*	0.51*	-0.60*
Macro	0.33*	0.35*	0.40*	0.11	0.14	0.40*	0.53*	0.25*	0.43*	-0.52*	0.01		-0.55*	-0.56*	-0.65*	0.02
Meso	-0.36*	-0.45*	-0.41*	-0.31*	-0.17	-0.53*	-0.64*	-0.41*	-0.47*	0.49*	0.48*	-0.55*		0.35*	0.43*	-0.29*
Micro	-0.24*	-0.05	-0.17	0.17	0.14	-0.23*	-0.28*	-0.24*	-0.44*	0.57*	0.70*	-0.56*	0.35*		0.85*	-0.45*
WHC	-0.45*	-0.27*	-0.37*	0.03	0.08	-0.49*	-0.49*	-0.36*	-0.53*	0.70*	0.51*	-0.65*	0.43*	0.85*		-0.49*
BD	0.28*	0.17	0.12	0.16	-0.22*	0.39*	0.33*	0.28*	0.31*	-0.44*	-0.60*	0.02	-0.29*	-0.45*	-0.49*	

p-values <0.05 marked with *

APPENDIX 2

Table A2.1. Arganda del Rey meteorological data. Average temperature (AT), average of the maximum temperature (AMT), average of the minimum temperature (AmT) and reference evapotranspiration calculated with FAO Penman-Monteith method (ET₀).

Year	Month	AT (°C)	AMT (°C)	AmT (°C)	Rainfall (mm)	ET ₀ (mm)	Total Rainfall (mm)	Total ET ₀ (mm)
2012	Oct	14.6	29.2	-0.1	39.4	63.6		
2012	Nov	9.9	20.8	-2.7	62.5	30.2		
2012	Dec	4.9	16.3	-4.6	8.6	17.6		
2013	Jan	5.8	18.3	-3.8	20.1	26.6		
2013	Feb	6.2	17.1	-3.4	20.9	43.5		
2013	Mar	9.3	17.2	-2.4	88.7	60.2		
2013	Apr	12.1	28.5	-1.2	64.3	99.7		
2013	May	14.4	28.0	2.5	45.4	128.1		
2013	Jun	21.3	35.9	4.5	1.8	186.4		
2013	Jul	26.9	38.8	11.2	18.5	219.0		
2013	Aug	26.1	38.9	12.7	15.9	190.4		
2013	Sep	21.6	34.0	10.5	18.1	121.8	404.2	1187.1
2013	Oct	15.7	27.8	0.4	46.4	67.2		
2013	Nov	8.2	23.1	-6.2	106.7	40.1		
2013	Dec	4.4	17.0	-6.7	43.0	24.2		
2014	Jan	7.7	17.2	-1.5	64.3	31.5		
2014	Feb	7.2	17.4	-3.0	34.0	41.4		
2014	Mar	10.8	25.0	-2.0	21.7	89.0		
2014	Apr	15.7	29.6	5.3	34.6	120.4		
2014	May	18.2	33.0	2.7	13.7	167.9		
2014	Jun	22.7	35.2	9.6	10.9	192.4		
2014	Jul	24.8	38.6	10.6	6.2	202.3		
2014	Aug	25.4	36.1	12.4	0.0	187.0		
2014	Sep	21.3	38.3	9.2	20.5	118.9	402.0	1282.2
2014	Oct	17.0	29.1	4.3	55.1	66.7		
2014	Nov	11.0	23.6	-0.7	75.4	37.5		
2014	Dec	5.4	16.0	-6.1	24.7	23.8		
2015	Jan	4.2	16.7	-6.4	21.3	29.3		
2015	Feb	6.4	17.6	-4.4	32.2	47.5		
2015	Mar	10.4	27.8	-3.2	42.6	76.2		
2015	Apr	14.4	25.7	2.5	37.6	112.1		
2015	May	20.0	37.8	5.4	0.4	179.0		
2015	Jun	24.6	40.9	9.0	18.5	192.0		
2015	Jul	29.2	41.7	15.3	1.6	223.0		
2015	Aug	25.8	39.6	10.3	3.0	187.0		
2015	Sep	20.0	32.2	6.9	10.8	121.7	323.1	1295.8

Table A2.2. Villa del Prado meteorological data. Average temperature (AT), average of the maximum temperature (AMT), average of the minimum temperature (AmT) and reference evapotranspiration calculated with FAO Penman-Monteith method (ET₀).

Year	Month	AT (°C)	AMT (°C)	AmT (°C)	Rainfall (mm)	ET ₀ (mm)	Total Rainfall (mm)	Total ET ₀ (mm)
2012	Oct	14.5	29.0	-1.0	34.1	61.9		
2012	Nov	10.0	20.4	1.3	58.6	31.2		
2012	Dec	6.1	15.6	-3.8	9.2	19.4		
2013	Jan	5.7	18.5	-4.7	18.7	26.3		
2013	Feb	6.6	16.8	-4.1	13.4	40.6		
2013	Mar	9.3	18.8	-1.4	57.7	55.7		
2013	Apr	12.4	29.4	0.1	57.8	96.4		
2013	May	15.1	28.8	2.7	27.6	130.1		
2013	Jun	21.5	35.4	6.1	0.0	177.4		
2013	Jul	26.5	39.4	8.7	0.0	197.0		
2013	Aug	26.2	39.1	11.6	0.0	178.1		
2013	Sep	21.6	34.7	10.0	47.2	116.7	324.2	1130.8
2013	Oct	15.7	27.0	0.9	62.9	63.7		
2013	Nov	9.2	24.2	-6.4	10.2	44.1		
2013	Dec	4.7	17.5	-7.3	71.3	22.5		
2014	Jan	7.7	17.4	-3.0	77.3	27.5		
2014	Feb	7.0	18.4	-4.0	80.4	35.7		
2014	Mar	10.5	24.6	-1.6	44.7	76.3		
2014	Apr	15.5	31.2	2.4	28.6	114.8		
2014	May	18.2	32.2	4.9	29.4	158.1		
2014	Jun	21.8	35.6	8.2	13.1	178.1		
2014	Jul	24.6	39.1	10.3	10.4	194.6		
2014	Aug	25.3	36.2	10.9	0.0	184.9		
2014	Sep	20.6	38.6	8.8	27.0	111.6	455.2	1211.9
2014	Oct	16.9	28.2	5.1	70.1	66.1		
2014	Nov	10.8	22.9	-1.0	33.7	31.4		
2014	Dec	6.2	17.0	-7.1	25.7	28.0		
2015	Jan	4.9	16.6	-6.2	23.4	33.2		
2015	Feb	6.8	17.3	-4.2	12.1	45.6		
2015	Mar	11.2	28.0	-3.5	45.4	84.3		
2015	Apr	14.4	25.6	2.0	44.2	111.2		
2015	May	19.8	37.5	4.2	18.0	173.6		
2015	Jun	24.5	41.4	9.6	14.0	193.5		
2015	Jul	29.4	41.5	14.1	0.3	226.1		
2015	Aug	25.6	38.7	11.6	5.1	183.0		
2015	Sep	19.9	32.0	7.6	24.2	117.4	316.2	1293.3

APPENDIX 3

Following, several images about runoff setup, simulation and plots are shown.

Figure A3.1. The 1000 l tank with the car is located at the top of the vineyard.

Figure A3.2. The intermediate 100 l tank has a 12v pump and a pressure meter to control water flow.

Figure A3.3. Sheet flow created by the drilled pipe. There are 49 perforations of 1 mm $\varnothing$.

Figure. A3.4. Spontaneous vegetation microplot (2 m long and 0.5 m long) during a runoff simulation. Sheet water movement can be noted.

Figure A3.5. One person ensure that pipe holes are free and that an homogeneous sheet flow is created while other is sampling the runoff water.

Figure A3.6. The runoff samples were filtered and storage in a fridge.

APPENDIX 4

Following, several images of rabbit damages on grape clusters, vine shoots and buds are reported.

Figure A4.1. Vine plant with dramatic rabbit damages.

Figure A4.2. Vine plant with rabbit damages in its lower part.

Figure A4.3. Vine plant with herbivory damages in its lower part and eaten clusters.

Figure A4.4. Detailed view of rabbit dama