Geoderma 271 (2016) 144–149

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Carbon input threshold for soil carbon budget optimization in eroding vineyards

Andrés García-Díaz [a], Ramón Bienes Allas [a], Luciano Gristina [b], Artemio Cerdà [c], Paulo Pereira [d], Agata Novara [b,*]

[a] Applied Research Department, IMIDRA, Finca El Encín, Alcalá de Henares, Spain
[b] Dipartimento di Scienze Agrarie e Forestali, Università degli Studi di Palermo, Palermo, Italy
[c] Soil Erosion and Degradation Research Group, Department of Geography, University of Valencia, Valencia, Spain
[d] Environmental Management Centre, Mykolas Romeris University, Vilnius, Lithuania

ARTICLE INFO

Article history:
Received 23 September 2015
Received in revised form 11 February 2016
Accepted 18 February 2016
Available online 2 March 2016

Keywords:
Agro-environmental measure
Soil erosion
Degradation
Organic carbon

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.

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., 2015; 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, 2015) 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., 2012). 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., in press).

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., 2016; 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., 2014; Ruiz-Colmenero et al., 2013; Virto et al., 2012). Hence, the adoption of soil-conservation practices is encouraged both to prevent erosion and to sequester atmospheric carbon dioxide (CO_2) in the soils. As a consequence of the 1992 reforms of the Common Agricultural Policy in Europe, agro-environmental policies have been developed through

* Corresponding author.
E-mail address: agata.novara@unipa.it (A. Novara).

http://dx.doi.org/10.1016/j.geoderma.2016.02.020
0016-7061/

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 CO_2 emissions or higher amounts of C in soil sediments that are transported from the field by erosion. Gao et al. (2012, 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?

1.1. 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) CO_2 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 CO_2 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 CO_2 emission. Both studies showed that erosion induced-CO_2 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):

$$OCloss_{sediment} = SE * SOC * E_r \quad (1)$$

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. (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. 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. 1).

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. (2 and 3):

$$Closs_{AEM} = Closs_{CT} \quad (2)$$

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

$$SE_{AEM} * SOC_{AEM} * E_{rAEM} = SE_{CT} * SOC_{CT} * E_{rCT}. \quad (3)$$

Based on Eq. (3), the C losses relative to SOC content with AEM and CT management are presented in Fig. 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.

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 $OCloss_{CT}$, the $OCloss_{AEM}$ will be reached with a SOC content equal to SOC_2. Values higher to SOC_2 will result in a higher OCloss 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. 2).

2. Materials and methods

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 (DOC) areas on the island (Fig. 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.

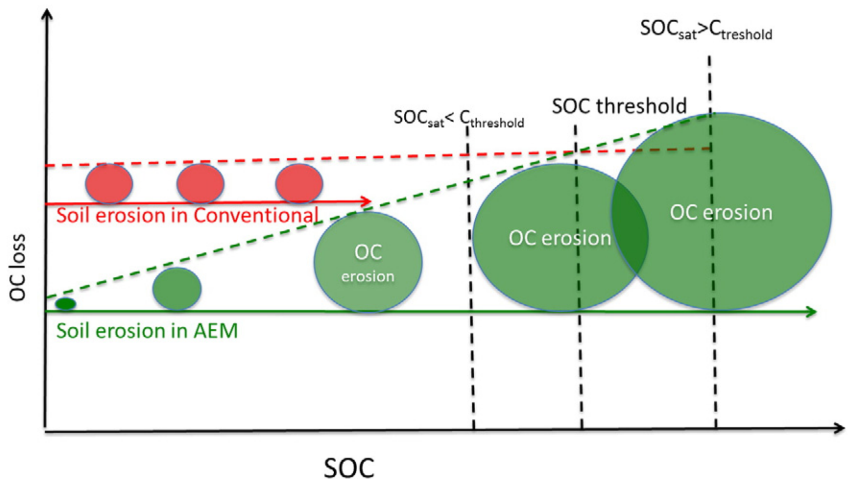

Fig. 1. Conceptual diagram of dynamic changes in OC loss in a sloping area with different soil management systems. The soil erosion is lower under AEM management (green line) than CT management (red line). The increase of SOC in AEM management (green circle) can entail an higher OC loss in AEM than CT. 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.

In the study area, 100 paired sites were chosen (Fig. 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 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).

2.2. SOC threshold calculation

The SOC threshold for each pair of sites was calculated according to Eq. (3). SE_{AEM} and SE_{CT} were estimated using the USLE equation (Wischmeier and Smith, 1978):

$$SE\left(Mgha^{-1}\right) = K * R * C * LS * P \tag{4}$$

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) was arranged as follows:

$$K_{AEM} * SOC_{AEM} = \frac{K_{CT} * SOC_{CT} * E_{rCT}}{E_{rAEM}} \tag{5}$$

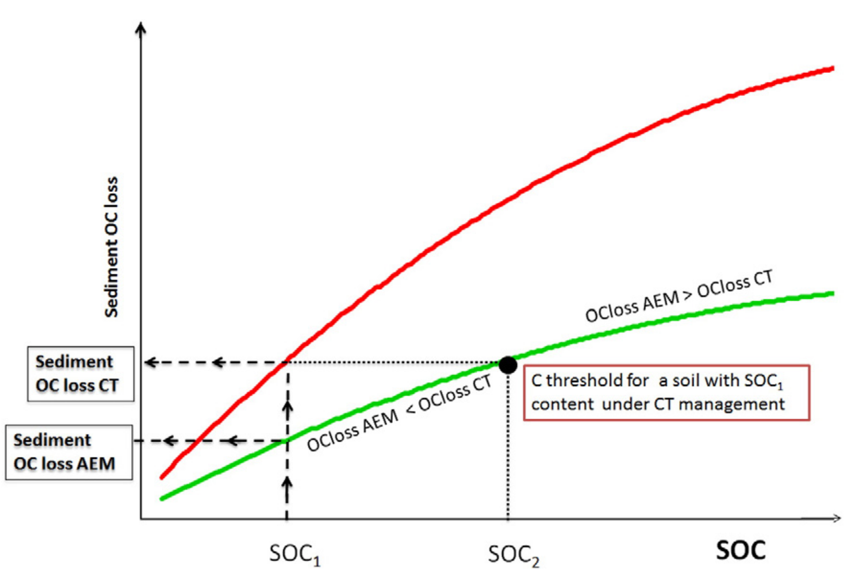

Fig. 2. C loss under two different soil managements. The black circle indicates the SOC threshold.

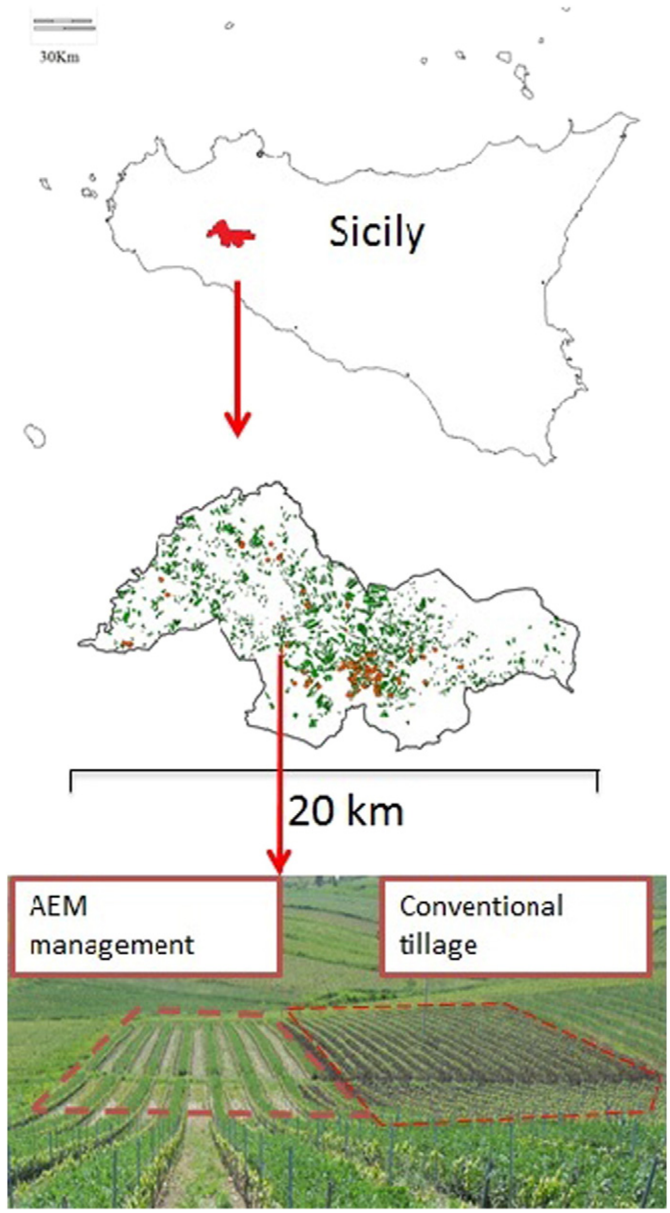

Fig. 3. The studied Santa Margherita DOC area (controlled denomination of origin) in Sicily, the selected paired sites (red bullets), in green vineyards of the studied area, and an example of paired site.

as:

$$K = f(SOC_{AEM}) \quad (6)$$

It follows:

$$SOCthreshold = SOC_{AEM} = \frac{K_{CT} * SOC_{CT} * E_{rCT}}{E_{rAEM} * f^{-1}}. \quad (7)$$

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

3. Results and discussion

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. 4). The C increase after AEM adoption was moderate relative to that reported in other studies (Batjes, 2014; Debasish et al., 2014; Jaiarree et al., 2014; Li et al., 2014; Lozano-García and Parras-Alcántara, 2014).

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., in press).

3.2. SOC threshold

The SOC threshold, which was calculated for each paired site according to Eq. (7), showed an exponential trend both for soil with high silt content and low silt content (Fig. 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-Rodriguez 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. 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.

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. 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.

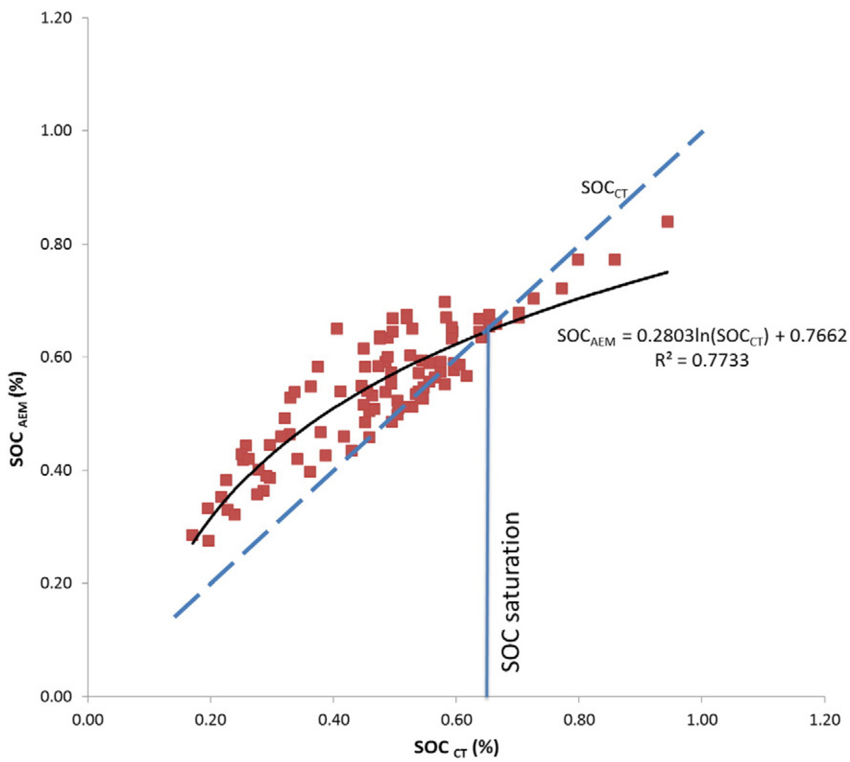

Fig. 4. Soil organic carbon (SOC%) in each paired site for the two soil managements. The dotted blue line represents SOC under Conventional tillage (CT). The crossing point between the logarithmic curve (black line) and linear equation (dotted line) describes the C saturation level. The distance between linear line and logarithmic curve represents the SOC change after AEM adoption.

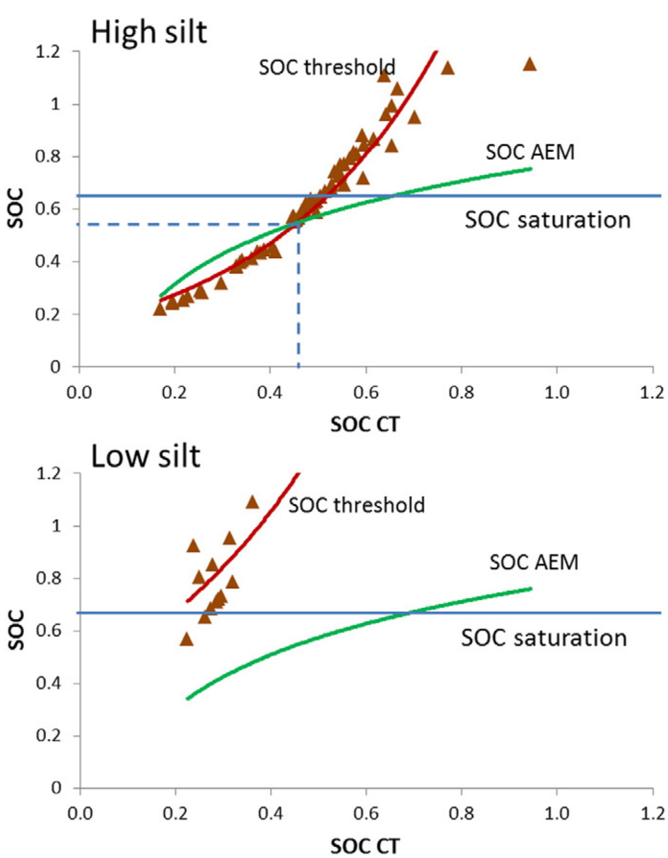

Fig. 5. SOC threshold and measured SOC after 5 years of AEM adoption in soil with high silt (a) and low silt (b) content.

4. Conclusion

AEM management using cover crops in vineyards increases SOC because it increases C inputs and reduces soil organic matter mineralization, such that there is a net increase in C stock with AEM management relative to CT management. 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

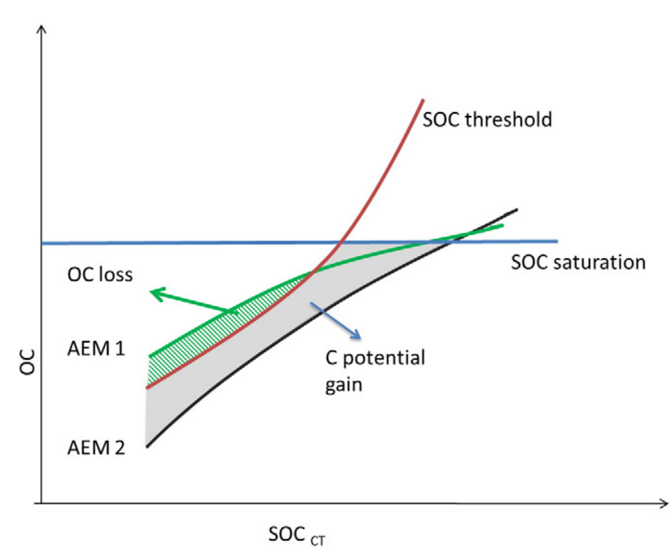

Fig. 6. Scenarios of OC loss and potential C sequestration in relation to different AEMs (AEM_1 and AEM_2).

loss resulting from AEM adoption (green area, Fig. 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. 6). Although the SOC stock can reach the saturation level after several years of AEM management (IPCC, 2007), 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.

Acknowledgments

We thank Dr. F. Guaitoli from Assessorato Regionale Risorse Agricole e Alimentari Dipartimento Interventi Infrastrutturali per Agricoltura Servizio VI Sistema Informativo Territoriale Regione Siciliana.

References

Balesdent, J., Chenu, C., Balabane, M., 2000. Relationship of organic matter dynamics to physical protection and tillage. Soil Tillage Res. 53, 215–230.

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.

Batjes, N.H., 2014. Projected changes in soil organic carbon stocks upon adoption of recommended soil and water practices in the Upper Tana River Catchment, Kenia. Land Degrad. Dev. 25, 278–287. http://dx.doi.org/10.1002/ldr.2141.

Biddoccu, M., Opsi, F., Cavallo, E., 2014. Relationship between runoff and soil losses with rainfall characteristics and long-term soil management practices in a hilly vineyard (Piedmont, NW Italy). Soil Sci. Plant Nutr. 60, 92–99.

Blavet, D., De Noni, G., LeBissonnais, 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 (26652528).

Brevik, E.C., 2013. The potential impact of climate change on soil properties and processes and corresponding influence on food security. Agriculture 3, 398–417. http://dx.doi.org/10.3390/agriculture3030398.

Carr, P.M., Brevik, E.C., Horsley, R.D., Martin, G.B., 2016. Long-term no-tillage sequesters soil organic carbon in cool semi-arid regions. Soil Horiz. (in press).

Cerdà, 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., González-Pelayo, Ó., Giménez-Morera, A., Jordán, A., Pereira, P., Novara, A., Brevik, E.C., Prosdocimi, M., Mahmoodabadi, M., Keesstra, S., García Orenes, F., Ritsema, C., 2016. The 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. (in press).

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 (1–2), 167–177.

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. http://dx.doi.org/10.5194/soil-1-443-2015.

Debasish, S., Kukal, S.S., Bawa, S.S., 2014. Soil organic cabon stock and fractions in relation tol and use and soil depth in teh degraded shiwaliks hills of lower Himalayas. Land Degrad. Dev. 25, 407–416. http://dx.doi.org/10.1002/ldr.2151.

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.

Gao, Y., Yu, G.R., He, N.P., He, H.L., Wang, Q.F., Fang, H.J., 2012. Is there an existing healthy threshold for carbon storage in the ecosystem? Environ. Sci. Technol. 46 (9), 4687–4688.

García-Orenes, F., Roldán, A., Mataix-Solera, J., Cerdà, A., Campoy, M., Arcenegui, V., Caravaca, F., 2012. Soil structural stability and erosion rates influenced by agricultural management practices in a semi-arid Mediterranean agro-ecosystem. Soil Use Manag. 28 (4), 571–579. http://dx.doi.org/10.1111/j.1475-2743.2012.00451.x.

Intergovernmental Panel on Climate Change (IPCC), 2007. Climate Change 2007: Synthesis Report. IPCC, Geneva.

Jacinthe, P.A., Lal, R., 2001. A mass balance approach to assess carbon dioxide evolution during erosional events. Land Degrad. Dev. 12, 329–339.

Jaiarree, S., Chidthaisong, A., Tangtham, N., Polprasert, C., Sarobol, E., Tyler, S.C., 2014. CarbonBudget and sequestration potential in a sandy soil treated with compost. Land Degrad. Dev. 25, 120–129.

Li, Q.J., 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. http://dx.doi.org/10.1002/ldr.2144.

Lieskovský, J., Kenderessy, P., 2014. Modelling the effect of vegetation cover and different tillage practices on soil erosion in vineyards: a case study en Vráble (Slovakia) using WATEM/SEDEM. Land Degrad. Dev. 25, 288–296. http://dx.doi.org/10.1002/ldr.2162.2014.

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.

Lozano-García, B., Parras-Alcántara, L., 2014. Variations in soil organic carbon and nitrogen stocks along a toposequence in a traditional Mediterranean olive grove. Land Degrad. Dev. 25, 297–304. http://dx.doi.org/10.1002/ldr.2284.

Martínez-Casasnovas, J.A., Ramos, M.C., Benites, G., 2015. Soil and water assessment tool soil loss simulation in the sub-basin scale in the Alt Penedès–Anoia vineyard region (NE Spain) in the 2000s. Land Degrad. Dev. http://dx.doi.org/10.1002/ldr.2240.

McHunu, C., Chaplot, V., 2012. Land degradation impact on soil carbon losses through water erosion and CO2 emissions. Geoderma 177, 72–79.

Mekonnen, M., Keesstra, S.D., Stroosnijder, L., Baartman, J.E., Maroulis, J., 2015. Soil conservation through sediment trapping: a review. Land Degrad. Dev. http://dx.doi.org/10.1002/ldr.2308.

Novara, A., Cerdà, A., Dazzi, C., Lo, Papa G., Santoro, A., Gristina, L., 2015. Effectiveness of carbon isotopic signature for estimating soil erosion and deposition rates in Sicilian vineyards. Soil Tillage Res. 152, 1–7.

Novara, A., Gristina, L., Guaitoli, F., Santoro, A., Cerdà, A., 2013. Managing soil nitrate with cover crops and buffer strips in Sicilian vineyards. Solid Earth 4, 255–262. 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.

Novara, A., La Mantial, T., Barbera, V., Gristina, L., 2012. Paired-site approach for studying soil organic carbon dynamics in a Mediterranean semiarid environment. Catena 89 (1), 1–7.

Pérez-Rodriguez, R., Marqués, 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.

Prosdocimi, M., Jordán, A., Tarolli, P., Keesstra, S., Novara, A., Cerdà, A., 2016. The immediate effectiveness of barley straw mulch in reducing soil erodibility and surface runoff generation in Mediterranean vineyards. Sci. Total Environ. 547, 323–330.

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). In: Yoder, D.C. (Ed.), U.S. Department of Agriculture, Agriculture Handbook 703; 1997.

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.

Ruiz-Colmenero, M., Bienes, D.J., 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.

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.

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.

Tarolli, P., Sofia, G., Calligaro, S., Prosdocimi, M., Preti, F., Dalla Fontana, G., 2015. Vineyards in terraced landscapes: new opportunities from lidar data. Land Degrad. Dev. 26 (1), 92–102.

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. http://dx.doi.org/10.5194/bg-7-3971-2010.

Vanmaercke, M., Poesen, J., Verstraeten, G., De Vewnte, J., Ocakoglu, F., 2011. Sediment yield in Europe: spatial patterns and scale dependency. Geomorphology 130, 142–161.

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. http://dx.doi.org/10.5194/soil-1-287-2015.

Virto, I., Imaz, M.J., Fernández-Ugalde, O., Urrutia, I., Enrique, A., Bescansa, P., 2012. 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 (4), 1121–1132.

Walkley, A., Black, A.I., 1934. An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 37, 29–38.

Wang, Y., Cao, S., 2011. Carbon sequestration may have negative impacts on ecosystem health. Environ. Sci. Technol. 45, 1759–1760.

Wischmeier, W., Smith, D., 1978. 1978. Predicting Rainfall Erosion Losses: a Guide to Conservation Planning. Agricultural Handbook No. 537. U.S. Department of Agriculture, Washington DC, USA.

Wischmeier, W.H., Johnson, C.B., Cross, B.V., 1971. A soil credibility nomograph for farmland and construction sites. J. Soil Water Conserv. 26, 189–193.