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# Effect of alternative soil management in Mediterranean vineyards to reduce sediment and Carbon losses due to water erosion

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**FINAL REPORT**

Because it reduces soil fertility, damages nearby roads, and causes floods, soil erosion is an important problem in vineyards (Lieskovský and Kenderessy, 2014; Martínez Casasnovas, 2015). Higher erosion rates have been recorded in vineyards than in other land use areas (Cerdan et al., 2010) in the Mediterranean region (Vanmaerke et al., 2011) because of several characteristics of the soil, soil management, and climate (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 contribute to an important reduction of the soil and nutrient losses in the Mediterranean region (Cerdà, 1998; Novara et al., 2013, 2015) and Africa (Mekkonnen 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 stony, which increases their vulnerability to soil erosion. Finally, the large vine-producing regions in Mediterranean region are hilly and experience high intensity rainfall events, both of which will obviously increase the potential for erosion.

Within this context, alternative management, such as reduced tillage, the application of mulch or organic fertilizer, or the planting of cover crops, have been developed to protect soil from erosion. These alternative management methods generally increase the input of soil organic matter (SOM). The importance of SOM in reducing soil erosion is well known, i.e., SOM reduces erosion by improving soil structure and aggregate stability (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 vineyard 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.

Although agricultural conservation practices, as well as the planting of cover crops are included in the Agro-environmental management (AEM), few studies have analyzed how the carbon (C) cycle and erosion processes are altered in vineyards 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 sediments, i.e., in soil that is transported from the field by erosion (Bienes et al., 2010). 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 C 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 occurs 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 under erosion processes.

The aim of the STS mission was to investigate the effect of different soil management in vineyards on soil organic matter content and erosion losses, comparing two Mediterranean regions (Italy and Spain). The study attempted to answer three questions with respect to vineyards located on hillsides in the the semi-arid environment of the Mediterranean region: i) Is increasing the SOC always desiderable?; ii) Can the SOC stock be increased under AEM without resulting in high C loss due to erosion? and iii) Is the C threshold measurable?

### 1.1 The C 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 (Jachinte and Lal, 2001). Among these pathways, the first is most important, i.e., 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 in different regions, Jachinte and Lal (2001) found that erosion-induced $CO_2$ emission rates ranged from 6 to 52 g C $m^{-2}$ $yr^{-1}$. Similarly, 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 ($Closs_{sediment}$) can be described by the following linear relationship (Starr et al., 2000):

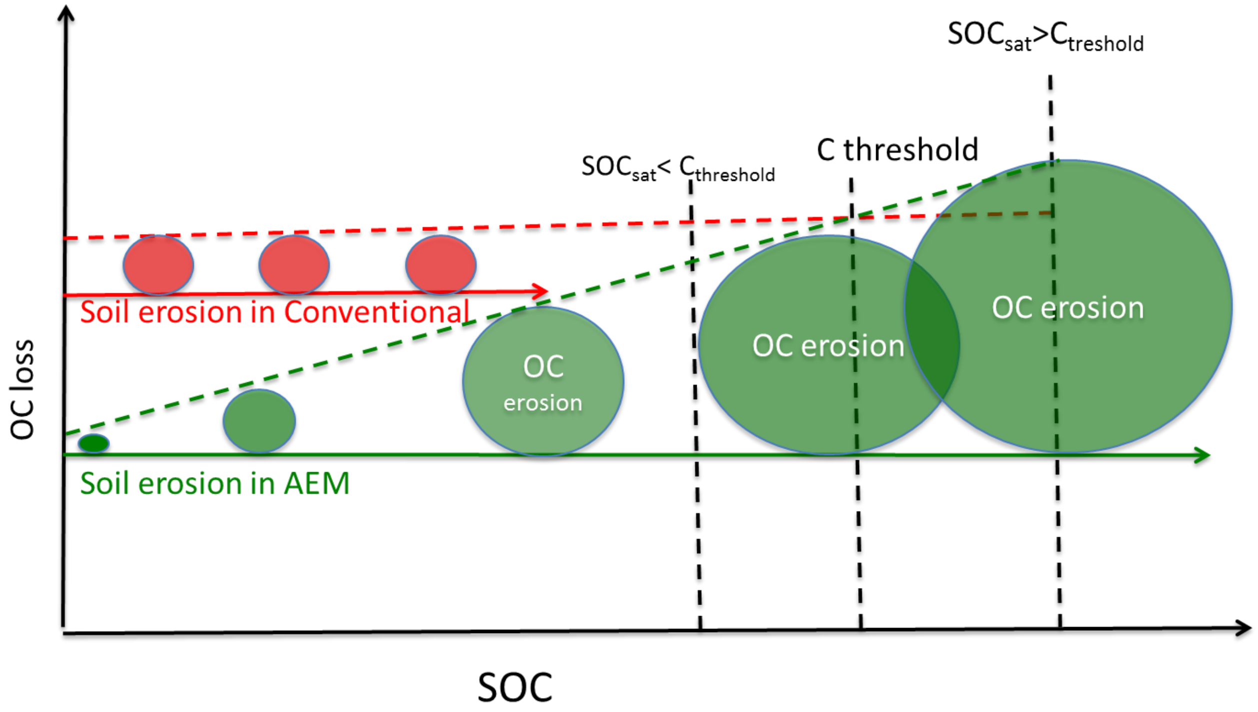
$$Closs_{sediment} = SE * SOC * E_r \qquad \text{(Eq. 1)}$$

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 equation 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 covercrop) reduces erosion relative to conventional tillage (CT) because the non-vine vegetation reduces the impact of rain drops on the soil, 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 (Figure 1). Considering that possibility and as noted earlier, we define the SOC threshold as that 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 ($Closs_{CT}$) (Figure 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 C threshold will correspond to a $C_{AEM}$ value; if the soil C saturation level is lower than the C threshold, the C threshold will be equivalent to the C saturation value. We indicated C saturation level (or C steady state) the maximum level of C accumulated in a certain soil, despite the C input increasing.

*Figure 1. Conceptual diagram of dynamical change in C loss in sloping area with different soil management. 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 dotted red line (OC loss under CT) and dotted green line (OC loss under AEM) is described as C threshold in sloping area.*




Considering constant for both soil managements the environmental conditions, the SOC threshold is calculated with the following equations (2 and 3):

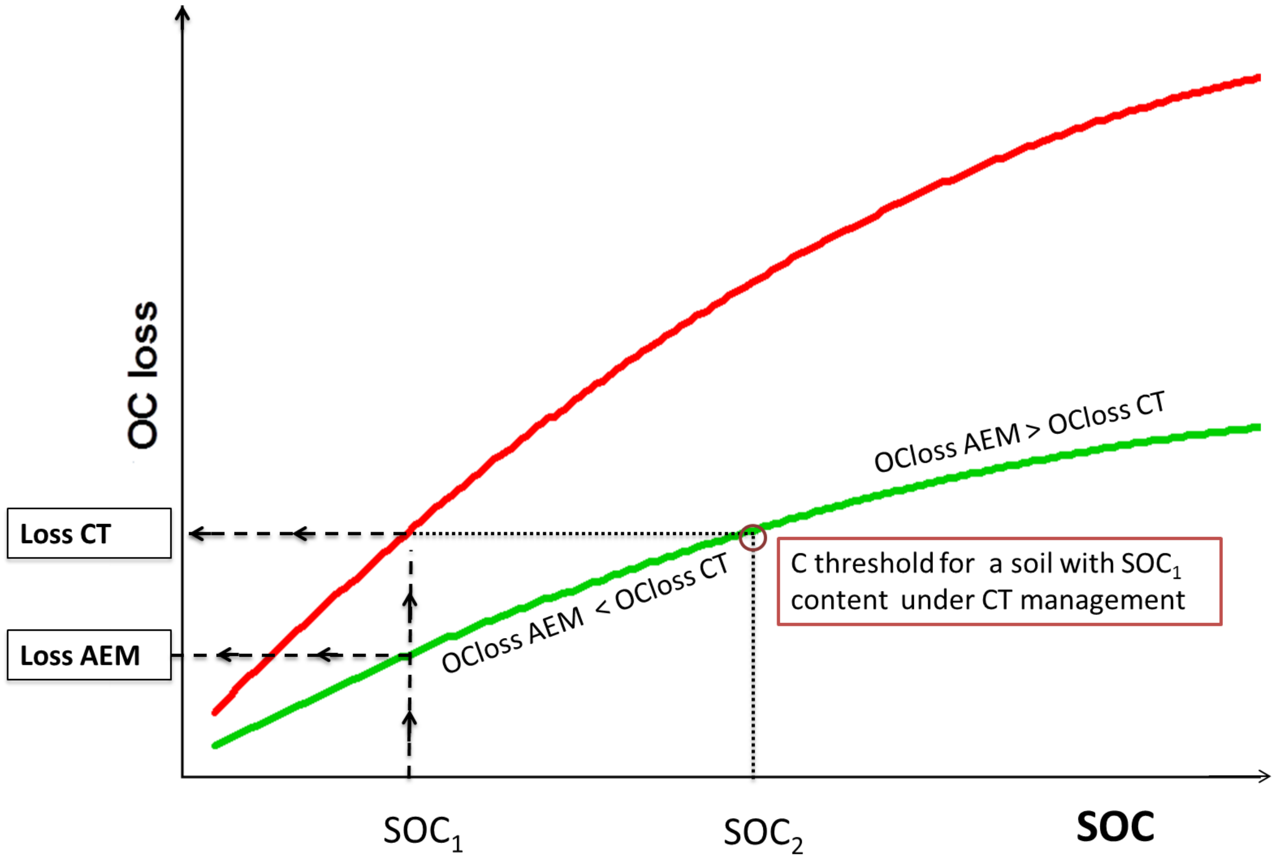
$$Closs_{AEM} = Closs_{CT} \quad \text{(Eq. 2)}$$

and according to equation 1, it follows that:

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

Based on equation 3, the C losses relative to SOC content with AEM and CT management are presented in Figure 2 (green and red lines). Considering the same value of SOC ($C_1$) for CT and AEM, Closs will be higher for CT ($Closs_{CT}$) than AEM ($Closs_{AEM}$), given that the erosion rate SE will be higher in CT than in AEM because of differences in soil cover.

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




If no disturbance occurs, the SOC content in CT can be considered constant over many years. Given a value of SOC under CT ($SOC_1$) with $Closs_{CT}$, the $Closs_{AEM}$ will be reached with a SOC content equal to $SOC_2$. Values higher to $SOC_2$ will determine a higher Closs in AEM than in CT. The $SOC_2$ value can, therefore, be considered the C threshold for a given soil that, if managed under CT, will contain a steady state level of SOC equal to $SOC_1$ (Figure 2).

## 2. Materials and Methods

### 2.1 Study area and soil sampling

The study areas were located in southern Sicily (IT) and in Valencia province (SP). Vineyards in Sicily and in Valencia 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 vineyards involves annual cover cropping using legumes like faba bean (*Vicia faba*) and vetch (*Vicia sativa*); after the covercrops  are disked into the soil in spring, the vineyard is subjected to two shallow tillages.

In the study areas, 95 paired sites were chosen (10 paired sites in Valencia and 85 paired site in Sicily). The paired-site approach was used to compare SOC stocks after 5 or more 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.

The AEM applied in Sicilian paired sites was Cover crop soil management with Vicia Faba; the AEM applied in Valencia were Cover cropping with Vicia sativa and application of organic manure. Three soil samples were collected at 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), The analysis were carried out in the Department of Geography, Valencia University.

**2.2 SOC threshold calculation**

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

$$SE\ (Mgha^{-1}) = K * R * C * LS * P \qquad \text{(eq. 4)}$$

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 site was calculated based on texture, organic matter content, and permeability according to equations presented by Wishmeier and Smith (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).

The equation 3 was arranged as follows:

$$K_{AEM} * SOC_{AEM} = \frac{K_{CT} * SOC_{CT} * E_{rCT}}{E_{rAEM}} \qquad \text{(Eq. 5)}$$

as:

$$K = f(SOC_{AEM}), \qquad \text{(Eq. 6)}$$

follows:

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

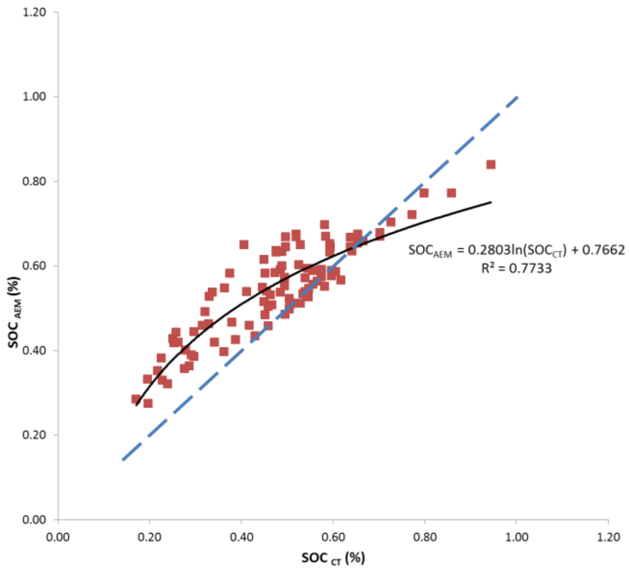
The mean and standard deviation of the SOC values were calculated for each plot.

## 3. Results and discussion

### 3.1 SOC as affected by CT and AEM soil management

After AEM management was initiated the C increase was moderate (Figure 3). Among the 95 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.

*Figure 3. Soil organic carbon (SOC%) in each paired site for the two soil managements. The dotted blu 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.*

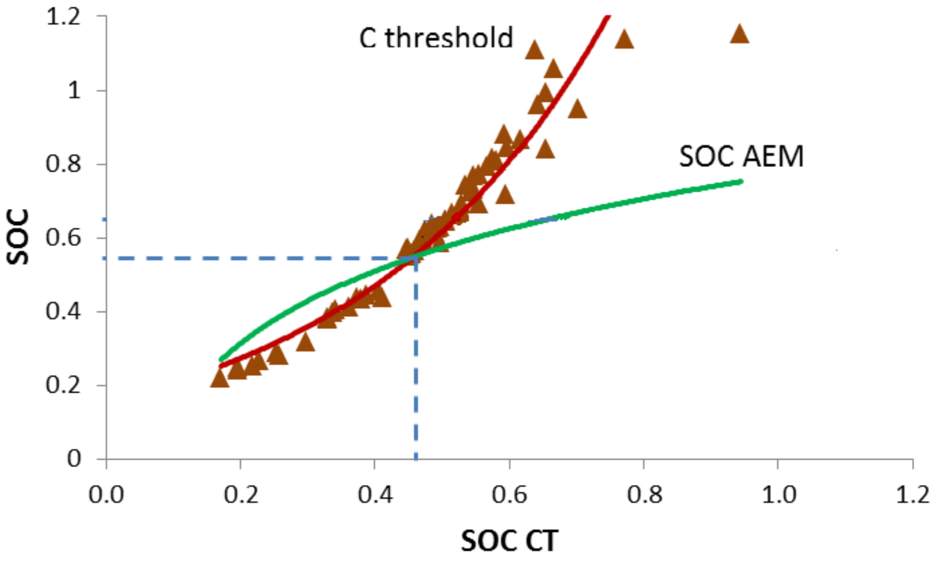



### 3.2 SOC threshold

The SOC threshold, which was calculated for each paired site according to equation 7, showed an exponential trend (Figure 4). 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 Closs increased with the silt content of soil (Perez-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. After AEM adoption, $SOC_{AEM}$ exceeded the SOC threshold in soils in which the CT plots had a 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 Closs 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 reach the SOC threshold.

*Figure 4. SOC threshold and measured SOC after AEM adoption*



## 4. Implications and 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 water erosion. Our results showed that in some cases (high C input through organic fertilization) 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; 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.

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. Knowledge about a soil's potential to sequester C or different scenario of AEM adoption is important for designing policy concerning vineyard soil management. This paper presents a method to evaluate the effects of AEM management to reduce erosion losses on both the increase in SOC and the risk of C loss. As consequence, this paper could provide a tool for payment diversification in relation to agro-ecosystem services provided by AEM management.

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