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The Impact of Soil-Improving Cropping Practices on Erosion Rates: A Stakeholder-Oriented Field Experiment Assessment

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Abstract: The risk of erosion is particularly high in Mediterranean areas, especially in areas that are subject to a not so effective agricultural management–or with some omissions–, land abandonment or wildfires. Soils on Crete are under imminent threat of desertification, characterized by loss of vegetation, water erosion, and subsequently, loss of soil. Several large-scale studies have estimated average soil erosion on the island between 6 and 8 Mg/ha/year, but more localized investigations assess soil losses one order of magnitude higher. An experiment initiated in 2017, under the framework of the SoilCare H2020 EU project, aimed to evaluate the effect of different management practices on the soil erosion. The experiment was set up in control versus treatment experimental design including different sets of treatments, targeting the most important cultivations on Crete (olive orchards, vineyards, fruit orchards). The minimum-to-no tillage practice was adopted as an erosion mitigation practice for the olive orchard study site, while for the vineyard site, the cover crop practice was used. For the fruit orchard field, the crop-type change procedure (orange to avocado) was used. The experiment demonstrated that soil-improving cropping techniques have an important impact on soil erosion, and as a result, on soil water conservation that is of primary importance, especially for the Mediterranean dry regions. The demonstration of the findings is of practical use to most stakeholders, especially those that live and work with the local land.

Keywords: soil erosion; soil-improving crop systems; sustainable land management; sustainable agriculture

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1. Introduction

Soil erosion is a primary biophysical process involving the detachment of soil particles from a given initial area and their transport and accumulation to a new depositional area [1]. It is considered one of the most severe natural threats worldwide, as it threatens soil fertility, water availability and crop productivity [2]. The risk of erosion is particularly high in Mediterranean areas, especially in areas that are subject to a not so effective agricultural management–or with some omissions–, land abandonment or wildfires [3].

Crete's Mediterranean soils are under imminent threat of desertification, characterized by loss of vegetation, water erosion, and subsequently, loss of soil. In particular, the serious impact of the expected climate change to the southern Mediterranean regions, together with the adoption of crop techniques by many olive groves' farmers that negatively affect the environment, such as intensive tillage, use of chemicals, burning of pruning branches in their fields, may lead to loss of ground's organic matter, putting the fields in possible drought hazard in the upcoming years [4,5]. Several studies have focused on the estimation of average soil erosion in the island. Most of the studies simulate erosion with the use of the revised universal soil loss equation (RUSLE) method. Kazamias et al. [6], for example, estimated average soil erosion rates for the Greek territory at 4.75 Mg ha^{-1} yr^{-1} and indicated that for over 12% of the Greek area higher ratings than 10 Mg ha^{-1} yr^{-1} are observed, mainly located at steep areas. Similar values are estimated for the Cyprus area (11.75 Mg ha^{-1} yr^{-1}) with October and November being the most erosive months [7]. Panagos et al. [8] estimated soil erosion rates between 6 and 8 Mg ha^{-1} yr^{-1} for the region of Crete and Kourgialas et al. [9] suggested ratings of an average 4.85 Mg ha^{-1} yr^{-1} for the western part of the island. Several other investigations assess soil losses as being orders of magnitude higher. Kouli et al. [10] provided an estimate of soil loss of up to 200 Mg ha^{-1} yr^{-1}, and Alexakis et al. [11] suggested that losses of more than 200 Mg ha^{-1} yr^{-1} were recorded for 2018. Polykretis et al. [12] assessed the intra-annual and inter-annual fluctuations, providing similar estimates. Furthermore, changes in rainfall patterns are foreseen to affect soil erosion in the area. Grillakis et al. [13] examined projected changes in erosivity for the island of Crete under three concentration pathways (RCP2.6, RCP4.5 and RCP8.5). Simulations suggest positive changes exceeding 30% for the 2021–2050 period, while for the far future, erosivity decreased with the increase in concentration, ranging from −10% to +30% on average, depending on the scenario and as a result of changes in extremes [14].

Despite the extensive literature devoted in the investigation of soil erosion at the regional scale, few studies focus on the local field scale, and in particular, at the major land use types and associated land management practiced. Olives are the most important crop grown on the island of Crete [15], covering 64% of the arable land and representing 86% of the tree plantations on the island. Despite the problem of phyloxera in the 1980s [16] and the Common Agricultural Policy (CAP) to reduce the area of vineyards, viticulture remains one of the most important production activities of Crete. Olive orchards and vineyards in Crete often suffer from extreme soil erosion by water due to farm slope and recent intensification of tillage practices [17–19]. There is a need to find practices that prevent soil erosion without reducing the profitability of both crops. Less tillage at the olive sites can improve soil health by reducing organic matter decline, keeping soil microbiology intact, and limiting compaction through less machine passes across fields, as well as reducing fuel use and related emissions [20]. In addition, the simplest and most natural way to prevent erosion in vineyards is through planting vegetation. Cover crops keep ground covered over storm events with high rain rates and winds, which can cause erosion [21,22]. Plants establish root systems which stabilize the soil and prevent erosion. Moreover, cover crops can reduce the need for fertilizer and supply organic nitrogen if leguminous [23,24].

Average erosion rates for orange groves on the island are estimated at 1 Mg ha^{-1} yr^{-1}, whereasthe average rates are assessed at 8 Mg ha^{-1} yr^{-1}, which is still above other cultivations. Moreover, in the Chania Prefecture of Crete, orange cultivation is a major crop, but due to severe market competition, producer prices have significantly dropped, leaving little or no profit. Recently, avocado plantations have been proposed as a potentially sustainable alternative over orange groves, with high profitability and increasing demand, but soil erosion for avocados has not been measured [25]. The cultivation is demonstrating to fit in warm seasons of Mediterranean regions [26].

The objectives of the present experimental study are: (i) to compare different tillage practices in olive orchards, as tillage is known to affect soil erosion rates; (ii) to test the use of a vetch cover crop in a vineyard compared to no vetch, with vetch being a nitrogen fixing cover crop; (iii) to compare the erosion rates as well as other soil quality parameters between a field that has remained an orange grove for 45 years and one that was converted to an avocado farm 20 years ago.

2. Materials and Methods

2.1. Study Site

The experiment was conducted on three real farm fields managed by farmers in three different areas of Chania, Crete, Greece. The first field is an olive orchard located at Biolea in Astrikas region, at an altitude of about 260 m and covers an area of about 3000 m^2 with a slope gradient of about 6%. The olive trees were planted in a dense of 90 trees per 1000 m^2. The field is 25 years old and had not been tilled for 7 years before the beginning of the project. The second field is a vineyard located in Alikampos region, in an area of about 3000 m^2 and an altitude of about 254 m. The slope gradient of the field is about 15%. The investment began in 2013. Since then, animal manure is the fertilizer applied every two years in the orchard, while moldboard ploughing at 20 cm depth is a standard farm operation. The field is also drip irrigated during the summer period. The third field is a fruit orchard (orange and avocado) located in Koufos region, in an altitude of about 86 m and covers an area of about 2000 m^2 with a slope gradient of around 10–15%. The orange trees were planted in 1988 and the conversion of part of the orange orchard to avocado orchard occurred in 1998. The Avocado trees' first plantation included 40 trees per 1000 m^2, whereas the orange trees' first plantation included 120 trees per 1000 m^2. The fruit orchards received ammonium sulphate and potassium fertilizers during the past 10 years, applied in the irrigation water during the summer period, whereas solid potassium nitrate is banded on the soil surface in the winter period. Every year, soil mulching with cut branches occurs in the form of wood chips. Manure is also applied every year on the avocado trees. Moldboard ploughing at 20 cm depth occurs every two years and glyphosate is banded on the soil surface every year for weed management. Finally, the field is drip irrigated according to the needs of each summer period. The topsoil of all sites has a clay loam texture according to the USDA classification system.

Each experimental site has a representative meteorological station. The closest meteorological station of the olive orchard field is Kolympari, whereas of the vineyards is Vrysses and of the fruit orchards is Alikianos. However, the time period of temperature, precipitation and evapotranspiration observations is not long. Vrysses started gauging in 2007, Alikianos in 2012, and Kolympari in 2016. Table 1 displays the yearly hydrometeorological records of the 2018–2020 period for the stations of interest.

Table 1. Overview of the yearly temperature, precipitation and ET0 for the experiments.

Station	Period/year	Tmax (°C)	Tmin (°C)	Precip (mm)	ET0 (mm)
Vrysses	2018	24	12	759	1304
Kolympari	2018	23	14	704	1129
Vrysses	2019	23	11	1867	1296
Kolympari	2019	23	14	1332	1137
Vrysses	2020	23	11	1454	1306
Kolympari	2020	23	14	667	1155
Alikianos	2020	23	13	1166	1220

Crete has a typical Mediterranean island environment with about 53% of the annual precipitation occurring in the winter, 23% during autumn and 20% during spring, while there is negligible rainfall during summer [27,28]. The average precipitation for a normal year on the island of Crete is approximately 934 mm, with a markedly non-uniform distribution, a reduction of almost 300 mm from the west to the east part of the island and a strong orographic effect. Noticeable are the high rainfall winters and the dry summers in the Chania Prefecture [14].

Regarding the hydrometeorological conditions during the years of the experiment, on 26 October 2017, as well as on 15 and 24 February 2019, Western Crete suffered excessive rainfall and flooding. The October 2017 event was a high-intensity and short-duration rain event, resulting in flash floods in the low-elevation agricultural and urban areas on the northern part of the Chania Prefecture. Persistent storm events in February 2019 resulted in flooding, extensive riverbank erosion, landslides and rocks throughout the road network of Chania Prefecture, as well as in the collapse of the 111-year-old historical Keritis bridge over Alikianos River. For the entire Chania region, 2018 was a dry year followed by an exceptionally wet 2019, mainly due to the record high precipitation accumulations of February (1202 mm/month for Askifou station, Chania), and a normal 2020.

As for relative mean climate conditions between the study sites during the course of the experiment, safe results cannot be extracted due to the distance of the meteorological stations from the sites, differences in altitude and microclimate. In general, the vineyard site located in Alikampos receives the highest amount of mean annual rainfall (~1400 mm) and has the lowest mean temperature (due to lower minimum temperatures at place). The fruit orchard (orange and avocado) is located in probably the most fertile and intensively cultivated valley of Chania prefecture with an average precipitation of about 1200 mm/year, while the olive orchard site located in Astrikas receives less precipitation and has higher mean annual temperature, despite the higher altitude.

2.2. Experimental Setup

The beginning of the experiment was in 2017, involving a control versus treatment (soil-improving cropping system, SICS) experimental design. At the olive orchard field, two treatments about soil cultivation were tested. A normally tilled area, which served as the control plot and tilled twice within SoilCare project (November 2017 and May 2019), was compared with the no-tilled one, which was the SICS plot. The tillage method was moldboard ploughing at 20 cm depth. Two olive varieties were located in the experimental organic farm of 0.29 ha, *Olea europaea* and *Koroneiki*. At the vineyard site, the experiment compared a vetch (*Vicia faba*) cover crop plot with one without a vetch cover crop. The plot with no vetch served as the control area and the other plot, which was tilled and seeded with vetch, served as the SICS area. The grape variety was *Vitis vinifera* and the plots were located on a corporate organic farm of 0.46 ha. All the farms were fully operated and managed by the farmers, and because of practical management issues, no replicate plots could be designed. At the fruit orchard field, the experiment compared an orange orchard area, served as the control plot, with a rotation crop area of avocado trees, served as the treatment (SICS). The orange orchard variety was *Citrus × sinensis*, whereas the crop switch variety was *Persea Americana*, and the plots were located on a family conventional farm of 0.5 ha.

Soil loss rate assessments of both the olive orchards and vineyards' fields were undertaken through cross sections' measurements. The total soil loss is estimated by the erosion/deposition (ER) equation:

$$ER = \frac{VOL \times BD}{TA} \quad (1)$$

where *VOL* is the volume (m^3), *BD* is the bulk density (kg/m^3), and *TA* is the total effective area (m^2).

In the olive orchard site, the soil loss rate monitoring occurred from November 2018 to June 2021 (32 months) with two cross sections, one per plot, having lengths of 5 and 5.8 m for the SICS and control plot, respectively. In the vineyard site, soil loss rate was monitored from January 2019 to June 2021 (2.5 years) through six cross sections, three per plot, of lengths ranging from 1.64 to 2.2 m. At the fruit orchards, soil loss rate assessments were undertaken through soil pins' measurements. The soil loss rate monitoring occurred from May 2018 to June 2021 (37 months), with three to four soil pins per plot, placed per 0.5 m. Figure 1 displays the three farm fields in which experiments were conducted.

Figure 1. (**a**) Tilled plot (up) and non-tilled plot (down) at the olive orchard site, (**b**) positions of the cross sections (CS) in which soil erosion measurements were performed at the vineyard site, and (**c**) oranges and avocado trees at the fruit orchard field.

Biophysical measurements were also performed both in the control and SICS plots regarding soil texture [29], saturated hydraulic conductivity [30,31], water stable aggregates [32], bulk density [33], mineral nitrogen [34,35], available phosphorous [36], exchangeable potassium, sodium and magnesium [37], soil organic carbon [38], soil pH [39], soil electrical conductivity [40] and earthworm count [41] in the three experimental fields at the end of October for the years 2019 and 2020.

Soil texture was measured with the Bouyoucos hydrometer method [42]. Saturated hydraulic conductivity was measured with the Beerkan method [43] but not in fully dry conditions as shown in Figure 2a. Soil aggregate stability was counted by sampling about 100 g of three to four soil aggregates from the topsoil per plot, which was air-dried for 20 days and thereafter immersed in water on a mesh of 0.4 cm diameter. The aggregates were observed for a few minutes for slaking [44]. The steps followed to perform the measurement are indicated in Figure 3. Bulk density was measured in a laboratory as an indicator of soil compaction. For its assessment, three soil samples from topsoil (10–20 cm) and three soil samples from subsoil (40–50 cm) per experimental plot (control and SICS) were taken with a metal ring with known volume of 246.42 cm^3. Figure 2b displays the collection of a soil sample for the bulk density measurement. The following procedure concerned, first of all, the weighting of an ovenproof container in which each one soil sample per time was placed on; the soil was dried for one night in a conventional oven at 105 °C and then weighted. The difference between the two weight measurements divided by the soil volume gave the calculation of the bulk density [44]. A mixed soil sample was collected from each experimental plot, with soil from under ten trees using a Z-shape sampling methodology in order to estimate mineral nitrogen, available phosphorous, exchangeable potassium, sodium and magnesium, soil organic carbon (SOC), soil pH, and soil electrical conductivity. All samples collected were air-dried, grounded to pass a 2-mm sieve, and analyzed for selected chemical properties. Concerning the available forms of the nutrients, NO_3^--N was extracted with 1M KCl and determined with spectrophotometry at wavelengths 210 and 270 nm. Olsen P was extracted by 0.5M $NaHCO_3$ with pH 8.5 and was quantitatively determined with molybdenum blue-ascorbic acid method [36] by using Vis-UV spectrophotometry. Exchangeable cations K^+, Na^+, and Mg^{2+} were extracted with 1M ammonium acetate, having pH 7 [45], and were analyzed by the inductively coupled plasma method ICP-OES. pH was measured in a soil/water suspension at a 1:2 ratio; SOC was determined with the wet oxidation method [38], whereas the electrical conductivity was measured in the saturation paste extract [46]. Earthworm density was evaluated as an indicator of the biological health and condition of the soil per experimental plot. The procedure followed was the mixing of 2 L of water with 20 g of mustard seed, the pouring of the half mixed on a 25 cm × 25 cm sample plot where vegetation and leaves were removed, and the observation of worms that came to surface over a period of 5 min, and then the pouring of the remaining mix and the waiting of another 5 min to gather worms that came to the surface. Figure 2c,d indicate the procedure followed for earthworm counting in the olive and vineyard field respectively.

Figure 2. (**a**) Infiltration rate experiment, (**b**) soil sampling for bulk density measurement, (**c**) pouring mix of water and mustard for earthworm test in Astrikas, and (**d**) worms coming out to surface after the pouring of the mix in Alikambos.

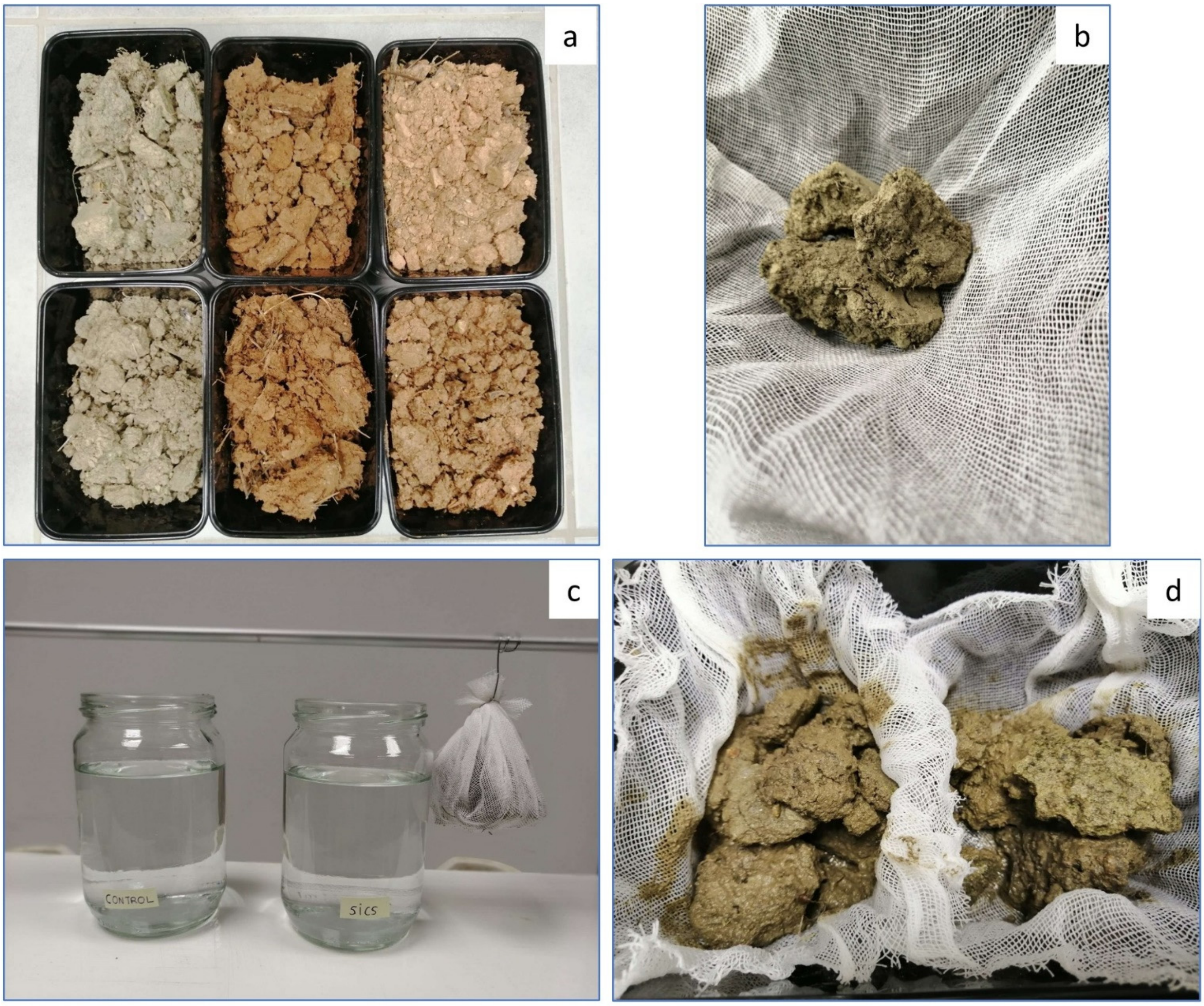

Figure 3. (**a**) Soil aggregates from both plots (control and SICS) of the three study sites: air-drying before slaking test, (**b**) 100 g of three aggregates of the Astrikas field to be used for the slaking test, (**c**) soil aggregates into the mesh before being immersed to water, and (**d**) soil aggregates after the immerse to water.

2.3. Stakeholder Engagement

Throughout the SoilCare project, two stakeholders' workshops and two stakeholders' meetings were held, either with physical presence or virtually. The first workshop occurred on 21 March 2017 at the Technical Chamber of Crete (West Crete Chamber), where 12 persons (4 female and 8 male) participated. The main participants were farmers, agronomists and researchers. The stakeholders introduced themselves and justified their interest in the SoilCare project objectives. They were asked to place themselves on a stakeholder matrix that determined the scale of motivation and perceived influence, graded from low to high. The stakeholders also participated and contributed their experience and knowledge on drivers, barriers and solutions for the soil erosion threat in their area. During the workshop, commonly accepted and applied practices to combat soil erosion, along with their benefits and drawbacks, were discussed for further evaluation and potential outspread to all farmers. The stakeholders were also asked to rank, in a scale from 1 to 6, suggested ways to receive information about SoilCare during the lifetime of the project, as well as the display ways they would receive information regarding new SoilCare practices. The questionnaire they had to fill also concerned their preference on dissemination manners of information and advice of farming practices being used in SoilCare, their three main questions that they would like to be answered when evaluating whether to apply a new practice, as well as the way they would normally find out about new farming practices, beyond the project.

A meeting was held in March 2018 on the premises of Technical University of Crete (TUC), which was attended by 6 people (2 women and 4 men). All the stakeholders were updated about the progress of the field experiments related to soil loss monitoring in the three agricultural fields and the installation of six sediment fences/traps for collecting deposited soil at all the study sites. The stakeholders were asked to evaluate the results of monitoring and soil loss collection thus far. Through a constructive discussion between stakeholders and researchers, it was agreed that the research should focus more on monitoring of soil erosion/deposition implementing additional approaches. In particular, among the following actions of the researchers, there would be the installation of triangular or square grid for monitoring sheet erosion, monitoring of soil roughness with means of images (stereopairs), multi-temporal monitoring and recording of rills in the study areas, as well as correlation of soil organic matter and spectral data (field spectroradiometric measurements) in terms of soil erodibility at a farm and watershed scales.

A research activity was afterward held within the period from April to June 2019 in Chania, which concerned the individual interviewing of 4 stakeholders/farmers (4 men) since it was not possible for them to be gathered in a group. Two of them were involved in the olive orchard experiment, one in the vineyard experiment, and one in the avocado/orange experiment. Toward the specific research activity, the stakeholders had to describe the expected benefits and impacts of the SICS being tested in their field. They also had to identify and describe the key barriers and enablers to SICS adoption. The factors evaluated were economic (farm and market) conditions, biophysical conditions (climate and geomorphology), technical barriers, knowledge and information barrier, and sociocultural factors, as well as institutional or policy regulations. Moreover, the stakeholders were asked to identify and assess feasibility of actions to promote SICS adoption at national and/or (sub)regional level by ranking the enabler and barrier factors from not so important to very important. In addition, they were requested to point out actions that would remove barriers and support enablers as well.

The final stakeholder workshop occurred via online meetings of small groups during various dates in February and March 2021 due to the COVID-19 pandemic restrictions in place. A total of 18 persons (6 female and 12 male) participated and discussed project findings. The main groups were farmers, researchers and agronomists. After the end of the online presentations, the participants, both men and women, and especially the farmers, raised useful questions. Indicatively, the olive groves' farmers wanted clarifications regarding tillage avoidance, especially in the dry season. The vineyard farmers showed particular interest in the application of the experiments. The orange cultivators were interested in understanding the way of further improving the biological health and condition of soil on avocado trees. An important question raised was whether an avocado market will exist for the trees currently planted which will be placed into production in five years. Afterward, the attendees validated whether the project findings were plausible and/or consistent with their understanding. They also identified the benefits that they gained from SoilCare already, as well as the ones that they found important for the future from the project findings. The stakeholders were requested as well to have an active role and state the way they can disseminate the project findings to more people who can benefit from them. The engagement of the stakeholders continued as they were asked to report the way that they would like to be supported in using or implementing project/research findings. Toward the end of the workshop, the attendees mentioned what impressed them most and how to implement what they learned from the workshop.

3. Results

3.1. Impacts on Soil Erosion

3.1.1. Olive Orchard Site

Concerning the sediment fences, although part of the study area was tilled, minimum difference was evident in the collected deposited soil between tilled and no-tilled area. This was considered as a common phenomenon as only few-deposited soil may be collected during winter when it rains more often, due to the presence of naturally grown winter cover crops retaining rainwater. Nevertheless, intensified tillage, which occurred twice in 18 months, contributed to increased soil erosion, as visually observed by the exposed rooting system. Apart from tillage, irrigation also increased soil erosion with the irrigated trees showing shallow roots accompanied with topsoil erosion. Regarding the cross-sectional soil loss measurements, results showed that the no-till treatment had a considerable impact on soil erosion rates. Soil loss rate monitoring revealed that the application of no-till treatment reduced mean soil erosion by over 14%, roughly from 3.3 to 2.9 Mg/ha during the 2.5 years experiment (November 2018 to June 2021).

3.1.2. Vineyard Site

Extreme storm events occurred on 15 February 2019 and 24 February 2019. The nearby rain station recorded the exceptional accumulation of 726.2 mm during this period. These events created rills in the examined field. In the vetch plot, the rills were shorter compared to the no vetch plot when compared visually. The application of the vetch treatment had a direct impact on soil erosion over the 2.5-year monitoring period (January 2019 to June 2021). Soil loss rate monitoring revealed that the vetch coverage reduced mean soil erosion by over 12% (roughly from 3.4 Mg/ha in the no vetch plot to 3 Mg/ha in the vetch plot) during the 2.5 years experiment.

3.1.3. Fruit Orchard Field

An extreme rainfall event occurred on 26 October 2017, leading to more than 2 kg of soil trapped in the sediment fences of 3 m^2 area, corresponding to about 7 Mg/ha. In the rest of the monitored period, the sediment traps did not collect considerable amounts of soil after events of light rain. Further extreme precipitation events, which caused severe flooding in the wider area, occurred in February 2019, triggering further erosion in the field. Field measurements showed that the crop switch to avocado trees significantly reduced the mean soil erosion compared to the orange orchards (control) over 3 years of monitoring (May 2018 to June 2021). Soil loss rate monitoring revealed that the avocado conversion caused over 34% reduce in mean soil erosion, roughly from 4.6 to 3 Mg/ha, during the 3-year experiment.

A one-way ANOVA was performed to compare the effect of the different treatments on the erosion rates, with 90% CI. The analysis revealed that there was a statistically significant difference in the erosion rates between the avocado and orange treatments ($p = 0.096$) (Figure 4iii) but not for the other treatments ($p = 0.745$ for the olive orchard, $p = 0.561$ for the vineyard). Figure 4i,ii indicate the mean soil erosion at the control and SICS plot of the olive orchard and vineyard site respectively after 2.5-year of monitoring through cross sections.

3.2. Impacts on Soil Properties

3.2.1. Olive Orchard Site

Topsoil bulk density was slightly higher in the no-till plot. Bottom soil bulk density was found at the same levels in both plots. Exchangeable magnesium had an increasing trend in both plots from 2018 to 2020. Mineral nitrogen and available phosphorus concentrations were lower in the no-till plots, both in 2019 and 2020. The soil organic carbon rate had an increasing trend in both plots from 2018 to 2020, and was slightly higher at the last year, which was probably due to the animal manure application. The crop yield was the same at both plots (till and no-till) and was increased in 2020 compared to the years

2018 and 2019. Earthworms' density per m^2, which can be used as a sensitive indicator to management changes were substantially higher in the non-tilled plot compared to the tilled one in the 2020 measurement, indicating better soil health and condition. Weed infestation was slightly higher (10%) in the non-tilled plot compared to the tilled one, which cannot be assumed as a considerable high hazard.

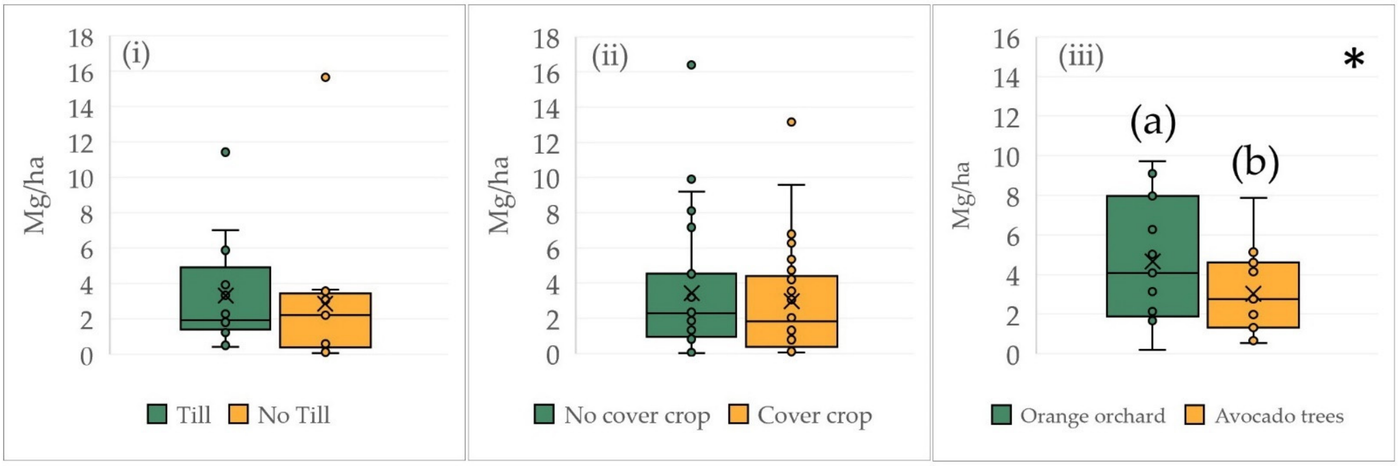

Figure 4. Mean soil erosion (Mg/ha) in (**i**) tilled and non-tilled plot at the olive orchard site during the 2.5-year of monitoring, (**ii**) no vetch and vetch plot at the vineyard site during the 2.5-year of monitoring, and (**iii**) orange and avocado plot at the fruit orchard field during the 3-year monitoring (* denotes significant differences at a 90% CI level).

3.2.2. Vineyard Site

By the end of 2020, top- and bottom soil bulk densities of the vetch plot were lower compared to the no vetch plot, indicating good soil functioning, improved water and solute movement as well as soil aeration. A soil aggregate stability test resulted in good soil stability and resistance to erosion for both plots; however, for the vetch applied plot, slaking effect was slightly less observed, indicating better structure maintenance. The soil organic carbon did not follow a specific trend; it was relatively satisfactory around 4% in both plots (control and SICS) from 2018 to 2020. The crop yield was the same at both plots (control and SICS), having a slightly decreasing trend during the 3-year monitoring. Earthworms per m^2, which is a soil health indicator, were considerably higher in the vineyard with the cover crop applied. The percentage of weed infestation was 20% less in the vineyard with the cover crop.

3.2.3. Fruit Orchard Field

The soil organic carbon rate was higher in the avocado trees compared to the orange orchards. The saturated hydraulic conductivity was considerably higher in the avocado trees plot compared to the orange trees plot, in the 2020 measurement. The exchangeable magnesium was also higher in the avocado trees compared to the orange orchards during the 3-year monitoring. The level of weed infestation was 10% less in the avocado field compared to the orange trees field. Electric conductivity values indicated high salinity levels in both plots, while higher values were observed for avocado trees.

Due to the lack of replicates, there was no efficient way to place error bars on the graphical values of soil properties. Nevertheless, the repetition of measurements every year demonstrated an important variation in properties′ values, as shown in Figure 5 regarding the 2.5-year of monitoring of the olive orchard site, Figure 6 concerning the 2.5-year of monitoring of the vineyard site, and Figure 7, which concerned the soil properties after 3-year monitoring of the fruit orchard field.

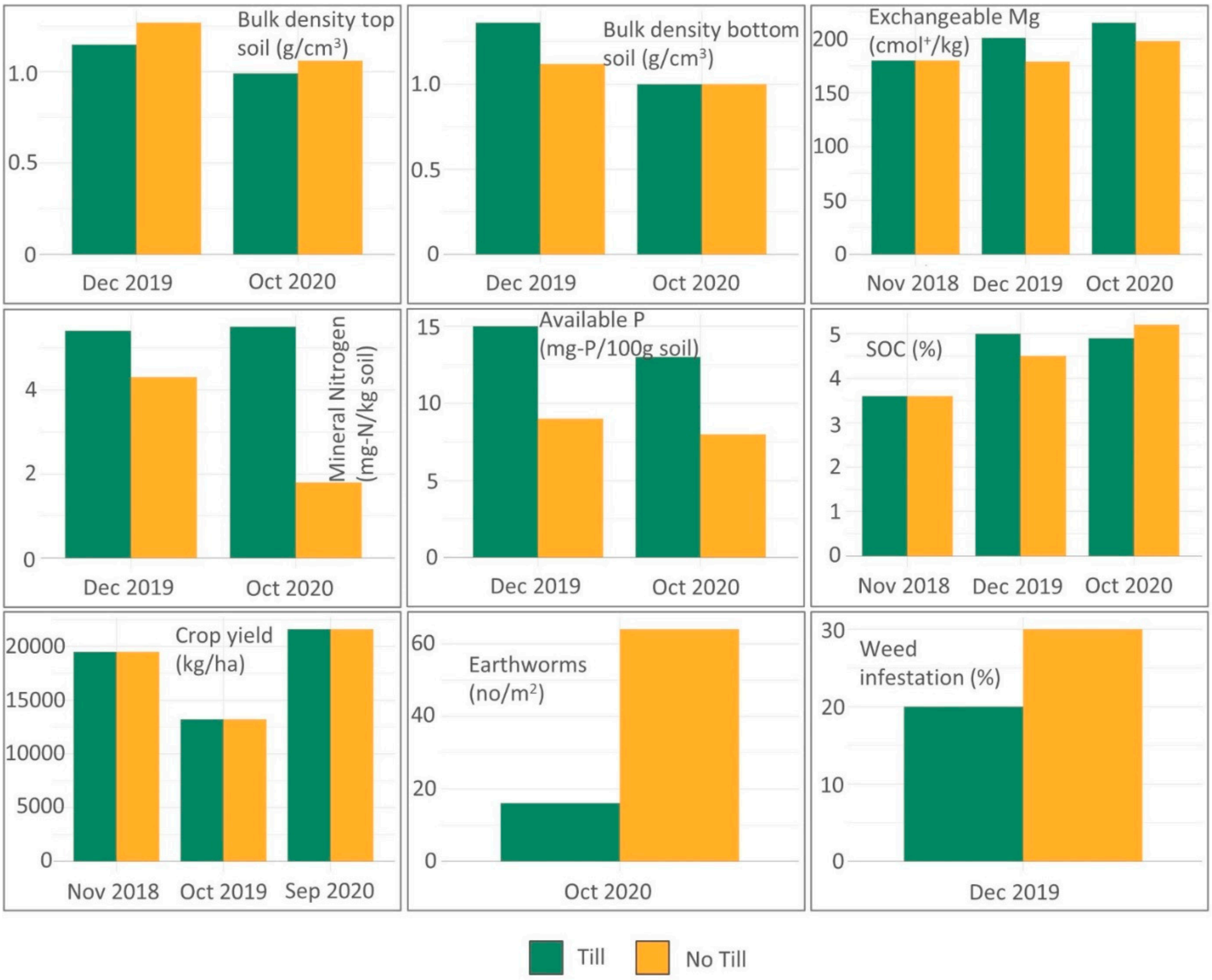

Figure 5. Soil properties in tilled and non-tilled plot at the olive orchard site during the 2.5-year monitoring.

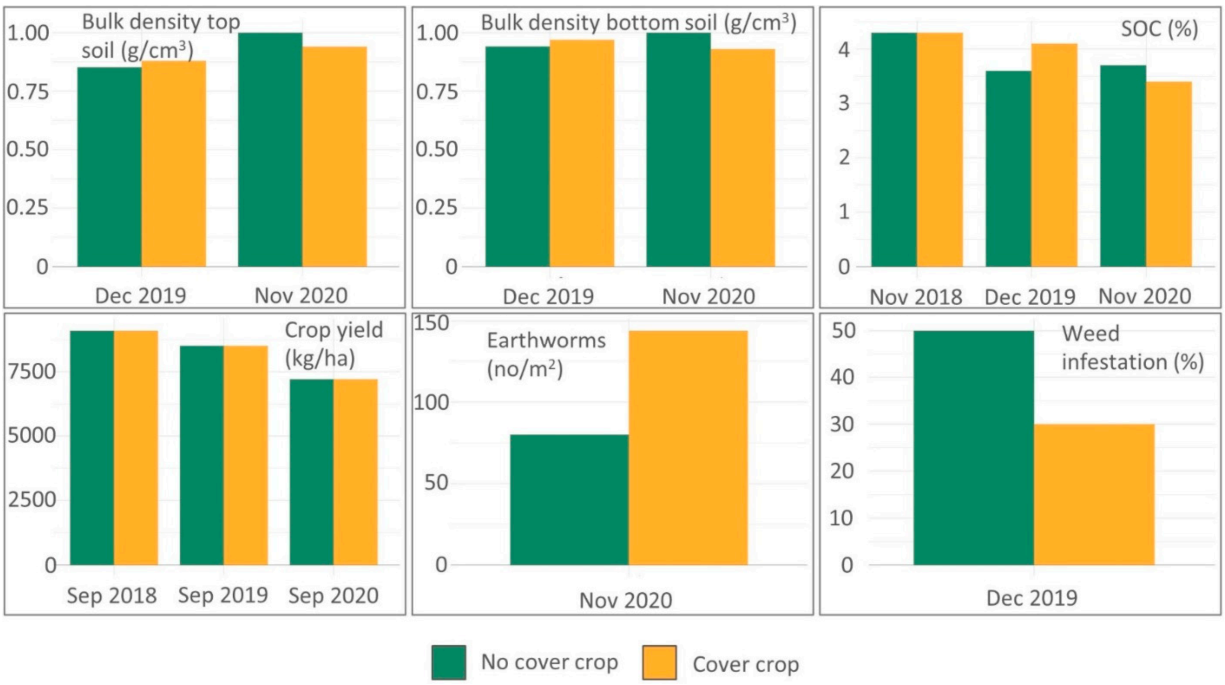

Figure 6. Soil properties in no vetch and vetch plot at the vineyard site during the 2.5-year monitoring.

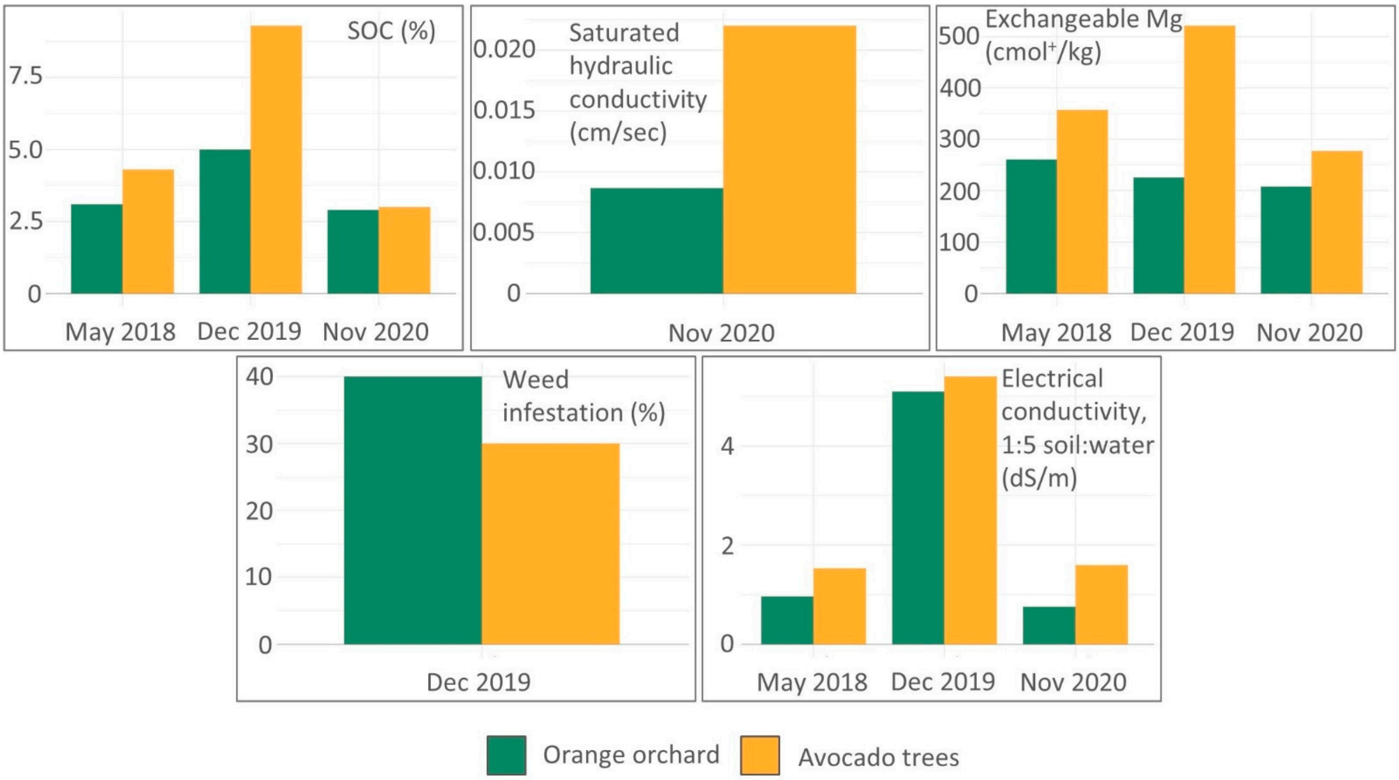

Figure 7. Soil properties in orange and avocado plot at the fruit orchard field during the 3-year monitoring.

3.3. Assessment of Stakeholder Engagement

3.3.1. First Stakeholder Workshop (21 March 2017)

Local stakeholders underlined that soil erosion mainly depends on geomorphology (slope), soil type, vegetation cover, climate, socio-economic and policy drivers, including human activities (land management, soil conservation techniques). They punctuated that soil erosion causes soil infertility, resulting in reduced production and thus income. Land users and agronomists showed the effects and the indicators of increased soil erosion on their cultivations, such as exposed tree roots, rills, reduced soil organic matter, soil pillars. They also seemed aware of the functions and services offered by the soil, as well as the impact of losing them. A few of the stakeholders perceived the soil functions and services as were presented in the meeting, but with high uncertainty on whether the knowledge will be consolidated. However, the meeting presentation was essential to discuss limits and effects of soil erosion before beginning a meaningful conversation at the local scale. The discussion with the stakeholders highlighted knowledge gaps of the interested parts regarding the extent that the erosion affects the performance and quality of production, the extent that different cultivation practices within the same crop or a total crop change affect the rate of soil erosion, and the most promising erosion mitigation approaches and technologies as well. Major barriers in adopting land management practices include the local administration lack of partaking in decision making, yet can implement and control what is already decided; agronomists perceive lack of interest of farmers (typically those with lower education level), including in regular testing of soil quality of their fields, being reactive rather than proactive; farmers' cooperatives often realize that competitive farmers are noncommitted to the cooperatives' objectives, whereas outsiders perceive cooperatives as less sustainable and profit oriented, or simply disagree with how resources are allocated; there is lack of financial motives (or motive awareness) for stakeholders; educational institutions lack the legislative freedom and means to interact with stakeholders for pilot/prototype practices for soil and land management. The stakeholders considered that government, local municipalities and individual farmers were responsible for providing solutions.

3.3.2. Research Activity (April to June 2019)

Based on the evaluation of the questionnaires, the olive farmers stated that the money saved from the no tillage practice is counterbalanced by the weed spraying costs or the time of cutting them off. The climate of Crete acts as an enabler for olives, whereas steep slopes, stones and rocks may significantly affect the crop. Drought may further raise the rooting system of the crop higher, affecting mostly the tilled plots. The vineyard farmer expected the yield to be increased through the cover crop. However, because of no directly visible benefits, the farmer, although willing to adopt the practice, stated the need for long-term experiments such that the benefits are proven and quantified. Yet, the presence of different crop within the vineyard competes with the soil structure in dry years. One farmer also noted that there is sufficient access to knowledge and information, but there is difficulty in convincing to test new alternative cultivation methods; it is preferable to recognize the benefits from other farmers and then adopt the new techniques. The avocado yield is expected to be profitable after the fifth year of the crop change, since the investment costs of the crop change process are high. However, there is a high interest for this investment since the climate conditions on Crete seem identical for the avocado crop. In addition, the avocado demand from European markets is expected to increase. The farmer asked for additional knowledge and advice from an experienced agronomist and identically visiting of demonstration sites.

The farmers claimed the need for guidance and advisory services of great expertise on soil data, soil analysis, fertilizers′ use, as well as extra skills to the specific SICS practices to remove barriers. They also indicated the necessity for financial support and incentives to adopt SICS practices. In addition, they suggested that the organization of workshops could support enablers with successful studies and practical applications that would emphasize the pros and cons of the proposed SICS. All farmers agreed that other farmers with experience in the specific SICS practices can provide important information to them. Social networks and videos can also help farmers adopt new techniques. New cultivation practices according to EU regulations can also be promoted from the State through seminars and programs.

3.3.3. Final Stakeholder Workshop (February and March 2021)

After the end of the online presentations, the soil specialists/consultants and the researchers had well understood the project results in the three fields of its application. The farmers generally found the presentations helpful in understanding the conceptualization of the problems faced in the three field studies, as well as the results obtained. They found the vetch cover crop easy to be applied, and the no-tillage practice feasible. Several of the orange cultivators realized that switching crops to avocados would bring them a great financial profit in long-term, while at the same time soil erosion would be reduced in their fields.

Regarding the benefits gained from SoilCare thus far, all the farmers stated that they gained better knowledge of their fields and the soil properties and functions as well as of the soil erosion's negative impacts and the way these can be avoided. The consultants noted the necessity to inform farmers of soil improving techniques, as well as the requirement for proper training in applying these techniques correctly. Concerning the benefits of the project findings for the future, farmers were willing to apply the proposed SICS practices to new sites or to the rest of the parts of their fields already tested. Several were interested in examining the tests which concerned the soil properties. The consultants were motivated to use the results and present them in workshops and other organized events aimed at farmers. Certain researchers were interested in monitoring the study fields for another 2–3 years, with the agreement of the farm owners, to examine if soil erosion continued to decrease in the SICS plot and at what rate.

About the dissemination of the project findings to more people who can benefit, the farmers suggested that they may share the results with other farmers either through the cooperative or through discussion with nearby growers. Another suggestion was the co-organization of events with local organizations, municipalities, or farmer cooperatives at the local level. Others proposed the local media. The consultants offered to organize training events for farmers in order to strengthen their skills on innovative soil improving mechanisms. Among the suggestions of the researchers for dissemination were informative brochures and workshops about the findings, in situ exhibitions of SoilCare case studies in Crete, video demonstration of SICS solutions, as well as guidance documents about new soil practices addressed both to farmers and agronomists.

As regards to the way the stakeholders would like to be supported in using or implementing project findings, the farmers seek subsidies for new machinery, seeds, including to avoid loans in the case of avocado investment. Several look for policy opportunities, guidelines for crop change, further development of the agricultural associations, and consulting services as well. The consultants seek additional seminars organized by government agencies on the way that they should train the farmers about the benefits of SICS. The researchers look for project funding for new SICS mechanisms and involvement of both farmers and stakeholders.

4. Discussion and Conclusions

Soil-improving cropping systems (SICS) application seems to play an alleviating role in soil loss processes, therefore it is recommended that farmers be properly informed about the tested practices within their fields.

No tillage practice is substantially beneficial for controlling soil erosion (over 14%), improving soil health and keeping good soil structure. Olive farmers should consider reducing tillage practices in olive orchards, control the tillage depth, and at the same time, limit its application especially during severe drought periods. In addition, the biological health and condition of the no-tilled plots were clearly better compared to the tilled ones. Water and solute movement as well as soil aeration were appropriate, including in the case of no-tillage. Weed management is a deterrent factor for this practice.

Vetch application is an inexpensive solution and is recommended to control soil erosion. The correct application of cover crop is a determinant in improving soil quality. Specifically, the biological health and condition of the vetch cover plots were clearly better compared to the no vetch. Furthermore, water and solute movement as well as soil aeration were slightly improved in the case of cover crop application.

Avocado farms, besides having significantly higher financial benefits, can also maintain a comparably overall good soil quality. However, the earthworm density experiment displayed that the biological health, and condition of the avocado plot were inferior to the orange tree plots. Conversely, water and solute movement as well as soil aeration were in good status for both cultivations, as identified by the top and bottom soil bulk density experiments. Moreover, the application of regular manuring resulted in higher values of SOC in the avocado field. The improvement of soil quality and structure through the increase of SOC as well as the control of soil erosion was additionally achieved by the organic material that accumulates from the intense foliage of avocados trees, resulting in a thick layer of organic material on the ground.

Different trends were found for erosion/deposition for the various cultivations and different treatment methods; however, the only statistically significant results were obtained for the orange to avocado treatment. In the olive tree cultivation, average erosion/deposition for the SICS plot with no tillage was 2.86 Mg/ha, ranging from 0.07 to 15.66 Mg/ha, depending on the observation periods. The control applied in this site was tillage twice in the period of study (November 2017 and May 2019). Tillage resulted to increased spread and mean erosion/deposition values of 3.33 Mg/ha (ranging from 0.43 to 11.42 Mg/ha). The application of crop cover treatment had a direct impact on mean and spread of soil erosion/deposition in the vineyard cultivation. The application of vetch treatment reduced mean erosion by 13% (reduced from 3.41 Mg/ha in the control to 2.98 Mg/ha in the SICS plot). A similar trend was found for the crop change experiment. Mean soil erosion/deposition reduced by over 34% (reduced from 4.66 Mg/ha in the orange to 3.04 Mg/ha in the avocado plot) by changing orange to avocado trees according to the measurements. The spread of the magnitude of these processes was also reduced. Comparing the three different experiments, lower values of soil erosion/deposition were obtained for olive orchards, and this may be due to the lower slope of the plot (~6%). Regarding vineyard plot, although the study site is located in an area with a slope of ~15%, the small sediment losses can be mainly attributed to the higher concentration of silt and clay and low sand content of the soil. The sandy soil (55.3% sand) of the orange and avocado plot may be the main reason of higher erosion/deposition values observed. An additional reason for not monitoring significant differences in the two experimental fields may also be the short-term application of the SICS treatments, whereas the conversion of orange to avocado happened already in 1998 and thus can be considered as a long-term experiment.

This experiment demonstrates that soil improving cropping techniques have a significant impact on soil erosion, and as a result, on soil water conservation, which is of primary importance, especially for the Mediterranean dry regions. As reported in other studies, tillage erosion is considered to be one of the most important processes of land degradation in cultivated areas. The effect of tillage in soil erosion was also recorded during the SoilCare experiment, including for the minimum tillage practice that was applied as a soil-improving cropping method. Results of the study also show that crop cover treatment (vetch) and crop type change have a substantial impact on soil erosion/deposition (12% to 34% lower, respectively). The proposed sustainable soil improving practices are already being applied in many parts of the region. In particular, the change in procedure from orange to avocado trees has been adopted by many farmers as a response to the reduced orange prices and the high income from avocado cultivation. These results highlight the crucial role of soil-improving cropping systems for sustainable land management.

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