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Regional Farmers' Perception and Societal Issues in Vineyards Affected by High Erosion Rates

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Abstract: We explore the current situation in a viticultural region in Eastern Spain from a holistic and multifaceted research approach, which allowed us to understand the biophysical conditions, economic cost, social impact, and perception of the farmers' community to the use of catch crops. A survey of the perception of the farmers, and an assessment of the biophysical impact of catch crops (CC) and tillage (C = Control plot) on soil organic matter, bulk density, infiltration capacity (single ring infiltrometer), and runoff generation and soil erosion (rainfall simulation experiments) was carried out. Two representative fields as study sites were selected in Les Alcusses valley, within Els Alforins wine production region. The results show that the use of CC increased soil organic matter, favored higher infiltration rates and runoff generation was delayed. Moreover, runoff rates and soil erosion were lowered. The perception of the farmers was mainly against the use of catch crops due to their view as it being 'dirty', their cost, and the loss of their reputation and respect by other farmers. Our survey proves that the farmers would accept the catch crops if a subsidy of 76.56 € ha^{-1} on average would be paid. Farmers see the use of a catch crop more as a benefit for the health of the Planet than for themselves. To achieve land degradation neutrality, education and dissemination programs should be developed to teach and inform the farmers of their key role in the proper management of vineyards.

Keywords: viticultural areas; catch crops; soil; sustainability; regional geographical approach; land management

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1. Introduction

Vineyards are well-known as bucolic landscapes that the scientific investigations show as a non-sustainable practice due to high soil erosion rates (in some areas higher than 10 Mg ha^{-1} yr^{-1} [1,2]) and degraded soils. The concept of "terroir" emerged to compile those environmental, societal, economic, historical, and geographical values [3,4]. Vineyards landscapes are a geological and geomorphological heritage [5,6], a reservoir of fauna and flora [7], a legacy of soils [8], and the vine-growers shaped the agrarian land throughout historical times [9]. However, vineyards today are not sustainable as a consequence of intense chemical agriculture based on bare soils that trigger erosion rates, biocides that damage the biodiversity, and the aging of the farmers' population that risk the farmers' replacement and succession [10,11]. To understand these issues, surveying farmers' and stakeholders' perception is key as other authors demonstrated in the Mediterranean belt [12,13] or developing countries [14,15]. A survey assesses in situ the "real" situation that rural inhabitants are facing daily, which will allow developing models at the regional scale.

A key factor that threatens the sustainability of the vineyards is the high erosion rates found in different regions of the world. The review conducted by Rodrigo Comino [16] as a world overview, and other local and regional approaches demonstrates that soil losses in vineyards are too high to maintain the requested soil quality to achieve sustainability [17–19]. In vineyards, there are difficulties regarding sustainability and soil contamination by biocides [20], chemical farming [21], negligible soil cover [22,23], abuse of herbicides [24], damages on soil fauna and microbiota [25]. The damage caused to the terroir as a consequence of several years of tillage [26] was accelerated as a consequence of the new powerful and heavy machinery that transformed the traditional agriculture landscapes [27,28]. The high erosion rates in vineyards have been researched as actual soil loss, soil redistribution, and as a tracer for connectivity of water and sediments [29].

Different strategies were developed to control high soil losses and preserve soil quality in vineyards [30]. The use of terraces is an old tradition over the world [31], and especially in the Mediterranean vineyards [32,33]; however, the mechanization of the agricultural land threatens the terraced landscapes in the Mediterranean. For example, we can find some representative examples such as Ramos et al. [34] researching the effect of drainage terraces, García-Diaz et al. [35] investigating the plant cover in vineyard inter-rows, or Schmidt et al. [36] considering the use of biochar. Additionally, there are other relevant advances such as those Pardini et al. [37] found with the use of cover crops, Besnard et al. [21] with the organic amendments, Vrsic et al. [38] with the use of different soil management systems, or Ramos and Martínez-Casasnovas [39] considering the use of cattle manure. However, the most efficient alternative strategy instead of tillage and herbicides is the use of catch crops, as they contribute to improving the soil quality, control soil losses, and benefit the fauna and flora [40,41].

The use of catch crops to reduce soil losses and increase soil fertility has been successfully applied in different crops such as olive orchards, beet, or hop gardens [42–44]. However, research databases on vineyards in other countries such as Portugal [45], Spain [46,47], Italy [48], France [49,50], or Germany [51] among other countries, do not show relevant information about the use of catch crops as an alternative management option to replace tillage or herbicides. One of the most interesting methods to assess the possible effectiveness of catch crops are the rainfall simulation experiments. The use of artificial rainfall allows controlling the environmental conditions of each experiment such as rainfall intensity, slope, roughness, and vegetation cover [52], enables an assessment of runoff initiation, and taking accurate samples of overland flow with a precise temporal resolution (intervals from 1 to 5 min) at the pedon scale (<1 m^2). Therefore, the main goals of this research are: (i) to conduct a biophysical approach (soil properties and runoff and erosion rates) to assess the impact of catch crops on soil erosion; (ii) to bring a regional societal and perception research approach to understand why the use of catch crops is not widespread in Mediterranean vineyards, such as the ones in Terres dels Alforins in Eastern Spain. We hypothesize that this study will shed light into how farmers and stakeholders could achieve land degradation neutrality. It is key to confirm if an education and dissemination program should be developed to teach and inform them of their key role in the proper management of vineyards.

2. Materials and Methods

2.1. Study Area

Within the Mediterranean viticulture area, we selected a region that is representative of the past, present, and future of vine production: the traditional viticulture region of Terres dels Alforins, in the south of Valencia province (Valencia, Eastern Spain; (Figure 1). This is a homogeneous region with three main municipalities: Moixent, Fontanars dels Alforins, and La Font de la Figuera. The experimental setup was located in Les Alcusses valley within the Moixent municipality, specifically in the Pago Casa Gran lighthouse farm managed by Carlos Laso. The wine production in this region is under a renewal process that brings tradition and innovation and shows how the vine production sector will evolve in the next decades. The climate at the Terres dels Alforins is typical of the Mediterranean characterized by a recurrent summer drought. The mean annual rainfall is 350 mm yr^{-1} and the average annual temperature is about 13.8 °C. The two plots selected to develop the research were selected in 2013 and a survey of the management was carried out for 4 years. In both plots, the soil is a Typic Xerofluvent [53] and they are located in the valley bottom where marls are the main parent material.

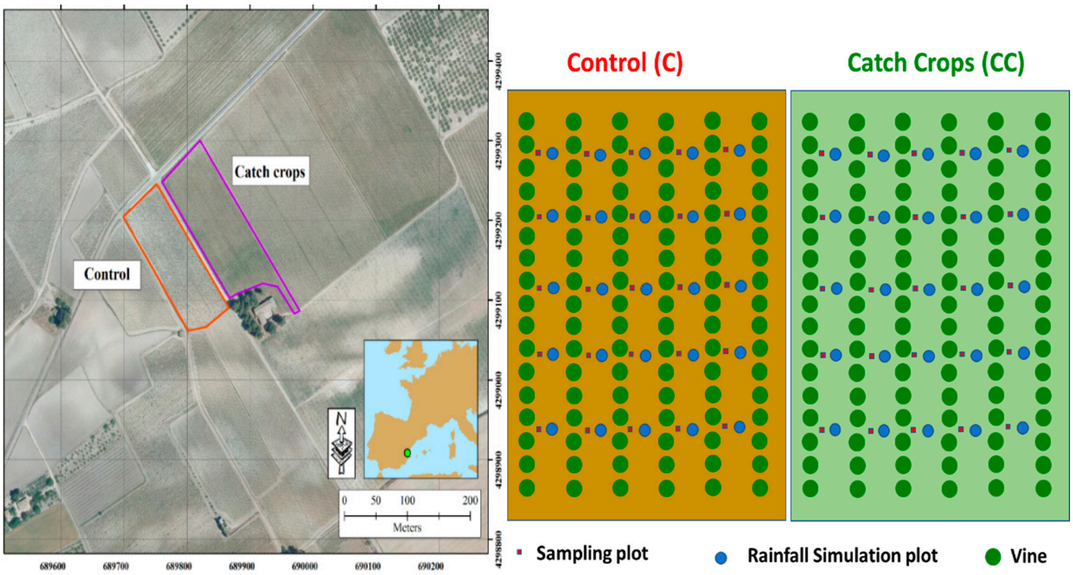

Figure 1. Study area location to the left and the sampling layout to the right for the control and catch crops plots.

We selected two paired study plots that are neighbors, but the farmers applied different soil management in July 2014. The catch crop (CC) site is the vineyard of the Pago Casa Gran winery and cultivated with the Riesling grape variety, under the organic farming rules (EU) following the supervision of the Valencia Organic Farming Committee (Comité d'Agricultura Ecologica Comunitat Valenciana) and Demeter. The CC study site applied no-tillage, although once every three years, a shallow plow up to 55 cm depth is applied to avoid soil compaction as the marl parent material results in an increase in the bulk density if tillage is not applied. Leguminous catch crops such as Vetch (*Vicia villosa* Roth) and Alfalfa (*Medicago sativa* L.) are harvested in October at a rate of 60 Kg ha^{-1} y^{-1}. The pruned branches, weeds, and catch crops are chipped into small chips (<25 mm), and manure is applied in a dose of 2 Mg ha^{-1} y^{-1}. Hedges with olive trees and aromatic plants are present on the farm to increase biodiversity. Figure 2 shows a view of the study sites.

The control plot applied chemical fertilization with NPK 8/4/12 at a rate of 150 kg ha^{-1} yr^{-1} and tillage to avoid the growth of any weeds (see Figure 2). The soil was plowed three times per year with a cultivator. The pruned branches were collected by a tractor and burnt. The tractor operated was a Lamborghini tractor (674-70SPRINT). The tires of the front and rear wheels were 320–24 and 480-30, respectively, and the wheelbase was 2056 mm, and a total weight of 2720 kg. This tractor was used to spray chemicals and plowing in the control plot, and to chip pruned branches and weeds, and catch crops in the catch crop plot.

2.2. Farmer's Perception Survey

To evaluate farmers' perception of soil management in the study region of Terres dels Alforins, a survey was carried out from August 2013 till July 2014. To get insights into the perception of the use of catch crops and of weeds, a set of questions (see Table 1) were addressed to 64 farmers. The questions were formulated to get a reply (yes or no) from the farmer, and it was recorded as 0 (no) and 1 (yes). The questions were formulated to understand the knowledge of the farmers about catch crops and other strategies to reduce soil losses, their perception of sustainable management, and how it can be promoted (subsidies). The gender and age of the farmer were also recorded and the municipality where he/she came from (Table 1). The farmers' response regarding the acceptance of payment (subsidy) for use for catch crops was noted in our interview files in € per ha.

Figure 2. View of the study sites and experimental setup. (**A**). View of the control plot during the rainfall simulation experiments. (**B**). View of one rainfall simulation plot at the control plot. (**C**) View of the catch crop plot. (**D**). Rainfall simulation plot at the catch crop study site. (**E**). Ring infiltrometer measurements at the control plot. (**F**). Interview with a farmer.

Table 1. Farmer's knowledge and opinions from survey responses of farmers (n = 64).

	Questions (n = 64)	Yes (n°)	Yes (%)
Gender	Female	8	12.5
Knowledge	Do you know what Vetch is?	42	65.6
	Do you know what Alfalfa is?	50	78.1
	Do you know what a catch crop is?	7	10.9
	Do you know what soil erosion is?	57	89.1
Opinion	Is soil erosion a problem for soil fertility?	16	25.0
	Is soil erosion a problem for vehicles and transport?	56	87.5
	Do you like to have catch crops in your vineyard?	18	28.1
	Do you use catch crops in your vineyard	3	4.7
	Do you think catch crops reduce soil losses?	17	26.6
	Do you know catch crops can enhance infiltration?	20	31.3

Table 1. *Cont.*

	Questions (n = 64)	Yes (n°)	Yes (%)
	Do catch crops compete with the water for the vineyards and damage the production?	49	76.6
	Do you think catch crops improve soil quality?	3	4.7
	Is catch-crop dirt management?	60	93.8
	Do you avoid catch crops because is more expensive	22	34.4
	Do you avoid catch crops because of enhancing pests??	43	67.2
Reputation and incomes and subsidies	Would you use catch crops if they will be subsidized?	30	46.9
	Is the use of catch crops improving your reputation as a farmer?	1	1.6
	Do the catch crops increase your income?	0	0.0
Organic versus chemical farming	Is organic farming a solution for the farmer?	13	20.3
	Is organic farming a solution for the farmer because of economic issues?	27	42.2
	Is organic farming a solution for the farmer because of health issues?	34	53.1
	Is chemical farming a problem for the farmer because of health issues?	41	64.1
	Do you have a successor for your farm?	21	32.8
	Does the use of chemicals will affect future generations?	54	84.4
	Have you been in contact with chemicals that are now recognized as no healthy?	60	93.8
	Did the EU policies (subsidies) improved the environmental conditions of your region??	41	64.1
	Did you see an improvement in the economy after the EU applied the CAP in your region?	29	45.3
	Did you see an improvement in the economy in the last 10 years for the farmers?	11	17.2
	Does it depend on the subsidies for the success of organic farming?	49	76.6
Age	How old are you?	52.91	

2.3. Plant and Soil Analysis

The sampling strategy along the two tested plots is shown in Figure 1. Plant, litter, rock fragment, and bare soil covers were measured before rainfall simulation experiments and were determined by measuring 100 points regularly distributed at each 0.25 m^2 plot. Soil samples were collected from 0–2 and 4–6 cm depth as runoff generation and soil losses are highly dependent on the soil surface properties. One sample per plot was collected to determine the biomass of the weed and catch crop cover. A sample was collected for every 0.25 m^2 and all the surface plants were sown and transported to the laboratory. Then, they were dried at 60 °C to determine the dry matter. The catch crop was sown on 15 October 2013 and harvested on 15 July 2014. The biomass was surveyed after harvesting 1 m^2 close to each plot. The sample was weighed in the field and then dried (60 °C) in the laboratory and weighed again to determine the dry biomass. The calculations allowed us to determine the moisture and dry matter found in the control and catch crop plots.

Soil sampling took place at each of the 50 research plots (25 catch crops and 25 tillage) before the rainfall simulation experiments and they were collected at two different depths (0–2 and 4–6 cm) as those layers are the key to understand the soil detachment and runoff generation. Grain size, organic matter, and bulk density were determined at each soil sample. The pipette method was used to determine grain size [54]. Bulk density was measured using the ring method. Soil organic matter was measured using the Walkley-Black method [55]. Soil moisture was determined by the desiccation method.

2.4. Ring Infiltration Measurements and Rainfall Simulation Experiments

In July 2014, a survey was carried out with simulated rainfall experiments and ring infiltrometers to test the impact of the contrasted management on soil and water losses. A single ring infiltrometer (100 mm depth × 100 mm width) test was carried out in each plot (25 control + 25 catch crop = 50 plots). The time intervals between readings were at 1, 2, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, and 60 min, and after each reading, the cylinder was filled again. The infiltration envelope was fitted to the Horton equation to calculate the steady-state infiltration rate [56].

Fifty (twenty-five paired plots) rainfall simulation experiments were carried out at 55 mm h^{-1} rainfall intensity for one hour on circular paired plots (0.24 m^2). At each plot, runoff flow was collected at 1-min intervals and water volume was measured. The runoff coefficient was calculated as the percentage of rainfall water leaving the circular plot as overland flow. Runoff samples were desiccated (until constant mass) and sediment yield was calculated on a weight basis to calculate soil loss per area and time (Mg ha^{-1} h^{-1}). During the rainfall simulation experiments, time for ponding (time required for 40% of the surface to be ponded; Tp, s), time for runoff initiation (Tr, s), and time required for the runoff to reach the outlet (Tro, s) were recorded. Tr-Tp and Tro-Tr were calculated which indicated how the ponding was transformed into runoff and how much time the runoff on the soil surface needed to reach the plot outlet. These parameters were accurate indicators of the hydrological connectivity within the plot [57].

2.5. Statistical Analysis

Infiltration and runoff characteristics were represented in the form of box plot graphics with median, averages, and outliers. Soil characteristics, biomass production, and rainfall simulation results were expressed in tables with averages, standard deviation (±), maximum and minimum values. To be able to make a comparison of the results obtained in both paired plots; a t-test was performed with Sigma Plot 14.0 (Systat Software Inc.). However, some results did not show a normal distribution after performing a Shapiro-Wilk normality test. Therefore, a Tukey test or Holm-Sidak test was carried out where significant differences at $P < 0.001$ level were assessed.

3. Results

3.1. Farmers' Perception

The opinions of farmers on soil management strategies are shown in Table 1. Farmers were on average 53-years-old (18 out of 64 were older than 60) and mainly men (8 women out of 64 interviewed farmers). Sixty-six percent of the farmers knew what vetch is. However, only 10% of the farmers knew what a catch crop is. The farmers of Terres dels Alforins knew the concept of erosion (83%), but they disagreed about soil erosion being a problem as they did not see erosion as a cause of soil fertility reduction (25 %) but they accepted that was a serious problem for vehicles and transport due to the gully and rill development and the damage on roads (87.5%).

Few farmers would like to have catch crops in the vineyard (28%). Three out of 64 farmers use catch crops in the vineyards, and 27% knew that catch crops reduced soil losses (and 19% for the weeds). A similar percentage (31%) of the farmers believed that catch crops enhanced soil erosion. However, 77% of farmers perceived that catch crops cultivated damaging plants that reduced the water available for the crop. The negative perception of farmers' opinions was that they damage the crop. Forty percent of the farmers thought that the catch crops improved fauna, which was a negative perception for them due to the damage that the rabbits and wild boards would then create. These opinions lead to the perception of farmers that tillage was the best management as it made the soil clean and tidy with no vegetation cover except the crop. Farmers (94%) considered catch crops to be dirty management. The reason was that it required more expensive management (34% for the catch crops) because it enhanced pests (67% for the catch crops), and farmers would only grow them if subsidized (47%). Only one farmer agreed that the catch crops improved the reputation of the farmers. No one trusted that the catch crops would increase their income. As a consequence, few farmers accepted organic farming as a solution (20%). Farmers agreed that organic farming can improve the economic circumstances (42%) and their health (53%), and 64% of the farmers accepted that chemical (conventional) farming was unhealthy for them.

From the social point of view, 67% of the farmers did not have a successor for their farms, and they informed us that during their life, they had been in contact with unhealthy chemical products (94%). Most of the farmers (64%) agreed that the EU policies improved the environmental conditions of the region, but the economic improvement was less accepted (45%), and only 17% believed that the economy was improved in the last decade. They accepted that organic farming can only be successful with subsidies (77%). This is related to the demand of the farmers to be subsidized for the seeds and sowing of the catch crops (92%). Farmers indicated that the subsidies and bureaucracy were making them sick of the system (92%), but that they will accept a payment of 76.56 € ha^{-1} for catch crops as a subsidy to cover all the expenses and the lack of reputation within the farmers' community as a clean and tidy vineyard should have no other plants other than vines. This monetary value was an average of the amount requested by each farmer.

3.2. Weeds and Catch Crop Cover and Biomass Production

Table 2 shows the vegetation cover at the plots and the fresh biomass and dry biomass production. The vegetation cover was negligible for the control plot where 2% of the plot was covered and had very low biomass that reached an average value of 3.66 g m^{-2}. The vegetation cover for individual plots ranged from 0 to 4%. The biomass ranged from 0.56 to 6.72 g m^{-2} for individual plots. In the CC treatment, the biomass included the weeds (wild) and catch crops sown. The results showed a contrasted response between the bare control plots and the catch crop covered ones. The plots with catch crops reached 143.6 g m^{-2} of fresh biomass. This was 0.41 and 17.4 g m^{-2} dry biomass for the control and catch crop plots, with insignificant differences shown among treatments. The amount of moisture in the vegetation of the catch crops and control was similar: 88 and 88.6%, respectively.

Table 2. Plant cover, biomass (fresh and dry), and moisture values. C: Control plot; CC: Catch crop plot. Av: Average; Sd: Standard deviation; Max: Maximum; Min: Minimum.

Unit	Plant Cover %		Fresh Biomass g		Fresh Biomass g m^{-2}		Dry Biomass g m^{-2}		Moisture g m^{-2}		Dry Biomass %		Moisture %	
	C	**CC**	**C**	**CC**	**C**	**CC**	**C**	**CC**	**C**	**CC**	**C**	**CC**	**C**	**CC**
Av	2.0	40.9	0.9	35.9	3.7	143.8	0.4	17.1	3.3	126.6	11.4	12.0	88.6	88.0
Sd	1	9	0	11	2	43	0	5	2	39	1	1	1	1
Max	6	57	2	55	8	221	1	27	7	196	14	16	90	89
Min	0	18	0	20	1	79	0	10	0	69	10	11	86	84

3.3. Soil Characteristics

In Figure 3, the main soil cover values are depicted in box plots. Rock fragments were rare in both plot managements (2% on average), and always below 8% with non-significant differences (P = 0.754). Vegetation cover reached 39.2% in the CC plot and only 2% in the control one. Litter cover amounted to 3 and 0.2% in the CC and C plots, respectively. In total, the C plots showed more than 95% of the bare surface against 55.4% of the CC one, even registering a higher intra-plot variability. The litter cover was null in the control plot, meanwhile, the catch crop plot showed a low cover that ranged from 0 to 7% (P = <0.001), with an average value of 4.6%. All of these soil characteristics showed significant differences when the Tukey test was performed (P < 0.001).

In Figure 4, soil properties at 0–2 and 4–6 cm showed differences due to the depth, but differences were not always found between the two managements. Catch crops (4.9%) and control (4.6%) plots showed little differences in soil moisture content at 0–2 cm (P = 0.043); however, at 4–6 cm, the control management showed higher soil moisture with significant differences (8.3 against 5.9%; *P* = <0.001). The impact of the catch crop on soil bulk density resulted in an increase from 1.28 to 1.44 g cm^{-3} at 0–2 cm depth, showing significant differences (*P* = <0.001), likewise from 1.29 to 1.47 g cm^{-3} at 4–6 cm depth as well. Soil organic matter was also higher on the catch crops: 1.79% at 0–2 cm depth and 1.17% for the 4–6 cm depth. Control plots showed an average soil organic matter of 1.12 and 1.05%, respectively. Both depths showed significant differences at *P* = <0.001. Grain size did not show any difference between catch crops and control plots, neither at 0–2 cm nor at 4–6 cm depth. For this reason, it was not shown in Figure 4. In the control plot, 38.94% sand, 40.87% silt, and 20.19% clay were registered. On the other hand, 41.59% sand, 41.88% silt, and 16.53% clay were registered in the CC plots.

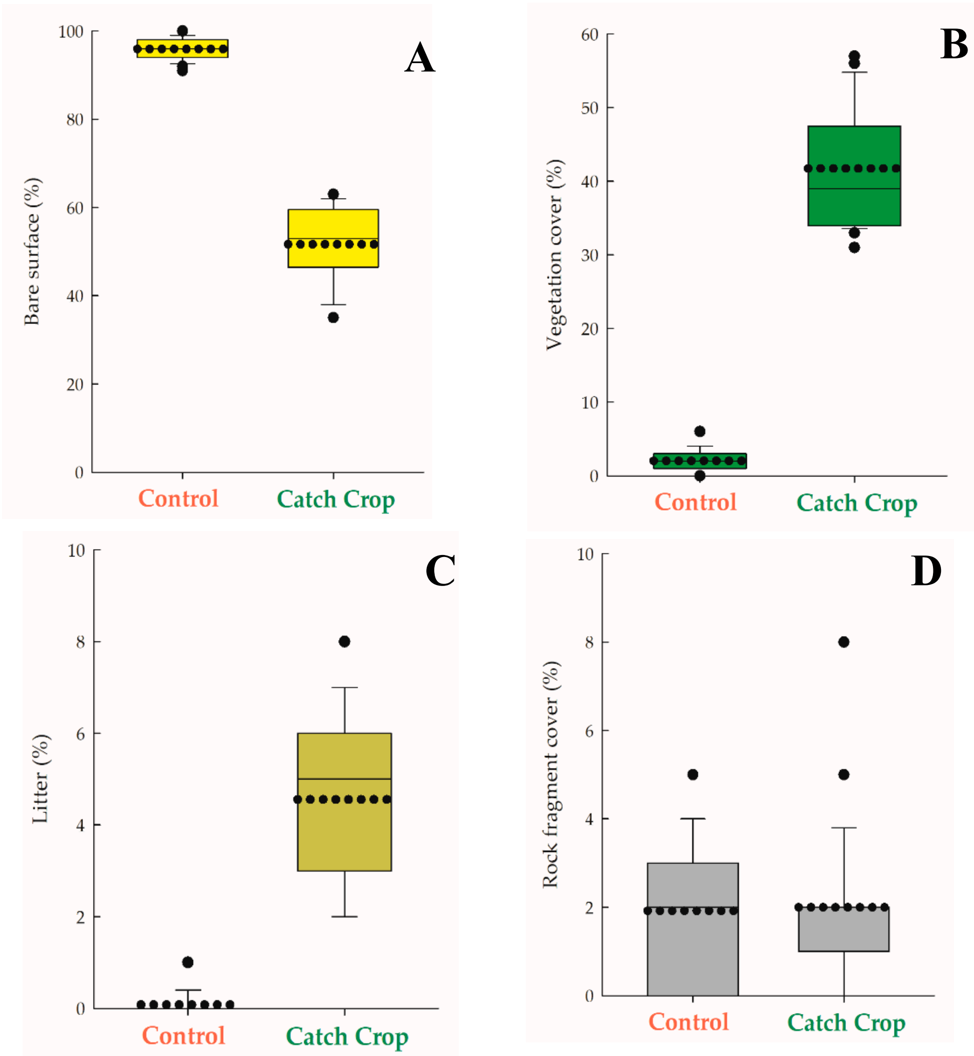

Figure 3. Soil cover characteristics in the control and catch crop (**A**) plots: vegetation (**B**), litter (**C**), and rock fragments cover (**D**). Continuous line: median values; dotted line: mean values; circles: outliers; 5th and 95th percentiles are also represented per box plot.

3.4. Infiltration Rates

In Figure 5, the steady-state infiltration rates showed that CC enhanced higher infiltration rates with values ranging from 80.05 to 142.2 mm h^{-1}, meanwhile, in the C plots, the values range from 15.38 to 31.91 mm h^{-1}. The average steady-state infiltration rates were 25.53 for C and 119.35 mm h^{-1} for catch crops. There were statistically significant differences ($p < 0.001$).

3.5. Runoff Initiation and Runoff Discharge

Runoff showed statistically significant differences between the input groups C (control with tillage) and CC (catch crops) ($P < 0.001$). In average values, at the control, the ponding was initiated after 84 s since the rainfall started, the runoff registered after 127 s and the runoff reached the drainage after 355 s. The catch crop plots generated ponding after 141 s, runoff after 459 s, and the runoff discharge was measured after 934 s. The delayed runoff generation in catch crops could be calculated with the parameter Tr-Tp and Tro-Tr, which showed the delayed time from ponding to runoff and the delay from runoff initiated in the soil surface to reach the plot outlet. For the control plots, the Tr-Tp and Tro-Tr were 43 and 228 s respectively and in average values. For the catch crops, the average values of the 25 plots were 319 and 454 s. This meant that the runoff generation was seven times faster in control plots and that the runoff velocity was twice as fast in control than in catch crop plots (Table 3).

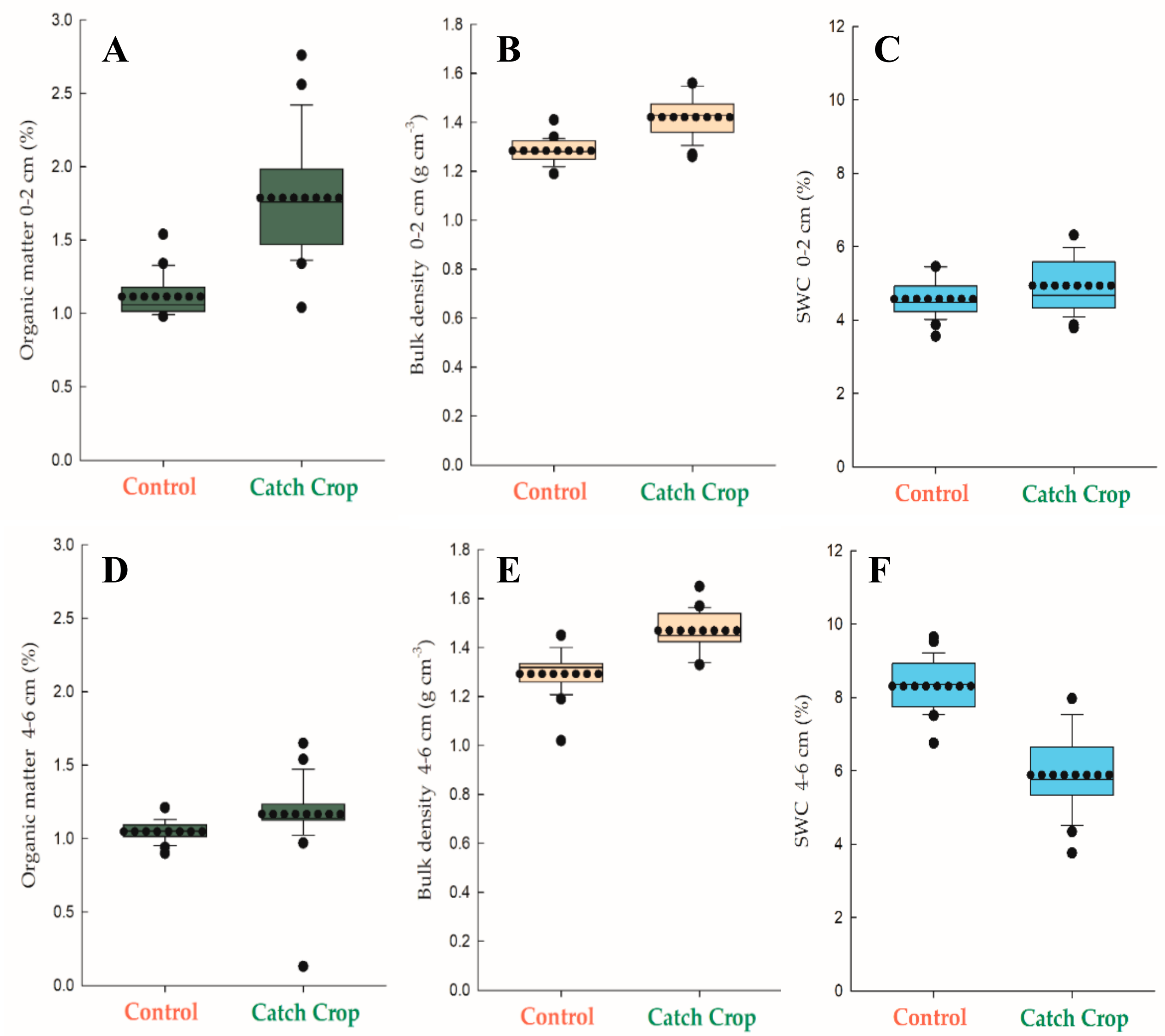

Figure 4. Soil properties at 0–2 and 4–6 cm of soil depth in the control and catch crop plots. SWC: Soil water content. Continuous line: median values; dotted line: mean values; circles: outliers; 5th and 95th percentiles are also represented per box plot. (**A**) soil organic matter (0–2 cm); (**B**) soil bulk density (0–2 cm); (**C**) soil water content (0–2 cm). And (**D**) soil organic matter (4–6 cm); (**E**) soil bulk density (4–6 cm); (**F**) soil water content (4–6 cm).

3.6. Runoff, Sediment Concentration, and Soil Erosion

In Figure 6, soil erosion results are summarized in different bar graphs to compare different soil management. The 0.25 m^2 plots received 13.75 mm in one hour of rainfall simulated in the experiment. In average values, the control plots had a runoff discharge of 5.52 L. On the contrary, the catch crop plots reached 1.08 L. This was a large difference in the mean runoff coefficient registered at the control plots (40.1%) and catch crops ones (7.8%). The sediment concentration in the runoff was 16.64 g L^{-1} and 2.88 g L^{-1} in average values for C and CC respectively. Sediment concentration ranged from 12.36 to 21.23 g L^{-1} in the control plot and was reduced to 1.98–4.25 g L^{-1} for the catch crops. The total sediment yield was 91.75 and 3.08 g for C and CC. Additionally, they show ranges between 69.71 and 114.23 g for C and 1.53 and 4.79 g for individual plots in CC.

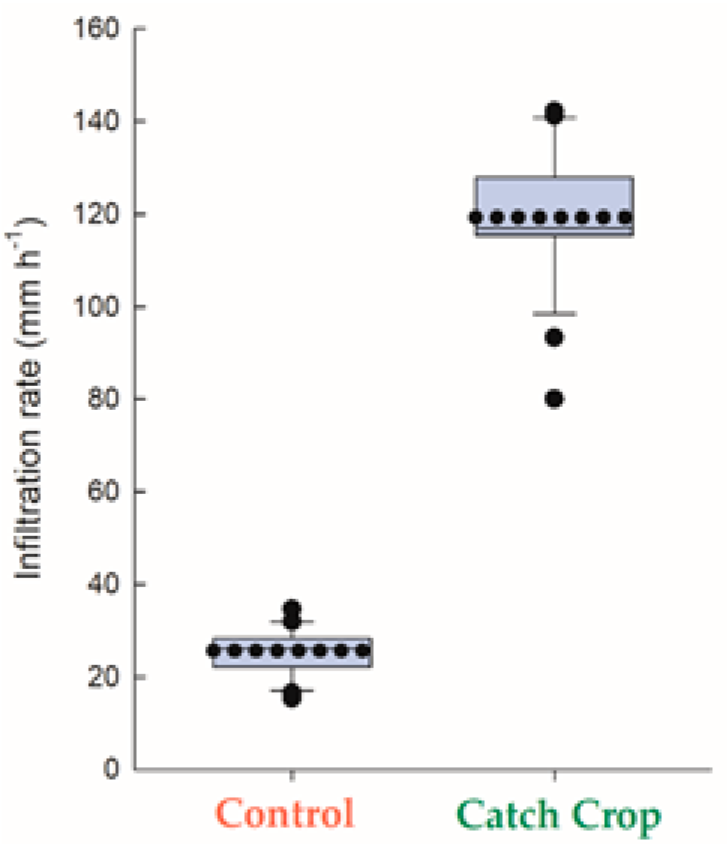

Figure 5. Variability of infiltration rates in the 25 different plots with catch crops and without them. In the box plot graph: continuous line: median values; dotted line: mean values; circles: outliers; 5th and 95th percentiles are also represented per box plot.

Table 3. Runoff parameters related to the hydrological responses in the catch crops (CC) and control plots (C). Av: Average; Sd: Standard deviation; Max: Maximum; Min: Minimum. Diff.: Differences. Tp: Time for ponding; Tr: Time for runoff generation; Tro: Time for runoff to the outlet.

Plots	**Tp (s)**		**Tr (s)**		**Tp-Tr (s)**		**Tro (s)**		**Tr-Tro (s)**	
n = 20	**C**	**CC**	**C**	**CC**	**C**	**CC**	**C**	**CC**	**C**	**CC**
Av	80.4	135.8	120.7	448.2	40.9	314.1	339.2	867.5	219.2	429.4
Sd	20	34	30	118	13	94	83	210	56	116
Max	98	173	142	598	60	460	401	996	282	610
Min	7.4	9.9	7.9	57.2	10.4	58.7	29.5	48.7	28.8	83.0
Diff.	*P* = <0.001		*P* = <0.001		*P* = <0.001		*P* = <0.001		*P* = <0.001	

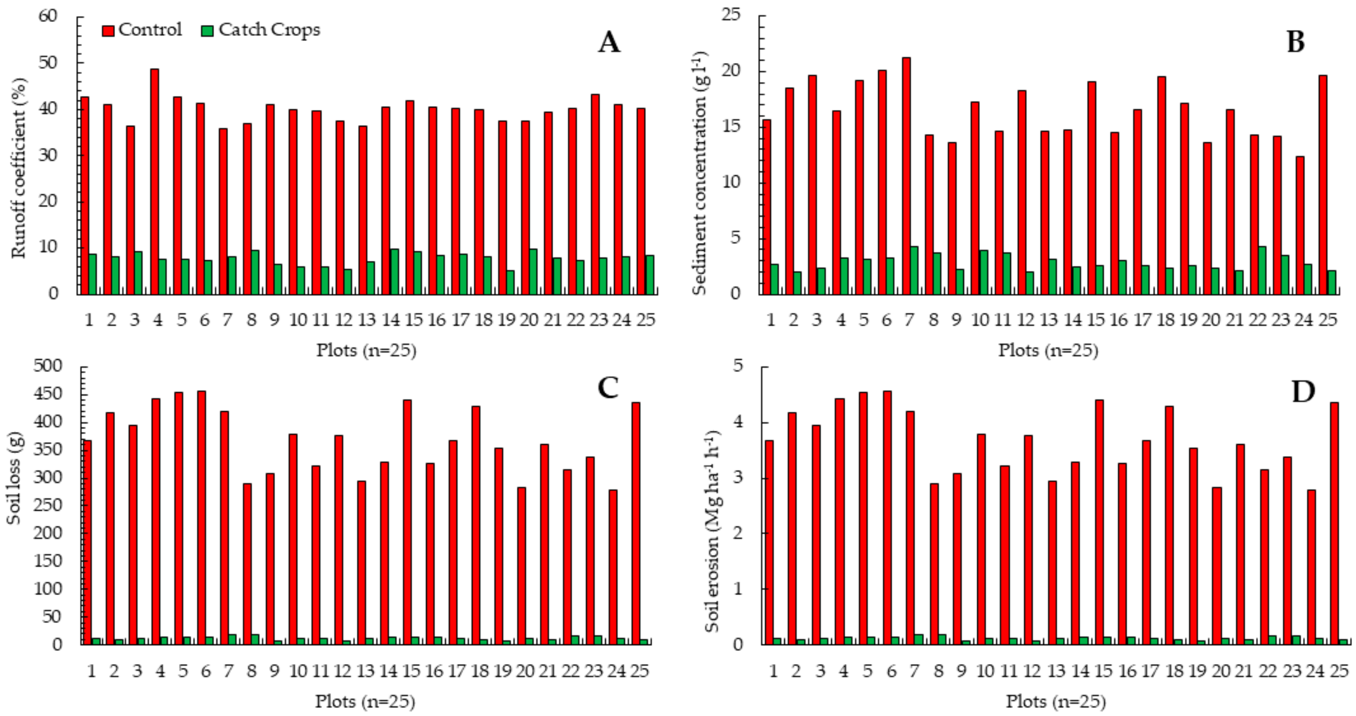

Figure 6. Soil erosion results obtained in the control and catch crops plots. (**A**) runoff coefficient; (**B**) sediment concentration; (**C**) soil loss; and, (**D**) soil erosion.

The soil erosion response of the control and catch crops plots was contrasted. The average soil erosion rates were 3.67 Mg ha^{-1} h^{-1} and 0.13 Mg ha^{-1} h^{-1} for the control and catch crops. The average values ranged from 2.82 to 4.57 Mg ha^{-1} h^{-1} and from 0.07 and 0.19 Mg ha^{-1} h^{-1} for the control and catch crops, respectively. The use of catch crops resulted in a reduction in soil losses of 30-fold. There was a significant statistical difference between the two managements.

4. Discussion

Land degradation processes are a threat to the terroir's sustainability. The most intense degradation is due to the high erosion rates found in conventional fields, mainly managed by tillage. In our experimental approach at the Terres dels Alforins wine production region, we found that soil erosion under tillage is very high on vineyards, which confirms previous findings in different regions throughout the world [16]. Nevertheless, the use of catch crops can reduce soil losses to low rates that will contribute to preserving more water, sediments, nutrients, and seeds than traditional tillage. Therefore, there is a solution to improve the quality of the soils and the land affected by millennia-old human disturbances [58]. Previous research into the use of catch crops in different regions of the world confirmed the potential of catch crops as sustainable management to control soil erosion rates [59]. Catch crops result in a plant cover that contributes to the sustainability of the vineyards such as was found at the Pago Casa Gran research site [60–62].

The positive effect of catch crops in the restoration of soil properties was demonstrated here at the Pago Casa Gran farm due to the larger biomass, the conservation of the soil organic matter, and the reduction in the soil losses (Figure 7). Other regions of the world report improvement in soil physical properties and the enzymatic activity such as Harasim et al. [63] in Loess soils under spring wheat monoculture. Salata et al. [64] found that catch crops improved the yield and chemical composition of winter garlic, and Kemper et al. [65] contributed with an explanation about the importance of the vertical root distribution as a key factor of catch crops to restore soil properties. Catch crops were also found by other scientists as management that will reduce the delivery of nitrogen to the fluvial system and then will preserve aquatic life. From a biophysical point of view, the research carried out at

Casa Pago Gran lighthouse farm shed light on the positive effects of catch crops to achieve the land degradation neutrality challenge such as Keesstra et al. [66] updated recently or that more generally assessed [67,68]. Catch crop use will definitively reduce soil losses, increase organic matter, and enhance the functions and services soils bring to society. The soil and land-related Sustainable Development Goals of the United Nations [69,70] will be achieved with solutions such as the use of catch crops. However, the physical land degradation processes that threaten sustainability need to be addressed more holistically than only focusing on the loss of soil and water, organic matter, and biomass production. There is a need to create an enabling environment in which the farmers will accept the new management strategy, to make them sustainable and non-dependent on the subsidies. Our research at the vineyards of Els Alforins found two main constraints to achieve the SDG's: the rejection of the farmers to apply catch crops, and the aging of the population that likely will not achieve a successor for their farms. There is a renewal of vines and vine varieties, new machinery in the farms, and the best wines ever produced, but the farmers' population is under the constraints of aging [71], and in one generation there will be difficulties replacing the current farmers' generation. Moreover, the current generation does not accept that catch crops are an alternative for tillage.

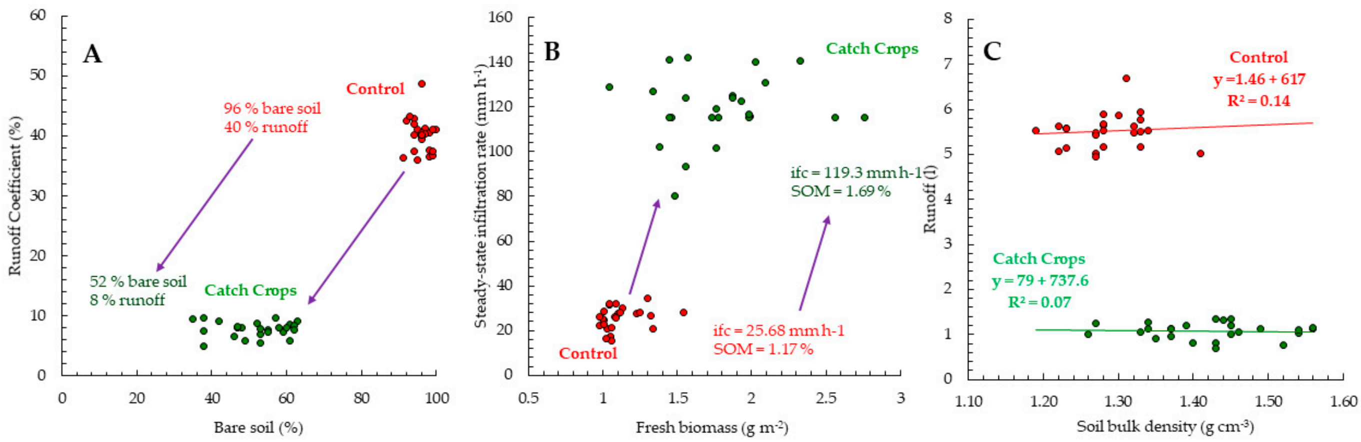

Figure 7. Relationships among variables related to runoff and conditioning factors. (**A**) Bare soil versus runoff coefficient; (**B**) fresh biomass versus steady-state infiltration rate; and (**C**) soil bulk density versus runoff.

The farmers' aging is a constraint in many agricultural lands in the developed world, as well as the lack of potential successors [72–74]. Aging also affects vineyards around the world as they are located mainly in rich regions such as the northern Mediterranean, California, and parts of Australia and South Africa [75]. In addition to improvements in the economy and technology [76,77], there is a need to renew the farmers' population. The renewal of the farmers over the next two decades should bring new ideas, and the new generation should embrace an education strategy with information on new management methods. This paper contributes to new solutions to high erosion rates. The new generation of farmers must understand the challenge of the society to achieve sustainability and for this, this new generation of farmers should be aware of the soil conservation strategies and make them part of the common knowledge of the farmers' community [78]. Our research at the Terres dels Alforins shows that the aging and lack of education of farmers in terms of environmental issues and new management are the most important constraints that have to be solved to be able to achieve sustainable wine production in the Mediterranean.

The use of catch crops reduces soil and water losses as we found in our experiments and previous research using other cover crops (e.g., [77,78]). However, most of the farmers in the Mediterranean did not see soil erosion as a relevant problem and they prefer to use tillage and keep the soil clean and tidy as other authors also demonstrated in Spain [12,13]. Some farmers are pioneers using alternative managements with successful farm management and commercial impact as their products provide high-quality food to the market and contribute to a healthy environment [79–82].

Pago Casa Gran is a lighthouse farm that is currently very successful within the field of international wine production due to their reputation as sustainable farmers and as fine wine producers (Figure 8). Pago Casa Gran is also well-known in academia as they follow the use of catch crops and hedgerows to promote biodiversity and preserve the traditional landscapes and they collaborate with scientific programs to develop a more sustainable wine production. However, Pago Casa Gran is not provoking a change in the perception of the farmers in the Terres dels Alforins region, and their strategies to preserve soil and water are not being disseminated in the region. During the interviews with farmers of the Terres dels Alforins region, we found that they did not see successful farms such as Pago Casa Gran as a reference, although it is well accepted by the other farmers that they are excellent farmers and winemakers. Few producers view the advanced and pioneering soil management strategies of Pago Casa Gran as the best alternative to non-sustainable and chemical farming. However, this is a seed that contributes to new farmers that will arrive in the agriculture sector. For this objective, we recommend empowering the lighthouse farm's strategies by the governments and developing a dissemination and education program that will enhance the contribution of the lighthouse farms to achieve sustainability.

Figure 8. Pago Casa Gran is a lighthouse farm as they produce different agriculture products under organic farming (**A**), and allow research to be conducted in their farm (**B**) with the use of catch crops (**C**) under the supervision of scientists (**D**); Dr Agata Novara and the Pago Casa Gran technicians) and they complement their management with the visit of scientists, farmers, and students (**E**,**F**). (**E**), show scientists from the different research stations at the Pago Casa Gran (Dr. Ramon Bienes at the forefront to the left in E) and also students such as the ones from the University of Wageningen attending the lecture of Artemi Cerdà, recently.

The use of catch crops resulted in a sudden reduction in runoff. Figure 7 shows how the use of catch crops reduces the runoff coefficient from 40 to 8%. The first impact of the catch crop establishment is the increase in the plant cover which acts as a soil conservation strategy. The plant cover reduces runoff discharge by increasing rainfall interception and infiltration rates. Moreover, the plant stems reduce the overland flow velocity and increase the infiltration rates. In the Pago Casa Gran, the impact of the catch crops reduced five times the runoff. Another impact of the catch crop is the increase in soil organic matter. The increase of organic matter in the soil is a slow process that requires decades [83]. However, a small increase in organic matter results in the activation of soil fauna, and with this comes the macropore flow and the increase in the infiltration rates. This is what we found at Pago Casa Gran where an increase from 1.17 to 1.69% of organic matter contributed to increasing the steady-state infiltration rate from 26 to 119 mm h^{-1}, which is mainly due to the development of macropores by soil fauna and grassroots.

The benefit of using catch crops has been widely demonstrated, here and in other scientific investigations, to reduce soil losses, increase soil infiltration, improve the vegetation cover, and enhance the soil organic matter accumulation. However, farmers do not support their use, mainly due to their perception of it being 'dirty' or 'sloppy' for the vineyards. Farmers prefer soil tillage with no other plant cover than the vines rather than soil covered with catch crops. They will only accept to use catch crops if a subsidy will be paid for this. A lighthouse such as the Pago Casa Gran in the Els Alforins wine production region can initiate a shift in the farmers' opinion, and this will power change towards more sustainable wine production. The constraints are the aging of the farmers and the lack of education and dissemination of the new and alternative management strategies such as catch crops.

The perception of farmers about the use of catch crops and other alternative management to achieve sustainable agriculture is negative. This response to the guidelines of technicians and the direction of the European Union Common Agriculture Policy is due to the tradition of the Mediterranean farmers to maintain the fields free of any plant that will be not a crop. This idea is deeply ingrained in the culture of what is a good farmer and allowing the use of catch crops, weeds, or mulches will damage the reputation of the farmers within their community. New farmers that arrive from other economic sectors such as tourism, industry, and private business, see the land as an opportunity to receive subsidies and this encourages them to initiate a program to change the management. On the contrary, the traditional farmers do not see foresee the benefits of changing the management as they do not have a successor for the farm, the profits in medium and small-sized farms are decreasing, and most of the farmers are part-time workers in other economic sectors. To change the perception of the farmers we need: (i) leaders in their community that will initiate the shift; (ii) education to inform the farmers of their contribution to sustainable development; (iii) dissemination to inform the society of the farmers' contribution to a sustainable world; (iv) subsidies that encourage the use of alternative management and show the farmers as successful business people to other farmers; and (v) a new generation of farmers that will invest in the new agriculture. Casa Pago Gran lighthouse farm is a key contribution to promote sustainable farming and will contribute to the shift to the new agricultural methods if the five conditions above are implemented.

5. Conclusions

The research conducted at the lighthouse farm Pago Casa Gran demonstrated a clear improvement of soil properties and soil functions due to the use of catch crops. A reduction in soil erosion rates, an increase in soil infiltration, and recovery of soil organic matter. Catch crops are remediating the soil degradation that has been affecting Mediterranean soils for centuries. However, the interviews done in the Terres dels Alforins wine production regions where Pago Casa Gran is located, demonstrated that the farmers' community does not see catch crops as a solution for their farms, although they do think it can work for the Planet as a whole. The aging of the farmers' population and the lack of information from the relevant authorities results in a negative opinion of the farmers towards the use of catch crops, and they will only accept the use of them if subsidized. They seek payment of 76.56 € ha^{-1} to grow catch crops and supplement their reputation as farmers.

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