PILOT ACTION REPORT

Spontaneous plant cover as a tool against soil erosion in a Rioja Alavesa vineyard

MONTCLIMA

Index

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Summary

More than 40% of the vineyards in Rioja Alavesa have an average slope of more than 10%, which makes them susceptible to erosive processes. Moreover, it is foreseeable that rainfall will be less evenly distributed and heavy rainfall will occur more frequently because of climate change. Bearing in mind that most of the vineyard soils in Rioja Alavesa are managed by tillage, the aim of this pilot project, which has been carried out within the framework of the INTERREG SUDOE MONTCLIMA project, was to evaluate the impact of different soil management methods on erosion, vegetative growth, vine yields and grape, must and wine quality. For this purpose, a trial was carried out with a randomised block design and three replications in a vineyard of the 'Graciano' variety with a slope between 10-20% during the years 2020, 2021 and 2022.

Three treatments were compared: traditional tillage, spontaneous plant cover and a combined management of both. Vegetative growth was clearly reduced in the cover crop treatment in all three years of the trial. Yield was also lower in the cover crop treatment, but the differences were significant only in the second and third year. In terms of quality, a higher malic acid content of the grapes was observed in the tillage treatment. In addition, a lower K content in wine was detected in the cover crop treatment. There was a clear decrease in average annual erosion in the cover crop treatment (2.1 t ha^{-1} yr^{-1}) compared to the tillage treatment (17.9 t ha^{-1} yr^{-1}). Spontaneous vegetation cover is a good option to reduce soil losses in sloping vineyards, but the cover exerts a competition for water and nutrients that must be considered in agronomic management.

Key words: Gerlach box, tillage, soil, Mediterranean climate.

1. Why is this pilot important?

Vineyards are one of the most important fruit crops worldwide (Ben-Salemet al., 2018) with an area of approximately 7.3 million ha and 260 million hL of wine per year. Spain is the third most important country in terms of wine production and 961,000 ha of vineyards are cultivated, being the largest extension of vineyards in the world (OIV, 2021). Among the most recognised designations of origin, the Rioja Qualified Designation of Origin (DO Ca Rioja) stands out, located in areas of the autonomous communities of La Rioja, the Basque Country, Navarre and Castile and Leon, accounting for 65,726 ha of surface area, 1,165,642 kg $year^{-1}$ of grapes (red and white) and 269 million L of wine $year^{-1}$ (Rioja Wine, 2020). More specifically, the wine-growing area in Álava reached 13,634 ha according to the 2020 agricultural census (Basque Government, 2020).

This territory therefore represents around 18% of the cultivated surface area of the CAPV (Autonomous Community of the Basque Country) and around 17% of the surface area of Álava. In turn, this area accounts for 20.5% of the total area under DOCa Rioja. The volume of grape and wine production also fluctuates between 18-24% of the DOCa total (Rioja Wine, 2020). About the definitive economic values of the CAPV in 2018, we find that vineyards in Alava represent around 45% of the Final Agricultural Production (FAP) of Alava and 22% of the total FAP of the ACBC (all vine cultivation in the ACBC would represent around 25% of the FAP). These figures highlight the socio-economic importance of the crop in the CAPV (Basque Government, 2018).

Soil is a finite and non-renewable natural resource that provides various ecosystem or environmental services (Burbano, 2016). Not only is it the natural basis for the production of food and raw materials on which global society depends (Silva and Correa, 2009; Montanarella, 2015), but it is also home to a quarter of our planet's biodiversity. However, soil degradation is one of the greatest threats of the 21st century. According to literature studies, soil degradation processes have already affected 33% of the earth's surface (Bini, 2009), leading to a significant reduction in soil quality and functionality (Lal, 2015). Among the soil degradation processes, water and wind erosion are among the most important. The European Environment Agency estimates that 115 million hectares are exposed to water erosion processes (12% of the European land area) and 45 million hectares to wind erosion (EEA, 2010). It is estimated that between 8 and 12 million hectares of fertile soil are lost annually in Europe, resulting in an economic loss of approximately €1.25 billion (Panagos et al., 2017).

Vineyards are one of the crops most susceptible to erosion in the Mediterranean region (Cerdán et al., 2010), since in sub-humid or semi-arid areas they are usually managed by keeping the soil bare through conventional tillage (Ruiz-Colmenero et al., 2011; Prosdocimi et al., 2016b) or by applying herbicides (Raclot et al., 2009). This absence of vegetation cover poses, on sloping soils, a strong risk in relation to erosion (López-Bermúdez et al., 1998). Moreover, it could cause related problems, such as nutrient loss and therefore lower productivity and reduced grape quality (Kirchhoff et al., 2017; Rodrigo Comino et al., 2015). It is important to note that vineyards under Mediterranean climates are particularly vulnerable due to their dry summers and intense rainfall events. These events involve periods without vegetation cover, leaving the soil exposed to precipitation and favouring erosion in the wetter seasons (autumn and spring) (Ferreira et al., 2018).

In the near future, the problems associated with soil loss will be aggravated by the effects of climate change (changes in rainfall patterns with increased periods of drought and precipitation in the form of torrential rains) (Bustins, 2018). In the face of this threat organic farming, regulated by certificates accredited by the European Convention (Regulation-EU-No203/2012), aims to mitigate erosion by implementing more sustainable techniques and conserving soil biodiversity (Kirchhoff et al., 2017). Among the most common and cheapest techniques that can be found are spontaneous or sown permanent vegetation cover and mulching, which have been shown to reduce soil and nutrient loss compared to tilled soils (Bienes et al., 2012; Rodrigo Comino et al., 2015; Marques et al., 2010).

2. What do we propose?

As a measure for the reduction of soil erosion and therefore the reduction of one of the most important soil threats in vineyards, we propose to encourage the use of cover crops. However, to promote this practice among vine growers, it is essential to quantify the effect of plant cover on soil erosion and to know the effect of this management on the vigour, yield and quality of the grapes.

Therefore, the aim of this pilot project was to study the effect of different soil managements in a sloping vineyard in Rioja Alavesa on erosion, vegetative growth, vineyard production and grape, must and wine quality. The results of this report will help us to present rigorous data on the improvement that plant cover has on soil erosion and how it affects the vineyard.

This work is part of the INTERREG SUDOE MONTCLIMA project: climate and natural hazards in the SUDOE mountains, co-financed by the European Regional Development Fund (FEDER) through the INTERREG SUDOE programme. The project aims to develop a transnational strategic framework for the prevention and management of natural risks in mountain areas. In this way, it deals with the search for sustainable management practices to cope with the effects of climate change in mountain areas, mainly focused on the risks of soil erosion, drought, floods, and forest fires.

3. Where did we work?

The experimental field object of this work belongs to the Maisulan winery, located in Elvillar/Bilar (Álava), where organic wine is produced inside Rioja Qualified Designation of Origin. It is a very small family winery (12 ha of vineyards), which tries to produce very careful and differentiated wines to gain a foothold in such a competitive market as the wine industry. The vineyard under study is located at an altitude between 515-535 m and has a slope between 10 and 20%. It was planted in 2007 with the 'Graciano' variety, with Trellis training and a single cordon pruning system. The planting frame is 2.45 x 1.2 metres (distance between rows 2.45 m and between vines 1.2 m), therefore, with a density of approximately 3,333 plants ha^{-1}.

The experimental field was selected because it has a very representative range of slopes in the Rioja Alavesa vineyard area (Figure 1), as more than 40% of the vineyard in this area is located on slopes of more than 10%, and 32% of the total has slopes of between 10 and 20%.

Figure 1 refers to the average slopes of Rioja Alavesa according to the information available in the Geoeuskadi viewer (https://www.geo.euskadi.eus/inicio), and prepared as follows: i) initially, SigPac data from 2019 and the digital terrain model (DTM) obtained from the 2017 LiDAR flight with a spatial resolution of 5 m were used; ii) with the slope map obtained in the first step and using the SigPac layer, the municipalities that make up Rioja Alavesa were selected and the agricultural land use for vineyards was selected. In this process the vector map of the vineyard plots in Rioja Alavesa was obtained; iii) calculation of the average value of the slope of each plot; and finally, iv) the plots were classified according to the average value of their slope. Table 1 shows the area and percentage of surface located on slopes numerically.

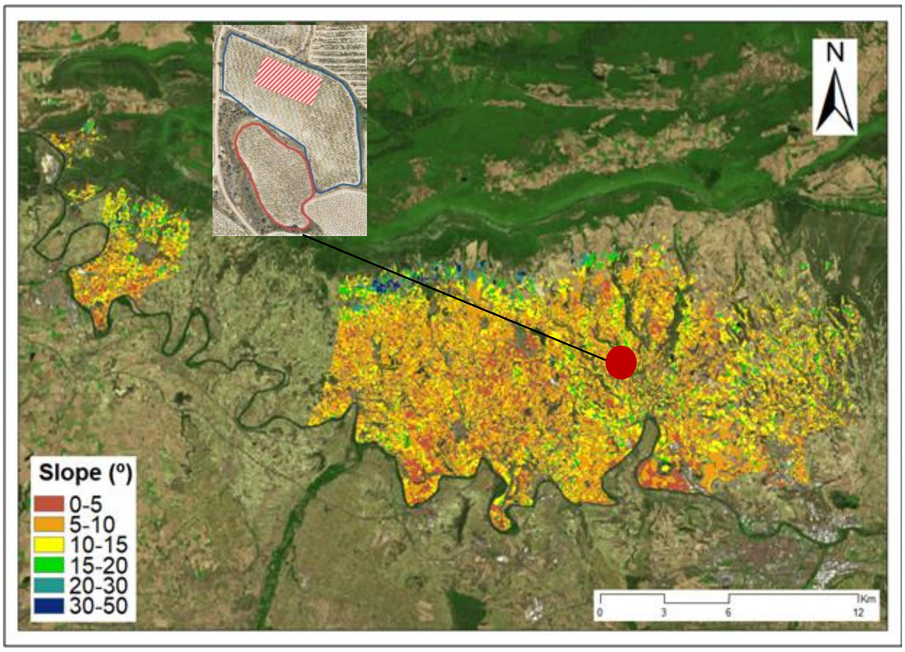

Figure 1 Slope map of the Rioja Alavesa vineyard and location of the experimental field.

Table 1 Distribution of vineyard surface area in Rioja Alavesa according to slope ranges (Geoeuskadi, 2020).

Slope (%)	Surface (ha)	(%)
<3	1914,70	14,34
3-5	1761,50	13,19
5-10	4052,53	30,35
10-20	4314,11	32,31
20-30	1106,66	8,29
30-50	201,64	1,51
>50	0,86	0,01

The climate of the area is characterised by the influence of a Continental-Mediterranean climate (Figure 2). According to the weather station in Páganos, located approximately 5 km from the experimental field, the average annual temperature in the period from 2004 to 2019 was 12.6ºC (average minimum temperature 7.9ºC and average maximum temperature 18ºC). The annual absolute maximum temperatures reach an average of 35.9ºC and the annual absolute minimum temperatures have an annual average of -5.1ºC.

The average annual rainfall is around 500 mm and does not reach 200 mm on average over the crop growing cycle (April-October).

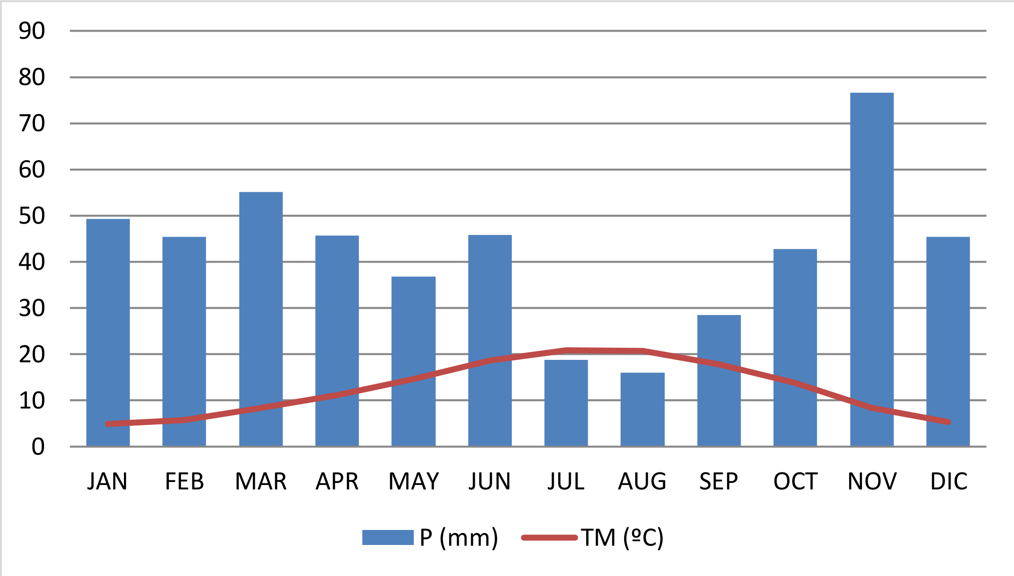

Figure 2 Average monthly accumulated precipitation and temperature (period 2004-2021) at the Páganos weather station (Euskalmet, 2022).

Considering the same period, the maximum rainfall in one day was 52.6 mm in November 2011, but the interannual average of maximum rainfall in one day is 33.1 mm. In the period from April to October, the most sensitive periods for the crop, 41.6 mm of maximum rainfall in one day has been recorded.

The lithology of the site consists mainly of calcareous sandstones, siltstones and red argillites (Geoeuskadi, 2020).

Prior to the installation of the trial, soil sampling was carried out in each elementary plot at two different depths (0-10 cm and 10-30 cm). The average value of the six samples analysed shows that the texture is loam and silt loam, with a pH above 8.5 (usual in the area), a high carbonate level of about 43 % and a relatively high level of active limestone (13-17 %). The soil content of organic matter, nitrate, ammonium, phosphorus, potassium, and magnesium is low (Table 2).

Table 2 Mean values of soil analysis in the plot (0-10 cm and 10-30 cm depth).

	(Uds)	1	2
Depth	(cm)	0-10 cm	10-30 cm
Large Sand	%	3,3	4,0
Fine Sand	%	29,9	30,0
Silt	%	49,7	50,1
Clay	%	17,1	15,9
Texture		Loam	Silt loam
Organic matter (W&B)	%	0,8	0,7
pH water (1:2.5, w/v)		8,7	8,6
C/N		7,2	7,6
Carbonates	%	43,5	43,6
Active lime	%	13,5	17,1
Total nitrogen	%	0,1	0,1
Fhosphorous Olsen	mg kg^{-1}	3,7	2,4
Available potassium	mg kg^{-1}	85,7	102,5
Aailable calcium	mEq $100g^{-1}$	9,9	10,0
Available magnesium	mEq $100g^{-1}$	0,6	0,7
Nitrate	mg N-NO3 kg^{-1}	2,4	1,4
Amonium	mg N-NH4 kg^{-1}	1,9	1,8

4. How was the pilot test carried out?

The pilot test has been carried out during the years 2020, 2021 and 2022 following a three randomised block experimental design with three treatments. Therefore, a total of nine plots or experimental units were analysed, with 36 vines in each plot (Figure 3). The treatments were as follows:

- Spontaneous cover crop (CV). In 2019, the last tillage was carried out, leaving the spontaneous vegetation to grow. 1-2 mowing passes per year are carried out as maintenance work.
- Conventional tillage (LAB). The soil was kept bare most of the year by 4-6 passes of tillage machinery (rotavator, chisel or tine harrow), at a depth of approximately 20-30 cm.
- Combined management (CM). One inter-row is not ploughed and is maintained by mowing (as with CV management), and the adjoining inter-row is ploughed only 2-3 times a year, avoiding the use of a rotavator. The management of the inter-row is

alternated annually, so each one is ploughed every two years.

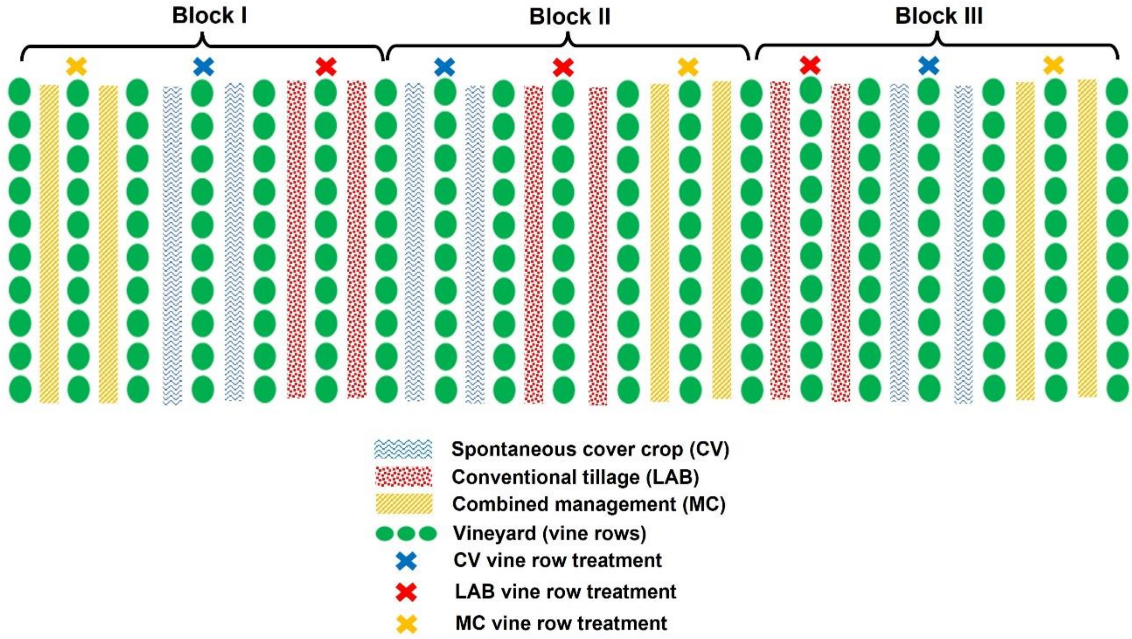

Figure 3 Experimental layout and design of the trial carried out in Elvillar (Araba) from 01/04/20 to 31/03/22 .

In each elementary plot, the usual tasks were carried out (ploughing, weeding, under row tilling, leaf removal, trimming, etc.), with the winery's machinery, following the pre-designed management guidelines.

Measuring erosion on experimental micro-plots

In order to measure soil erosion in a controlled manner, in the most extreme management (CV and LAB), six micro plots were installed, one in each block, independent for erosion recording, in the centre of the vineyard inter row, at the end of each elementary plot. Each micro-plot allowed the isolation of an area of 1.2 m2 (4 metres long x 0.3 metres wide), with metal plates of approximately 25 cm in height, allowing the passage of machinery without damaging it (Figure 4). In these micro plots smaller machinery was used than that normally employed in the rest of the elemental plots but following the same dates and management.

The micro-plot is completed with the installation at the end of a Gerlach box through which the runoff water is channelled (Gerlach, 1967). The box has a bottom outlet which is connected by a hose to a 30-litre drum for water storage. In this way it is possible to periodically collect sediments carried by surface runoff, on the one hand, those that are trapped in the Gerlach box, and on the other hand, those that are dissolved in the runoff water stored in the drum (Figure 4). Samples were collected approximately every 15 days, but more frequently if weather conditions required it (rainfall events > 10 mm).

Figure 4 Installation of the experimental micro-plots for measuring erosion, with Gerlach boxes and water storage drums for the trial of vegetation cover versus ploughing carried out in Elvillar (Araba) from 01/04/2020 to 31/03/2022.

Quantification of dissolved solids in Gerlach boxes

The samples collected in the field contained the soils trapped in the Gerlach boxes, which were removed using common tools (brushes, spatulas, and teaspoons). Subsequently, they were preserved in plastic containers with their respective labelling and then the samples were processed in the laboratory. To homogenise the measurement, moisture was removed from the soil samples at 30 C º for 72 hours. Three fractions were quantified: on the one hand, organic material (remains of leaves, wood, animal remains, etc.), on the other hand, soil passing through a 2 mm sieve and finally coarse elements (Figure 5).

Figure 5 Detail of the material used in the process of soil collection in the Gerlach box of the experimental field of cover crop versus tillage carried out in Elvillar (Araba) from 1/04/20 to 31/03/2022.

Quantification of dissolved solids in runoff water

On the other hand, the second part of the sample of each experimental microplot is the water with dissolved solids collected in each drum connected to the Gerlach box. The total volume of water collected was measured and a representative sample was taken in sterilised containers. In turn, 250 ml of each sample (or the amount collected in each if less) was taken and evaporated in a forced air oven at 80 C⁰ for 24 hours (Figure 6). In this way, the dissolved solids in the sample were obtained by the difference in weight of the containers with and without sample, so that it could be calculated on the total amount of water collected in the drums.

Figure 6 Water samples processing and measurement of soluble solids in the canister of the cover crop versus tillage experimental field carried out in Elvillar (Araba) from 1/04/20 to 31/03/2022).

Quantification of total erosion

Once the soil collected in the Gerlach box and the dissolved solids in the canister had been quantified, the two values were added together to give the total erosion rates for each treatment. Calculations were then made to express the result in kg ha^{-1}.

Nutritional status of the vineyard

Analysis of the concentration of N, P, K, S, Ca, Mg, Fe, Mn, Cu and Zn was carried out on the petiole at veraison, taking between 50-60 leaves per elemental plot. The adult leaves were fully formed, healthy, without necrosis or yellowing and in the opposite position to the second bunch. The petioles were collected at veraison, on 26 August 2021 and 17 August 2022. Once the samples had been processed (drying at 65ºC, grinding and sieving), digestion was carried out in a closed vessel, using microwave equipment. The digestion was carried out with a mixture of nitric acid (0.5 ml) and water (2.5 ml). Once the samples were digested, the analytical reading of minerals and metals in foliar samples was carried out in an optical ICP. This was the process carried out for all nutrients except for N, which was measured by electrothermal combustion (DUMAS method).

Vegetative growth and yield properties

The yield, number of bunches, number of shoots and weight of pruning wood of all vines in each elementary plot (36 vines $plot^{-1}$) were measured during the three years of thefield experiment, in the harvest years 2020, 2021 and 2022. The harvests took place on 29 September 2020, 18 and 19 October 2021 and 20 and 21 October 2022.
Consequently, other parameters and indices of interest can also be calculated: average bunch weight, average shoot weight, fertility index and Ravaz index.

Grape, must and wine quality properties

Once the grapes were harvested, all the grapes were taken to the Maisulan winery in boxes identified by each treatment and elementary plot. The grapes were processed (destemmed and crushed) for subsequent vatting in the fermentation tanks (stainless steel tanks, always-full style, 150 L capacity). Once vatted, the must was homogenised so that 100 ml of sample were taken individually for qualitative analysis in the laboratory of the Provincial Council of Alava (Casa del Vino), located in Laguardia (Alava). The parameters analysed were probable alcohol content, pH, total tartaric acidity, L-malic acid, tartaric acid and yeast assimilable nitrogen.

The same proportional management was applied to the microwinemakings of each plot, with no acidity correction (basically because the Graciano variety is sufficiently acidic to withstand fermentation) and receiving the same dose of sulphur dioxide (SO_2), yeasts, nutrients, and bacteria to carry out the malolactic fermentation (MLF), depending on the volume of each tank (between 60-90 L approximately).

During alcoholic fermentation (AF), a gentle daily punching down (manual pumping over to break the cap and allow oxygen to enter and improve skin contact) was carried out and the temperature (ºC) and density of each tank were recorded daily to control the rate of fermentation and avoid stoppages or other fermentation problems.

To confirm the completion of AF, the reducing sugars were analysed to verify that the wine was "dry". Similarly, to confirm the completion of malolactic fermentation, the level of L-malic acid was analysed and, if necessary, other parameters such as volatile acetic acidity, pH and levels of free SO_2 and total SO_2, in order to correct the levels of free sulphur in the wine and keep it protected.

In any case, once the completion of the MLF was confirmed, a complete study of each tank was carried out, analysing the parameters: acquired degree, pH, total tartaric acidity, colour intensity, total polyphenol index, tannins, anthocyanins, potassium and yeast assimilable nitrogen. If it is of interest, the analysis could also be completed with parameters such as: lactic acid, or total dry extract.

Determination of precipitation

To determine the daily rainfall, the records of the reference meteorological station located in Páganos (Euskalmet, 2022) were considered. To cross-check this information and to identify more localised storms, rain gauges with an accuracy of 0.2 mm were installed in each elementary plot of the trial.

Statistical analysis

A total of 43 sampling dates of suspended solids were quantified during the two years of sampling, between 01/04/2020 and 31/03/2022. To determine the efficiency of the use of cover crops against erosive processes versus tillage, an analysis of variance was carried out using SAS v 9.3 (SAS Institute Inc., North Carolina, USA) for each of the dates. When the probability associated with the analysis was less than 10%, the means analysed were different. Analyses of variance were also carried out for total erosion and for all the properties analysed related to vegetative growth, production, nutritional status, and quality of grape must and wine.

5. What results have we obtained from the pilot action?

Soil properties

Figure 7 and Figure 8 show the daily rainfall collected at the weather station in Páganos during the test period. In the period from 1/04/2020 to 31/03/2021 a total of 490 mm accumulated rainfall was measured and 503 mm from 1/04/2021 to 31/03/2022. The most relevant rainfall events, in terms of accumulated rainfall in one day, around summer season occurred on 25/06/2020 with 26.3 mm and on 16/06/2021 with 27.1 mm. In the case of the autumn-winter months, a total of 350 mm accumulated in 2020 and 240 mm in 2021 in the period November-January. In addition, there were 9 precipitation events of more than 15 mm in these months. The most extreme event was recorded on 28/11/2021 with 39 mm in one day.

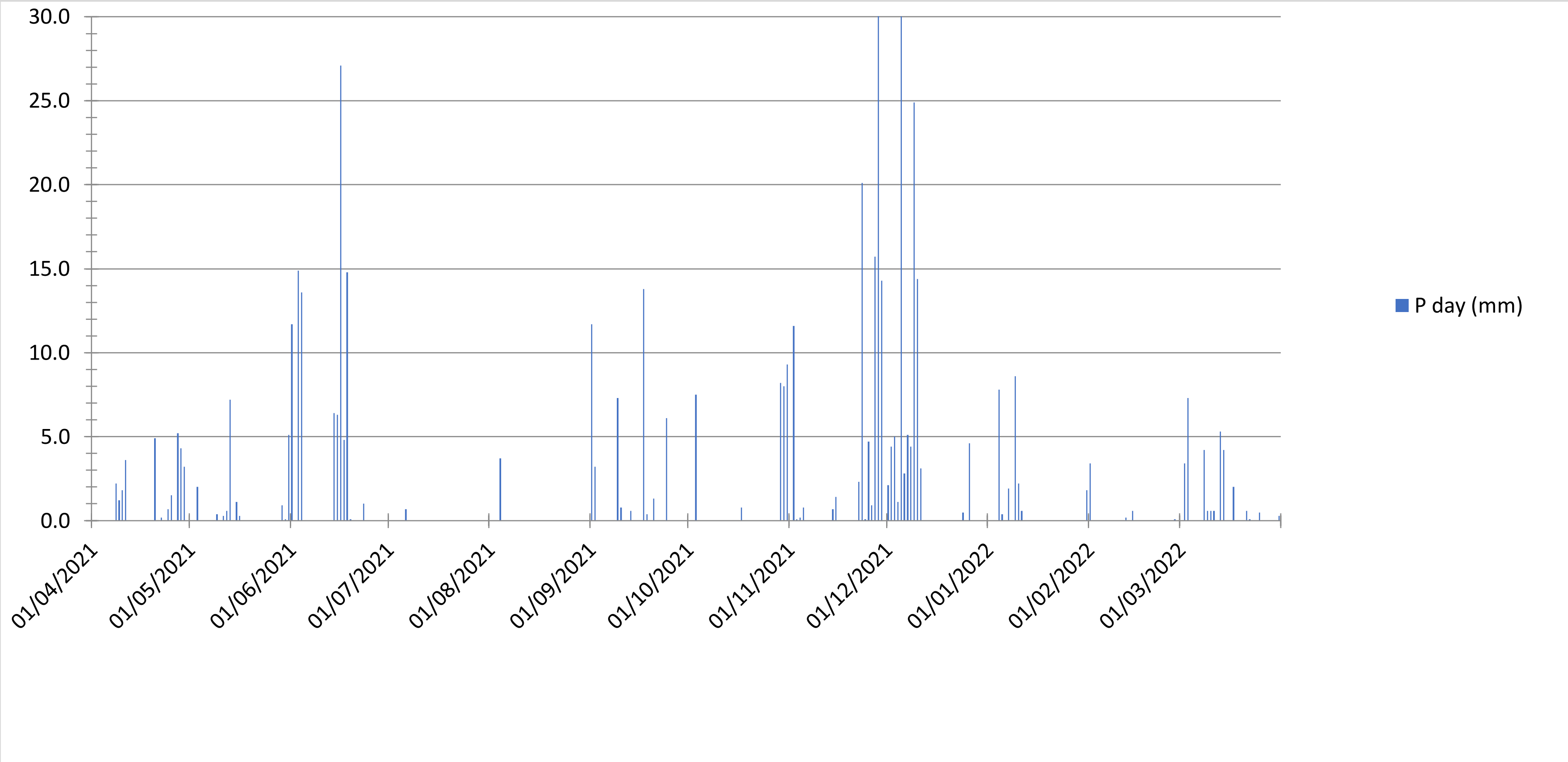

Figure 7 Daily precipitation collected at Páganos weather station in the period 1/04/2020 - 31/03/2021.

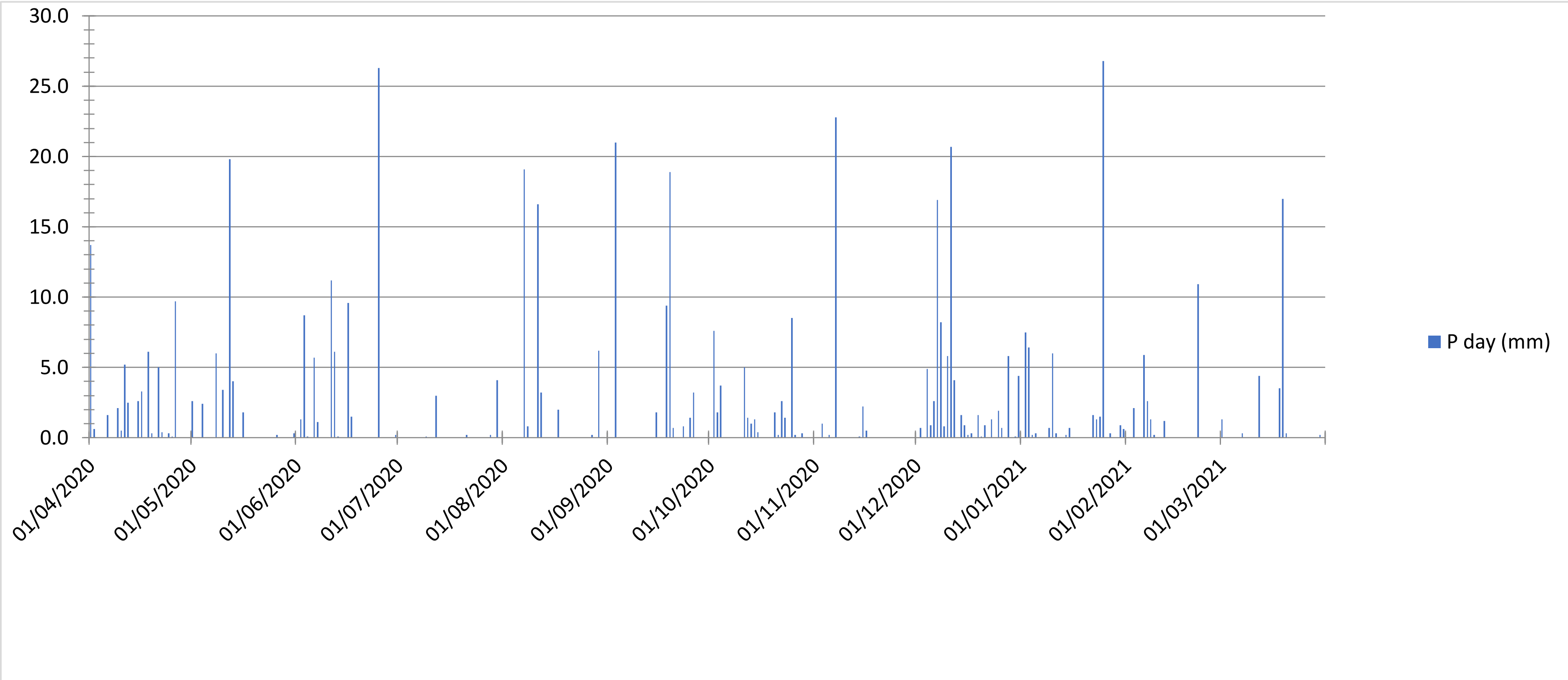

Figure 8 Daily precipitation collected at Páganos weather station in the period 1/04/2021 - 31/03/2022.

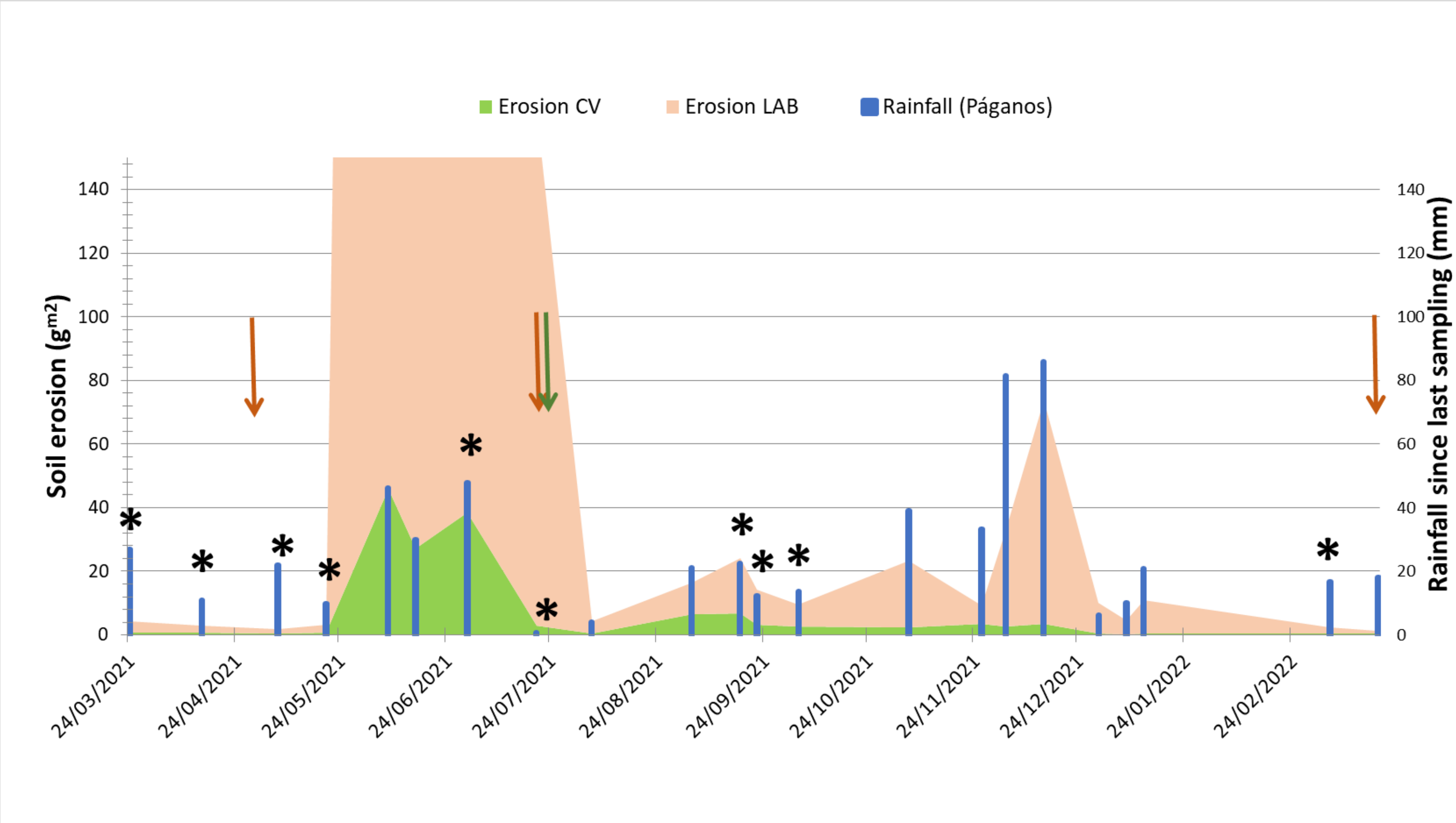

Figure 9 Accumulated precipitation between samples taken at the Páganos weather station and at the rain gauge located in the experimental field and erosion rates for each treatment (CV, vegetation cover and LAB, tillage) in the Elvillar trial (Álava). Brown arrow indicates date of ploughing, green arrow indicates date of cutting the vegetation cover.* Significant differences in erosion between the two treatments tested. The maximum value of very intense erosion events has not been represented in order to better appreciate those with a lower erosion rate. Period 2020-2021.

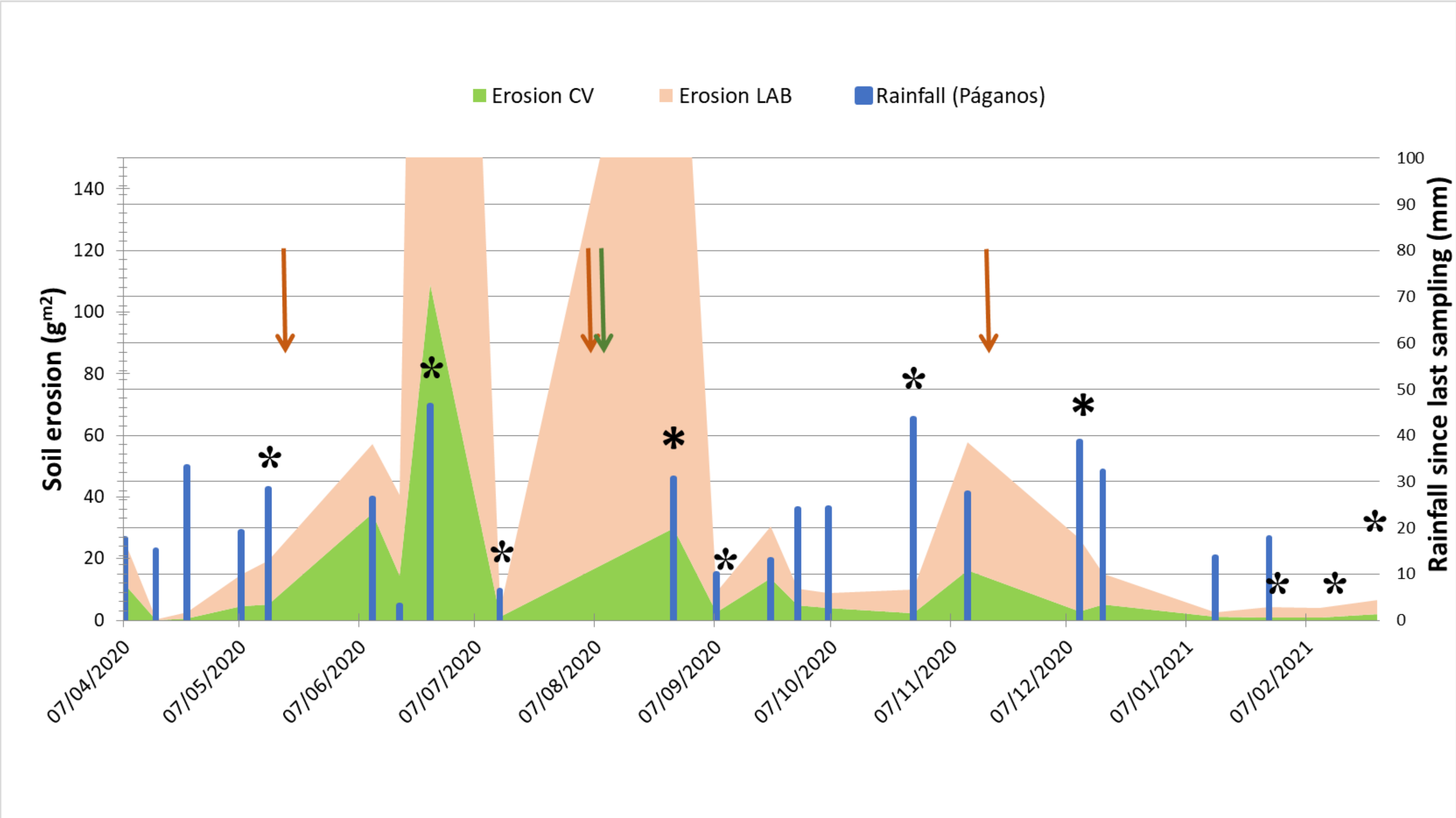

Figure 10 Accumulated precipitation between samples taken at the Páganos weather station and at the rain gauge located in the experimental field and erosion rates for each treatment (CV, vegetation cover and LAB, tillage) in the Elvillar trial (Álava). Brown arrow indicates date of ploughing, green arrow indicates date of cutting the vegetation cover.* Significant differences in erosion between the two treatments tested. The maximum value of very intense erosion events has not been represented in order to better appreciate those with a lower erosion rate. Period 2021-2022.

Figure 9 and Figure 10 show that the amount of sediment mobilised is clearly higher in the tillage treatment than in the cover crop treatment in all samplings. According to the statistical analyses carried out, significant differences were found between the cover crop and tillage treatments on twenty sampling dates (Table 3). In all cases, measured erosion was higher in the tillage treatment.

Table 3 p-value resulting from the analysis of variance that evaluates whether the means of each treatment are significantly different in the trial carried out in Elvillar (Araba) from 1/04/20 to 31/03/2022. CV, cover crop, LAB, tillage treatment.

Date	CV (g m^{-1})	LAB (g m^{-1})	p value
14/05/2020	5,26	14,02	0,0822
25/06/2020	108,89	477,43	0,0192
13/07/2020	1,08	2,52	0,0395
27/08/2020	29,93	227,78	0,0935
07/09/2020	2,47	6,67	0,0344
28/10/2020	2,19	7,71	0,00116
10/12/2020	2,78	23,70	0,0971
28/01/2021	0,98	3,36	0,048
10/02/2021	0,96	2,99	0,00931
25/02/2021	1,96	4,59	0,0083
24/03/2021	0,76	3,56	0,00362
14/04/2021	0,72	2,32	0,037
06/05/2021	0,41	1,50	0,0207
20/05/2021	0,74	2,49	0,0289
30/06/2021	38,47	694,22	0,0193
20/07/2021	3,02	161,64	0,0603
17/09/2021	6,66	17,56	0,0689
22/09/2021	3,14	11,13	0,00166
04/10/2021	2,52	7,13	0,0346
07/03/2022	0,50	1,89	0,00333

Events where more than 100 g m^{-2} of sediment was collected in the tillage treatment occurred between June and August and were generally preceded by rainfall greater than 15 mm day^{-1}. In 2021 it was in the months of June and July that rates greater than 100 g m^{-2} of erosion were collected in the tillage treatment. One of these samplings was on 30 June and was preceded by rainfall greater than 15 mm day^{-1}, but this was not the case for the 20 July sampling. As the plot rain gauge recorded cumulative rainfall it is not possible to know if a heavy storm occurred on any of the days prior to sampling. Summer storms tend to be very localised, and it is possible that a storm occurring at the plot did not occur at the Páganos station. It should be noted that on the dates mentioned in the previous paragraphs, there was also an erosion peak in the vegetation cover treatment, but in this case the values recorded were much lower.

Period	Spontaneous crover crop		Conventional tillage	
	Average	Standard deviation	Average	Standard deviation
01/04/2020 – 31/03/2021	2,7	0,23	9,3	1,06
01/04/2021 – 31/03/2022	1,5	0,13	26,5	3,11
Annual average (t ha^{-1} $year^{-1}$)	2,1	0,09	17,9	1,14

Table 4 Total average accumulated erosion per treatment during the two field experiment campaigns, from 1/04/2020 to 31/03/2022, in Elvillar (Araba).

Analysing cumulative erosion, the bare soil treatment causes more erosion than the treatment with spontaneous vegetation cover (Table 4). If these values are expressed in tonnes per hectare, considering the difficulties of changes in scale, the average annual loss for each treatment would have been 2.1 (±0.09) t ha^{-1} yr^{-1} in the case of vegetation cover and 17.9 (±1.14) t ha^{-1} yr-1 in the case of tillage. In other words, the tillage treatment caused eight times more erosion than the spontaneous vegetation cover treatment.

Vineyard nutrition related properties

Table 5 Nutrient concentration in petiole at veraison in 2021 and 2022 for each treatment in the field experiment in Elvillar at the Maisulan winery.

		N (g 100g-1)	P (g 100g-1)	K (g 100g-1)	Ca (g 100g-1)	Mg (g 100g-1)	S (g 100g-1)	Mn (mg kg-1)	Fe (mg kg-1)	Cu (mg kg-1)	Zn (mg kg-1)
2021	Spontaneous crover crop	0,40	0,08	2,80 a*	2,07	0,71 a	0,09	11,9 b	<150	126,7	47,1 a
	Conventional tillage	0,36	0,13	2,23 b	2,32	0,77 a	0,09	16,0 a	<150	71,3	32,4 b
	Combined management	0,38	0,14	2,92 a	2,13	0,62 b	0,10	9,5 b	<150	91,4	41,3 ab
2022	Spontaneous crover crop	0,35	0,06 b	2,39	2,10	0,84	0,07	17,0	<150	3,3	31,9
	Conventional tillage	0,36	0,11 a	2,27	2,33	0,93	0,07	16,3	<150	2,8	27,5
	Combined management	0,37	0,11 a	2,80	2,16	0,78	0,08	13,0	<150	4,1	31,9

*Means with different letters correspond to significantly different values between treatments.

In the year 2021, the K and Zn content in the petiole was higher in the cover crop (Table 5) than in the tillage treatment. In contrast, the Mn level was higher in the tillage treatment. In the case of Mg, cover crop and tillage obtained similar values, higher than in the combined management treatment. In 2022, significant differences were only detected for P, whose content was higher in the tillage and combined management treatments and lower in the cover crop treatment..

Properties related to vegetative growth and yield

Differences in vegetative growth are already observed in the first year (Table 6), with higher growth in the tillage treatment. In the second year, these differences are accentuated and a decrease in pruning weight of 32% is observed in the combined management and 47% in the cover crop treatment. In 2022, the weight of pruning in the cover crop and combined management treatments is maintained with respect to the previous year, but the decrease in growth in the tillage treatment with respect to the other two is greater, probably due to the severe drought experienced that year. However, the tillage treatment still had a higher pruning weight than the other two treatments. In both years, the combined management treatment showed intermediate growth compared to the cover crop and tillage treatments.

Regarding yield, in the first year no significant differences were detected between treatments, although the trend is clearly towards lower production as the intensity of the cover increases. In the second and third year, these differences are clearer and the two cover treatments show a significant reduction in yield of 21-38%. It should be noted that the experiment is located in the most productive area of the whole field, therefore the average yield of the commercial plot is lower. These differences in yield between treatments are due to the lower number of bunches and to their lower weight (Table 6).

Grape, must and wine quality properties

In the first two years of the experiment there were no differences in the probable must grade between treatments, but in the last year a lower value was observed in the tillage treatment (13.9 %) compared to the cover crop treatment (15.0 %) (Table 6).

The tillage treatment showed a higher concentration of malic acid in must which was only significant in the first and third year The K concentration in wine was lower in the mulch treatment in the second and third year (Table 6).

Table 6 Average values of yield, vegetative growth, and quality of grape, must and wine as a function of year and treatment at the Elvillar experimental field.

	2020			2021			2022		
	Spontaneus cover crop	Combined management	Tillage	Spontaneus cover crop	Combined management	Tillage	Spontaneus cover crop	Combined management	Tillage
Yield (kg cepa^{-1})	2,47	2,52	2,72	3,18 b	3,37 b	4,26 a	2,47 b	2,91 b	3,98 a
Cluster number (cluster vine^{-1})	8,4	8,6	8,2	10,4 b	10,4 ab	12,1 a	9,1 b	8,6 b	11,3 a
Average cluster weight (g)	301	304	329	304 b	326 ab	351 a	255 b	330 a	358 a
Prunning wieght (g vine^{-1})	676 b*	628 b	866 a	384 c	493 b	725 a	360 c	480 b	560 a
Probable degree (must) (% Vol)	13,6	13,1	13,3	13,2	13,4	13,4	15,0 a	14,8 ab	13,9 b
pH (must)	3,18	3,14	3,19	3,19	3,23	3,26	3,31	3,32	3,31
Total tartaric acidity (must) (g L^{-1})	5,46	5,64	5,56	5,19	5,15	5,03	4,22	4,25	4,35
Malic-L-acid (must) (g L^{-1})	1,4 b	1,4 b	1,7 a	1,2	1,4	1,5	0,7 b	0,9 ab	1,1 a
Yeast assimilable nitrogen (must) (mg L^{-1})	57	50	60	81	86	96	37	40	44
Colour intensity (wine) (A420, A520, A620)	-	-	-	11,92	11,39	11,26	18,34	17,19	16,07
Total poliphenolic Index (wine) (A280)	-	-	-	38	39	40	61	60	53
Anthocyanins (wine) (mg L^{-1})	-	-	-	411	418	394	719	681	587
Tannins (wine) (g L^{-1})	-	-	-	1,48	1,55	1,58	2,31	2,30	2,06
Potassium (wine) (mg L^{-1})	-	-	-	632 b	761 a	774 a	919 b	1007 a	962 ab

*Means with different letters correspond to significantly different values between treatments.

6. Discussion

Soil properties

Figure 9 and Figure 10 showed the difference between the erosion rates for the two treatments, where in the case of rainfall events above 15 mm they are approximately four times higher than in the case of events below 15 mm. Therefore, light rainfall events distributed over time do not have as high erosion rates as torrential rainfall events.

As for the erosion rates observed in the autumn and winter months, it must be taken into account that these are the periods when the greatest amount of accumulated rainfall and nine rainfall events greater than 15 mm are collected. This explains the peak observed in erosion rates in November-January, when the soil had the lowest infiltration rate due to the high moisture content and high compaction of the plough layer (Kosmas et al., 1997).

Similarly, we observed that regardless of rainfall intensity, vegetation cover treatment results in lower erosion rates compared to tillage. This is because the vegetation cover creates a physical barrier on the surface, increasing the tortuosity of surface water flow, thus reducing the capacity of runoff to carry sediment (Kosmas et al., 1997). This difference is also due to the natural creation of a crust on bare or tilled soils. The splash effect is caused by the impact of raindrops, which behave like small pumps when falling on exposed soil, displacing soil particles and creating a crust or seal (Angulo-Martínez et al., 2012). This crust minimises infiltration capacity and increases runoff considerably, and consequently water erosion (Bienes et al., 2012). Although some studies show that higher erosion rates coincide with tillage dates (Kirchhoff et al., 2017), no such relationship was found in this work (Figure 9 and Figure 10). This may be due to the fact that newly tilled plots increase roughness, impeding the advance of the runoff water sheet. Therefore, after the first rainfall, tilled soils generate little runoff, but subsequently, if they are not tilled, they generate the aforementioned sealing, increasing runoff and erosion (Garcia-Díazet al., 2019).

Marques et al. (2010) stated that the benefits of vegetation cover increased with increasing rainfall intensity. According to their study, soil loss under traditional tillage treatments was five times higher than in the cover crop treatment under low intensity storms but increased to 30 times higher under extreme rainfall. These differences were also apparent in this trial, where the total soil loss under tillage treatment was on average 8 times higher than in the cover crop treatment, but increased to 20 times higher in the case of extreme rainfall events such as the one recorded on 30/06/21, which was preceded by a rainfall event of 27.1 mm.

On the other hand, this study shows that the vegetation timing of the cover is also a factor to be considered. It can be observed that the highest rates of soil loss were quantified during summer storms, when vegetation is naturally reduced due to the dry conditions and torrential rainfall characteristic of this climate (Nicolau et al., 2002).

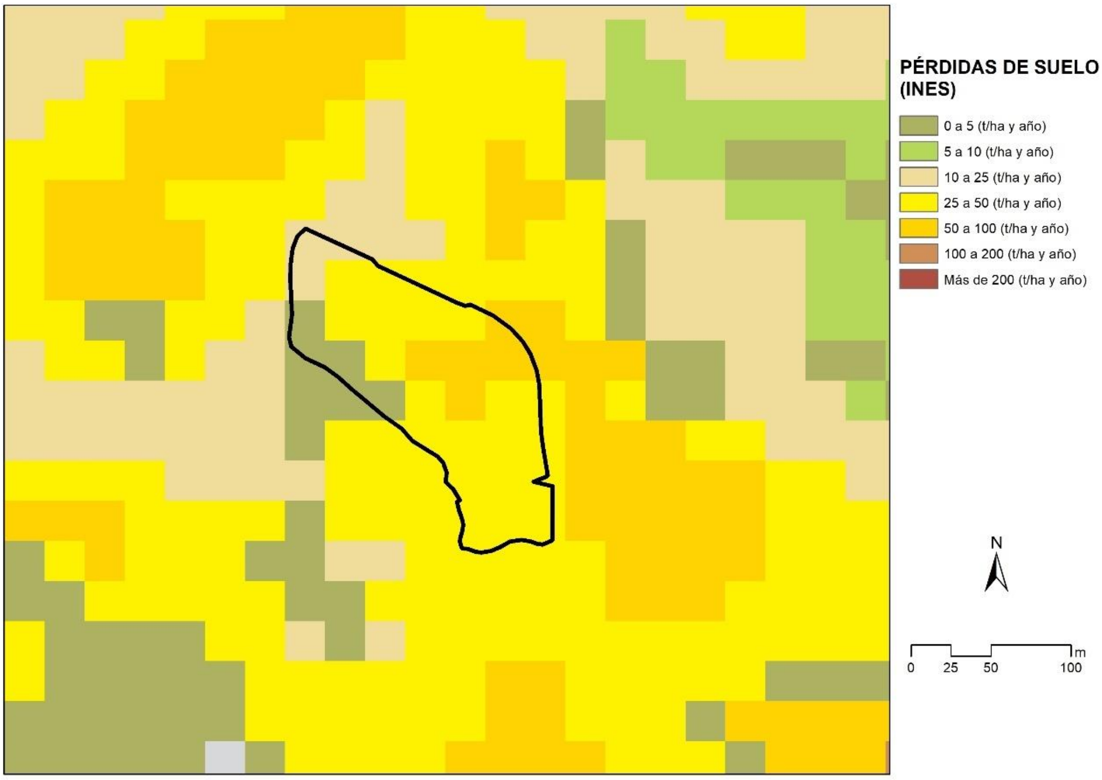

Figura 11 Real soil erosion rates calculated according to the RUSLE model in the experimental field in Elvillar (Álava) where the erosion test was carried out (INES, 2018).

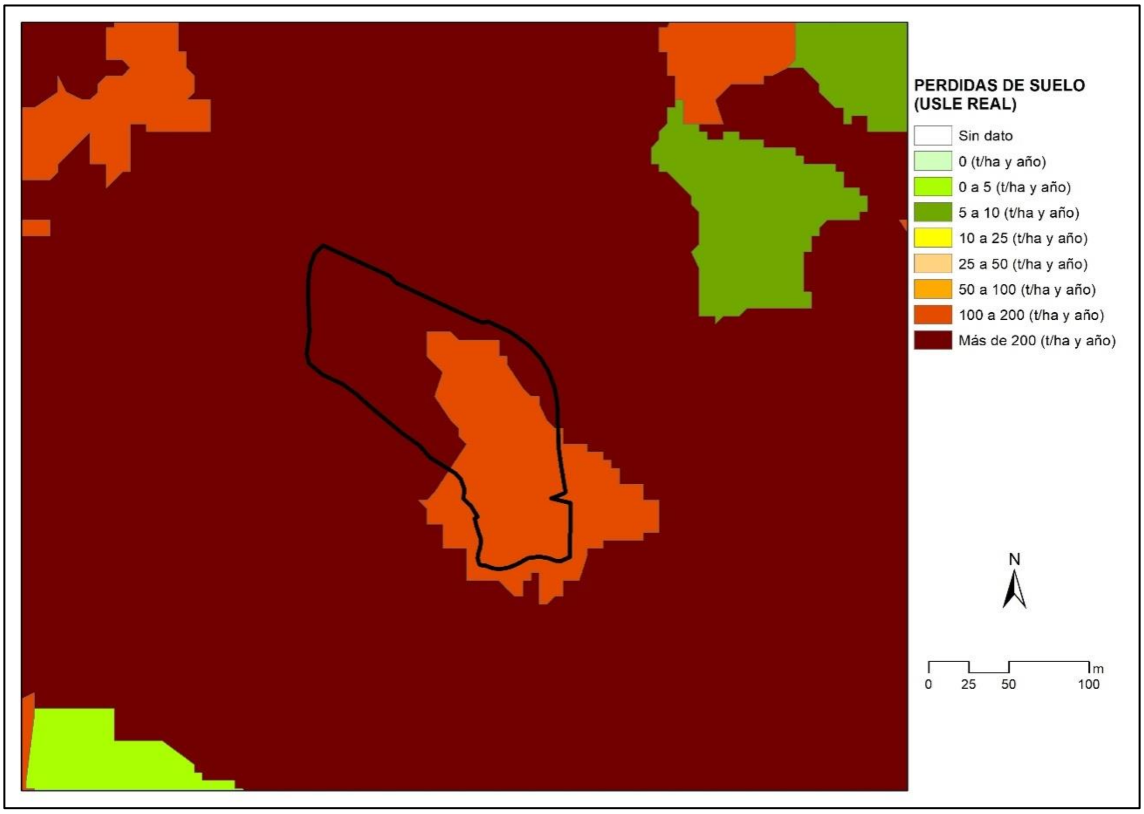

Figura 12 Real soil erosion rates calculated according to the USLE model in the experimental field in Elvillar (Álava) where the erosion test was carried out (IDER, 2005). The map according to the RUSLE model is not presented because it did not have data for the field in question.

The results show that the differences between the two treatments increase in the second year, with erosion rates decreasing in the case of cover crop and increasing in the case of tillage. According to the study carried out by Nicolau et al. (2002), a decrease in soil loss over time was observed with vegetation cover, with almost no soil loss. It would be of great interest to carry out long-term studies with different plant cover alternatives suitable for the climate studied, to analyse whether it is possible to reduce erosion to natural values.

The estimated tolerable soil loss rate to ensure soil sustainability is 1 t ha^{-1} yr^{-1} (Verheijen et al., 2009). However, in Europe, erosion rates are between 3 and 40 times higher than this limit, with considerable spatial and temporal variation. Erosion rates in vineyards under Mediterranean climate were measured as high as 16 t ha^{-1} yr^{-1} in Sicily, Italy (Novara et al., 2017), 10.9 t ha^{-1} yr^{-1} in levelled vineyards in Barcelona, Spain (Ramos et al., 2006), 0.4 and 1.8 t ha^{-1} yr^{-1} under conventional tillage and 0.02 and 0.32 t ha^{-1} yr^{-1} with different plant covers (*Brachypodium distachyon*, spontaneous vegetation, rye and barley) in Madrid and Cuenca, Spain (Bienes et al., 2012) and between 4.5 and 90 t ha^{-1} yr^{-1} under conventional tillage and between 0.7 and 42.7 t ha^{-1} yr^{-1} with vegetation cover in vineyards in France, Spain and Portugal (Gómez et al., 2011).

The annual erosion rates obtained in this study are found to be in the same range as those found in other vineyards under Mediterranean climate, although, of course, there are variations probably due to different soil types, slope, type of cover, etc. In any case, both the literature and the data presented in this work reflect the lack of sustainability of soil management by tillage.

The amount of soil loss estimated in the study Inventario Nacional Erosión Suelos (INES, 2018) for the area of the experiment in the study plot ranged between 25 t ha^{-1} yr^{-1} and 50 t ha^{-1} yr^{-1} (Figura 11). These values coincide with those obtained in this study for the traditional tillage treatment (17.9 t ha^{-1} yr^{-1}). However, the real erosion values according to the USLE equation obtained in the work of IDER (2005), which is uploaded on Geoeuskadi's Visor, are much higher (Figura 12) than those obtained in this work (between 100 and more than 200 t ha^{-1} yr^{-1}).

Vineyard nutrition related properties

In 2021, the K content in petiole in the cover crop and combined management treatments was higher than in the tillage treatment. The higher yield of the latter treatment may be the cause of these differences, since it is known that the fruit is an important sink for this nutrient, which lowers the K content in the leaf. Decreases in leaf K concentration due to fruit production have been reported by several authors (Bould, 1966; Van der Boon et al., 1966; Hansen, 1973; Jadczuc, 1993; Sadowski et al., 1995). On the other hand, Mn content was higher in the tillage treatment and lower in the cover crop treatment, and the opposite was true for Zn. In another study (Kortabarria, 2017) carried out in Rioja Alavesa, it was observed that plant cover tended to favour the concentration of Mn and Zn in leaves. This does not coincide with the results of this study in the case of Mn. The reason given for the increase in leaf Mn and Zn concentration under cover crop management was the acidification of the rhizosphere due to the release of H^+ by the roots. The roots of some plants tend to release H^+ when the total uptake of cations exceeds that of anions, causing a decrease in pH in the rhizosphere (Grinsted et al., 1982). Therefore, considering that Zn solubility is higher at more acidic pH (Sims, 1986), it may be that plant covers would have resulted in higher Zn availability for grapevines (Abbas et al., 2016).

In 2022, the only nutrient for which significant differences were observed between treatments was P. Thus, the cover crop treatment had lower concentrations in the petiole than the other two. This may indicate that the vineyard roots are exploring deeper layers of soil than the other treatments, since soil P content tends to decrease in depth. It may also be due to the competition for this nutrient that increases in the case of plant cover, especially considering that the P content in the soil is very low. Perhaps the behaviour of Zn may be influenced by that of P, since they are nutrients that behave antagonistically to each other. It should be noted that although the P content in petiole does not vary significantly depending on the treatment, in 2021 the trend observed for this nutrient is the same as in 2022.

Vegetative growth and yield properties

The decrease in vegetative growth in the spontaneous plant cover treatment coincides with the findings of Abad et al. (2021) in their systematic review. Thus, in 50% of the studies reviewed, the reduction in growth was greater than 20%, and in 45% of the studies less than 20% with respect to the tillage treatment. It should be noted that in a trial conducted over five years in the same region in the town of Oion (Araba), a reduction in pruning weight was observed due to the plant cover (in this case barley) despite the fact that the soil had a high water storage capacity due to its great depth (Kortabarria, 2017).

As for the decrease in yield, other authors, such as Aguirrezábal et al. (2012) in a 10-year trial carried out in Navarra, also detected it and related it to the % of soil covered. This reduction is partly caused by a decrease in the number of bunches from the second season onwards, which is also observed in this study. The reduction in the number of bunches could be explained by the competition of spontaneous vegetation for nitrogen and water that occurred in the first season during floral differentiation, as explained by Guilpart et al. (2014). In addition, a lower bunch weight was also detected in the cover crop treatment, but as observed by Aguirrezábal et al. (2012) in the combined management treatment there were no differences in bunch weight with respect to tillage.

Grape, must and wine quality properties

No differences were observed for pH, total tartaric acidity, colour intensity, total polyphenol index, anthocyanins and tannins. These results coincide with the findings of Abad et al. (2021) in their article, where 90% of the works consulted showed no differences in pH. However, in the case of polyphenols, they detected divergent results and pointed to yield reduction as the cause of the increase in polyphenols in those cases where a loss of yield caused by plant cover was observed. In the case of the Kortabarria (2017) trial, in general, both polyphenols and colour as well as anthocyanins improved with the treatment of barley cover crop in a deep soil.

The probable must grade was reduced in the year 2022 in the cover crop treatment, and did not vary in the other two years. This is in line with Abad et al. (2021) who found that in general (68% of cases) there was no difference in grape sugar concentration. However, in cases where plant cover caused a probable increase in alcohol content, it was associated with a decrease in yield, as in this case.

K concentration in wine was lower in the 2022 canopy treatment, indicating that there was competition for this nutrient. The potassium content of the soil in this plot was not very high (86 and 102 mg kg^{-1} from 0-10 and 10-30 cm depths respectively), and was probably not sufficient to provide the necessary nutrients to the cover crop without competing with the vineyard. In other studies such as the one carried out by Pérez-Álvarez et al. (2015) and Kortabarria (2017), this decrease in K in wine was not observed in the treatments with cover crop, but the K content in soil was significantly higher. It is worth noting the low values of yeast assimilable nitrogen, which, however, did not show significant differences between treatments.

7. Conclusions

The first erosion measurements carried out in a vineyard in Rioja Alavesa show that spontaneous cover crop reduce erosion losses compared to tillage. Thus, annual soil losses would be 2.1 t ha-1 yr-1 and 17.9 t ha-1 yr-1 for cover crop and tillage treatments respectively. This is very interesting, especially for vineyards such as the one studied, which are on a slope. However, under the soil and climatic conditions analysed, the reduction in erosion rates is not sufficient to avoid soil degradation, as even the plant cover treatment exceeded the estimated tolerable soil loss rate to ensure soil sustainability (1 t ha^{-1} yr^{-1}).

Cover crop competed with the vineyard for water and nutrients, and this leads to reduced vegetative growth and yield of the vineyard. In the three years of field experiment, variations in quality were not significant. It is important to know the magnitude of the yield decline, as well as the variation in grape and wine quality, for growers to make the most appropriate soil management decisions.

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