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Sustainable Viticulture: Effects of Soil Management in *Vitis vinifera*

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Received: 19 October 2020; Accepted: 8 December 2020; Published: 11 December 2020

Abstract: Soil management in vineyards is of fundamental importance not only for the productivity and quality of grapes, both in biological and conventional management, but also for greater sustainability of the production. Conservative soil management techniques play an important role, compared to conventional tillage, in order to preserve biodiversity, to save soil fertility, and to keep vegetative-productive balance. Thus, it is necessary to evaluate long-term adaptation strategies to create a balance between the vine and the surrounding environment. This work sought to assess the effects of following different management practices on *Vitis vinifera* L. cv. Cabernet Sauvignon during 2017 and 2018 seasons: soil tillage (T), temporary cover cropping over all inter-rows (C), and mulching with plant residues every other row (M). The main physiological parameters of vines (leaf gas exchange, stem water potential, chlorophyll fluorescence, and indirect chlorophyll content) as well as qualitative and quantitative grape parameters (technological and phenolic analyses) were measured. Significant differences in gas exchanges related to the different season and inter-row management were observed. C showed more negative values of water potential, due to the grass–vine competition, especially when water availability was lower. The competition exerted by C led to differences in fruit setting with impact on yield; therefrom, significant differences also in sugar and anthocyanic content were observed.

Keywords: soil quality in vineyard; sustainable viticulture; soil management; *Vitis vinifera* L.; grape quality; soil; tillage; mulching; cover cropping; cabernet sauvignon

1. Introduction

The European Community's focus on environmental protection issues and increased sensitivity on the part of agricultural entrepreneurs drive scientific research to sustainable production techniques for the environment [1]. To achieve sustainable viticulture, innovative techniques with low environmental impact must be identified and used, ensuring that productivity and quality are maintained over time [2,3].

Agriculture must be the natural balance between plant and atmosphere, to obtain healthier products and ward off environmental degradation [4–7].

Vineyard soil management has implications for wine quality [8,9]: soil conservation, weed management, improvement of soil nutrients, water content, biodiversity for pest control, and resource availability regulation (i.e., water, nutrients) is very important aspects to control vine vigor, vine growth, and influencing desirable targets in wine quality [10–14].

Inter-row vegetation, in vineyards, is controlled by grassing, green manure, mulching, tillage, and/or the application of broadband herbicides [15–20]. The knowledge about the effects of tillage on soil biodiversity and soil biological properties is of great interest [21–23].

It has been shown that the vineyard inter-row soil management affects grapes; nonchemical weed control (harrowing, mulching), tillage and nutrient application, and other interventions affect vine functioning to varying extents [24–26].

Soil management methods have an effect on photosynthesis and stomatal conductance of the vines [27,28] and the nutrient uptake of the grapes is affected by soil temperature, soil compaction, and soil moisture. For example, a positive correlation between the high soil temperature and the uptake of nitrogen (N), potassium (K), calcium (Ca), and magnesium (Mg) exists [29].

Unfavorable soil conditions, such as low water content due to mishandling of soil, can cause plant stress, with negative effects both on growth and yield [30–32]. Water deficit also decrease photosynthetical activity [33,34] and affects the differentiation and abortion of flowers, fruit sets, and berry sizes [35,36].

Cover cropping, in territories with very low summer rainfall and with high evaporative demand, can be detrimental if the competition for water leads to severe vine water stress and consequently to negative effects on berry quality, yield, and growth [37]. Grapevines growing under heat stress experience a significant drop in photosynthesis due to stomatal limitations, leading to a reduction in water use efficiency [38]. In high vigor situations, the management of the green soil covers can lead to an improvement in the state of the vines because the increase in water consumption can lead to reduction of the vegetative growth of the vine and as a result an advantage in the microclimate of the fruit area and in the quality of the grapes can be obtained [39–41]. Many scientific experiments and tests have been carried out to better detect the influence of different floor covers in grapevine vegetative growth, yield, berry, and wine quality [9,41–43]. In the Mediterranean basin vineyard cover cropping is still debated and the few results of the scientific experiments are often contradictory and conflicting [44].

Cover cropping is considered as the practical application of ecological principles such as diversity, crop interaction, and other natural regulation mechanisms [45]. Available resources, such as light, water, and nutrients are more efficiently used by the intercrop than by the main crop. Management of these differences in competitive capacities between crops and intercropping species could lead to yield advantages and produce crop quality improvements with consequent changes in grape quality, and decrease the herbicide use and associated risks, such as vine damage by spray drift, evolution of weed resistance [46,47].

Cover cropping in vineyards was a common practice in Europe [48]. Nowadays, vineyard cover cropping is widely used in areas with frequent summer rainfall to remove excess water and nitrogen, but the benefits of cover crops also include soil erosion control [49,50], nitrogen and organic matter management. For example, a reduction in the soil nitrate can induce a low level of must nitrogen content [51,52], improve soil structure, increase water penetration [53] and retention, decrease direct soil water evaporative losses, reduce grapevine vegetative vigor, thus enhancing grape and must quality [54,55].

According to Guerra and Steenwerth [9], cover crops can improve soil and vine health, and may influence vine vigor by adjusting parameters such as canopy efficiency and shoot growth period. Moreover, cover crops increased juice anthocyanins, soluble solids, and other phenolic components and decreased titratable acidity.

It is necessary to have a balanced vineyard system/intercropping, picking out crop species accurately and applying a suitable management to obtain benefits; the same studies [56–58] have shown that the use of cover crops in vineyards has detrimental effects, such as yield reductions due to water and nutrients competition.

Several studies found that pH were reduced by cover cropping relative to tillage due to an increase in the ratio of tartaric to malic acids [8,59]; another observed an increase in juice anthocyanins and tannins as affected by permanent cover crop [12,60]; this is probably due to a yield reduction and subsequent must concentration.

Mulch is any material, other than soil, placed or left on the soil surface for soil and water management purposes [61] and mulching involves leaving crop residues or other materials on the soil surface for soil and water conservation and keeping favorable and stable environments for vine growth [62]. The positive effects of mulching (both organic and/or synthetic) can be summarized as follows: (i) soil protection against the impact of rain and consequent erosion reduction [63], (ii) major water storage [64], (iii) improved infiltration capacity [65], (iv) decrease in evaporation [66], (v) improved soil structure and organic content [67], (vi) best root development [68], (vii) growing activity of some species of earthworms and crop performance [69].

Use of mulches in orchards has been found to increase plant growth and yields [70]; the yield increase as a result of mulch treatment was attributed to the improved soil environmental conditions of reduced diurnal temperature fluctuations and increased soil water availability for vine production [71]. Moreover, mulched compost can reduce water loss by evaporation and drainage into deeper soil horizons [72] and increased photosynthesis per vine (μmol CO_2 plant^{-1} s^{-1}) at flowering, when the berries were pea sized and at maturity [73].

Mulch composed of fresh plant residues increased grape juice titratable acidity (TA) and, in dry years, increased juice soluble solids [74] and increased the K content with a resulting slight increase in grape juice pH [75]. According to Coventry [76] mulch increased Brix, total phenolics, flavonols, and anthocyanins of "Cabernet Franc" berries at harvest compared to tillage.

Vineyard soil management practices with sustainable objectives can be considered as a first protection strategy to improve grapes quality and reduce the effects of climate change [77].

Considering the above, a research project to evaluate the effect of soil management practices on *Vitis vinifera*, cv. Cabernet Sauvignon was carried out in a Tuscan vineyard.

2. Materials and Methods

2.1. Experimental Design and Settings

The experiment was set up in the Chianti Classico area (Lat 43°39′35″ N–Long 11°11′5″ E), Tuscany, Italy, located at an elevation of 270 m a.s.l. facing South-West exposure. The measurements were performed from 2017 to 2018. The 10-year-old vineyard of the red cv. Cabernet Sauvignon (*Vitis vinifera* L.), clonal selection R 5, grafted on 420 A rootstock, was planted with a spacing of 1.2 m (between vines) × 2 m (between rows) (≈4166 vines/ha). Vines were trained on a vertical shoot positioning and spur-pruned with a single cordon system, at 70 cm above ground with six spurs (12 buds per vine).

The vines did not have irrigation and were grown using standard cultural practices. Soil horizons presented a clay texture with the following characteristics: clay 39.8%; silt 34.8%; sand 25.4%; organic matter 2.0%; pH (H_2O) 7.6. Soil analyses were performed according to the official method by the Italian Ministry of Agriculture.

The following three soil management methods were tested: mulching with straw and vegetable residues (M), cover crop (33% *Trifolium incarnatum*, 33% *Lolium multiflorum*, 33% *Festuca arundinacea*), (C) and mechanical cultivation tillage (T). Every treatment was located in five contiguous rows, with five replications per treatment. There was a total of 25 rows per management practice.

With mechanical cultivation, the soil was cultivated three times after the autumn ploughing. The straw and vegetable mulch were applied in the year 2017 (7 kg/m^2), and it was renewed in May 2018. The thickness of straw mulch layer was 3 cm based on the study by Sharma et al. [78]. The length of the trimmed vegetable mulch was about 5 cm.

Mean, maximum, minimum air temperatures (°C), and global radiation (W m^{-2}) of the growing season were collected daily from a weather station nearby (Ecotech, Germany) as well as rainfall (mm) and air relative humidity (%).

Eco-physiological measurements (as described thereafter) were performed on 10 vines/management (10 vine per treatment; two vine per replication) at three phenological stages: full veraison (100% of the berries presented full color change; 7 July 2017 and 17 July 2018; E–L 36 stage; [79]), mid maturation (28 July 2017 and 15 August 2018; E–L 37 stage; [79]), and full maturation (5 September 2017 and 17 September 2018; E-L 38 stage; [79]).

2.2. Leaf Gas Exchanges, Stem Water Potential, Leaf Chlorophyll a Fluorescence and Content

Net photosynthesis (P_n), stomatal conductance (g_s), and transpiration rate (E) were measured between 10 and 12 a.m. on 10 fully developed and intact leaves per treatment (one each vine, 10 replicates) using a portable infrared gas analyzer (model Ciras 3, PP Systems, Amesbury, MA, USA). Water use efficiency (*e*WUE) was calculated as the ratio of photosynthesis to transpiration. Measurements were performed, setting the leaf chamber flow at the prevailing environmental condition (ambient temperature, ambient CO_2 concentration ≈400 ppm, saturating photosynthetic photon flux of 1300 μmol $m^{-2}s^{-1}$) at the three phenological stages as mentioned above.

Stem midday water potential (MPa, Ψ_m) was determined between 12:30 a.m. and 13:30 p.m. with a pressure chamber (model 600, PMS Instrument Co., Albany, OR, USA) on 10 fully expanded leaves for soil management covered with aluminum foil at least 60′ before measurement [80].

Chlorophyll *a* (Chl-*a*) fluorescence transients of 30′ dark-adapted leaves were recorded using a chlorophyll fluorometer (Handy-PEA®, Hansatech Instruments, Norfolk, UK). F_v (the variable) and F_m (the maximal) Chl-*a* fluorescences were collected by applying a saturating flash of actinic light at 3000 μmol photons $m^{-2}s^{-1}$ for 1″ and used to calculate *Fv*/*Fm*: the maximum quantum yield of photosystem PSII following Maxwell and Johnson methodology [81]. Chl-*a* content in leaves was estimated by 502 SPAD device (Konica Minolta Inc., Tokyo, Japan).

Chl-*a* content, Chl-*a* fluorescence, and midday stem water potential were taken on the same leaves used for leaf gas exchange measurements at the same three stages.

2.3. Berry Composition

At harvest 100 berries were randomly harvested from each replication of every soil treatment (M, C, T) choosing 10 sample vines (10 berry samples per plant) to perform technological maturity assessments (total of 500 berries per treatment). The samples were individually weighed with a digital scale (PCE Italia Ltd., Capannori, Italy) and the berries were squeezed to analyze the content of sugar, pH, and titratable acidity (TA). The Brix (sugar content) was evaluated using a refractometer (ATAGO, Bellevue, WA, USA); pH was evaluated using a portable pH meter (Hanna instrument, Woonsocket, **RI**, USA), and g L^{-1} tartaric acid (TA) was calculated by manual glass burette on a 10 mL sample using 0.1 M NaOH to an end-point of pH 7.0. Another 100-berry sample/replication/treatment (10 berry samples per plant) was used to determine phenolic maturity parameters (i.e., phenolic contents and total and extractable anthocyanin) in berry [82].

2.4. Statistical Analysis

Soil treatments were investigated with one-way ANOVA ($p \leq 0.05$). Mean values (calculated and expressed as mean ± SE) were separated by Fisher's least significant difference (LSD) post-hoc test ($p \leq 0.05$). All statistical analyses were performed using SPSS Statistic 25 (IBM, Armonk, NY, USA).

3. Results

3.1. Climate Parameters

The 2017 and 2018 microclimate conditions of the experimental area are reported in Figure 1.

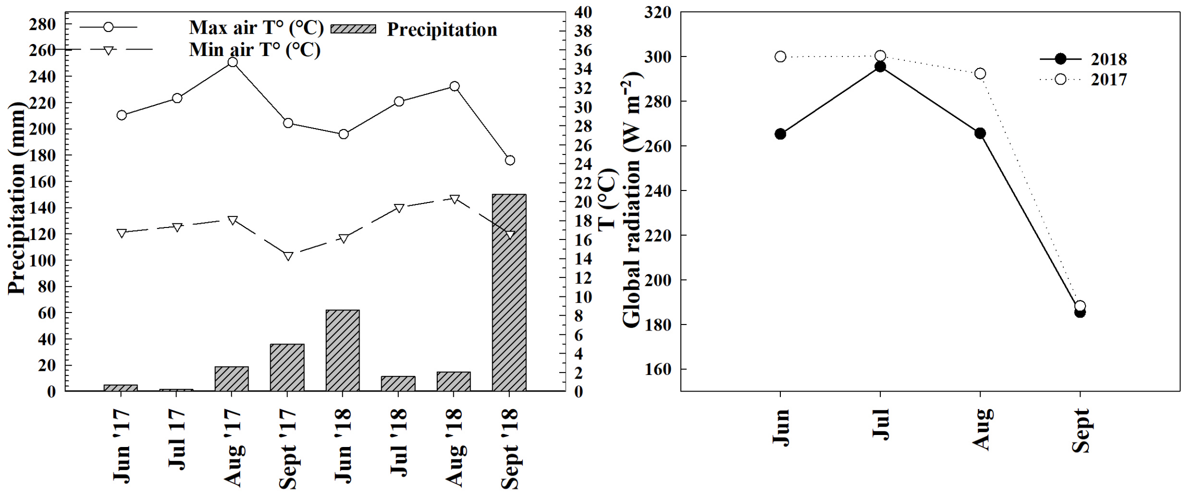

Figure 1. Climate parameters of the experimental location. Monthly averages of mean, maximum, and minimum air temperature (°C), summation monthly rainfall (mm), and global radiation (RAD, W m^{-2}) were measured from June to September (2017–2018).

Average, maximum, and minimum air temperatures were measured in both seasons during the experiment (June–September). The 2017 season proved to be the warmest and the least rainy, on the contrary 2018 proved to be a rainy and cooler year. The warmest period in both years was August: in 2017 the average monthly temperature was 2 °C higher than in 2018.

3.2. Leaf Gas Exchanges, Stem Water Potential, Leaf Chlorophyll a Content, and Chlorophyll Fluorescence

The physiological parameters of *V. vinifera* in the three different soil managements (mulching, M; cover cropping, C and tillage T) are presented in Table 1 and Figure 2.

Table 1. Physiological parameters. Net photosynthesis (P_n), stomatal conductance (g_s), water use efficiency (*eWUE*), and midday stem water potential (Ψ_m) of *V. vinifera* treated with three different soil management practices. Measurements were conducted at full veraison, mid maturation, and full maturation. Data (mean ± SE, n = 10) were subjected to one-way ANOVA. Different letters within the same parameter and row indicate significant differences among M, T, and C (Least Significant Difference (LSD) test, $p \leq 0.05$).

Stage	P_n (µmol CO_2 m^2 s^{-1})			g_s (mmol H_2O m^2 s^{-1})		
	T	C	M	T	C	M
7 July 2017	15.04 ± 0.92 a	16.02 ± 1.30 a	18.75 ± 1.24 b	170.20 ± 16.71 a	200.50 ± 29.94 b	246.14 ± 19.61 c
28 July 2017	13.05 ± 1.76 a	11.91 ± 0.38 a	14.01 ± 1.45 a	165.00 ± 16.53 a	152.16 ± 7.35 a	130.67 ± 16.78 a
5 September 2017	3.78 ± 0.66 a	2.93 ± 0.69 a	6.60 ± 1.06 b	92.67 ± 14.57 a	80.50 ± 12.46 a	93.17 ± 4.81 a
17 July 2018	16.70 ± 4.19 b	14.02 ± 1.82 a	17.9 ± 0.24 b	256.00 ± 21.13 a	254.20 ± 19.01 a	254.40 ± 9.30 a
15 August 2018	7.28 ± 1.37 b	4.64 ± 0.63 a	8.54 ± 0.75 c	151.80 ± 42.17 a	186.60 ± 27.47 a	193.6 ± 9.15 a
17 September 2018	7.2 ± 1.64a	6.64 ± 0.95 a	10.88 ± 0.84 b	159.80 ± 21.85 a	167.6 ± 11.70 a	196.80 ± 3.01 a
Stage	***eWUE* (µmol CO_2/mmol H_2O)**			**Ψ_m (MPa)**		
	T	**C**	**M**	**T**	**C**	**M**
7 July 2017	3.18 ± 0.26 a	2.83 ± 0.24 a	3.24 ± 0.24 a	−1.16 ± 0.04 b	−1.26 ± 0.01 c	−1.11 ± 0.01 a
28 July 2017	2.26 ± 0.42 a	2.12 ± 0.09 a	2.93 ± 0.22 b	−1.14 ± 0.02 a	−1.28 ± 0.75 b	−1.12 ± 0.03 a
5 September 2017	1.33 ± 0.24 a	1.18 ± 0.29 a	2.55 ± 0.73 b	−1.34 ± 0.03 b	−1.50 ± 0.05 c	−1.23 ± 0.03 a
17 July 2018	3.33 ± 0.82 b	2.73 ± 0.36 a	3.79 ± 0.08 c	−0.94 ± 0.04 b	−1.00 ± 0.02 c	−0.86 ± 0.02 a
15 August 2018	1.18 ± 0.23 b	0.92 ± 0.11 a	1.67 ± 0.17 c	−1.29 ± 0.04 b	−1.20 ± 0.05 ab	−1.18 ± 0.03 a
17 September 2018	1.89 ± 0.31 a	1.68 ± 0.24 a	2.77 ± 0.38 b	−1.18 ± 0.03 ab	−1.28 ± 0.03 b	−1.13 ± 0.04 a

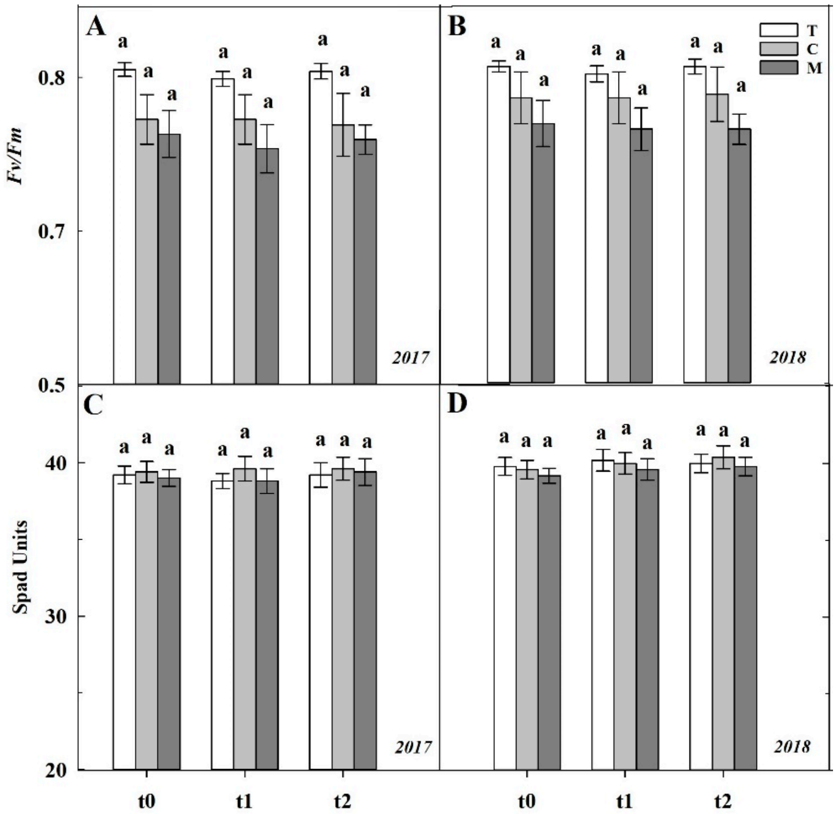

Figure 2. Maximum quantum yield of PSII (*Fv*/*Fm*) (**A**, 2017; **B**, 2018) and chlorophyll content (**C**, 2017; **D**, 2018) of *V. vinifera* with three different soil management practices: T (tillage; white columns), C (cover cropping; light grey columns), and M (mulching; dark grey columns). Measurements were conducted at full veraison (t0: 7 July 2017 and 17 July 2018), mid maturation (t1: 28 July 2017 and 15 August 2018), and full maturation (t2: 5 September 2017 and 17 September 2018). Data (mean ± SE, n = 10) were subjected to one-way ANOVA. Values with different letters are statistically different. (LSD test, $p \leq 0.05$).

No significant differences were found in physiological parameters (P_n, g_s) of 28 July 2017 among the different soil management practices (Table 1).

In vines with mulching in both vintage higher values of P_n, *eWUE*, and Ψ_m were generally found.

No significant difference was found in *Fv*/*Fm* and chlorophyll content in leaves of *V. vinifera* (Figure 2A–D).

3.3. Berry Composition

Tables 2 and 3 show the composition of *V. vinifera* berries among three different soil management practices, under two years, in terms of technological and phenolic maturity.

Table 2. Technological maturity. Sugar content (Brix), titratable acidity (TA), pH, and berry weight of *V. vinifera* treated with tillage (T), cover cropping (C), and mulching (M), during two seasons (2017–2018). Measurements were conducted at three times: full véraison (7 July 2017 and 17 July 2018), mid maturation (28 July 2017 and 15 August 2018), and full maturation (5 September 2017 and 17 September 2018). Data (mean ± SE, n = 10) were subjected to one-way ANOVA. Different letters within the same parameter and row indicate significant differences among M, C, and T (LSD test, $p \leq 0.05$).

Stage	Sugar Content (Brix)			TA (mg L^{-1} tartaric acid)		
	T	C	M	T	C	M
7 July 2017	20.40 ± 0.08 a	20.00 ± 0.00 a	20.40 ± 0.08 a	12.50 ± 0.04 a	12.50 ± 0.04 a	13.30 ± 0.04 a
28 July 2017	26.80 ± 0.08 ab	27.2 ± 0.22 b	25.8 ± 0.09 a	6.00 ± 0.06 ab	5.10 ± 0.04 a	6.10 ± 0.08 b
5 September 2017	28.53 ± 0.15 ab	29.47 ± 0.15 b	27.93 ± 0.07 a	4.83 ± 0.05 b	4.00 ± 0.05 a	5.50 ± 0.12 b
17 July 2018	16.00 ± 0.09 a	17.60 ± 0.18 b	17.00 ± 0.06 b	10.5 ± 0.06 a	10.9 ± 0.07 a	10.9 ± 0.12 a
15 August 2018	22.6 ± 0.13 a	22 ± 0.11 a	22.2 ± 0.17 a	6.70 ± 0.04 b	5.50 ± 0.012 a	6.60 ± 0.08 b
17 September 2018	24.64 ± 0.23 ab	25.57 ± 0.21 b	24.28 ± 0.32 a	4.52 ± 0.09 b	4.0 ± 0.03 a	4.54 ± 0.11 b
Stage	**pH**			**Berry weight (g)**		
	T	**C**	**M**	**T**	**C**	**M**
7 July 2017	2.95 ± 0.01 a	2.96 ± 0.09 a	2.92 ± 0.01 a	0.61 ± 0.01 a	0.60 ± 0.02 a	0.75 ± 0.01 a
28 July 2017	3.40 ± 0.03a	3.34 ± 0.05 a	3.40 ± 0.03a	0.83 ± 0.11 a	0.78 ± 0.23 a	0.81 ± 0.45 a
5 September 2017	3.64 ± 0.08 a	3.58 ± 0.02 a	3.53 ± 0.03 a	0.74 ± 0.34 ab	0.51 ± 0.25 a	0.77 ± 0.30 b
17 July 2018	3.04 ± 0.02 a	3.03 ± 0.06 a	3.04 ± 0.08 a	1.31 ± 0.04 b	1.19 ± 0.02 a	1.30 ± 0.02 b
15 August 2018	3.21 ± 0.03 a	3.21 ± 0.01 a	3.26 ± 0.07 a	1.37 ± 0.07 ab	1.30 ± 0.03 a	1.44 ± 0.04 b
17 September 2018	3.64 ± 0.02 a	3.61 ± 0.02 a	3.69 ± 0.01 a	1.40 ± 0.05 ab	1.25 ± 0.03 a	1.46 ± 0.05 b

Table 3. Phenolic maturity. Total anthocyanin (Tot. Anth.), extractable anthocyanin (Extr. Anth.), total polyphenol (Tot. Polyp.), and extractable polyphenol (Extr. Polyp.) contents of *V. vinifera* treated with tillage (T), cover cropping (C), and mulching (M), during two seasons (2017-2018). Measurements were conducted at three times: full veraison (7 July 2017 and 17 July 2018), mid maturation (28 July 2017 and 15 August 2018), and full maturation (5 September 2017 and 17 September 2018). Data (mean ± SE, n = 10) were subjected to one-way ANOVA. Different letters within the same parameter and row indicate significant differences among treatments (LSD test, $p \leq 0.05$).

Stage	Tot. Anth. (mg L-1)			Extr. Anth. (mg L^{-1})		
	T	C	M	T	C	M
7 July 2017	1330.00 ± 29.70 a	1512.00 ± 18.78 a	1482.25 ± 18.08 a	633.50 ± 12.34 a	661.50 ± 15.65 a	637.00 ± 24.40 a
28 July 2017	2422.00 ± 30.22 a	2392.25 ± 21.09 a	2317.00 ± 25.87 a	1139.25 ± 27.91 b	1025.50 ± 21.06 a	1237.25.10 ± 15.08 c
5 September 2017	1796.33 ± 36.48 a	2004.50 ± 29.15 b	1876.83 ± 23.24 a	673.16 ± 16.56 a	782.25 ± 15.12 c	714.58 ± 34.05 b
17 July 2018	1038.50 ± 22.76 a	1050.75 ± 32.56 a	1180.25 ± 22.40 a	344.75 ± 19.36 a	393.75 ± 28.07 a	350.00 ± 12.12 a
15 August 2018	1812.50 ± 20.11 a	2050.50 ± 24.17 c	1950.75 ± 26.13 b	638.75 ± 24.78 a	623.70 ± 22.08 a	595.66 ± 32.12 a
17 September 2018	1338.75 ± 18.32 a	1623.25 ± 19.21 c	1514.75 ± 21.23 b	607.10 ± 15.80 a	790.50 ± 33.11 b	727.75 ± 32.70 ab
Stage	**Tot. Polyp. (mg L^{-1})**			**Extr. Polyp. (mg L^{-1})**		
	T	**C**	**M**	**T**	**C**	**M**
7 July 2017	4125.91 ± 37.18 a	4054.82 ± 41.00 a	3701.91 ± 25.65 a	3534.37 ± 53.08 a	3463.28 ± 43.13 a	3186.55 ± 21.67 a
28 July 2017	4049.75 ± 28.05 a	3912.65 ± 34.77 a	3910.11 ± 21.22 a	4016.74 ± 34.16 b	3983.45 ± 35.81 b	3902.49 ± 42.08 a
5 September 2017	3850.56 ± 63.25 a	3607.15 ± 56.46 a	3976.97 ± 39.17 a	3241.56 ± 64.15 a	3382.88 ± 65.56 a	3469.21 ± 45.52 a
17 July 2018	3220.20 ± 21.00 a	3181.18 ± 25.70 a	3163.41 ± 19.70 a	2843.53 ± 20.08 a	2792.59 ± 30.60 a	2893.52 ± 33.90 a
15 August 2018	3523.64 ± 18.30 a	3505.86 ± 42.00 a	3652.13 ± 20.20 a	2493.17 ± 32.75 a	2409.39 ± 34.80 a	2490.63 ± 20.08 a
17 September 2018	3792.39 ± 21.20 a	3877.94 ± 12.43 ab	3999.12 ± 21.10 b	2661.82 ± 30.56 a	2690.47 ± 53.78 a	2646.59 ± 51.00 a

To determine the optimum harvesting time, grapes from three different experimental plots were periodically tested with a digital hand refractometer and harvesting time was considered when the content of berries attained approximately more than 25 Brix. No significant difference in pH was found (Table 2). On the contrary, at mid maturation and full maturation a significant difference in sugar content, berry weight, and acidity between mulching and cover cropping were observed in two seasons (Table 2).

The greatest differences were found under the composition of anthocyanins (Table 3). At mid and full maturation, C berries showed significantly higher extractable anthocyanin content than M and T berries in 2017. At full maturation, C berries showed significantly higher extractable content than T and it showed significantly higher total anthocyanin content than T and M for berries in 2018. No difference in both vintages in the extractable polyphenols at full maturation were observed.

4. Discussion

Current vineyard soil management practices derive from research conducted over the last 30–40 years with the aim of preserving organic matter. The recommended techniques are designed to balance the winemaker's conflicting objectives. The main objective is to maintain a soil environment that promotes proper vegetative growth of the vine taking into account both the needs of the vine and the characteristics of the site, ensuring that nutrients and water are not excessively consumed by competing vegetation [83].

The present study assessed, at a subregional level, the importance of soil management as a potential adaptation measure to ensure the future sustainability of grapevine yields in Tuscany.

In our study, at veraison 2017, full maturation 2017, and veraison, mid, and full maturation 2018, Pn, eWUE, were lower in T and C than in M plants. It is probable that, in vine C and T, photosynthesis, and consequently the eWUE, were almost exclusively depressed by water stress (i.e., decreased water potential) [84], as a consequence of the hottest period of the growing season (maximum temperature high above 40 °C). In full maturation (2017 and 2018) the values of photosynthesis, water use efficiency, and water potential in C were lower than the others, this may derive from a competition of the cover crop with the vines: cover crops can affect soil properties, including spatial and temporal modification of the water in the soil profile [85].

On the contrary, physiological parameters were positively influenced in the M practice, probably due to better water retention in the soil (i.e., less negative water potential).

Similarly, several authors reported that the application of mulching can enhance physiological and/or growth parameters in different horticultural species [86–90] and showed that mulching can indeed improve yields in regions under low water availability [28,91,92]. Results highlight the importance of water availability as a widely recognized main limiting factor for grapevine productivity under Mediterranean like environmental conditions [93,94]. The better water relation in M practice could be due to the reduction in soil water evaporation limited by the mulching. Some investigation on root system depth could help to clarify this aspect.

No differences were found in *gs* in the hottest period in both vintages: Cabernet Sauvignon reflects its conservative behavior (i.e., anisohydric) under water-stress condition without witnessing a drop in values [95,96].

The fluorescence of chlorophyll providing different parameters on photosynthetic flows (considered a reliable indicator of plant stress monitoring; [97–99]) leads us to the conclusion that in both years there were no excessively limiting situations for plants (no significant differences were found in the two vintages).

In terms of grape traits, in our study, technological maturity was influenced by soil management practices. At full maturation (5 September 2017 and 17 September 2018) C showed higher sugar content than M in accordance with Zang et al. [100]. Mulch composed of fresh plant residues and tillage increased grape juice TA while, in dry years, C increased juice soluble solids [72,74]. This is probably due to a reduction in soil water availability that leads to a greater concentration of the must in the berries. Unlike Carsoulle [101], in our study no differences in pH were found.

There were also increases in the berry weight on 5 September 2017 and in all three times in 2018 in favor of M and T. This is probable due to the enhancement of physiological performances promoted by mulch that may have positively affected berry metabolism and on the growth of berry resulting in improved grape quality (berries more hydrated). Like many studies [12,102,103], we have found that the titratable acidity was reduced by the cover crop compared to the other treatments probably due to an increase in the ratio of tartaric acid to malic acid. In berries with cover cropping, berry weight decreased in comparison with M and T: maybe severe heat stress and water scarcity, especially in 2017 with a stem water potential of 1.5 Mpa, promoted the dehydration of berries through water loss via apoplast path to rachis [104], with declines in productivity (i.e., lower berry weight in C). Cover cropping definitely competes with vines because of nutrients and water. As regards the total and extractable anthocyanins, the differences were found starting from 28 July in 2017 and from 15 August in 2018.

Both in 2017 and 2018 in full maturity, differences in the anthocyanin content were found: C turned out to be the one with the highest content expressed in mg/L, indeed it has been shown that sugar levels in the grape berry are closely associated with accumulation of pigment and total phenolics [105,106], (i.e., C on both 5 September 2017 and 17 September 2018 showed a higher sugar content than T and M).

The relationship between levels of anthocyanins, total sugars, and berry weight in the ripening grapes was studied in the fruit during the period from veraison to maturity from many authors [107–109]. The higher anthocyanin content in C is deduced to be also due to a greater water stress which led to a lower berry weight [35].

Vineyard floor management has multiple goals that encompass improving weed management and soil conservation, reducing soil resource availability to control vine vigor, and influencing desirable aspects in wine quality [9]. Compared to tillage and mulching, cover cropping showed a higher use of water during the season [41], which induced a lower leaf water potential up to harvest in both years. These differences in the state of the vine water influenced the weight of the berry, the accumulation of sugar in the fruits, and the anthocyanin content. Conversely even the literature suggests that mulch conserves water [71,110–112]; mulch enhanced grapes quantity and quality, in general the sugar content was more balanced (Brix) while maintaining an excellent anthocyanin and total polyphenol content of the Cabernet Sauvignon berries in both harvests. Mulch also reduced the water stress and increased photosynthesis.

5. Conclusions

One of the objectives of modern viticulture is in fact to look for more balanced and less alcoholic wines while maintaining a correct content of polyphenols and anthocyanins [113].

Our results indicate that mulching can be a valuable tool for enhancing wine quality in this wine growing region for soils with low water availability; it therefore appears to be a valid soil management technique that is sustainable, conservative, and less impactful than tillage.

Our results allow to conclude that the choice for a cover crop is not the best one due to plant-cover crop water competition that leads to excessive stress on the plants affecting grape quantity and quality and leading to excessively alcoholic and unbalanced wines.

Although the cultivation of the vine compared to most other crops requires less water for its growth and maturation, the expected climate changes (i.e., the reduction of rain and rising temperatures; [114,115]) will intensify the water stress on the vines, particularly in regions with limited water availability.

The best practice for each vineyard site is determined in part by vineyard design, soil type, and climatic conditions of the vineyard site [116,117]. However, long-term trials are needed in order to verify these effects, particularly on water stress and its consequences for quality.

Author Contributions: G.B.M. and E.C. designed, conceptualized, and organized the experiment. E.C., L.S. and S.S. followed the execution of treatments, made measurements of gas exchanges, water potentials, and sampled berries. E.C. also processed data and carried out statistical analyses. E.C. wrote the original draft manuscript, which was edited and improved by G.B.M. and P.S. All authors have read and accepted the published version of the manuscript.

Funding: This research has not received any specific grant from funding agencies in private or public commercial sectors.

Acknowledgments: The authors acknowledge the researchers of the Council for Agricultural Research and Economics, Research Center for Viticulture and Enology (CREA-VE), Arezzo, Italy for their support in the field and for the implementation of the experimental plan. The authors acknowledge Villa Montepaldi, (Montepaldi Srl Farm, Montepaldi 12 street—50026 San Casciano Val di Pesa—Italy) for the location of the experiment.

Conflicts of Interest: All the other authors have no conflict of interest with the trial carried out.

References

1. Di Natale, A. Aspetti normativi e legislazione fitosanitaria a sostegno della difesa eco-sostenibile delle colture. *Bullettin Gioenia Acad. Nat. Sci. Catania* **2019**, *52*, DECA5–DECA9. [CrossRef]
2. Sadras, V.; Moran, M.; Petrie, P. Resilience of grapevine yield in response to warming. *OENO One* **2017**, *51*, 381–386. [CrossRef]
3. Fiera, C.; Ulrichb, W.; Popescuc, D.; Buchholzd, J.; Quernerd, P.; Buneae, C.I.; Straussf, P.; Bauerf, T.; Kratschmerd, S.; Winter, S.; et al. Tillage intensity and herbicide application influence surface-activespringtail (Collembola) communities in Romanian vineyards. *Agric. Ecosyst. Environ.* **2020**. [CrossRef]
4. Moore, J.C. Impact of agricultural practices on soil food web structure: Theory and application. *Agric. Ecosyst. Environ.* **1994**, *51*, 239–247. [CrossRef]
5. Zaller, J.G.; König, N.; Tiefenbacher, A.; Muraoka, Y.; Querner, P.; Ratzenböck, A.; Bonkowski, M.; Koller, R. Pesticide seed dressings can affect the activity of various soil organisms and reduce decomposition of plant material. *BMC Ecol.* **2016**, 37. [CrossRef] [PubMed]
6. Travlos, I.S.; Gkotsi, T.; Roussis, I.; Kontopoulou, C.K.; Kakabouki, I.; Bilalis, D.J. Effects of the herbicides benfluralin, metribuzin andpropyzamide on the survival and weight of earthworms (Octodrilus complanatus). *Plant Soil Environ.* **2017**, *63*, 117–124.
7. Zaller, J.G.; Cantelmo, C.; Dos Santos, G.; Muther, S.; Gruber, E.; Pallua, P.; Mandl, K.; Friedrich, B.; Hofstetter, I.; Schmuckenschlager, B.; et al. Herbicides in vineyards reduce grapevine root mycorrhization and alter soil microorganisms and the nutrient composition in grapevine roots, leaves, xylem sap and grape juice. *Env. Sci. Poll. Res.* **2018**, 23215–23226. [CrossRef]
8. Wheeler, S.J.; Black, G.J.; Pickering, A.S. Vineyard floor management improves wine quality in highly vigorous Vitis vinifera 'Cabernet Sauvignon' in New Zealand. *N. Z. J. Crop Hortic. Sci.* **2005**, *33*, 317–328. [CrossRef]
9. Guerra, B.; Steenwerth, K. Influence of floor management technique on grapevine growth, disease pressure, and juice and wine composition: A review. *Am. J. Enol. Vitic.* **2012**, *63*, 149–164. [CrossRef]
10. Afonso, J.M.; Monteiro, A.M.; Lopes, C.M.; Lourenço, J. Enrelvamento do solo em vinha na região dos Vinhos Verdes. Três anos de estudo na casta 'Alvarinho'. *Ciência Téc. Vitiv.* **2003**, *18*, 47–63.
11. Thomson, L.J.; Hoffmann, A.A. Effects of ground cover (straw and compost) on the abundance of natural enemies and soil macro invertebrates in vineyards. *Agric. For. Entomol.* **2007**, *9*, 173–179. [CrossRef]
12. Nazrala, J.B. Influencia del manejo del suelo y las coberturas vegetales en el microclima de la canopia de la vid, la composición de la uva y el vino. *Rev. Fac. de Cienc. Agrar.* **2008**, *40*, 85–104.
13. Sharley, D.J.; Hoffmann, A.A.; Thomson, L.J. The effects of soil tillage on beneficial invertebrates within the vineyard. *Agric. For. Entomol.* **2008**, *10*, 233–243. [CrossRef]
14. Trivellone, V.; Paltrinieri, L.P.; Jermini, M.; Moretti, M. Management pressure drives leafhopper communities in vineyards in Southern Switzerland. *Insect Conserv. Divers.* **2012**, *5*, 75–85. [CrossRef]
15. Agnelli, A.; Bol, R.; Trumbore, S.E.; Dixon, L.; Cocco, S.; Corti, G. Carbon and nitrogen in soil and vine roots in harrowedand grass-covered vineyards. *Agric. For. Entomol.* **2014**, *193*, 70–82.
16. Likar, M.; Vogel-Mikuš, K.; Potisek, M.; Hančević, K.; Radić, T.; Nečemer, M.; Regvar, M. Importance of soil and vineyard management in the determination of grapevine mineral composition. *Sci. Total Environ.* **2015**, *505*, 724–731. [CrossRef] [PubMed]
17. Pardini, A.; Faiello, C.; Longhi, F.; Mancuso, S.; Snowball, R. Cover crop species and their management in vineyards and olive groves. *Adv. Hortic. Sci.* **2002**, *16*, 225–234.
18. Saladin, G.; Magné, C.; Clément, C. Stress reactions inVitis vinifera L. following soil application of the herbicide flumioxazin. *Chemosphere* **2003**, *53*, 199–206. [CrossRef]
19. Zehetner, F.; Djukic, I.; Hofmann, R.; Kühnen, L.; Rampazzo-Todorovic, G.; Gerzabek, M.H.; Soja, G. Soil organic carbon and microbial communities respond to vineyard management. *Soil Use Manag.* **2015**, *31*, 528–533. [CrossRef]
20. Mandl, K.; Cantelmo, C.; Gruber, E.; Faber, F.; Friedrich, B.; Zaller, J.G. Effects of glyphosate, glufosinate and flazasulfuron based herbicides on soil microorganisms in a vineyard. *Bull. Environ. Contam. Toxicol.* **2018**, *101*, 562–569. [CrossRef]
21. House, G.J. Soil arthropods from weed and crop roots of an agroecosystem in a wheat-soybean-corn rotation: Impact of tillage and herbicides. *Agric. For. Entomol.* **1989**, *25*, 233–244. [CrossRef]

22. Horne, P.A.; Edwards, C.L. Effects of tillage on pest and beneficial beetles in the Wimmera region of Victoria, Australia. *Aus. Entomol.* **1998**, *37*, 60–63. [CrossRef]
23. Sánchez-Moreno, S.; Castro, J.; Alonso-Prados, E.; Alonso-Prados, J.L.; García-Baudín, J.M.; Talavera, M.; Durán-Zuazo, V.H. Tillage and herbicide decrease soil biodiversity in olive orchards. *Agron. Sustain. Dev.* **2015**, 691–700. [CrossRef]
24. Wheeler, S.J.; Pickering, G.J. Optimizing grape quality through soil management practices. *Food Agric. Environ* **2003**, *1*, 190–197.
25. Pickering, G.J.; Wheeler, S. The effects of soil management techniques on grape and wine quality. In *Fruits Growth, Nutrition, and Quality*; Dris, R., Ed.; WFL Meri-Rastilan tie 3 C: Helsinki, Finland, 2006.
26. Jacometti, M.A.; Wratten, S.D.; Walter, M. Understorey management increases grape quality, yield and resistance to Botrytis cinerea. *Agric. Ecosyst. Environ.* **2007**, *122*, 349–356. [CrossRef]
27. Marangoni, B.; Toselli, M.; Venturi, A.; Fontana, M.; Scudellari, D. Effects of vineyard soil management and fertilization on grape diseases and wine quality. *IOBC WPRS Bull.* **2001**, *24*, 353–358.
28. Judit, G.; Gábor, Z.; Ádám, D.; Tamas, V.; Gyorgy, B. Comparison of three soil management methods in the Tokaj wine region. *Mitt. Klosterneuburg* **2011**, *61*, 187–195.
29. Bogoni, M.; Panont, A.; Valenti, L.; Scienza, A. Effects of soil physical and chemical conditions on grapevine nutritional status. *Acta Hortic.* **1995**, *383*, 299–312. [CrossRef]
30. Shellie, K.C. Vine and berry response of Merlot (Vitis vinifera L.) to differential water stress. *Am. J. Enol. Vitic.* **2006**, *57*, 514–518.
31. Peterlunger, E.; Castellarin, S.; Leon, M.; Battistutta, F.; Bi-Got, G.; Bregant, F. Stress idrico della vite e qualità dell'uva e del vino. *Notiziario ERSA* **2007**, *3*.
32. Montemurro, F.; Fiore, A.; Campanelli, G.; Tittarelli, F.; Ledda, L.; Canali, S. Organic fertilization, green manure, and vetch mulch to improve organic zucchini yield and quality. *Hort. Sci.* **2013**, *48*, 1027–1033. [CrossRef]
33. Lu, C.; Zhang, J. Effects of water stress on photosynthesis, chlorophyll fluorescence and photoinhibition in wheat plants. *Funct. Plant Biol.* **1998**, *25*, 883–892. [CrossRef]
34. Escalona, J.M.; Flexas, J.; Bota, J. Distribution of leaf photosynthesis and transpiration within grapevine canopies under different drought conditions. *Vitis* **2003**, *42*, 57–64.
35. Matthews, M.A.; Kriedemann, P.E. Water deficit, yield, and berry size as factors for composition and sensory attributes of red wine. In Proceedings of the Australian society of viticulture and oenology 'Finishing the Job'-Optimal Ripening of Cabernet Sauvignon and Shiraz. Australian Society of Oenology and Viticulture, Mildura Arts Centre, Mildura, VIC, Australia, 21 July 2006; pp. 46–54.
36. Mendez-Costabel, M.; Wilkinson, K.; Bastian, S.; Jordans, C.; Mccarthy, M.; Ford, C.; Dokoozlian, N. Effect of winter rainfall on yield components and fruit green aromas of *Vitis vinifera* L. cv. Merlot in California. *Aust. J. Grape. Wine Res.* **2014**, *20*, 100–110. [CrossRef]
37. Williams, L.E.; Matthews, M. A Grapevine (Chapter 34). In *Irrigation of Agricultural Crops. Agronomy Monographs*; Stewart, B.J., Nielsen, D.R., Eds.; American Society of Agronomy: Madison, WI, USA, 1990; pp. 1019–1055.
38. Moutinho-Pereira, J.M.; Correia, C.M.; Gonçalves, B.M.; Bacelar, E.A.; Torres-Pereira, J.M. Leaf gas exchange and water relations of grapevines grown in three different conditions. *Photosynthetica* **2004**, *42*, 81–86. [CrossRef]
39. Escalona, J.M.; Flexas, J.; Medrano, H. Stomatal and non-stomatal limitations of photosynthesis under water stress in field grown grapevines. *Aust. J. Plant Physiol.* **1999**, *26*, 421–433. [CrossRef]
40. Flexas, J.; Bota, J.; Escalona, J.M.; Sampol, B.; Medrano, H. Effects of drought on photosynthesis in grapevines under field conditions: An evaluation of stomatal and mesophyll limitations. *Funct. Plant Biol.* **2002**, *29*, 461–471. [CrossRef]
41. Monteiro, A.; Lopes, C.M. Influence of cover crop on water use and performance of vineyard in Mediterranean Portugal. *Agric. Ecosyst. Environ.* **2007**, *121*, 336–342. [CrossRef]
42. Muscas, E.; Cocco, A.; Mercenaro, L.; Cabras, M.; Lentini, A.; Porqueddu, C.; Nieddu, G. Effects of vineyard floor cover crops on grapevine vigor, yield, and fruit quality, and the development of the vine mealybug under a Mediterranean climate. *Agric. Ecosyst. Environ.* **2017**, *237*, 203–212. [CrossRef]
43. Reeve, A.L.; Skinkis, P.A.; Vance, A.J.; McLaughlin, K.R.; Tomasino, E.; Lee, J.; Tarara, J.M. Vineyard floor management and cluster thinning inconsistently affect 'Pinot noir'crop load, berry composition, and wine quality. *Hort. Sci.* **2018**, *53*, 318–328.
44. Mercenaro, L.; Nieddu, G.; Pulina, P.; Porqueddu, C. Sustainable management of an intercropped Mediterranean vineyard. *Agric. Ecosyst. Environ.* **2014**, *192*, 95–104. [CrossRef]

45. Sanguankeo, P.P.; León, R.G. Weed management practices determine plant and arthropod diversity and seed predation in vineyards. *Weed Res.* **2011**, *51*, 404–412. [CrossRef]
46. Powles, S.B.; Preston, C.; Bryan, I.B.; Jutsum, A.R. Herbicide resistance: Impact and management. *Adv. Agron.* **1997**, *58*, 57–93.
47. Rodriguez-Lovelle, B.; Soyer, J.P.; Molot, C. Incidence of permanent grass cover on grapevine phenological evolution and grape berry ripening. *Acta Hortic.* **2000**, *526*, 241–248. [CrossRef]
48. Pou, A.; Gulías, J.; Moreno, M.; Tomàs, M.; Medrano, H.; Cifre, J. Cover cropping in Vitis vinifera L. cv. Manto Negro vineyards under Mediterranean conditions: Effects on plant vigour, yield and grape quality. *Oeno One* **2011**, *45*, 223–234. [CrossRef]
49. Gulick, S.H.; Grimes, D.W.; Munk, D.S.; Goldhamer, D.A. Cover-crop-enhanced water infiltration of a slowly permeable fine sandy loam. *Soil Sci. Soc. Am. J.* **1994**, *58*, 1539–1546. [CrossRef]
50. Le Bissonnais, Y.; Lecomte, V.; Cerdan, O. Grass strip effects on runoff and soil loss. *Agronomie* **2004**, *24*, 129–136. [CrossRef]
51. Le Golf-Guillou, I.; Marsault, J.; Riou, C. Impacts de l'enherbement sur le fonctionnement de la vigne, la composition des mouˆts, les dure'es de fermentation et la qualite´ des vins. *Progre's Agric. Vitic.* **2000**, *117*, 103–110.
52. Maigre, D.; Aerny, J. Enherbement permanent et fumure azote´e sur cv. 'Gamay' dans le Valais Central. Revue Suisse. *Vitic. Arboric. Hortic.* **2001**, *33*, 343–349.
53. Caspari, H.W.; Neal, S.; Naylor, A. Cover crop management in vineyards to enhance deficit irrigation in a humid climate. *Acta Hortic.* **1997**, *449*, 313–320. [CrossRef]
54. van Huyssteen, L. The effect of soil management and fertilization on grape composition and wine quality with special reference to South African conditions. In Proceedings of the 7th Australian Wine Industry Conference, Adelaide, Australia, 13–17 August 1989; pp. 16–25.
55. Morlat, R.; Jacquet, A.; Asselin, C. L'enherbement permanent controle des sols viticoles: Principaux resultats obtenus en Anjou. In Proceedings of the 7e´me Colloque Viticole et Oenologique, GESCO 1993, Rheims, France, 1 January 1993; pp. 89–95.
56. Hirschfelt, D.J. Soil fertility and vine nutrition. In *Cover Cropping in Vineyards*; Ingels, C.A., Bugg, R.L., McGourty, G.T., Christensen, L.P., Eds.; University of California: Okland, CA, USA, 1998; pp. 61–68.
57. Krohn, N.G.; Ferree, D.C. Effects of low-growing perennial ornamental groundcovers on the growth and fruiting of 'Seyval blanc' grapevines. *Hortic. Sci.* **2005**, *40*, 561–568. [CrossRef]
58. Smart, D.R.; Schwass, E.; Lakso, A.; Morano, L. Grapevine rooting patterns: A comprehensive analysis and a review. *Am. J. Enol. Vitic.* **2006**, *57*, 89–104.
59. Nauleau, F. Nouvelles techniques d'entretien des sols viticoles. Conséquences œnologiques. Synthèse de 5 années d'experimentation menés dans différents vignobles français. *Progrès Agric. Vitic.* **1997**, *114*, 188–190.
60. Morlat, R.; Jacquet, A. Grapevine root system and soil characteristics in a vineyard maintained long-term with or without interrow sward. *Am. J. Enol. Vitic.* **2003**, *54*, 1–17.
61. Jordán, A.; Zavala, L.M.; Muñoz-Rojas, M. Mulching, effects on soil physical properties. In *Encyclopedia of Agrophysics*; Gliński, J., Horabik, J., Lipiec, J., Eds.; Springer: Dordrecht, The Netherlands, 2011; pp. 492–496.
62. Jordán, A.; Zavala, L.M.; Gil, J. Effects of mulching on soil physical properties and runoff under semi-arid conditions in southern Spain. *Catena* **2010**, *81*, 77–85. [CrossRef]
63. Sadeghi, S.H.R.; Gholami, L.; Homaee, M.; KhalediDarvishan, A. Reducing sediment concentration and soil loss using organic and inorganic amendments at plot scale. *Soild Earth* **2015**, *6*, 445–455. [CrossRef]
64. Cook, H.F.; Valdes, G.S.B.; Lee, H.C. Mulch effects on rainfall interception, soil physical characteristics and temperature under *Zea Mays L.*. *Soil Tillage Res.* **2006**, *91*, 227–235. [CrossRef]
65. Wang, J.; Huang, J.; Zhao, X.; Wu, P.; Horwath, W.R.; Li, H.; Jing, Z.; Chen, X. Simulated study on effects of ground managements on soil water and available nutrients in jujube orchards. *Land Degrad. Dev.* **2014**, *27*, 35–42. [CrossRef]
66. Cook, H.F.; Lee, H.C. Water relations in a soil amended with composted organic waste. In *Soil Management in Sustainable Agriculture*; Wye College Press: Wye, Ashford, UK, 1995; pp. 453–460.
67. Karami, A.; Homaee, M.; Afzalinia, S.; Ruhipour, H.; Basirat, S. Organic resource management: Impacts on soil aggregate stability and other soil physico-chemical properties. *Agric. Ecosyst. Environ.* **2012**, *148*, 22–28. [CrossRef]

68. Riddle, W.C.; Gillespie, T.J.; Swanton, C.J. Rye mulch characterization for the purpose of microclimatic modelling. *Agric. For. Meteorol.* **1996**, *78*, 67–81. [CrossRef]
69. Wooldridge, J.; Harris, R.E. Effect of organic mulches and plastic sheet on soil temperature. *Deciduous Fruit Grower* **1991**, *41*, 118–121.
70. Lanini, W.T.; Shribbs, J.M.; Elmore, C.E. Orchard floor mulching trials in the USA. *Fruit Belgique.* **1988**, *56*, 228–249.
71. Chan, K.Y.; Fahey, D.J.; Newell, M.; Barchia, I. Using composted mulch in vineyards effects on grape yield and quality. *Int. J. Fruit Sci.* **2010**, *10*, 441–453. [CrossRef]
72. Pinamonti, F. Compost mulch effects on soil fertility, nutritional status and performance of grapevine. *Nutr. Cycl. Agroeco.* **1998**, *51*, 239–248. [CrossRef]
73. Nguyen, T.T.; Fuentes, S.; Marschner, P. Effect of incorporated or mulched compost on leaf nutrient concentrations and performance of Vitis vinifera cv. Merlot. *J. Soil Sci. Plant Nutr.* **2013**, *13*, 485–497. [CrossRef]
74. Varga, P.; Májer, J. The use of organic wastes for soil-covering of vineyards. *Acta Hortic.* **2004**, *652*, 191–197. [CrossRef]
75. Chan, K.Y.; Fahey, D.J. Effect of composted mulch application on soil and wine grape potassium status. *Soil Res.* **2011**, *49*, 455–461. [CrossRef]
76. Coventry, J.M.; Fisher, K.H.; Strommer, J.N.; Reynolds, A.G. Reflective mulch to enhance berry quality in Ontario wine grapes. *Acta Hortic.* **2004**, *689*, 95–102. [CrossRef]
77. Fraga, H.; Santos, J.A. Vineyard mulching as a climate change adaptation measure: Future simulations for Alentejo, Portugal. *Agric. Syst.* **2018**, *164*, 107–115. [CrossRef]
78. Sharma, R.A.; Upadhay, M.S.; Tomar, R.S. Water use efficiency of some rainfed crops on a Vertisol as influenced by soil and straw mulching. *J. Indian Soc. Soil Sci.* **1985**, *33*, 387–391.
79. Eichhorn, K.W.; Lorenz, D.H. Phänologische Entwicklungsstadien der Rebe. Nachrichtenblatt des Deutschen Pflanzen- schutzdienstes. *Braunschweig* **1977**, *29*, 119–120.
80. Scholander, P.F.; Hammel, H.T.; Bradstreet, E.D.; Hemmingsen, E.A. Sap pressure in vascular plants. *Science* **1965**, *148*, 339–346. [CrossRef] [PubMed]
81. Maxwell, K.; Johnson, G.N. Chlorophyll fluorescence: A practical guide. *J. Exp. Bot.* **2000**, *51*, 659–668. [CrossRef] [PubMed]
82. Ribéreau-Gayon, P.; Glories, Y.; Maujean, A.; Dubourdieu, D. *Handbook of Enology, Volume 2: The Chemistry of Wine-Stabilization and Treatments*; John Wiley & Sons: Hoboken, NJ, USA, 2006; Volume 2.
83. Pool, R.M.; Dunst, R.M.; Lakso, A.N. Comparison of sod, mulch, cultivation, and herbicide floor management practices for grape production in nonirrigated vineyards. *J. Am. Soc. Hortic. Sci.* **1990**, *115*, 872–877. [CrossRef]
84. Schultz, H.R. Differences in hydraulic architecture account for near-isohydric and anisohydric behaviour of two field-grown *Vitis vinifera* L. cultivars during drought. *Plant Cell Environ.* **2003**, *26*, 1393–1405. [CrossRef]
85. Celette, F.; Gaudin, R.; Gary, C. Spatial and temporal changes to the water regime of a Mediterranean vineyard due to the adoption of cover cropping. *Eur. J. Agron.* **2008**, *29*, 153–162. [CrossRef]
86. Li, F.M.; Guo, A.H.; Wei, H. Effects of clear plastic film mulch on yield of spring wheat. *Field Crops Res.* **1999**, *63*, 79–86. [CrossRef]
87. Ibarra-Jiménez, L.; Zermeño-González, A.; Munguia-Lopez, J.; Rosario Quezada-Martín, M.A.; De La Rosa-Ibarra, M. Photosynthesis, soil temperature and yield of cucumber as affected by colored plastic mulch. *Acta Agric. Scand. Section B-Soil Plant Sci.* **2008**, *58*, 372–378. [CrossRef]
88. Gao, Y.; Niu, J.; Xu, R.; Wang, Y.; Li, C.; Qi, D. Effects of different film mulching on photosynthesis, transpiration rate and leaf water use efficiency of maize. *Acta Prataculturae Sin.* **2012**, *21*, 178–184.
89. Luo, H.H.; Zhang, Y.L.; Zhang, W.F. Effects of water stress and rewatering on photosynthesis, root activity, and yield of cotton with drip irrigation under mulch. *Photosynthetica* **2016**, *54*, 65–73. [CrossRef]
90. Yang, Y.; Ding, J.; Zhang, Y.; Wu, J.; Zhang, J.; Pan, X.; He, F. Effects of tillage and mulching measures on soil moisture and temperature, photosynthetic characteristics and yield of winter wheat. *Agric. Water Manag.* **2018**, *201*, 299–308. [CrossRef]
91. Dilley, C.; Nonnecke, G. Effect of living or straw mulch on vineyard weed and soil quality management. *HortScience* **2007**, *42*, 960–961.
92. De Vetter, L.W.; Dilley, C.A.; Nonnecke, G.R. Mulches reduce weeds, maintain yield, and promote soil quality in a continental-climate vineyard. *Am. J. Enol. Vitic.* **2015**, *66*, 54–64. [CrossRef]

93. Keller, M. Managing grapevines to optimise fruit development in a challenging environment: A climate change primer for viticulturists. *Aust. J. Grape Wine Res.* **2010**, 56–69. [CrossRef]
94. Keller, M. *The Science of Grapevines: Anatomy and Physiology*; Elsevier, Inc.: Amsterdam, The Netherlands, 2010; p. 400.
95. Chaves, M.M.; Zarrouk, O.; Francisco, R.; Costa, J.M.; Santos, T.; Regalado, A.P.; Rodrigues, M.L.; Lopes, C.M. Grapevine under deficit irrigation: Hints from physiologicaland molecular data. *Ann. Bot.* **2010**, *105*, 661–676. [CrossRef] [PubMed]
96. Sade, N.; Gebremedhin, A.; Moshelion, M. Risk-taking plants: Anisohydric behavior as a stress-resistance trait. *Plant Signal Behav.* **2012**, *7*, 767–770. [CrossRef] [PubMed]
97. Strasser, R.J.; Tsimilli-Michael, M.; Srivastava, A. Analysis of the Chlorophyll a fluorescence transient. In *Chlorophyll a Fluorescence: A Signature of Photosynthesis*; Papageorgiou, G.C., Govindjee, Eds.; Springer: Dordrecht, The Netherlands, 2004; pp. 321–362.
98. Murchie, E.H.; Lawson, T. Chlorophyll fluorescence analysis: A guide to good practice and understanding some new applications. *J. Exp. Bot.* **2013**, *64*, 3983–3998. [CrossRef]
99. Mitra, S.; Irshad, M.; Debnath, B.; Lu, X.; Li, M.; Dash, C.K.; Qiu, D. Effect of vineyard soil variability on chlorophyll fluorescence, yield and quality of table grape as influenced by soil moisture, grown under double cropping system in protected condition. *Peer J.* **2018**, *6*, 5592. [CrossRef]
100. Zhang, Q.; Wang, S.; Li, L.; Inoue, M.; Xiang, J.; Qiu, G.; Jin, W. Effects of mulching and sub-surface irrigation on vine growth, berry sugar content and water use of grapevines. *Agric. Water Manag.* **2014**, *143*, 1–8. [CrossRef]
101. Carsoulle, J. L'enherbement permanent du vignoble. Influence sur la production viticole et son environment. *Phytoma* **1995**, *478*, 38–41.
102. Agulhon, R. Enherbement permanent, ENM et mulch, comparés à la non culture. *Phytoma* **1998**, *511*, 46–48.
103. Maigre, D.; Aerny, J. Enherbement et fumure azotée sur cv. Gamay dans le Valais central. 2. Résultats analytiques et organoleptiques. *Rev. Suisse Vitic. Arboric. Hortic.* **2001**, *33*, 199–204.
104. Matthews, M.A.; Nuzzo, V. Berry size and yield paradigms on grapes and wine quality. *Acta Hortic.* **2007**, *754*, 423–436. [CrossRef]
105. Pirie, A.; Mullins, M.G. Interrelationships of sugars, anthocyanins, total phenols and dry weight in the skin of grape berries during ripening. *Am. J. Enol. Vitic.* **1977**, *28*, 204–209.
106. González-Sanjosé, M.L.; Diez, C.J.F.C. Relationship between anthocyanins and sugars during the ripening of grape berries. *Food Chem.* **1992**, *43*, 193–197. [CrossRef]
107. Thimann, K.V.; Edmondson, Y.H.; Radner, B.S. The biogenesis of anthocyanin. II1. The role of sugars in anthocyanin formation. *Arch. Biochem. Biophys.* **1951**, *34*, 305–323. [CrossRef]
108. Pirie, A.J.G.; Mullins, M.G. Changes in anthocyanin and phenolics content of grapevine leaf and fruit tissues treated with sucrose, nitrate and abscisic acid. *Plant Physiol.* **1976**, *58*, 468–472. [CrossRef]
109. Jones, G.V.; White, M.A.; Cooper, O.R.; Storchmann, K. Climate change and global wine quality. *Clim. Change* **2005**, *73*, 319–343. [CrossRef]
110. Benoit, G.R.; Kirkham, D. The effect of soil surface conditions on evaporation of soil water. *Soil Sci. Soc. Am. J.* **1963**, *27*, 495–498. [CrossRef]
111. Nachtergaele, J.; Poesen, J.; Van Wesemael, B. Gravel mulching in vineyards of southern Switzerland. *Soil Tillage Res.* **1998**, *46*, 51–59. [CrossRef]
112. Leal, G.R. Influence of Reflective Mulch on Pinot noir Grape and Wine Quality. Ph.D. Thesis, Lincoln University, Lincoln, New Zealand, 2007.
113. Meillon, S.; Dugas, V.; Urbano, C.; Schlich, P. Preference and acceptability of partially dealcoholized white and red wines by consumers and professionals. *Am. J. Enol. Vitic.* **2010**, *61*, 42–52.
114. Palliotti, A.; Tombesi, S.; Silvestroni, O.; Poni, S. *Gestione Degli Eccessi Termici e Radiativi*; La nuova Viticoltura Edagricole: Bologna, Italy, 2015; pp. 207–214.
115. Tombesi, S.; Poni, S.; Palliotti, A. Stress idrico in Vitis vinifera: Variabilità delle risposte fisiologiche intra-specifiche e loro potenziale sfruttamento nella mitigazione degli effetti dei cambiamenti climatici. *Italus Hortus.* **2016**, *23*, 45–53.
116. Ripoche, A.; Celette, F.; Cinna, J.P.; Gary, C. Design of intercrop management plans to fulfill production and environmental objectives in vineyards. *Eur. J. Agron.* **2010**, *32*, 30–39. [CrossRef]

117. Sweet, R.M.; Schreiner, R.P. Alleyway cover crops have little influence on Pinot noir grapevines (Vitis vinifera L.) in two western Oregon vineyards. *Am. J. Enol. Vitic.* **2010**, *61*, 240–252.