Biniari K *et al.* (2024)
Notulae Botanicae Horti Agrobotanici Cluj-Napoca
Volume 52, Issue 4, Article number 13954
DOI:10.15835/nbha52413954
Research Article

Effect of soil management techniques and different vine nutrient methods on the physiology and grape quality of vines of cv. 'Robola' (*Vitis vinifera* L.) in Kefalonia

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Abstract

The aim of the study was to be determine the effects of conventional and organic soil and vine nutrition management on the growth, physiology and grape quality of vines of cv. 'Robola' in Kefalonia island, Greece. The overall aim was to understand and evaluate the combined effects of these different viticultural practices on soil quality (fertility) and on the physiological parameters of the vine as well as on grape quality, in terms of production sustainability and environmental biodiversity. The physiological parameters that were assessed and determined were leaf assimilation rate, leaf stomatal conductance, leaf transpiration and chlorophyll content. Additionally, grape and berry mechanical properties were also evaluated. The results of all the combinations of the two soil treatments with the three different nutrition methods (organic and two conventional), showed no statistically significant difference regarding the grape and berry mechanical properties. Moreover, the viticultural practice with reduced tillage and the application of slow-release fertilizer appears to show higher concentration of total soluble solids and higher pH and titratable acidity. Finally, the viticultural practice with the usual tillage (milling) and the application of fertilization with stems exhibited the highest values in the physiological parameters that were studied.

Keywords: assimilation rate; fertilization; grapevine; nutrition; soil properties

Introduction

Soil fertility plays a crucial role in the production of high-quality products. Regardless of how enriched the soil is in nutrients, the vines consume significant amounts of nutrients for the annual production, especially

Received: 11 Jun 2024. Received in revised form: 26 Nov 2024. Accepted: 20 Dec 2024. Published online: 20 Dec 2024.
From Volume 49, Issue 1, 2021, Notulae Botanicae Horti Agrobotanici Cluj-Napoca journal uses article numbers in place of the traditional method of continuous pagination through the volume. The journal will continue to appear quarterly, as before, with four annual numbers.

in the last decades and the intensification of vine cultivation (Stavrakakis, 2019). Intensive grapevine cultivation affects run-off, absorption and soil water retention, soil quality and consequently both the quantity and quality of the grapes produced (Zalidis *et al*., 2002). Mediterranean vineyards are extremely vulnerable to a significant risk of soil quality degradation, due to the gradual reduction of organic matter, erosion, contamination from the continuous and excessive use of fertilizers, as well as compaction due to the heavy machinery use. In the case of intensive vine cultivation, the perpetual, continuous and repetitive activities with the use of heavy machinery in combination with the continuous and periodic tillage are usually responsible for the increase of soil erosion rates and CO_2 emissions (Cerdà *et al*., 2017).

The above-mentioned management technique, especially taking into consideration the implications of climate change, raises questions as far its long-term sustainability is concerned (Rajwade *et al*., 2015). Soil erosion in vineyards, due to the extreme rainfall, can cause a nutrient loss of 12% of nitrogen and 60% of phosphorus, which is applied annually (García-Ruiz, 2010). As a result, analyses and research begin to focus on innovative management strategies to improve soil fertility, reduce topsoil nutrient loss, balance water consumption, which in turn will result in the increase of grape quality (Zhang *et al*., 2011).

Therefore, and under the effect of climate change, it is necessary for the wine grower, to implement a series of strategies with the aim of maintaining and enhancing the quality of the grapes. In viticulture, soil management in combination with sustainable strategies are of great importance for the improvement of modern viticultural systems. Several authors compared soil characteristics of the vineyard with grape quality characteristics after the application of treatments with different grass management practices (e.g., sowing different grass types: *Trifolium incarnatum*, *Hordeum vulgare*, *Festuca arundinacea*, *Brassica juncea*, *Lolium perenne*, *Festuca ovina* and *Poa pratensis*) (Smith *et al*., 2008; Steenwerth and Belina, 2008) and after application of organic or inorganic fertilizer (Bustamante *et al*., 2011; Calleja-Cervantes *et al*., 2015).

The chemical composition of the soil and its sustainable management in the vineyards are directly related to the quality of the grapes (Mackenzie and Christy, 2005). The strengthening of the physicochemical properties of the soil and its sustainable management positively affects the quality of the grapes. Soil management includes various agricultural practices that all affect soil function. Organic fertilization of the soil improves its structure and the content of solid organic matter (Navel and Martins, 2014). On the other hand, the usual tillage can reduce soil organic matter content, modify soil biological activity at different nutrient levels and gradually cause physical degradation in the vineyard's soil, thus reducing grape quality (Schreck *et al*., 2012).

Moreover, the practice of covering the soil between the rows positively contributes to important processes such as water infiltration, nutrient supply and retention, carbon sequestration and reduction of soil erosion (Peregrina *et al*., 2010; Mazzoncini *et al*., 2011; Ruiz-Colmenero *et al*., 2013). Organic matter input is an important way to restore and maintain soil fertility and is a common practice especially in soils that are characterized by high salinity (Guénon and Gros, 2016; Srivastava *et al*., 2016).

At the same time, the wine industry can constitute an important source of organic waste used in vineyards to improve soil composition. This process is presented as a viable strategy for managing winery by-products. The exclusive addition of fertilizer is no longer considered the best method for vine nutrition and plant pathogen control (Burg *et al*., 2014). The main organic wastes include dewatered sludge, grape marcs, dregs, wine lees and lees (Nerantzis and Tataridis, 2006). In an experimental vineyard located in the city of Timisoara (variety 'Otonel') where compost was applied (20 t ha^{-1}), the following were observed: increase in foliar chlorophyll concentration, less nutrient deficiencies in the leaves, reduced effect of drought on the vines, which in turn also exhibited a better response to diseases (Nistor *et al*., 2014). Results after long-term application of green waste compost to vines of cv Chardonnay showed that the long-term addition of compost to a vineyard could prove to be beneficial for soil characteristics, including nitrate sodium content and organic matter, but at the same time, it exhibited no effect on plant growth and grape quality characteristics (Mugnai *et al*., 2012).

The aim of the present study was to assess the effect that different tillage soil management techniques in combination with the addition of different fertilization methods have on the physiology of grape cultivar 'Robola', under vineyard conditions.

Materials and Methods

Plant material

The experiment took place in a non-irrigated vineyard in Kefalonia island, during the cultivation season 2023. Vines of grape cultivar 'Robola' were selected in order to evaluate the effect of the soil management techniques and different vine nutrient methods on the physiology and grape quality of the vines selected. The 20-year-old vines were selected for study via an assay of their polyphenolic profile on the basis of (a) their morphology and (b) being the most representative of the variety. The vines selected are grafted on rootstock Richter 110, are bilateral cordon- trained (bilateral Royat) at 2 m x 1.5 m intervals, and manually spur-pruned to 3-node canes per arm. There were fifteen (15) buds in total per vine. The vines selected were all grown in the same area and under the same conditions. The meteorological data of the region are shown in Figure 1.

Month	Mean Temp	Mean High Temp	Mean Low Temp	Abs High Temp	Day	Abs Low Temp	Day	Acum Rain	Max Daily Rain	Day	Mean Wind Speed	Abs High Speed	Day	Dom Dir
-01	12.5	16.2	8.8	20.3	19	5.3	28	217.0	64.2	25	5.1	54.7	26	S
-02	11.3	15.2	7.6	22.7	28	4.7	12	5.6	4.8	04	8.8	75.6	09	S
-03	14.0	17.9	10.0	20.8	26	6.8	18	86.4	47.0	07	6.3	67.6	28	NNW
-04	14.9	18.7	11.2	21.2	24	7.4	09	120.0	46.2	16	6.2	57.9	06	NNW
-05	19.6	23.6	15.9	28.6	15	13.1	06	78.6	27.8	04	6.4	62.8	15	ESE
-06	23.8	28.1	20.0	32.1	25	17.5	04	9.2	4.2	15	6.3	45.1	16	NNW
-07	27.9	33.4	23.4	39.3	23	20.5	10	0.0	0.0	01	7.9	54.7	07	NNW
-08	27.4	32.0	23.2	38.6	22	21.3	08	11.4	11.0	05	6.5	48.3	08	NNW
-09	24.9	29.3	21.0	32.4	23	18.1	14	18.8	7.2	26	7.2	61.2	08	NNW
-10	22.2	26.6	18.0	29.5	11	15.2	30	16.4	11.6	26	4.9	48.3	17	NNW
-11	18.0	21.4	14.1	25.4	03	7.6	27	136.0	30.6	01	7.0	69.2	26	ESE
-12	13.9	17.3	10.7	21.9	02	5.8	19	37.4	18.6	15	4.9	66.0	17	NNW
	19.2	23.3	15.3	39.3	07	4.7	02	736.8	64.2	01	6.5	75.6	02	

Figure 1. Climatic parameters during the year of the experiment (2023)

Grape cultivar 'Robola' is considered one of the most important white wine grape cultivars of western Greece and of the Ionian Islands, with main cultivation center the island of Kefalonia (Figure 2), which is the only island in the wider area that produces PDO (Protected Designation of Origin) wines. Grape cultivar 'Robola' has been known at least since the 14th century C.E., with its first written mention appearing in an official inventory document of the Church (Stavrakakis, 2021). It is a quite vigorous and productive variety, and exhibits high adaptability to dry, warm, infertile soils of semi-mountainous areas, resulting in high quality wine products (Stavrakakis, 2021).

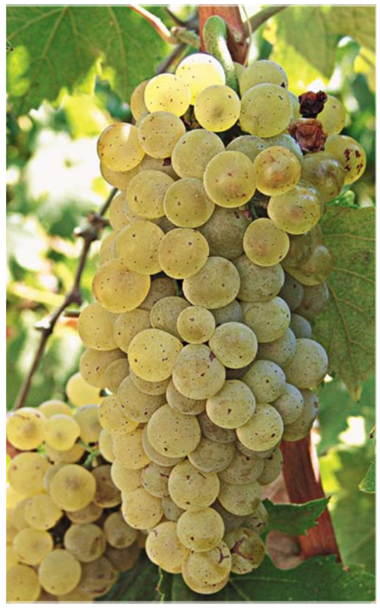

Figure 2. Typical grape of grapevine cultivar 'Robola'

Experimental design and treatments

Vines from grape cultivar 'Robola' underwent a combination of treatments, one related to different soil management techniques (the usual tillage applied in the region and reduced tillage) and one related to different fertilizations.

In the viticultural zone of Kefalonia, the usual practice for an effective weed management control is rototilling (tillage) about twice a year and the typical fertilization of the region is conventional fertilization using synthetic fertilizers, which served as control treatment.

The alternative soil management technique tested in this experiment (reduced tillage) was achieved by cutting weeds without soil disturbance, while rototilling was conducted once a year in a narrow strip solely for the purpose of incorporating the fertilizer.

The alternative fertilization systems that were tested in this experiment were: (i) slow release fertilizer, involving the use of nitrogen fertilizers with nitrification inhibitor (NFNI) on soil moisture conservation and nutrient availability during critical stages of the growing season, for example to reduce N losses due to denitrification and leaching during the winter, and (ii) organic fertilization through the recycling of plant materials and by-products of viticultural production (winery pomace). All fertilizations were incorporated into the soil.

The Randomized Complete Block Design was selected as experimental design. The vineyard was divided into three experimental blocks randomly distributed. Each of these blocks was, in turn, divided into six experimental units, also randomly distributed within the experimental blocks. Each experimental unit within the block was subjected to a different treatment as follows (Figure 3):

- F1: usual tillage with conventional fertilization
- F2: usual tillage with slow-release fertilizer
- F3: usual tillage with composting winery waste (organic fertilization)
- F4: reduced tillage with conventional fertilization
- F5: reduced tillage with slow-release fertilizer
- F6: reduced tillage with composting winery waste (organic fertilization)

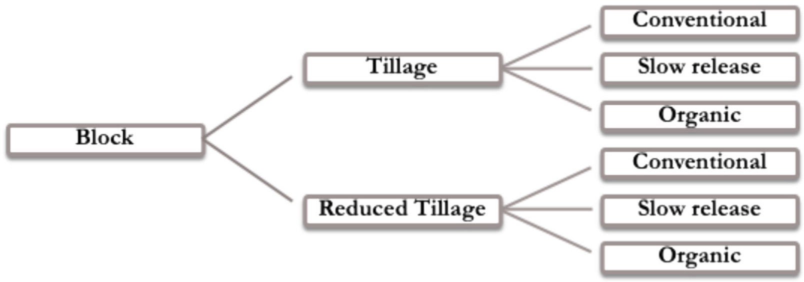

Figure 3. Graphic representation of the different treatments applied

More specifically, in treatments F3 and F6 where organic fertilization was applied, organic phosphorus from animal bones was used (0-27-0), while in the other treatments, conventional phosphorus was used (0-46-0). In treatments F1 and F4, conventional nitrogen (21-0-0) was used, while in treatments F2 and F5, conventional nitrogen (21-0-0) was also used, but with the addition of nitrification inhibitor.

Regarding the time of applications, organic fertilization took place in January 2023, phosphorus was applied in the beginning of February 2023, while nitrogen was applied in the end of February 2023. Regarding the usual tillage treatment, the first rototilling took place after the first fertilization with the aim to incorporate the fertilizer into the soil, and the second rototilling took place in March 2023. Regarding the reduced tiilage treatment, there was only one rototilling which took place after the first fertilization.

Sampling

Grapes were randomly selected from different vines of the six (6) treatments and three (3) sampling processes took place. The grapes were collected from the main shoots of different positions. Each sampling constituted one replication. A total of three (3) replications per treatment took place.

Leaf-related measurements

Leaf assimilation rate (μmol CO_2 m^{-2} s^{-1}), leaf stomatal conductance (mol H_2O m^{-2} s^{-1}) and leaf transpiration (mmol H_2O m^{-2} s^{-1}) were obtained by measurement of inlet and outlet CO_2 and H_2O relative concentration using a portable photosynthesis system (Li-6400XT, Li-Cor, Lincoln Nebraska, USA). The measurements were taken on three different phenological stages of the grapevine (fruit set, véraison, fruit maturity).

These measurements were obtained during specific hours (09:30-11:30) on five primary leaves, in the same day and on different vines per treatment, which were marked and were the same for the three phenological stages. The leaves were fully mature and exposed to direct sunlight. On the same leaves, the chlorophyll content was determined (μg cm^{-2}) by measuring the leaf absorbance in red and near-infrared regions (the light is emitted by two LEDs with peak wavelengths at 650 nm and 940 nm), using the SPAD-502 instrument (Konica Minolta, Inc.).

Mechanical properties of the berries

Random grapes from different vines of 'Robola' for the different treatments were collected during harvest, at a total number of nine (9) grapes. For each grape collected, three random groups of fifty (50) berries were sampled in order to measure their weight using a precision scale, their length and width using calipers of an 0.01 accuracy (Biniari *et al*., 2018). Regarding the berry humidity, three (3) replications per treatment were carried out in which five (5) berries were collected, their weight was measured using a precision scale, and they were then placed in a chamber for dehydration for five (5) days. Then, their weight was once again measured in order to determine the weight difference before and after the drying process, thus calculating the berry humidity percentage for each treatment (Bouza et al., 2024). Moreover, three (3) groups of 15 berries per treatment were separated in skins, seeds and flesh in order to separately measure the weight of the skins and seeds, as well as the weight of the flesh. Through these measurements, the percentage of skin and seed weight was calculated.

Characters of the must

The characters of the must, namely total soluble solids, total titratable acidity and pH were determined as described in Biniari *et al*. (2020). The ratio of ripening was calculated by dividing the total soluble solids to the total titratable acidity.

Statistical analysis

All results were expressed as mean ± SE (Standard Error) of the three (3) replications out of three (3) samples/bunches (i.e. the three bunches were considered as one replication). All determinations were analyzed in triplicate. Data were processed by analysis of Variance (ANOVA) and the statistical significance was processed using the Tukey's range test at ≤ 0.05. All statistical analyses and correlations were obtained using JMP v. 10 statistical software (SAS Institute Inc., Cary, NC, USA).

Results

According to Table 1, statistically significant differences were observed between the different treatments. The highest length and width of the berries was recorded in treatment with reduced tillage and the addition of conventional fertilization. The weight of 50 berries was higher in treatments F3 and F5, without statistically significant differences. The treatment with reduced tillage and composting winery waste exhibited the lowest values for the three measurements.

Table 1. Mechanical properties of the berries, in relation to the different treatments

Treatments	Berry length (mm) (avg of 10 berries)	Berry width (mm) (avg of 10 berries)	Weight of 50 berries (g)
F1	13.61 ± 0.18 bc	13.78 ± 0.15 b	86.87 ± 0.15 b
F2	14.01 ± 0.29 ab	14.10 ± 0.23 b	88.33 ± 0.12 b
F3	13.23 ± 0.02 c	13.35 ± 0.32 b	91.18 ± 0.64 a
F4	14.41 ± 0.07 a	15.09 ± 0.05 a	86.84 ± 0.75 b
F5	14.26 ± 0.02 ab	14.14 ± 0.04 b	92.55 ± 0.35 a
F6	13.09 ± 0.04 c	13.47 ± 0.13 b	81.07 ± 0.67 c

Values are the means of triplicates. In each cell the results are presented as mean ± Standard Deviation. Values on the same column carrying a different letter (a–c) are significantly different at significance level $p \leq 0.05$, according to Tukey's test.

According to Table 2, all treatments exhibit similar humidity levels ranging from 70.98% (treatment F3) to 72.14% (treatment F5). Treatments F1 to F5 present similar values in skin weight per berry, ranging from 13.11% to 14.16%, with no statistically significant difference recorded. Treatment F6 recorded significantly lower percentage of skin weight (11.47%), with a statistically significant difference compared to the other treatments. This implies that treatment F6 decreased the percentage of skin in the berry.

Table 2. Percentages of berry humidity, berry skin-seed-flesh weight, in relation to the different treatments

Treatments	Berry humidity (%)	Skin weight per berry (%)	Seed weight per berry (%)	Flesh weight per berry (%)
F1	71.07 ± 0.50 a	13.21 ± 0.77 a	2.43 ± 0.20 a	84.34 ± 0.68 a
F2	71.91 ± 0.87 a	13.69 ± 1.76 a	3.21 ± 0.12 a	83.09 ± 1.68 a
F3	70.98 ± 0.83 a	13.11 ± 0.41 a	3.08 ± 0.28 a	83.80 ± 0.68 a
F4	71.75 ± 0.58 a	14.16 ± 1.54 a	3.21 ± 0.31 a	82.62 ± 1.33 a
F5	72.14 ± 0.94 a	14.15 ± 0.91 a	2.78 ± 0.59 a	83.05 ± 1.50 a
F6	71.01 ± 0.74 a	11.47 ± 0.51 b	2.78 ± 0.23 a	85.74 ± 0.66 a

Values are the means of triplicates. In each cell the results are presented as mean ± Standard Deviation. Values on the same column carrying a different letter (a–b) are significantly different at significance level $p \leq 0.05$, according to Tukey's test

Regarding the characters of the must, the different treatments exhibit statistically significant differences (Table 3). More specifically, the highest concentration of total soluble solids, the highest pH values and the highest total titratable acidity were recorded in the treatment with reduced tillage and the addition of slow-release fertilizer (treatment F5), with statistically significant difference compared to the other treatments.

As mentioned earlier, the ratio of ripening was calculated by dividing the total soluble solids to the total titratable acidity, and the highest ratio was recorded in treatment with usual tillage and the addition of conventional fertilization (treatment F1), followed by the treatment with usual tillage and slow-release fertilizer (treatment F2), with a statistically significant difference compared to the other treatments.

Table 3. Characters of the must, in relation to the different treatments

Treatments	Total soluble solids (°Brix)	pH	Total titratable acidity (g tartaric L^{-1} must)	Ratio of ripening
F1	19.61 ± 0.10 a	3.57 ± 0.03 ab	5.60 ± 0.07 c	3.50 ± 0.03 a
F2	19.18 ± 0.08 ab	3.54 ± 0.01 ab	5.72 ± 0.01 c	3.35 ± 0.01 a
F3	19.71 ± 0.34 a	3.47 ± 0.01 b	6.55 ± 0.01 a	3.01 ± 0.05 b
F4	19.96 ± 0.12 a	3.58 ± 0.03 ab	6.04 ± 0.08 b	3.30 ± 0.06 a
F5	20.15 ± 0.39 a	3.61 ± 0.02 a	6.64 ± 0.05 a	3.04 ± 0.04 b
F6	18.35 ± 0.18 b	3.55 ± 0.02 ab	6.25 ± 0.02 b	2.94 ± 0.0 b

Values are the means of triplicates. In each cell the results are presented as mean ± Standard Deviation. Values on the same column carrying a different letter (a–b) are significantly different at significance level $p \leq 0.05$, according to Tukey's test

Regarding the measurements related to vine physiology and more specifically, the physiological processes of the leaves, statistically significant differences were recorded. The treatment with usual tillage and the addition of composting winery waste increased the chlorophyll content, leaf stomatal conductance, leaf transpiration, inert carbon dioxide and as a result, the assimilation rate, with a statistically significant difference compared to the other treatments. Soil management with reduced tillage regardless of the fertilizer used resulted in an overall significant decrease in leaf transpiration, leaf stomatal conductance as well as significantly decrease in leaf photosynthesis (assimilation rate) in the case of conventional fertilization (treatment F4).

The data showed that higher values in chlorophyll are associated with different values of assimilation rate, suggesting a positive correlation between the two. Higher assimilation rate is accompanied by higher transpiration values. At the same time, stomatal conductance is directly correlated with transpiration, since the higher values of both stomatal conductance and transpiration are recorded in treatment F3, and the lower values are recorded in treatment F6.

Table 4. Chlorophyll content, leaf assimilation rate, leaf transpiration and leaf stomatal conductance at harvest, in relation to the different treatments

Treatments	Chlorophyll content	Leaf assimilation rate ($\mu mol\ CO_2\ m^{-2}\ s^{-1}$)	Leaf transpiration ($mmol\ H_2O\ m^{-2}\ s^{-1}$)	Leaf stomatal conductance ($mol\ m^{-2}\ s^{-1}$)
F1	38.00 ± 0.30 bc	9.51 ± 0.19 ab	3.29 ± 0.025 c	0.103 ± 0.003 ab
F2	39.93 ± 0.33 a	7.71 ± 0.13 d	3.25 ± 0.024 c	0.083 ± 0.014 c
F3	40.23 ± 0.08 a	9.63 ± 0.15 a	3.85 ± 0.020 a	0.113 ± 0.016 a
F4	37.2 ± 0.05 c	7.64 ± 0.10 d	3.06 ± 0.023 d	0.093 ± 0.008 bc
F5	39.26 ± 0.48 ab	8.96 ± 0.07bc	3.61 ± 0.044 b	0.106 ± 0.012 ab
F6	39.86 ± 0.18 a	8.49 ± 0.05 c	2.49 ± 0.051 e	0.086 ± 0.008 c

Values are the means of triplicates. In each cell the results are presented as mean ± Standard Deviation. Values on the same column carrying a different letter (a–e) are significantly different at significance level $p \leq 0.05$, according to Tukey's test

Discussion

The investigated techniques are designed to balance the viticulturist and winemaker's conflicting objectives. The main objective of the present study 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 terroir, ensuring, in addition, the vines' nutrition (Pool *et al*., 1990).

Soil management with the usual tillage technique could result in a decrease of soil organic matter concentration, due to its direct decomposition and the direct uptake of nutrients by the vines (Schreck *et al*., 2012). As a result, the grapes exhibited a higher degree of ripening for this treatment in combination with the addition of conventional fertilizers (quick release fertilizers). The above-mentioned process could gradually, in the future, lead to a natural degradation in the vineyard soil, thus in the reduction of grape quality (Cerdà *et al*., 2017; Lohar, *et al*., 2021).

At the same time, this should be taken into consideration by the wine grower when deciding to have an early or delayed ripening, as it seems the different techniques of soil management and nutrition affect the vegetative cycle of vine and therefore the quality and quantity characteristics of the grapes (Ripoche *et al*., 2011).

Reduced tillage does not favour the immediate decomposition of plant residues and therefore can cause a temporary decrease in the vigour of the vines through the sequestration of nutrients and carbon on the soil surface in the form of plant residues (Peregrina *et al*., 2010; Mazzoncini *et al*., 2011; Ruiz-Colmenero *et al*., 2013). Soil management with reduced tillage resulted in the increase of the length and width of the berry. Despite the positive effect on soil physical properties, manure did not exhibit a significant effect on crop production when compared with chemical fertilizers (Edmeades, 2003).

In this work, the addition of organic fertilizers, associated with the accumulation of organic matter, which is not directly decomposed, did not exhibit concrete results. As suggested by Chen *et al.* (2017), a combination of manures and chemical fertilizers are essential in order to sustain high yield and improve soil properties. In view of climate change implications, different cultivation protocols with the use of combined application of different tillage systems and appropriate fertilization type could lead to the conservation and optimal utilization of soil water and nutrients while limiting soil erosion.

Furthermore, the composting process with winery waste in both techniques applied to soil (usual and reduced tillage) seems to have a positive contribution to the weight of the grapes by reducing their size and increasing their number, which is critical for the winemaking process, as sorting by berry size or colour will lead to wines with a pronounced difference in aroma compounds, acidity and α-amino nitrogen (Šuklje *et al*., 2012; Friedel *et al*., 2016).

In addition, these smaller berries showed a higher total soluble solid content, a result which is in agreement with other studies (Roby *et al*., 2004; Šuklje *et al.,* 2012). The high sugar accumulation may reflect the response to high photosynthesis and the other physiological parameters, which were studied in the treatments applied in this work.

All the above makes the cultivation and management of white grapes very delicate. It is, therefore, necessary that the winemaker adapts to the new conditions caused by climate change and therefore choose the soil and nutrition strategy aimed at preserving and enhancing the potential quality of white grape varieties in order to optimize the results of harvesting.

In other words, a specific wine style demands a particular set of ripening parameters, as the ones that are influenced by the treatments applied in the present study, and of course, the concept of grape quality at harvest should be considered in terms of the required wine composition and sensorial properties, especially during the white winemaking process (Ribéreau-Gayon, *et al*., 1998).

The best soil and nutrition management for a vineyard is determined in part by the characteristics of the vineyard as well as by the climatic conditions that prevail in the area of the vineyard terroir and additionally by the winemaker's goal for the type and style of wine desired to produce, taking into account a sustainable model of viticulture (Ripoche, *et al*., 2010).

Conclusions

In general, the different tillage and nutrition techniques affect differently the physiological parameters of the vine and the dimensions (length, width), weight and composition of the berry. However, berry composition can exhibit differences depending on the soil, climate conditions and viticultural practices applied at any given vineyard.

Compared to conventional tillage and continuous inputs, the techniques related to sustainable strategies investigated and proposed in this study give a primary role to the preservation of biodiversity, the maintenance of soil fertility and the vegetative-productive balance.

The adoption of such techniques would mean that viticulture would contribute to the global efforts to offset atmospheric concentrations of greenhouse gases, increasing organic matter in vineyards, while maintaining the quality of the grapes and wine products.

Authors' Contributions

Conceptualization: KB, MS, ID, DB; Data curation: KB, MS, ID, DB, DMS; Formal analysis: MS, ID, DMS; Funding acquisition: KB; Investigation: ; Methodology: KB, ID, AF, TC, EK, AG; Resources; Supervision: KB, MS, EK; Validation: ID, TC ; Writing - original draft: KB, MS, ID, DB; Writing - review and editing: KB, MS, ID. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

Acknowledgements

This work was supported and received funding in the context of Action 2 of Sub-Measures 16.1-16.5 "Establishment and operation of Operational Groups of the European Innovation Partnership for the productivity and sustainability of agriculture" of the Rural Development Program (RDP) 2014-2020.

Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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