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Cover Crops Affect Performance of Organic Scarlotta Seedless Table Grapes Under Plastic Film Covering in Southern Italy

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Abstract: In sustainable or organic vineyard systems, the introduction of cover crops could represent a powerful tool for farmers to influence, positively, the agro-ecosystem by promoting the whole soil-plant system equilibrium. Concerning table grape production, nitrogen fertilizers are medium-high; for environmental aspects, organic viticulturists are more interested in legume inter-row cover crops. Research on cover crop effects was carried out in 2015–2016, on organic table grapes (the Sugranineteen variety) in Mediterranean conditions. Three inter-row soil management techniques were compared: (TR) inter-row spacing was cultivated with subterranean clover; (V) inter-row spacing with common vetch incorporated in the soil as green manure, and (RC) inter-row spacing with common vetch flattened by the roller crimper technique, making a living mulch. No significant difference was recorded in grapevine water status among the treatments. RC vines performed the highest net photosynthesis rate from shoot growth to veràison. Cover crops did not affect cluster weight, berry weight, and juice composition; however, they influenced berry detachment force. Our research findings confirmed that legume cover crops (subterranean clover and common vetch) increased soil organic matter and could represent an economic and sustainable soil use to reduce the amount of nitrogen fertilizers applied in table grape production.

Keywords: organic viticulture; vine characteristics; soil management; water status; leaf gas exchange

1. Introduction

In the last years, vineyard inter-row soil management through mechanical tillage in viticulture has substantially decreased. In viticulture, the inter-row cover crops (permanent or temporary) determine the reduction of water runoff, prevent soil erosion, increase soil organic matter, and microbial activity [1]. Other effects related to the introduction of cover crops in vineyards are the reduction of water evaporation from the soil surface, the increase of beneficial soil organism especially earthworms and, if cover crops are legumes, the reduction of input of nitrogen (N) fertilizers [2]. Moreover, research data from South Africa's vineyards confirmed that, by using grazing vetch (*Vicia dasycarpa*) as a cover crop on sandy soil, the organic matter content increased in the 300 to 600 mm soil layer after a period of ten years, whereas frequent vineyard clean cultivation reduced the organic matter content [3]. Other results found by Fourier [4] confirmed that cover crops versus soil tillage determine, as much as 86%, more organic matter content as compared to tillage treatment in the 0 to 150 mm soil layer after a medium period. In a warm Mediterranean climate, where soil organic carbon matter content is very low, a sustainable inter-row soil cultivation strategy with winter continuous cropping of annual cereals and legumes resulted in increased soil organic carbon (up to 163%) compared to a minimum soil cultivation treatment, in which no cover crops were sown. It represents a positive strategy to contrast the negative effects of global warming [3,4]. Some of the negative effects related to the inter-rows with cover crops in a warm climate, with limited rainfall in the summer season, are a lower vine vigor and yield, a reduction of N content in the leaf petiole, and a greater frost hazard and grapevine pests [5,6].

Table grape growers in Mediterranean regions are not very favorable to the introduction of cover crops in relation to water and nutrient competition between cover crops and vines. However, in organic viticulture, legume cover crops could represent the main inter-row soil management technique [7–9].

Each cover crop mixture has advantages and disadvantages, but the growers prefer to utilize a mixture of grass and legumes, since the latter fix atmospheric N that becomes available over several months after cover crop termination. In horticulture trials, the use of common vetch (*Vicia sativa L.*) as a cover crop has improved soil fertility and increased the yield of subsequent crops in rotation. These positive effects are the result of the roots and/or canopy plant biomass, which contain a high amount of N and a low carbon-to-nitrogen ratio (C/N), which determines a rapid release of plant-available N [10]. There are different methods of cover crops termination, such as mechanical chopping, plowing, field disking, mowing, or crushing with a roller crimper. The roller crimper is a water-filled drum with angle iron blades that rolls and crimps the stems, lays the cover crops uniformly on the ground, creating a dense, mulch layer, with one or two passages of the shaped roller to flatten the cover crops. The effect of mulch remaining on the soil is to reduce weed growth; increasing soil water content by limiting evaporation from the soil. The cover crop termination method affects the timing of the burying of the cover crops biomass and the rate of N mineralization [10].

In order to advance or to delay table grape ripening, the growers use plastic film to cover the top of the vineyards, and the effect of plastic film changes in relation to the covering period [11–13]. If the goal of the grower is to advance ripening, plastic film covering is applied after winter pruning to very early season table grape varieties. In this case, the effect of the plastic film cover is to increase inside air temperature to advance the budbreak and subsequent stages. On the contrary, for harvest delay, the plastic film covering is applied from veràison on mid-late season table grape varieties. Plastic film used in the latter case protects clusters and canopy from rain, wind, and hail and delays the harvest season to December. Under plastic film covering, the incidence of bunch root disease (mainly *Botrytis*) is greatly reduced, with positive effects on vine eco-physiological activity, berry growth, and yield per vine related to variations in photosynthetic active radiation, relative humidity, and air CO_2 concentration [14]. Plastic film coverings are made with low-density polyethylene (LDPE) and ethylene-vinyl acetate (EVA) films. In relation to their spectral transmissivity, which defines the radiometric properties (the fraction of the incident solar energy radiant flux that is transmitted at a specific wavelength), they influence the microclimate inside the protected cultivation [12]. The increase of air temperature inside the covering (the screen effect) determines a lower incidence of grapevine diseases, such as downy mildew (*Plasmopara viticola*) and botrytis bunch root, with limited pesticide treatments. Nowadays, worldwide consumer demand is oriented towards seedless table grapes with little or no pesticide residue, as well as being organically grown.

Organic table grape production is complex, and in organic viticulture inter-row, the cover crops are considered an optimal sustainability method for the soil management. Even if the cover crop effects on wine grape vineyards have already been evaluated, there is a lack of knowledge on the influence of cover crops on organic table grape production in Mediterranean conditions. Therefore, the aim of our trial was to study the different cover crops in an organic table grape vineyard. To accomplish this objective, we investigated yield, cluster components, crop quality, and organic matter status in an organic table grape experiment located in a typical area of the Mediterranean environment.

2. Materials and Methods

2.1. Experimental Site

The research was carried out in 2015 and 2016 in an organic table grape vineyard on *Vitis vinifera* cv Sugranineteen (Scarlotta seedless brand), grafted onto 140 Ruggeri (*Vitis berlandieri* x *Vitis rupestris)* rootstock. Vines (3 years old) were spaced 3.5 m between rows and 2.0 m within the row (1.428 vines ha^{-1}) located in the Gioia del Colle area (Apulia region—South Italy), 364 m above sea level (40°47′49″ N 16°52′55″ E).

The climate of the area, where the research was conducted, was the Mediterranean—warm, with summers characterized by high evaporation and low, relative humidity (August temperature of 31 °C) and minimum temperatures, in February, of about 3 °C. The rainy period is concentrated from September to April, with a low and irregular summer season rainfall. Meteorological data were collected from an agro-meteorological station located near the experimental vineyard.

Sugranineteen is a seedless variety characterized by late ripening (end of September); berries are crisp, juicy, and elliptical in shape. Berries attain a large size without the need for exogenous application of gibberellic acid, and possess a naturally red, commercially acceptable coloration, even when grown in shade canopy [15]. Vines were cane pruned (four eight-node canes were retained, 32 buds per vine) and trained to the Y trellis system, drip-irrigated, and covered on top of each row with plastic film from budbreak to harvest, to protect canopy and clusters from the negative effects of rain, hail, and wind. The transmissivity coefficients of the plastic film covering were measured over different wavelength bands: Ultraviolet A (UV-A—320–380 nm), Photosynthetic Active Radiation (PAR—400–700 nm), Solar Infrared Radiation (IR—700–2500 nm), Solar (300–2500 nm), and Long Wave Infrared Radiation (LWIR—7500–12500 nm) wavelength ranges.

2.2. Experimental Design

In this research, three inter-row soil management strategies were compared: (TR) mechanical cultivation along the rows, while inter-row spacing was sown with subterranean clover cover crops (*Trifolium subterraneum* L. *ssp. brachycalicinum* cv Antas); (V) Mechanical cultivation along the rows, while inter-row spacing was sown in November with vetch (*Vicia sativa* cv Aitana), incorporated as green manure, in which the biomass was chopped and ploughed (to a 15–20 cm depth) at the end of legume flowering. Finally, (RC) mechanical cultivation along the rows while inter-rows spacing was sown with vetch (*Vicia sativa* cv Aitana) flattened mulch, obtained by the roller crimper technique, in which the mulch layer remained in place, covering the soil surface, and mown after flowering.

Subterranean clover was sown one time at the rate of 60 kg·ha^{-1} in October, while common vetch was sown at the rate of 80 kg·ha^{-1} every year in the V and RC treatments in November. The seedbed preparation was done with a disc harrow approximately two weeks before the seeding date. After mechanical sowing, the subterranean clover and vetch seeds were covered using a disc harrow. More precisely, the vineyard soil management is divided in two zones: the rows, a 70 cm wide area underneath the vines, which are managed by mechanical tillage, and the space between the rows, with cover crops. Vine row cultivation was tilled every 5 to 6 weeks during spring and summer seasons with a cultivator provided with a trunk sensor to avoid vine mechanical damage.

A complete randomized design with three replicates of vines was adopted. Each replication consisted of four parts of rows, each one composed by 12 vines for a total row length of 36 vines. In each replicate, we had 48 vines and 144 vines for each treatment. The measurements were made on the two central rows to avoid the border effect.

Drip irrigation was applied uniformly across all treatments with a single irrigation line per row and pressure-compensated emitters, with a discharge rate of 10 L h^{-1} per vine, respectively. The soil of the vineyard has a clay-loam texture with an approximate rooting depth of 0.70 to 1.0 m and 170 mm/m available water over the rooting depth. Soil analyses pointed out 36%, 37%, and 27% of sand, silt, and clay, respectively, 1.7 g kg^{-1} organic matter, and 7.64 soil pH. Both agronomic and canopy management practices (included infertile shoot thinning, basal leaf removal, and cluster positioning) were performed by field workers.

At the beginning (January 2015, no cover crops) and at the end (December 2016, presence of cover crops) of the two-year trial (To and Tf, respectively), soil was sampled in five different points per each experimental plot (treatment and replication) at 0–30 cm depth. Then, these five samples were pooled in one, and each soil sample was air-dried and sieved to <2 mm for the chemical analyses. Total nitrogen (Total N) was determined according to the Kjeldahl method, while Total Organic Carbon (TOC) was according to the Springer and Klee method [16].

2.3. Vines Measurements

On 15 vines per each treatment (five vines per each replication) shoots and clusters number per vine was recorded and fruitfulness was calculated. Midday stem water potential (Ψ_{stem}), an indicator of vine water status, was periodically measured with a pressure chamber on 10 main leaves of similar maturity per treatment (3005F01, Soil moisture Equipment Corporation, Santa Barbara CA, USA). For the measurement, plastic bags covered with aluminum foil to reflect sunrays were placed on well-exposed mid-shoot leaves one hour before the onset of Ψ_{stem} measurements.

A hand-held chlorophyll meter (Soil Plant Analytical Development - SPAD 502, Minolta Corporation, Tokio, Japan) was used for non-destructive measurement of relative leaf chlorophyll concentrations. The measurements were made on five leaves per vine (10 vines per plot), located two nodes above the second cluster on a middle vigorous shoot. Five SPAD readings were measured on the leaf surface and then averaged to represent the value of each leaf data. Midday measurements of leaf gas exchange were periodically recorded between 12:00 and 14:00 solar time on well-exposed main leaves of the second node above the distal cluster on a middle vigorous shoot (4 leaves per each replication), at ~1500 μmol m^{-2} s^{-1} of photosynthetic photon flux with portable infrared gas analyzer (ADC, LCpro SD, ADC BioScientific Ltd., Hoddesdon, UK).

Each year at commercial harvest (second week of September), carpometric parameters, such as bunch and berry mass, cluster length, and berry diameters were determined on samples of 45 clusters per treatment (15 clusters were selected from the middle shoot of a randomized vine per replication, and 20 random berries per each cluster). The optimal harvest period was reached when clusters had the minimum soluble solids for table grape commercialization (18 Brix). In the lab, the total soluble solids (Brix) were determined on samples of fresh grape juice extracts with the use of a digital refractometer (Atago Co Ltd, Tokyo, Japan). Titratable acidity, expressed as g L^{-1} of tartaric acid equivalent with titration of 0.1 N NaOH, was measured with an auto-titrator, while juice pH was measured using a pH meter.

Skin firmness and berry detachment force were determined on 50 berries randomly sampled per each treatment using a digital penetrometer (Digital Fruit firmness tester, TR Turoni S.r.l., Forlì, Italy). Moreover, the following berry skin color parameters were determined on a sample of 50 berries per each treatment by using a reflectance colorimeter (Croma Meter CR 400, Minolta, Japan) on the CIELAB color system: lightness (L*), redness (a*) measure of color range from green (−) to red (+) and yellowness (b*) measure of color range from blue (−) to yellow (+). From these data, chroma (C*, saturation) ($(a^2 + b^2)^{1/2}$) and Color Index for Red Grapes (CIRG), the main parameter used in literature to describe the skin color of red grape varieties defined as ((180-h)/(L*+C*)), were calculated [17].

To determine the total leaf area per vine, six vines per each treatment were entirely defoliated after the harvest, and the leaf area with a leaf area meter (area-meter Li-3100, LI-COR, USA) was measured. Subsequently, the leaf area/crop weight ratio was calculated. During winter pruning, the vegetative growth was quantified by measuring one-year-old pruning weight and the yield to pruning weight ratio.

The data collected on two growing seasons were subjected to statistical analyses using Systat v11 package (SYSTAT Software Inc., Richmond, CA, USA), considering years and replicates as random effects, whereas the soil management treatments as fixed effect. The data were analyzed using One-Way analysis of variance (ANOVA) and Student Newman Keuls (SNK) test to identify the difference among means. Since the ANOVA of the full analysis of variance, which involved the first order variables and the interaction, was not significant ($p < 0.05$) for the interaction of all parameters analyzed for years x soil management treatments, the data were presented by the means of treatments.

3. Results and Discussion

The plastic film adopted in the vineyard was characterized by high value of PAR total transmissivity coefficient, equal to 85.5%, and the solar diffuse transmissivity coefficient, which reached 32%. The plastic film allowed to pass the lowest fraction of UVA radiation, equal to 36.9%, while for the LWIR wavelength range, the film was characterized by the 58.8% LWIR transmissivity coefficient (Table S1).

Rainfall distribution was different in 2015 and 2016, with more frequent precipitation before veràison in 2015. Precipitation measured from budbreak (April) through September (harvest) were greater than the average period 2000–2014 (189 mm) in 2015 (208 mm), but much less (148 mm) than average in 2016. Therefore, the 2015 season was cooler than the average period, whereas 2016 was much warmer (Table S2).

No significant difference was found among soil management treatments on vegetative and productive parameters of Sugranineteen vines (Table S3); therefore, the cover crops did not influence grapevine bud fertility. Considering that different parameters, such as light conditions, temperature, grapevine water status, and mineral nutrition are the main factors affecting the formation of grapevine inflorescences during season, no negative action correlated to cover crops was identified [18]. Furthermore, no significant difference was found between V and RC treatments in all measured parameters, indicating that it is possible to apply the roller crimper cover crop management in table grapes without reducing the vegetative and productive characteristics. The results show the possibility to adopt this agro-ecological strategy in another farming system, as it improves crops biodiversity and sustains the sustainability of the agro-ecosystem, as found in other cropping systems [19,20].

Midday stem water potential from fruit set to harvest showed no differences among treatments and different cover crops did not affect vine water status, although a mild water stress was recorded in all treatments (Table S4). During berry growth up to harvest, average Ψ_{stem} values ranged between 0.43 to 0.80 MPa (negative values). These data confirm, once again, that midday stem water potential is a good plant-based indicator of grapevine water status [21].

The mean SPAD values of treatments were the same at pea-size stage, while from berry growth to harvest the values differed significantly. In particular, the SPAD index of vines under clover cover crops was characterized by an increase of greenness during berry growth (+6%), probably in relation to higher N availability, which is related to early and fast vegetative growth of *Trifolium subterraneum* compared to the vetch. The positive effect of temporary subterranean clover cover crops on the leaf nutritional status of vines was reduced at veràison (July) stage, since the clover is dried up on the soil and had only mulching effect and no water demand. From veràison to harvest vetch, the roller crimper influenced the leaf nutritional status showing the highest SPAD index. The lowest SPAD was recorded at harvest on vine plots with vetch incorporated as green manure (Table 1).

Table 1. Effect of soil management on leaf SPAD index in 2015–2016. (Values are means ± SD).

Treatments	Pea-Size	Berry Growth	Veráison	Harvest
TR	40.1 ± 2.8 a	40.4 ± 3.1 a	39.4 ± 3.1 b	38.5 ± 4.3 b
V	41.1 ± 3.2 a	38.1 ± 3.3 b	40 ± 3.5 ab	36.1 ± 4.2 c
RC	41.5 ± 2.6 a	38.3 ± 4.6 b	41.6 ± 3.2 a	41.6 ± 4.5 a

In the columns, values followed by the same letters did not differ significantly, according to the SNK test ($p < 0.05$). Note. SPAD = Soil Plant Analytical Development; SD = Standard deviation; TR = subterranean clover; V = common vetch; RC = roller crimper vetch; SNK = Student-Newman-Keuls.

The SPAD values measured on vines with RC treatment were significantly higher compared to the V one, at least in the last part of the vine cycle. The positive influence of leaving mulch on SPAD was not found in other vegetable crops, indicating that this influence is linked with the crop species [22,23].

Leaf gas exchange showed that RC vines performed the highest net photosynthesis rate from flowering period to veràison (Figure 1). After this phase, no significant difference in terms of assimilation rate was detected among treatments. Other parameters, such as stomatal conductance and leaf transpiration, showed high rates on RC vines during berry growth, determining a higher stomatal aperture, photosynthetic activity, and transpiration per unit of leaf area, inducing same instantaneous leaf water use efficiency (Figure 2; Figure 3). Leaf temperature (data not shown) results correlated with vine transpiration; thus, allowing the intense eco-physiological activity of RC vines.

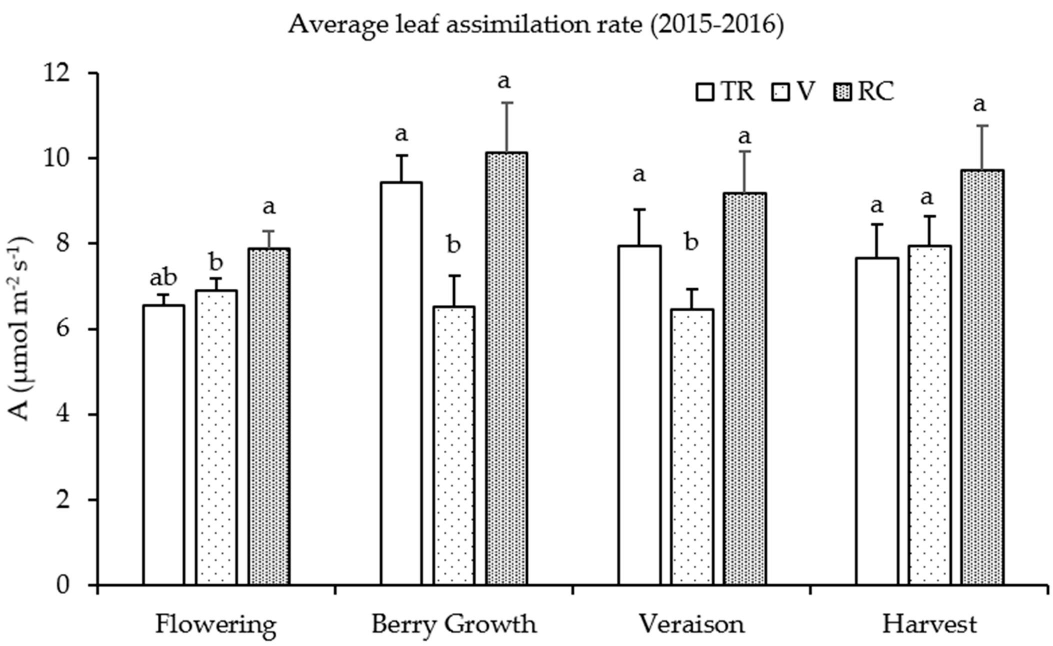

Figure 1. Soil management effects on leaf assimilation rate. (Different letters indicate statistical difference at $p < 0.05$; error bars indicate the standard error; n. of rep. 9). Note. TR = subterranean clover; V = common vetch; RC = roller crimper vetch.

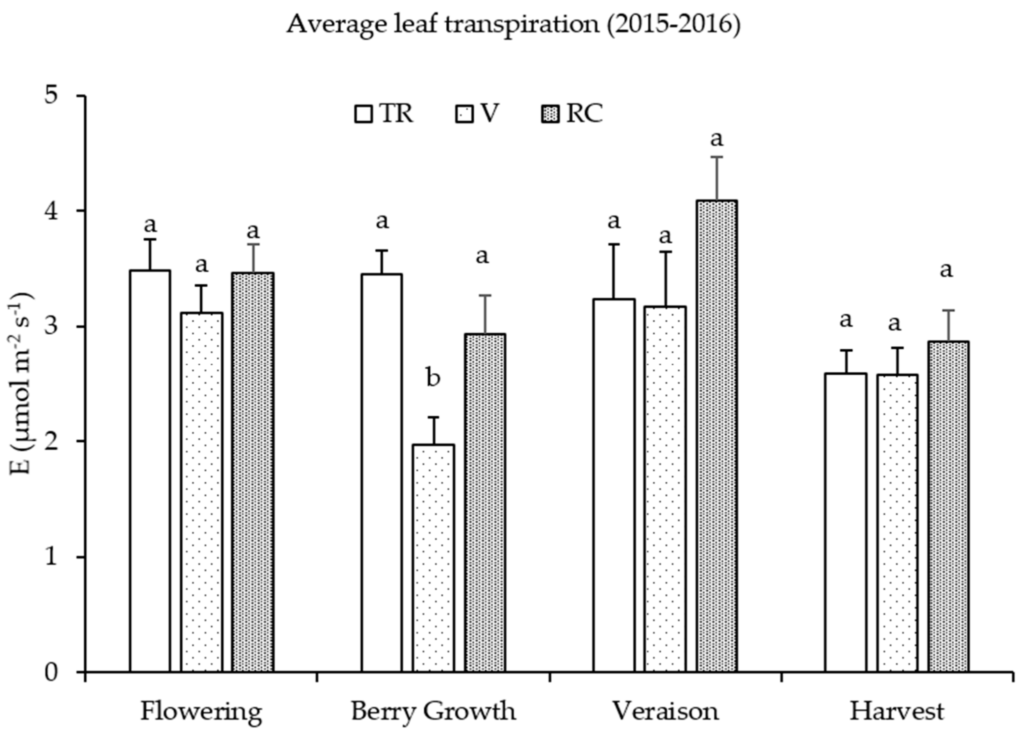

Figure 2. Soil management effects on leaf transpiration. (Different letters indicate statistical difference at $p < 0.05$; error bars indicate the standard error; n. of rep. 9). Note. TR = subterranean clover; V = common vetch; RC = roller crimper vetch.

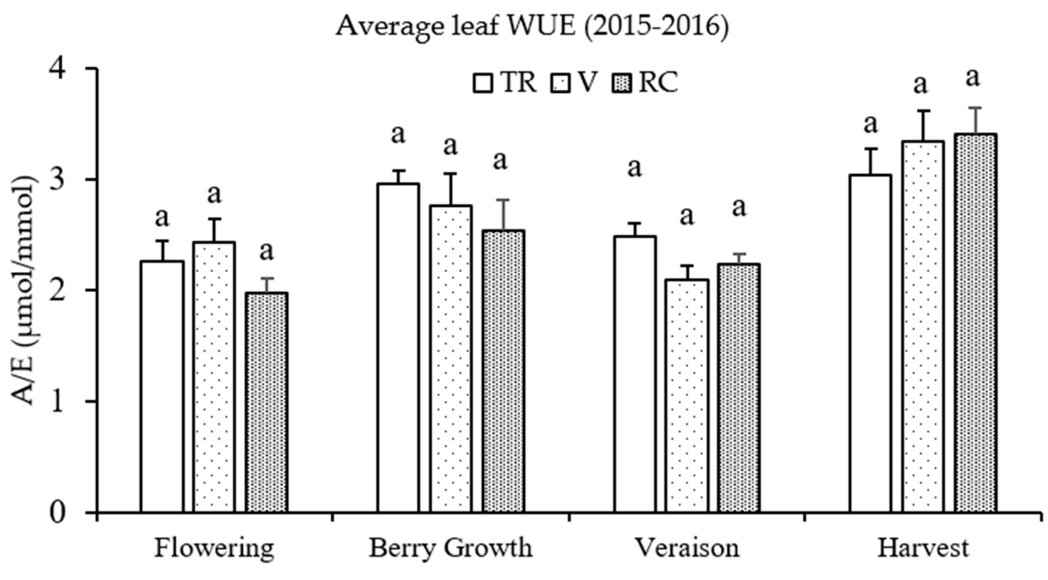

Figure 3. Instantaneous water-use efficiency (WUE) on fully expanded leaves. (Different letters indicate statistical difference at $p < 0.05$; error bars indicate the standard error; n. of rep. 9). Note. TR = subterranean clover; V = common vetch; RC = roller crimper vetch.

At harvest, no significant difference among treatments was found for bunch and berry weight during the two seasons of experiment. Besides, no variation in berry number per cluster was recorded, probably due to the limited water competition of these types of cover crops during vine blooming period. No effect was found on the berry shape since no difference was recorded for the berry length and diameter (Table 2).

Table 2. Soil management effects on cluster and berry parameters in 2015–2016. (Values are means ± SD).

Treatments	Bunch Weight (g)	Berry Weight (g)	Berry Length (mm)	Berry Width (mm)	T.S.S. (Brix)	T.A. (g L^{-1})	pH	Berry Detachment Force (N)	Firmness (N)	CIRG
TR	858.43 ± 136.4 a	5.17 ± 0.6 a	24.23 ± 2.3 a	18.79 ± 1.2 a	19.42 ± 1.2 a	5.70 ± 0.2 a	3.28 ± 0.08 a	3.32 ± 1.9 b	12.09 ± 3.6 a	5.06 ± 0.5 a
V	812.68 ± 135.1 a	5.12 ± 0.4 a	24.08 ± 1.5 a	19.08 ± 0.9 a	19.10 ± 0.7 a	5.74 ± 0.6 a	3.26 ± 0.03 a	3.20 ± 1.3 b	12.15 ± 3.1 a	5.13 ± 0.6 a
RC	818.44 ± 208.5 a	5.28 ± 0.5 a	24.62 ± 1.4 a	19.37 ± 0.9 a	19.30 ± 1.2 a	5.71 ± 0.5 a	3.27 ± 0.06 a	4.21 ± 1.8 a	12.18 ± 3.3 a	5.15 ± 0.6 a

In the columns, values followed by the same letters did not differ significantly, according to the SNK test ($p < 0.05$). Note. SD= Standard Deviation; TR = subterranean clover; V = common vetch; RC = roller crimper vetch; T.S.S.= Total Soluble Solids; T.A.= Titratable acidity; CIRG=Color Index of Red Grapes.

In our trial, berry composition and berry skin firmness were not influenced by soil management techniques, which are more influenced by the genotype and environment. This finding was different from the results obtained in horticultural crops where the cover crop management also influence the production quality [22]. Soil management did not affect berry firmness with very crunchy berries in all treatments, while the highest berry detachment force, which indicates a very low berry drop, was observed on the clusters produced in RC plot. For the evaluation of berry skin color by the CIRG index, we observed that clusters from different treatments developed the typical berry color of Sugranineteen. According to color index classification of Carreño et. al. (1996) [17], this table grape may be classified as a dark violet variety (Table 2).

Cover crops induced significant differences in grape yield (Table 3). In particular, the lowest yield per vine was reached on vetch plot (−10%), while no statistical difference was recorded on TR and RC plots. It is known that vetch cover crops may affect vine vegetative, since that vetch provided from root fixation N equivalent to about 90 to 100 kg ha^{-1} fertilizer N, annually [24].

Table 3. Soil management effects on the vegetative and vine efficiency parameters in 2015–2016. (Values are means ± SD).

Treatments	Pruning Weight Per Vine (g)	Total Leaf Area Per Vine (m^2 per vine)	Yield Per Vine (Kg)	Leaf Area/Grape Yield (m^2 kg^{-1})	Cane Weight (g)
TR	2605 ± 708.6 a	16.98 ± 4.2 b	25.17 ± 1.9 a	0.67 ± 0.03 b	108.54 ± 42.8 a
V	2514 ± 491.4 a	21.31 ± 4.4 a	22.73 ± 1.4 b	0.94 ± 0.05 a	96.96 ± 31.5 a
RC	2180 ± 475.5 a	16.15 ± 4.2 b	25.54 ± 1.7 a	0.63 ± 0.07 b	93.31 ± 28.6 a

In the columns, values followed by the same letters did not differ significantly, according to the SNK test ($p < 0.05$). Note. SD = Standard Deviation; TR = subterranean clover; V = common vetch; RC = roller crimper vetch.

Our results showed a positive relationship between grape yield and photosynthetic activity. As previously reported, vetch cover crops effectively reduced grapevine assimilation rates from flowering to veràison. Consequently, an increase of leaf area development (dense canopy) with a reduction of available solar light intensity inside the canopy was observed. The shaded canopy effect of grapevines may explain the moderate leaf gas exchange measured on these V vines [25]. Our results agree with several findings on vegetable crops, which showed that cover crops flattened by the roller crimper technique can help reduce the amount and cost of nitrogen fertilization without yield reduction [10,23]. The influence of cover crops was also found in a traditional way of termination in both vegetable [24] and vineyard [26] crops.

Besides, different cover crop treatments induced significant differences in the total leaf area per vine. Vetch cover crops increased the total leaf area per vine (+28.6%) and vines had the highest crop weight ratio (+44.6%) leaf area. Kliewer and Dokoozlian [27] found that the optimal leaf area per fruit weight for grape ripening was 0.8 to 1.2 m^2 kg^{-1}. In our study, the leaf areas per fruit weight were 0.67, 0.94, and 0.63 m^2 kg^{-1} for the TR, V, and RC vines, respectively. All three cover crops induced the same growth and vigor expressed by the fresh one-year-old pruning weight per vine and similar cane weight (Table 3).

Finally, from beginning to the end of research (To and Tf, respectively), the total nitrogen and soil organic matter in the inter-row zone significantly increased 18% and 33%, respectively (Table 4), as mean value of the three treatments. This result confirmed other studies, in which the introduction of cover crops in organic production increased these important soil parameters [22,28]. However, no significant differences were found at the end of the experiment (Tf) among treatments in both total nitrogen and soil organic matter, even if they showed different behavior. In particular, the V treatment did not improve soil's total N, and had only a slight effect on soil organic matter, while the other two treatments increased, more substantially, the soil parameters. Our data shows that leguminous cover crops can contribute to reduce N fertilization intensity in organic viticulture, improving soil microbial activity. It is estimated that 40% of the N content in a legume cover crop may become available in the soil in the first year, while the remaining 60% will be available if the plant biomass is incorporated as green manure [29].

Table 4. Soil management effect on total nitrogen and soil organic matter. (Values are means ± SD).

Period/Treatment	Total Nitrogen ($g\ kg^{-1}$)	Soil Organic Matter ($g\ kg^{-1}$)
To/No cover crops	0.84 ± 0.03 b	17.29 ± 1.2 b
Tf/Cover crops		
TR	1.23 ± 0.05 a	25.51 ± 1.8 a
V	0.80 ± 0.02 b	20.00 ± 1.2 a
RC	0.93 ± 0.06 a	23.62 ± 1.5 a

In the columns, values followed by the same letters did not differ significantly, according to the SNK test ($p < 0.05$). Note. SD = Standard Deviation; TR = subterranean clover; V = common vetch; RC = roller crimper vetch.

In our study, the presence of cover crops mainly affected the vine photosynthetic activity, the relative leaf chlorophyll concentrations, the yield per vine, and only one physical berry characteristic related to the marketability of the table grape. Common vetch and subterranean clover cover crops showed a low grass competitiveness during berry growth and veràison stages in the Mediterranean climate, and under the effect of a plastic film covering. This can be explained by a shorter vegetative cycle of vetch and subterranean clover crop related to higher air temperature and relative humidity inside the covering, which also determines a fast vine shoot growth and canopy expansion [11]. Other factors that reduced weed competitiveness on vines were the distance between rows (3.5 m) and a wide area underneath the vines, which was managed by mechanical tilling. This agronomic practice is particularly important and confirms that the cover crop management has the potential ability to control weeds, as found in vegetable organic production [30,31].

In our experiment, cover crops slightly influenced the vine water status, probably due to mild competition of legume cover crops for soil water content. Nowadays, vineyards with cover crops are increasing in Mediterranean regions, due to the possibility of improving many soil properties, such as modifying grapevine root systems in order to explore other soil zones (so increasing water uptake). Our results confirmed the findings of an experiment carried out in southern France on Sauvignon blanc by Celette et. al. [32], which observed low competition of tall fescue (*Festuca arundinacea* L.) inter-row cover crops, since the soil area of maximum water and nutrient uptake by the vine root system was concentrated in the soil under the row. Once again, our findings confirmed the results obtained in organic vegetable cropping systems [33,34].

Possibly, also, the shade effect on cover crops due to the plastic film and large grapevines canopy, contributed to reduce cover crop competitiveness on vines. However, the effect of cover crops on table grape vines is conditioned by the plastic film characteristics used for covering (color, chemical composition, spectral transmissivity, thickness etc.) and may be different in relation to table grape variety. This is supported by research data on the effect of cover crops vs. mechanical cultivation in the same vineyard, but with a different variety (Sugrathirteen) under three plastic films (coded as Yellow, Red, and Neutral) [8]. Our results showed high interactions between different soil managements and plastic films in terms of sugar content, titratable acidity, and berry mass. Besides, it was pointed out that the eco-physiological leaf parameters, more sensible to variation induced by soil management under plastic film covering, are both leaf transpiration and stomatal conductance [8]. The study showed that the roller crimper termination method adopted on vetch cover crops increased the permanence of mulch layer on the soil surface with a consequent reduction of water evaporation from the soil with a positive effect on grapevine water status, as showed by stem water potential values. The same effect was found by subterranean clover that showed under plastic film covering a short vegetative cycle, with early desiccation on soil during the summer drought period (from the second week of June until the end of August). The mulching presence delayed the development of vegetation during the berry growth period and increased both soil water content and organic matter [3].

Our results are in accordance with research on grapevines in South Africa, by using grazing vetch (*Vicia dasycarpa)* as a cover crop on sandy soil, the organic matter content was increased [3,4]. The same positive results were confirmed in other research on leguminous cover crops, carried out on horticultural crops in a Mediterranean environment [20,28].

Finally, cover crops have been shown to enhance the population of beneficial insects (parasitoids and generalist predators) and can affect soil microbial biomass, representing a sustainable agricultural technique to improve biological control in organic agroecosystems [35,36].

4. Conclusions

Preliminary results have shown that the roller crimper technique on common vetch improved leaf functioning from flowering to veràison and induced good berry development. Considering that leguminous crops, such as subterranean clover and common vetch used in this trial, are characterized by fixing N from atmospheric sources, their use can reduce the cost of table grape fertilization. The maintenance of mowed vegetation (grass cover crops) between vine rows is a possible sustainable technique, with respect to mechanical tillage in organic table grape vineyards in a Mediterranean environment. Nowadays, organic grape cultivation surfaces are increasing, and cover crop introduction represents the main method to increase biodiversity in agro-ecosystems to reduce the input for phytosanitary products by increasing the biodiversity.

Finally, in organic viticulture, the introduction of cover crops (with leguminous crops and their management) represents an ecological method to increase soil organic matter, with respect to the mechanically cultivated soil for the development of healthy and productive soil.

Supplementary Materials: The following are available online at http://www.mdpi.com/2073-4395/10/4/550/s1, Table S1. Radiometric coefficients of the plastic film covering, Table S2. Climatic parameters in 2015–2016, Table S3. Vegetative and productive characteristics of Sugranineteen vines. (Values are means + SD), Table S4. Effect of soil management on midday stem water potential (MPa). (Values are means + SD).

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