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Strawberry Living Mulch in an Organic Vineyard

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Abstract: A living mulch system can provide beneficial biodiversified phytocoenoses and spatial competition against weeds; however, it may also compete for water with the main cultivated crop under Mediterranean climate conditions. Strawberries employed as living mulch in a rain-fed hill vineyard of central Italy were evaluated for two years through a participative approach involving the farmer. A local wild strawberry was propagated by stolons to obtain small plantlets easily uprooted after the summer and then transplanted to a one-year-old vineyard. The densities of two and four strawberry plants per grapevine were compared with no living mulch in a randomized complete block design. A horizontal blade weeder was used once a year in all treatments. The results showed that strawberries as living mulch plus application of a blade weeder avoided the need for further soil tillage and assured a full soil cover during winter for both initial planting densities. The strawberry living mulch did not alter the grapevine transpiration during an incident of water stress in summer. Moreover, the yield per vine and the grape quality were comparable with those of the soil without living mulch. The growth of strawberry mulch was relevant in the area surrounding the vines. Furthermore, the living mulch guaranteed a constant soil cover reducing the risk for soil erosion while increasing the vineyard's biological diversity. This may imply a higher resilience.

Keywords: phytocoenosis; weed management; soil cover; *Fragaria vesca*; sustainability

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1. Introduction

The standard method of floor management in intensively managed, monospecific orchards and vineyards consists of maintaining permanent grassing between the rows (planted or spontaneous grass and other plants that are kept low by cutting) and herbicide treatments, or traditional tillage, between trees along the rows. The repeated use of both tillage and herbicide will (or tend to) decline the overall soil quality [1] and reduce orchard biodiversity [2]. The organic residues of a single crop are documented to cause problems with increasing risks of pest infestation and soil-borne diseases in several intensive fruiting areas of Europe [3–6]. Diversifying the cropping system by companion species, cover crops, intercropping and the presence of a permanent stripe (or area) of grass cover between the rows induces higher diversification of organic residues. This brings an increase in soil fertility, improving biological diversity while mitigating soil quality loss due to monoculture [7]. Soil quality can be restored by maintaining an adequate soil coverage, and this can also contribute to weed control and to various functional ecosystem services [2,8–10]. Living mulches between fruit trees or vines have been shown to improve soil organic matter [11], soil microorganism populations [12,13] and soil nutrient content, particularly nitrogen [14,15]. They reduce soil erosion and improve overall soil quality [16,17] while reducing floor management costs. Likewise, cover crops may be beneficial to juice and wine quality [18]. They may increase soluble solids and phenolic compounds and decrease titratable acidity in berry juice [19], ultimately improving the overall sensory quality of the wine [20].

In addition, more diverse plant communities may improve soil biological fertility, and plants applied (or grown) as living mulches may attract insects that may be beneficial for the main cultivated crop. Intercropping several species, including edible ones, could also have a positive aesthetic impact besides enhancing a productive function and possibly providing a secondary income [21,22]. For instance, cash crops, such as strawberries, could be considered as an intercrop, which could compete efficiently enough with weeds to act as a living mulch, and could potentially also provide additional income, thus reinforcing both economic and ecological sustainability [23]. Living mulches may also consist of aromatic herbs, which have the potential to provide farmers with an additional income, as well as beneficial effects for orchard biodiversity, without impairing tree root development or soil nutrient status [10].

Therefore, practicing a more ecological approach to weed control could become feasible and inviting for fostering long-term sustainability in organic orchards and vineyards.

However, such systems often lead to new challenges, such as jeopardizing efficient weed control; increasing energy and water consumption in living mulch management; and potential competition between main and cover crops [24]. Living mulches may compete for water and nutrients [1] and negatively affect vine growth, berry size and grape yield [25–27]. In addition, living mulches may serve as a habitat for vole populations, which may seriously destroy the roots of cropped plants [15]. The selection of mulching species can reduce such problems. Farmers have various options for selecting cover crops, including annuals, biennials or perennials, and these may be grasses, legumes or other broadleaf plants [28]. Less competitive species may be chosen to avoid mulches turning to weeds [2], and it is important to choose species that do not attract pests or diseases. Concurrently, the main function should be kept in mind: the mulch species should outcompete weeds effectively and maintain adequate soil coverage [28]. A soil coverage by the selected living mulch of 50% or more in the vineyard exponentially increases the weed management capacity of the system [29].

Therefore, a selection of promising species should be based on some relevant characteristics, such as vegetative aptitude and high adaptability to local pedoclimatic conditions. Some stoloniferous species (with offshoots/runners) possess several desired characteristics. They can be collected from the local flora; i.e., several subspecies of Potentilla and Fragaria are particularly promising [30]. The choice of these species is mainly related to limited rooting depths and high stoloniferous capacity, which induce a weaker competition for water and nutrients, yet they rapidly cover the soil, which is one of the key factors to veer orchards and vineyards toward sustainability.

New intercropping strategies between trees or vines along the rows with permanent vegetation cover as proposed, e.g., by Neri [30], mimic nature [22], increase biodiversity and provide ecological services [21,31]. These systems must be evaluated with a multi-stakeholder approach in a practical setting, aiming to improve the economic and ecological sustainability of the farm in question [23].

In collaboration with a local farmer who was looking for a more sustainable soil management along the rows of his vineyard, a local wild strawberry was identified among the spontaneous plant species present in the area. This wild ecotype fulfilled all the requirements for a sustainable living mulch and was hence chosen to be the object of our study. The goal of the living mulch with a local strawberry ecotype was to create a stable and weakly competitive plant community within the grapevine agroecosystem as a more sustainable solution for weed management. Thus, in this study, the hypotheses to verify were if strawberry living mulch could cover the soil and control weeds along the row under the vines and if the presence of living mulch would affect the grapevine transpiration during summer water stress and grape yield and quality.

2. Materials and Methods

A local wild strawberry (*Fragaria vesca* L.) from the Sibillini mountains (central Italy) was propagated by stolons to obtain plantlets easy to be uprooted after the summer. The trial was set in a young organic vineyard (planted in 2016 at Castelraimondo, MC, central Italy, 43°12′15.6″ N and 13°02′08.2″ E). The local climate is Csa type in Köppen–Geiger climate type [32]. Figure 1 reports rain and air temperature data throughout the experimental period. The soil on the site is a silty loam soil with pH 8.3 and contains 3.2% organic matter in the top 20 cm.

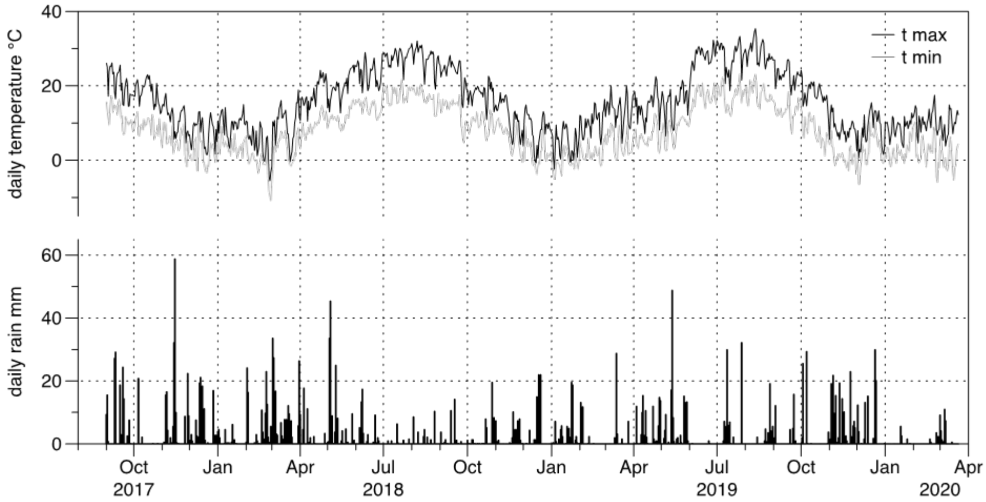

Figure 1. Daily rain and maximum and minimum daily temperatures were measured during the experiment by a meteorological station 10 km from the experimental field (Sistema Informativo Regionale Meteo-Idro-Pluviometrico).

The grapevine plants were a local clonal selection of "Verdicchio" cultivar grafted on the rootstock "Kober 5bb". The vineyard has a planting density of 2.75 m × 1.25 m, and it is trained as a Guyot system. The strawberry plants obtained from stolons were planted in the row on both sides of each vine in autumn 2017. The experimental design included three treatments: 4 strawberry plants per vine (4 plants), 2 strawberry plants per vine (2 plants) and 0 strawberry plants per vine (control) as shown in Figure 2. Treatments were located in a randomized complete block design (RCBD) with 4 blocks (rows). Each block included 96 vines (32 per treatment), for a total of 384 grapevines.

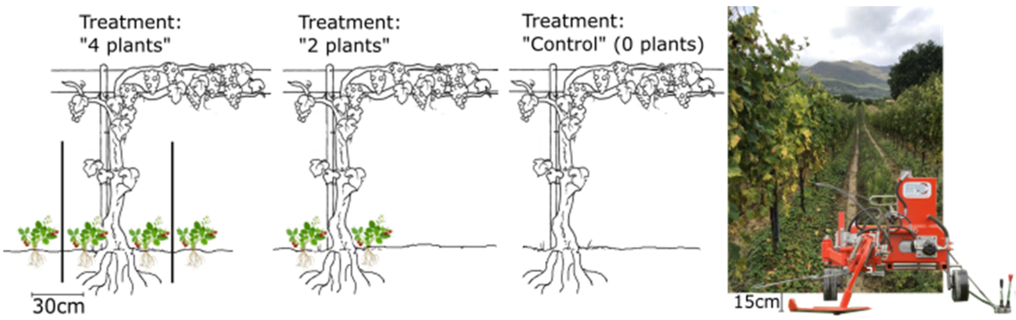

Figure 2. Scheme of the treatments. On the right the in-row horizontal blade weeder, which works 15 cm deep. In the "4 plants" treatment, note the position of the iron rods between the strawberry plants.

The soil in the rainfed vineyard was managed in all the treatments with a horizontal blade weeder (Arrizza SRL, Fossacesia, CH, Italy). Blade weeding was carried out once a year in spring to cut the tap roots of the most aggressive weeds without altering the soil profile. Green manure with leguminous species was applied between the rows.

The 4 plants treatment had an iron rod inserted between the strawberry plants (see Figure 2) to avoid plantlets far from the vine being mowed by the weeder blade.

The plant canopy covering 0.5 × 0.5 m^2 of soil around each vine was recorded as the percentage of soil covered to describe the weed infestation and strawberry development in the row. This evaluation was accomplished twice during the first two years after strawberry planting (July 2018, November 2018, June 2019 and August 2019).

In the study region, June is the month with the most vigorous growth of both strawberry plants and the most abundant weed species. In June 2019, the biomass and dry weight of aboveground strawberry and weed plants were recorded at 12 sites per treatment inside a frame sized 0.25 m^2, placed in the row in the proximity of the vine.

In July 2018, the biodiversity of the weeds was recorded as the number of plants per weed species inside a frame of 0.25 m^2. Ten samplings per treatment per row (total of 40 sectors per treatment) were evaluated.

In August 2019, when temperatures reached very high values (maximum 39 °C), SPAD values and gas exchange parameters of vine plants were measured using SPAD 502 (Minolta) and Lcpro+ (ADC Bioscientific Ltd., Hoddesdon, UK). SPAD is a chlorophyll meter that provides immediate readings in a leaf non-destructive way; the measurements with an optical density difference at 2 wavelengths match the leaf chlorophyll content [33]. Those measurements were performed in a moment of very high heat to ascertain if living mulch in case of severe climatic conditions could cause additional stress to the vine plants.

In September 2019, the grape production per vine was recorded at harvest to verify if the presence of strawberry living mulch influenced yield or grape quality. The chemical composition of the "grape juice" was evaluated at three different times during the 20 days before the harvest.

The mass of pruned wood per vine was measured in February 2020, and the Ravaz index was calculated as grape production divided by the mass of pruned wood (kg per vine) to show the ratio between grape production and vegetative growth.

Normality of data was assessed, and the statistical analysis consisted of one-way ANOVA and Tukey's HSD (honestly significant difference) test ($p \leqq 0.05$) and was conducted using JMP Software (Release 8; SAS Institute Inc., Cary, NC, USA, 2009).

3. Results

The strawberry plants grew vigorously during the first summer and autumn and reached a coverage of 60–80% of the soil surface under the vines in November 2018 (Figure 3, upper row). In the second season, the strawberry canopy had slightly declined during winter and then grew from June to August less vigorously than during the first season. Whereas the proportion of soil covered by strawberry plants was significantly higher for the 4 plants treatment than the 2 plants treatment at all dates of observation, the effect on weed coverage did not differ significantly between these treatments except for the observation in June 2019. However, both treatments had much less coverage of soil by weeds than the control (Figure 3, bottom row).

Concerning weed biodiversity, in July 2018, the mean number of weed plants in the 0.25 m^2 sector was significantly lower in the 2 plants and 4 plants treatments than in the control (Figure 4). As it can be seen in Figure 5, the presence of strawberry living mulch reduced the presence of all the weed species identified, and it is worth noting that the lowering effect occurred mainly on bindweed (*Convolvolus* spp.), which are particularly aggressive in local vineyards (Figure 5).

In the second season, the total biomass of the plants surrounding the vine was higher with the living mulch of strawberry plants (Figure 6). Both strawberry treatments reduced the amount of weed biomass more than 50% in comparison to the control (58 and 65% reduction for 2 plants and 4 plants, respectively).

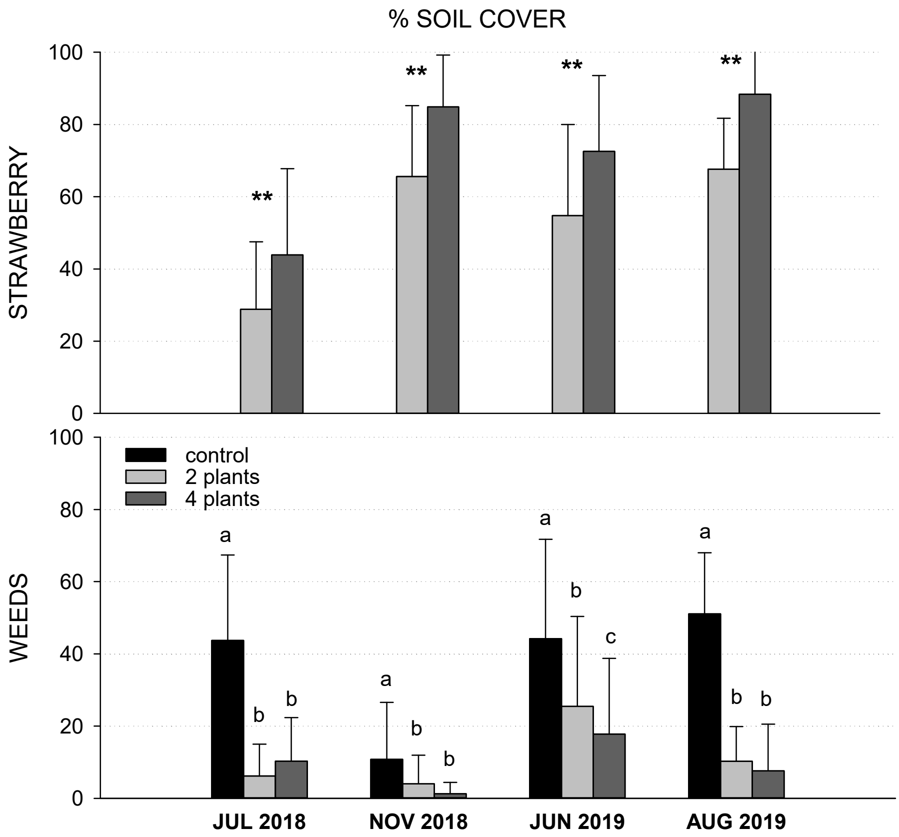

Figure 3. Percentage (%) of soil covered by strawberry plants (**top**) and weeds (**bottom**) (mean ± SD). Asterisks (**) and different letters indicate statistically significant difference (Tukey's HSD test).

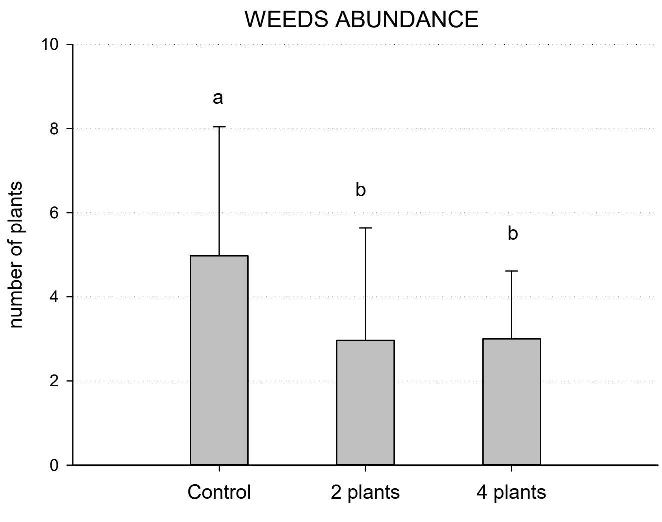

Figure 4. Number of weed plants (abundance) found in 0.25 m^2 in the row (mean ± SD). Letters indicate significant differences of Tukey's HSD test.

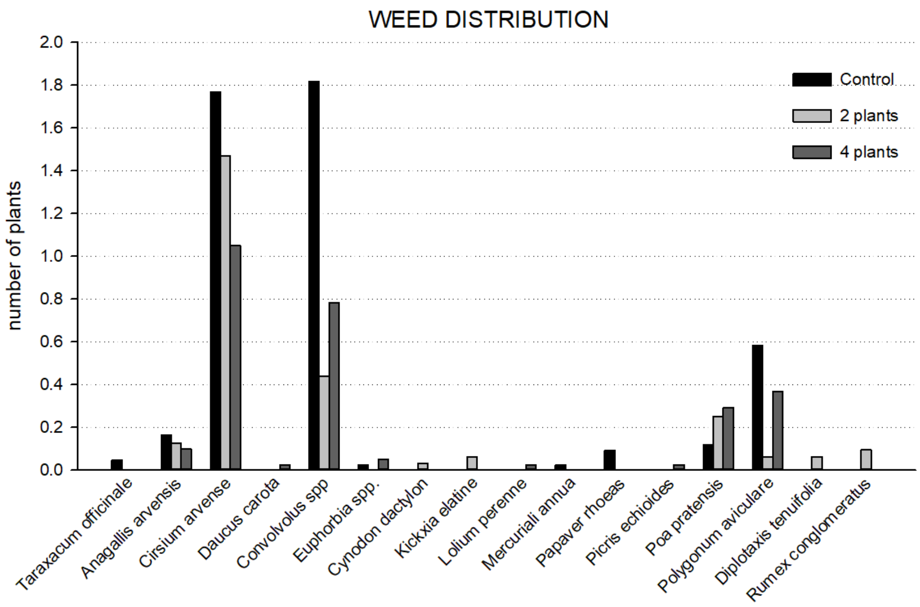

Figure 5. Number of plants per each weed species (distribution) found in 0.25 m^2 in the row (mean ± SD).

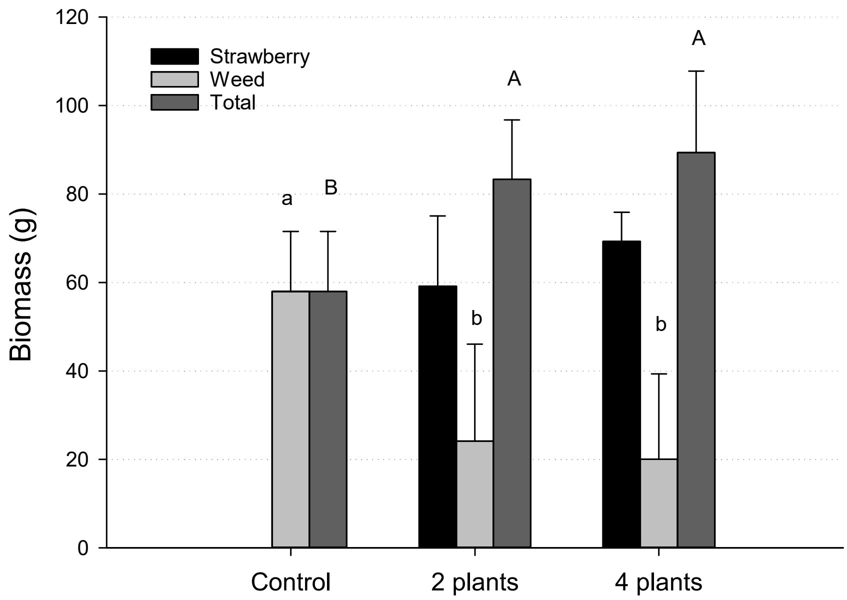

Figure 6. Dry biomass of strawberry, weeds and total (mean ± SD) found in 0.25 m^2 in the row. Different letters indicate significant differences for Tukey's HSD test for weed and total biomass.

During a week of exceptionally high temperatures (max 36 °C) in August 2019 (Figure 1), the strawberry treatments slightly affected grapevine physiological activity as revealed by the SPAD and gas exchange values. The effects were only visible in the 4 plants treatment, while the 2 plants treatment showed results similar to the control. More specifically, SPAD values were lower in the 4 plants treatment compared with the 2 plants treatment. Stomatal conductance (g_s) was also lower, as was internal CO_2 concentration (Ci). On the other hand, transpiration rate (E) and net assimilation rate (A) were not affected by the strawberry treatments (Figure 7). These results indicated that in the treatment with 4 strawberry plants, the vines showed more stomatal closure, which was probably due to the onset of drought leading to water stress due to the high temperature in August. This stress also brought a slight reduction in chlorophyll content.

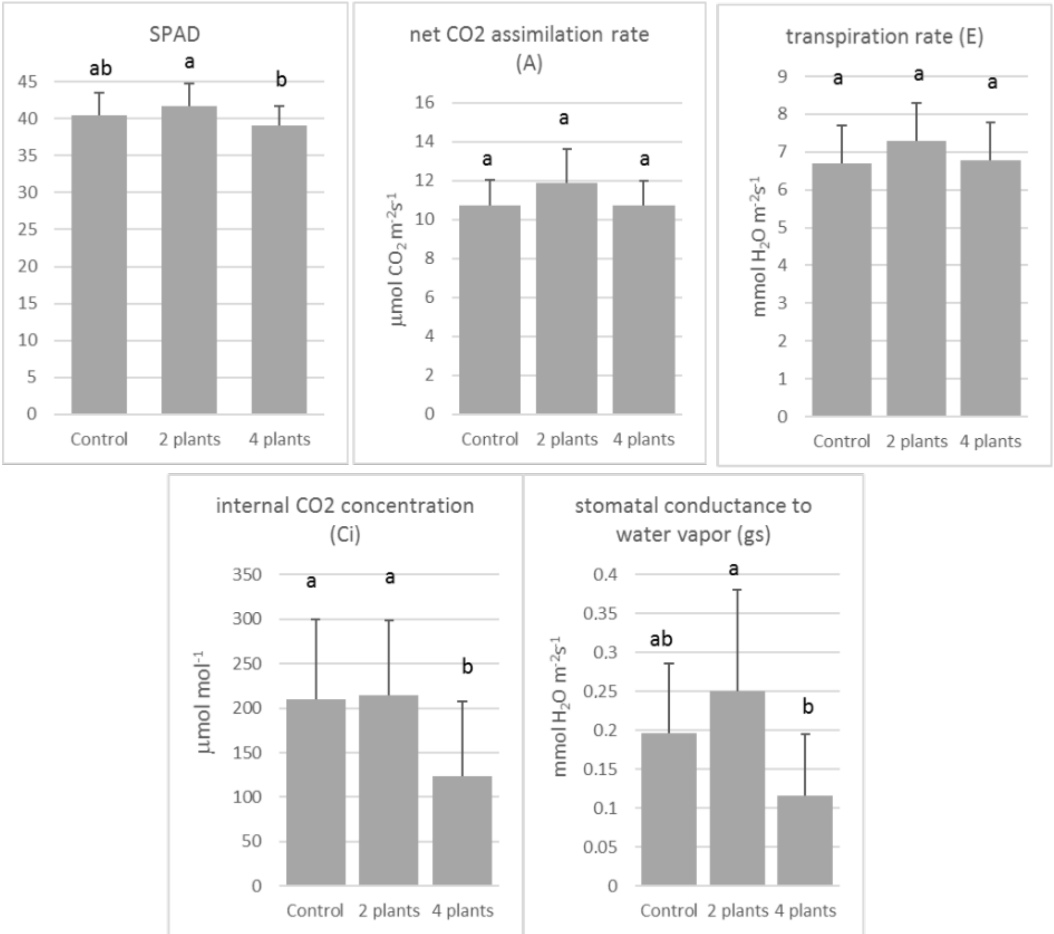

Figure 7. Values of grapevine gas exchange and SPAD unit, measured on 6 August 2019. Different letters represent significant difference from Tukey's HSD test.

However, the grape yield and the chemical composition of the grape juice were not significantly different in all treatments (Table 1), showing that the competition of the living mulch was limited, and the summer stress did not cause permanent damage to the photosynthetic apparatus of the vines. The strawberry treatments did not influence grape production or quality; hence, it can be hypothesized that the rains before harvest guaranteed complete leaf recovery before fruit maturation.

Pruned wood per vine was not significantly influenced by strawberry living mulch, but the Ravaz index indicated a tendency of living mulch to slightly increase fruit production per kg of pruning wood, where the number of strawberry plants per vine increased from 0 to 4 (Figure 8).

Table 1. Weight of vine pruning and grape yield and data from analyses of grape juice at three times during the grape ripening process with mean ± SD. All differences among treatments were not significant for Tukey HSD test.

	Treatment		
Analysis	**Control**	**2 Plants**	**4 Plants**
Pruning (kg)	1.32 ± 0.31	1.28 ± 0.31	1.28 ± 0.22
Yield (kg)	2.02 ± 0.74	2.10 ± 0.64	2.18 ± 0.50
BABO degree			
27/08/2019	10.2 ± 0.69	10.17 ± 0.96	9.76 ± 0.71
07/09/2019	15.16 ± 0.82	14.96 ± 0.74	14.28 ± 0.64
17/09/2019	19.16 ± 0.50	18.52 ± 0.52	18.48 ± 0.30
Malic acid (g/L)			
27/08/2019		Values too low to be measured	
07/09/2019	4.84 ± 0.78	5.13 ± 0.52	5.06 ± 0.64
17/09/2019	4.45 ± 0.35	4.32 ± 0.50	4.42 ± 0.63
Tartaric acid (g/L)			
27/08/2019	6.9 ± 0.72	6.45 ± 1.21	6.91 ± 1.30
07/09/2019	6.63 ± 0.40	6.85 ± 0.31	6.7 ± 0.18
17/09/2019	7.07 ± 0.33	6.95 ± 0.59	7.25 ± 0.32
Ammonic N (mg/L)			
27/08/2019	192.2 ± 42.4	201.6 ± 18.23	184.8 ± 15.5
07/09/2019	219.4 ± 8.0	211.8 ± 14.6	211.4 ± 20.8
17/09/2019	211.4 ± 8.11	199.4 ± 7.23	210 ± 9.38
NH_4 (mg/L)			
27/08/2019	237.8 ± 24.1	229.6 ± 21.34	207.6 ± 20.5
07/09/2019	166.2 ± 13.9	175.2 ± 4.76	169.8 ± 10.3
17/09/2019	154.8 ± 17.5	153.2 ± 7.29	160 ± 11.1
K (mg/L)			
27/08/2019	1566.6 ± 394.9	1515.5 ± 336.7	1596.8. ± 185.6
07/09/2019	1685.6 ± 118.4	1647.0 ± 47.3	1634.6 ± 55.5
17/09/2019	1816.3 ± 105.1	1718.9 ± 88.1	1788.9 ± 88.3

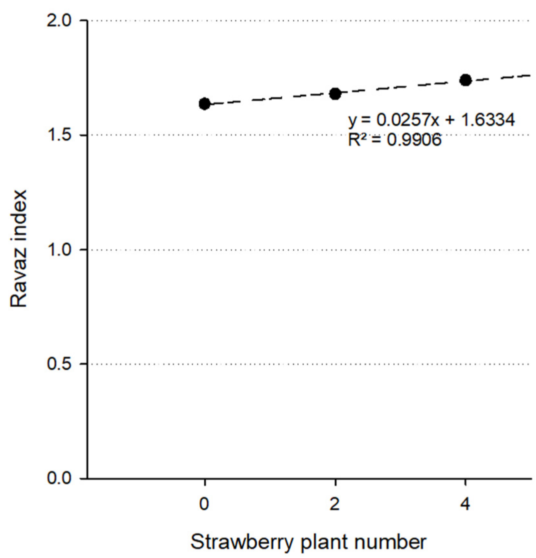

Figure 8. Ravaz index compared to strawberry plant number.

4. Discussion and Conclusions

From the results of the experimental work under a humid Mediterranean climate, where rain precipitations also occur in the spring–summer seasons, it appears that strawberry living mulch combined with a horizontal blade weeder limited the need for further soil management. The trials started from the second year after vine planting. The strawberry along the vine rows determined a complete soil coverage in less than two years, thus ensuring a wide soil cover before the winter season and reducing the risk of soil erosion [2,16]. The strawberry living mulch reduced the propagation of weeds without reducing the vine vigor or the grape quality, while enhancing grapevine efficiency (higher Ravaz index) in the tested conditions.

The strawberry living mulch sustained a diversified phytocoenosis, preserving a high number of weed species, while reducing the number of plants of every single unwanted species. The strawberry living mulch enriched the biomass while maintaining weed diversity, which reduced the impact of bindweed, the most invasive weed species (*Convolvulus* spp.). Because soil management techniques are normally evaluated for the effectiveness of weed reduction and for the effect on vine development and production [19,34], the potential living mulch problems consist of a possible competition of the mulch species with vines for water and nutrient uptake [18]. It is worth noting that in our experiment, the gas exchange data showed that the presence of strawberry living mulch caused narrow modifications in stomatal conductivity and no changes in transpiration or in CO_2 uptake. The physiological differences with control vines were low and probably limited to the period of highest summer temperatures. Therefore, grape production and quality were not influenced by the presence of strawberry living mulch. It is common knowledge that strawberry plants have a superficial fasciculate root system and stolon propagation, and they are poorly active in the summer, with temperatures above 30 °C. As it was found with other herb species suitable for living mulches in apple orchards [10], these do not exert any strong competition with the deep tree root system. Decisively, the rains were sufficiently frequent and high at the end of August to permit the full grapevine yield at harvest.

From a practical point of view, applicable to growers in areas with mild winter climates, such as in central Italy, strawberry plants can be transplanted under the rows of vines in autumn at the beginning of the rainy season. Two strawberry plants per vine are sufficient to start the cultivation of the living mulch; however, double the density may favor the early competition of living mulch against weeds at their initial stage without any negative effect on fruit yield and quality. One shallow tillage per year with the horizontal blade is sufficient to damage the tap root of weeds to spur the growth of strawberries.

In conclusion, strawberry plants used as living mulch under the vines along the row guaranteed an extensive soil cover without detrimental effects on grapevine physiology or yield. Strawberry plants showed a limited summer growth (a sort of stasis or summer dormancy) and easily overcame the winter frost, while being effective in covering the soil and inhibiting weed growth in the vineyard.

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Data Availability Statement: All data are available under email request to the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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