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Effects of Mechanical Winter Pruning on Vine Performances and Management Costs in a Trebbiano Romagnolo Vineyard: A Five-Year Study

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Abstract: Vineyard mechanical winter pruning has been spreading worldwide, and the physiological basis ascribable to it has been consolidated throughout the years. Despite labor savings and reduction of costs having been proven, the demonstration of its economic viability might be challenging. In this context, this work aims to evaluate the vine performances and the costs of different degrees of the mechanization of winter pruning over a five-year trial (2011–2015). In a vineyard of cv. Trebbiano Romagnolo (*Vitis vinifera* L.) located in northern Italy, three pruning treatments were laid out as follows: (a) manual pruning (MAN); (b) mechanical pre-pruning and simultaneous manual follow-up (MP + F); (c) mechanical pruning without a manual follow-up (MP). The results showed a strong increase in the node number of MP. Nevertheless, the yield compensation factors (i.e., the shoot fruitfulness and cluster weight) limited the increase in productivity. Soluble solids did not differ between the pruning treatments, while titratable acidity resulted slightly higher only on the MP berries. The MP treatment was the most economically convenient, with a vineyard surface of 1.5 hectares, while mechanical pruning with manual finishing resulted more advantageous, compared to manual pruning when the vineyard surface was greater than 2.9 hectares. The agronomic and economic results obtained in this five-year trial suggest that mechanical pruning may be profitably applied also on grapevine varieties characterized by low basal bud fruitfulness, such as Trebbiano Romagnolo.

Keywords: cost analysis; grape composition; mechanization; shoot fruitfulness; *Vitis vinifera* L.; yield compensation

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1. Introduction

Over the last decades, vineyard mechanical winter pruning has been spreading worldwide and has been consolidated as a way to diminish the labor required to perform traditional and time-consuming manual operations. Indeed, one of the crucial factors that drive winegrowers toward mechanization is the aim of reducing production costs [1] without penalizing product quality. Hand pruning accounts for up to 75% of the yearly labor demand, and such high labor can be lowered through mechanization by 50 to 90%, according to the training system used and the extent of hand clean-up [2–5]. Moreover, mechanization may support the competitiveness of wines as it allows them to satisfy the wide market demand and can also be used to obtain high-quality wines in appropriate areas for modern mechanized and economically sustainable viticulture [6,7]. Indeed, the development of trellis systems suitable for mechanization has represented a further step to ensure the profitability of wineries in an increasingly competitive international market [8]. The integration between mechanical winter pruning and the trellis system, indeed, resulted as a key factor in the success of this operation. However, much of the mechanization technology currently available for winter pruning seems under-utilized in Italy since the gap between the actual adoption of the machines for winter pruning and the amount of information gathered since the early 1970s on vine performances is considerable [9].

Mechanically pruned vines are subjected to self-regulation mechanisms that downregulate the bud break percentage, shoot fruitfulness, and, to a lesser extent, cluster weight, reaching an appreciable balance of the crop load to grape composition, despite being characterized by a higher bud load rather than vines manually pruned [10–14]. Vineyard crop load management is an integration of farming practices to control both the assimilation and partitioning of vine resources for consistent and sustainable production [15]. Furthermore, Poni et al. [9] reported that the yield compensation is more effective in the varieties characterized by low-to-medium basal bud fruitfulness rather than highly fruitful basal buds, which might bring on overcropping.

Mechanical winter pruning is indeed facilitated when performed on high-wire trellises with free-growing vegetation in the upper part of the cordon [4]. Although the most common mechanical pruner unit, once equipped with feelers and swinging devices to avoid posts, can conduct appreciable work on the traditional hedgerows of vertically shoot-positioned trellises, the real breakthrough for mechanical pruning is the modified Geneva Double Curtain (GDC) training system and the single high-wire cordon trellis [9,11]. Both training systems, characterized by a permanent cordon and free self-supporting canopy that exclude the use of catch-wires, are particularly suitable for the mechanization of winter pruning because the cutting bars find no obstacle and may operate as close as possible to the cordon [11].

The final evaluation of the economic convenience of applying mechanical pruning and the influence that the surface of the vineyard and the labor costs have on this are issues that have received little attention in previous studies [3,5,16]. The economic aspect is decisive for the vineyard management choices, especially at a time when the shortage of the labor force is becoming one of the major emerging issues of agriculture in advanced countries, where this need is often accompanied by progressive wage growth [17,18]. Although recent studies on the evaluation of the opportunity cost of winter pruning mechanization are few, their comparison is made difficult by the specificity of the training system considered, the topography of the terrain (a flat or slope site), and the level of mechanization adopted [3,5,9,18,19].

The newest prospects of mechanization in viticulture are both on the application of precision viticulture techniques and on demonstrating its economic viability for maintaining or even improving the grape composition in light of the current global warming scenario. Given these considerations, this research aims to evaluate and compare the long-term effects of two different levels of winter pruning mechanizations compared to hand pruning and on vine vegetative behavior, yield, grape composition, and management costs of *Vitis vinifera* L. cv. Trebbiano Romagnolo. Therefore, our hypothesis was that the mechanization of winter pruning is economically sustainable, but its application is subject to vine performances, management costs, and vineyard size. In this study, we analyzed the case of the Trebbiano Romagnolo, which is a high-yielding variety with low basal bud fruitfulness and widely cultivated (approximately 15,000 ha) in the oriental area of the Emilia-Romagna Region [20].

2. Materials and Methods

2.1. Plant Material and Experimental Design

The study was carried out over five years, from 2011 to 2015, in a not-irrigated vineyard of cv. Trebbiano Romagnolo (*Vitis vinifera* L.), clone TR 3T, grafted onto SO4 rootstock (*Vitis berlandieri* x *Vitis riparia*), planted in 1997, and located in the fertile flat land near Faenza (latitude 44°17′ N, longitude 11°46′ E, 50 m above sea level), in the north of Italy. Vines were trained to the GDC with horizontal and self-supporting arms. Vines were spaced 4 m between the rows and 1 m within the row, presenting on both sides of the trellis structure two permanent cordons of 1 m each. The soil was classified as Fluvic Cambisols [21], characterized by sand, 25%, silt, 48%, clay, 27%, a pH of 8.2, total nitrogen, 0.62 g kg^{-1}, and organic matter, 17 g kg^{-1}. The floor management was conducted as follows:

the inter-row was covered with spontaneous weeds, which were mowed 2–4 times per year to avoid excessive evapotranspiration, while in the under-row, an offset-type cultivator performed, periodically, soil tillage to avoid the growth of weeds. The vines were sprayed to control downy mildew, powdery mildew, and insects (i.e., *Eupoecilia ambiguella*, *Lobesia botrana*, and *Scaphoideus titanus*), according to Emilia-Romagna Region's standard practices.

The experiment was conducted on 60 vines along three adjacent rows of 300 vines each, and three pruning treatments were laid out in a randomized block design, with four blocks of 15 vines each. In each block, five vines per treatment were used as experimental units (n = 20). The compared pruning treatments were: (a) manual pruning performed from the ground retaining spurs with 3–4 count nodes and some shorter spurs to avoid the depletion of the permanent cordon (MAN); (b) mechanical pre-pruning performed by a four-cutter bars unit applied close to the curtain to leave about 3–4 count nodes per spur and a simultaneous manual follow-up conducted by two operators with pneumatic shears from a tractor-drawn platform to thin out the machine-pruned wood (MP + F—Figure 1A); (c) mechanical pruning performed, as previously described, but without a manual follow-up (MP—Figure 1B). The cutter unit (model Trimmer, Tanesini Technology, Faenza, Italy) was side-mounted on a tractor and was set up with four bars with hydraulic control, three featuring a C cut profile and a fourth bar to remove the few internal canes. Vines were pruned during dormancy in January, and all the treatments were applied on the same day.

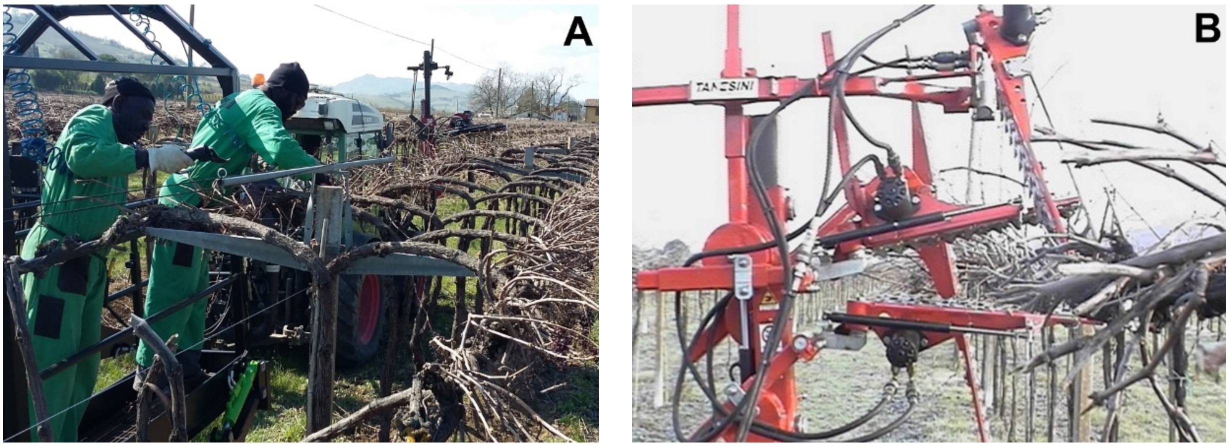

Figure 1. Mechanical pruning with manual finishing (**A**) and mechanical pruning (**B**) on cv. Trebbiano Romagnolo.

It is worthy of notice that those pruning treatments were imposed in 2005 and were repeated on the same vines every year before the beginning of the experiment. From 2011 to 2015, the time needed for the pruning of each tested treatment was registered.

2.2. Climate Data

Daily average temperature and rainfall data were kindly provided by the meteorological service of the Emilia-Romagna Region (ARPAE), which has a weather station close to the vineyard. The average growing degree days from 1 April to 31 October of the period 2010–2019 was 2170, corresponding to Region IV, as reported by Winkler et al. [22].

The seasonal trend of the weather data of the 5-year trial (Figure 2) showed that the daily mean temperature in the summer of 2014 was lower (19.9 °C) and those of 2011 and 2012 were higher (21.5 °C), as compared to 2013 and 2015. Cumulative rainfall from April to October of 2014 was the highest (487 mm), and that of 2011 was the lowest (185), while in 2012, 2013, and 2014, it ranged from 308 mm to 360 mm.

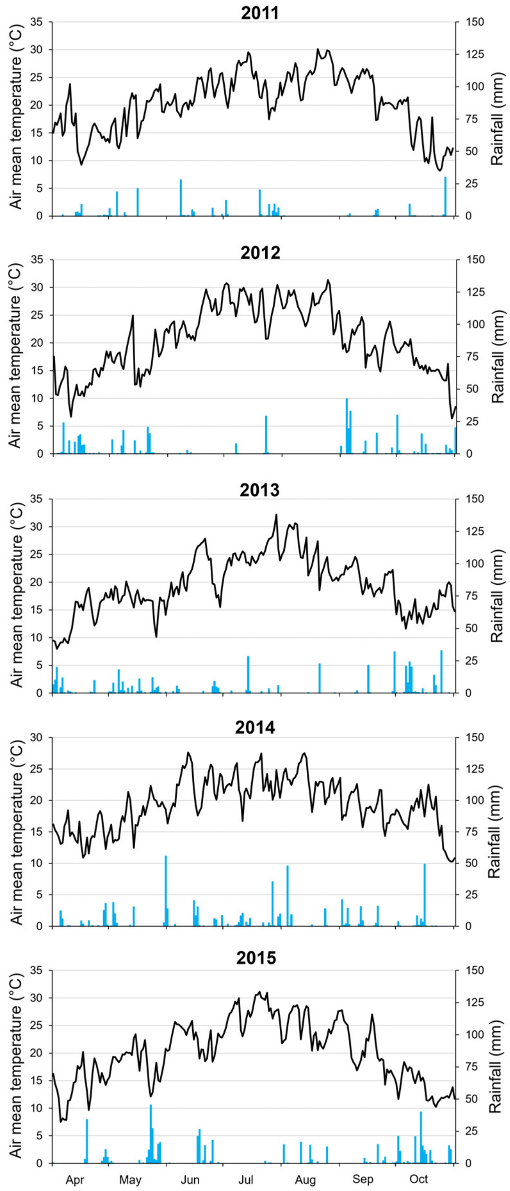

Figure 2. Daily mean air temperature (°C) and rainfall (mm) recorded from 1 April to 31 October of the five years of the experiment (2011–2015) at the experimental site (Faenza, Italy).

2.3. Vegetative Growth and Yield Components

From 2011 to 2013, during dormancy, the number of retained spurs and the relative number of count nodes were recorded, while after the budburst, the number of shoots was counted to calculate the budburst percentage. In 2013, at BBCH 53 with inflorescences clearly visible [23], the number of shoots with their inflorescences, which originated from the different count nodes of each spur, was recorded to describe the bearing behavior of the pruning treatments.

All the following assessments were carried out from 2011 to 2015. At harvest, conducted on the Day of the Year (DOY) 255 in 2011 (12 September), 256 in 2012 (12 September), 274 in 2013 (1 October), and 267 in 2014 and 2015 (24 September), the yield of the tagged vines was weighed, and the number of clusters was counted. The incidence of cluster rot was assessed by estimating the percentage of berries with visual symptoms, and cluster compactness was evaluated according to the International Organization of Vine and Wine (OIV) code 204 [24]. These observations were performed on all the harvested clusters.

In January 2016, at the end of the experiment, all the tagged vines were pruned by hand, and the removed wood was weighed.

2.4. Berry Sampling and Biochemical Analysis of Must

Berries were sampled at harvest by collecting 30 berries per tagged vine (600 berries per treatment) and brought to the laboratory for the following analysis: total soluble solids concentration (TSS), determined using a temperature-compensating Maselli R50 refractometer (Maselli Misure, Parma, Italy); must pH and titratable acidity (TA), measured using a Crison Titrator (Crison Instruments, Barcelona, Spain).

2.5. Pruning Cost Estimates

The three pruning treatments were applied in February of each year. Each treatment was attributed to the entire row by measuring the speed and turning time. The mean cutting frequency per minute was measured on a length of 10 m for both operators, while for the mechanical pruning, the maximum level of cut frequency was kept. The economic evaluation was carried out by assuming different areas of the vineyard. The effective field capacity, Ca [25], was calculated (Equation (1)):

$$\mathrm{Ca}\ (\mathrm{ha\ h^{-1}}) = 0.1 \cdot s \cdot w \cdot E_f \tag{1}$$

where:

- s = field speed (km h^{-1});
- w = half distance between rows (m);
- E_f = field efficiency, considering the time required for turning and maneuvering at the ends of the field [26].

The pruner machine costs were calculated by including fixed and variable costs of the machine [25]. The simple annual depreciation was determined considering a rate of 4.0% on the average investment. The remaining value and the costs of insurance, housing, repair, and maintenance were calculated as a percentage of the purchase price (Table 1), and the repair and maintenance costs were compared with the information reported by the winegrowers interviewed [3,27]. The cost of the manual labor was assigned using a value of € 15 per hour, including taxes, social security contributions, and severance pay (personal communication, November 2, 2022, from the Italian Confederation of Agriculture) and considering two pruners in the MAN and MP + F treatments and no pruner in the fully mechanized pruning. The tractor driver's wage in the MP and MP+F mechanized treatments was included in the total hourly cost of € 45 per hour, which took into account both the price of the tractor and the driver's fee [28].

Table 1. Cost parameters of pruning machinery.

Parameters	Units	Cutting Bar Unit	Tractor-Drawn Platform
Purchase price	€	12,000	6000
Estimated life	h	2000	2000
Remaining value [a]	%	10	10
Insurance and housing [a]	%	1.0	1.0
Repair and maintenance [a]	%	60	60

[a] Based on purchase price.

2.6. Statistical Analysis

All the vegetative and yield data were subjected to a combined analysis of variance over the years performed using the mixed procedure available in SAS v9.0 (SAS Institute, Inc., Cary, NC, USA). Treatment comparisons were analyzed using Tukey's HSD (Honestly Significant Difference) with a mean separation with a cut-off at $p \leq 0.05$. The comparison of average data of the pruning time among the different treatments was assessed by applying the Standard Error (±SE).

3. Results

3.1. Effects of Pruning Treatments on Vine Performances

The adoption of the appropriate forward speeds of the mechanical pruning permitted to limit the damage on the spurs mainly consisted of sporadic longitudinal fractures or other irregularities of the cutting surface and very few serious breakages.

The three-year mean of the count nodes per vine increased in the MP + F by about 57% as compared to MAN, while it was more than doubled in the MP (Table 2). Similarly, the spurs per vine in the MP increased drastically as compared to MAN, while the increase of the MP+F was less intense. On the other hand, the mechanical pruning treatments reduced the number of count nodes per spur. Considering that mechanical pruning did not affect the bud break (around 80% in all the treatments), the number of shoots followed the same trend as that of the nodes. Moreover, the number of clusters resulted higher in the MP compared to MAN, but in this case, the increase was limited to 38% since the shoot fertility level was almost halved by the MP. In both of the two last parameters, the MP + F reached an intermediate level compared to the other treatments.

Table 2. Influence of manual and mechanical winter pruning on bud load and vegetative parameters of cv. Trebbiano Romagnolo vines (data averaged over 2011–2013).

Treatment	Count Nodes (n°/Vine)	Spurs (n°/Vine)	Count Nodes (n°/Spur)	Shoots (n°/Vine)	Bud Break (Shoots/Node)	Clusters (n°/Vine)	Shoot Fruitfulness (Clusters/Shoot)
MAN	43.2 c	14.5 c	2.98 a	34.4 c	0.79	24.2 b	0.61 a
MP + F	68.0 b	27.7 b	2.45 b	56.5 b	0.83	30.4 ab	0.44 b
MP	118.4 a	48.4 a	2.44 b	94.7 a	0.80	33.4 a	0.31 c
Significance	**	**	**	**	ns	**	**
Year effect	NS	NS	NS	**	*	**	**
T × Y interaction	NS	NS	NS	NS	NS	NS	NS

* $p < 0.05$; ** $p < 0.01$; NS, not significant. Different letters within a column indicate a significant difference after Tukey's honestly significant difference test. MAN, manual pruning; MP + F, mechanical pre-pruning and simultaneous manual follow up; MP, mechanical pruning; T × Y, treatment × year interaction.

The survey conducted in 2013 showed that manual pruning mainly left spurs of three- and four-count nodes and a few shorter spurs, while the mechanical pruning treatments showed bell-shaped-curves, indicating that the most representative spurs were those with three nodes and that left both a few shorter and longer spurs (Figure 3).

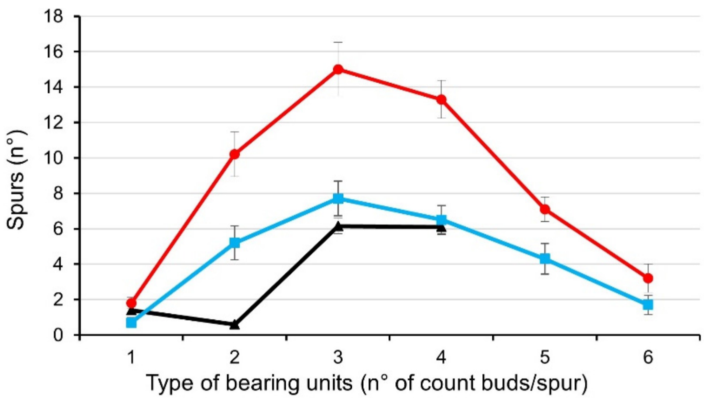

Figure 3. Number of spurs of different lengths (from 1 to 6 count nodes) of Trebbiano Romagnolo vines subjected to different pruning treatments. MAN, manual pruning (▲); MP + F, mechanical pre-pruning and simultaneous manual follow up (■); MP, mechanical pruning (●). Data recorded in 2013. Bars indicate SE.

The number of shoots originated by the spurs of different lengths increased almost linearly in all the treatments as the number of nodes raised (Figure 4); while considering the clusters, the trend of the growth was characterized by a higher slope in MAN and a lower in the MP (Figure 5), indicating that spurs with the same number of nodes produced shoots with a higher number of clusters in MAN than in the MP. For example, taking into consideration spurs with three-count nodes, which are the most representative in all the treatments, they produced about 2.5 shoots and two clusters in MAN, while they produced about 2 shoots and only one cluster in the MP. The MP+F showed an intermediate trend for all the considered parameters.

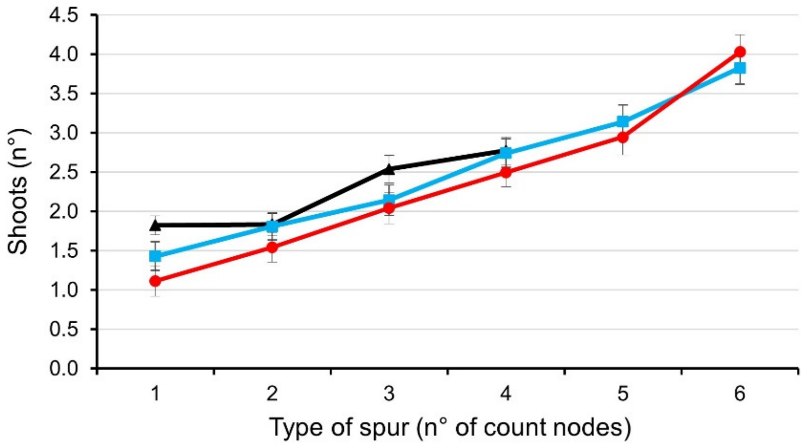

Figure 4. Number of shoots in spurs of different lengths (from 1 to 6 count nodes) of Trebbiano Romagnolo vines subjected to different pruning treatments. MAN, manual pruning (▲); MP + F, mechanical pre-pruning and simultaneous manual follow up (■); MP, mechanical pruning (●). Data recorded in 2013. Bars indicate SE.

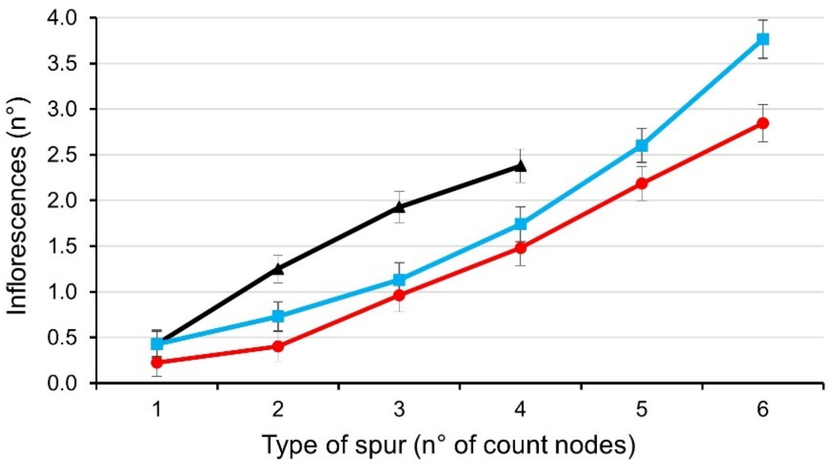

Figure 5. Number of inflorescences in spurs of different lengths (from 1 to 6 count nodes) of Trebbiano Romagnolo vines subjected to different pruning treatments. MAN, manual pruning (▲); MP + F, mechanical pre-pruning and simultaneous manual follow up (■); MP, mechanical pruning (●). Data recorded in 2013. Bars indicate SE.

No significant difference was found concerning cluster compactness and the incidence of cluster rot, but the mechanical pruning treatments increased the yield per vine (Table 3), and the estimated crop level resulted higher than 19 t/ha in the MP+F and MP, while MAN reached 17 t/ha. Conversely, the cluster weight was reduced by about 10% and 25% in the MP+F and MP, respectively. Also, the berry weight decreased significantly with the increase of the node number, but a significant pruning x year interaction occurred. The berry weight was notably lower for the MP as compared to MAN for the five years, while the MP+F was about the same level as MAN in 2011, 2012, and 2014 and lower in 2013 and 2015 (Figure 6).

Table 3. Influence of manual and mechanical winter pruning on the bunch morphology, cluster rot severity, and yield components of cv. Trebbiano Romagnolo vines (data averaged over 2011–2015).

Treatment	Cluster Compactness (OIV 1–9)	Cluster Rot (%)	Yield (kg/Vine)	Cluster Weight (g)	Berry Weight (g)
MAN	7.1	5.0	6.81 b	284.5 a	2.67 a
MP+F	6.7	3.4	7.80 a	255.4 b	2.59 ab
MP	6.4	5.1	7.68 a	214.7 c	2.40 b
Significance	NS	NS	*	**	**
Year effect	**	**	**	**	**
T × Y interaction	NS	NS	NS	NS	*

* $p < 0.05$; ** $p < 0.01$; NS, not significant. Different letters within a column indicate a significant difference after Tukey's honestly significant difference test. MAN, manual pruning; MP + F, mechanical pre-pruning and simultaneous manual follow up; MP, mechanical pruning; T × Y, treatment × year interaction.

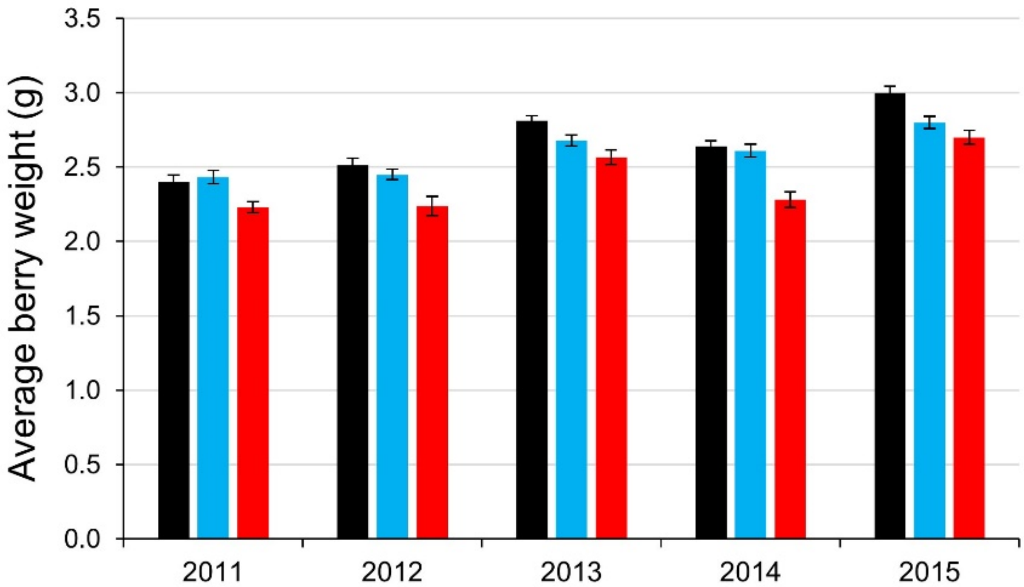

Figure 6. Interactive effect of treatments and year on berry weight of Trebbiano Romagnolo vines subjected to different pruning treatments. MAN, manual pruning (■); MP+F, mechanical pre-pruning and simultaneous manual follow up (■); MP, mechanical pruning (■). Data recorded over 2011–2015. Bars indicate SE.

The soluble solids concentration did not differ between the pruning treatments (Table 4), but again, a significant treatment x year interaction was observed, and it denoted the higher sugar concentration of MAN found in 2013 (Figure 7). The year effect may be attributed to the different climatic conditions, which were notably verified in 2011 and 2014 and characterized by the highest and lowest average temperature, respectively (Figure 2). No difference was found regarding the juice pH, while the titratable acidity of the MP resulted higher than in MAN and the MP+F. The titratable acidity also showed a significant treatment × year interaction due to the notable differences found between the pruning treatments in the last three years of the experiment (Figure 8). In particular, the high level of rain and the low temperatures that occurred in 2014 may have promoted the increase of acidity concentration, even in the MAN berries.

Table 4. Influence of manual and mechanical winter pruning on grape composition (data averaged over 2011–2015) and pruning weight (data of January 2016) of cv. Trebbiano Romagnolo vines.

Treatment	Total Soluble Solids (°Brix)	pH	Titratable Acidity (g/L)	Pruning Weight (kg/vine)
MAN	19.7	3.43	6.85 b	0.81 a
MP + F	19.7	3.41	6.74 b	0.63 b
MP	19.5	3.39	7.19 a	0.48 c
Significance	NS	NS	**	*
Year effect	**	**	**	-
T × Y interaction	**	NS	**	-

* $p < 0.05$; ** $p < 0.01$; NS, not significant. Different letters within a column indicate a significant difference after Tukey's honestly significant difference test. MAN, manual pruning; MP+F, mechanical pre-pruning and simultaneous manual follow up; MP, mechanical pruning; T × Y, treatment × year interaction.

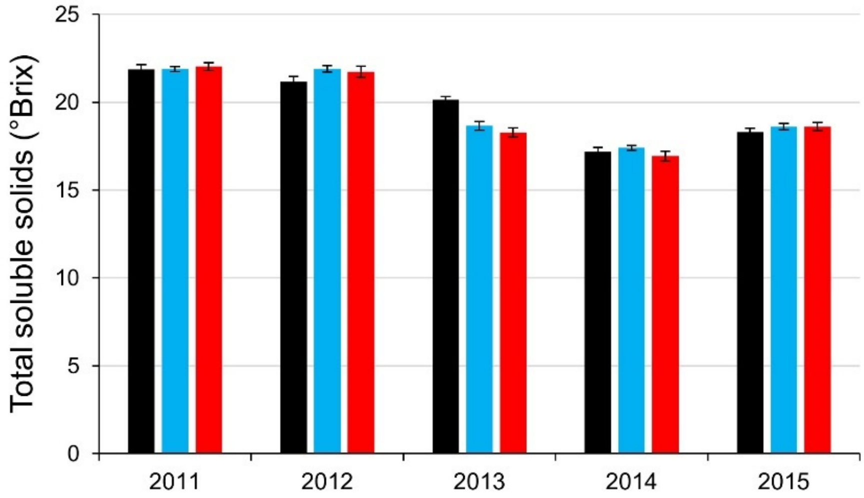

Figure 7. Interactive effect of treatments and year on total soluble solids concentration of Trebbiano Romagnolo berries subjected to different pruning treatments. MAN, manual pruning (■); MP+F, mechanical pre-pruning and simultaneous manual follow up (■); MP, mechanical pruning (■). Data recorded over 2011–2015. Bars indicate SE.

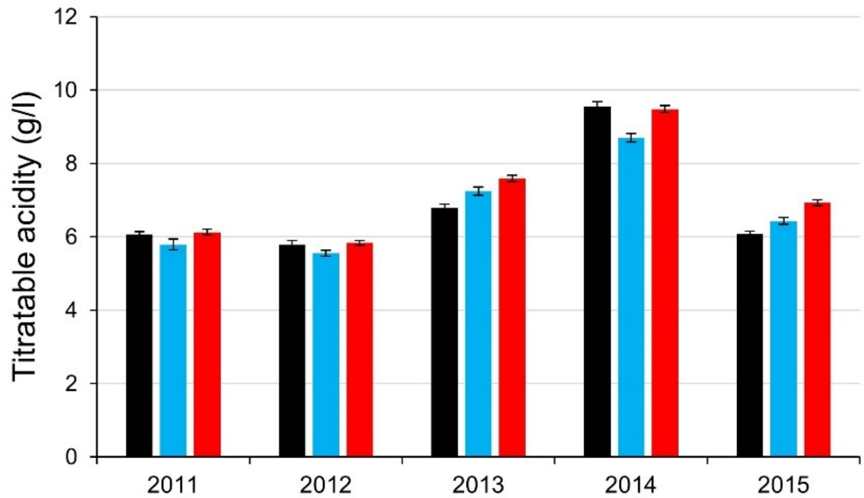

Figure 8. Interactive effect of treatments and year on titratable acidity of Trebbiano Romagnolo berries subjected to different pruning treatments. MAN, manual pruning (■); MP+F, mechanical pre-pruning and simultaneous manual follow up (■); MP, mechanical pruning (■). Data recorded over 2011–2015. Bars indicate SE.

The pruning weight recorded at the end of the experiment resulted much higher in MAN as compared to the MP, while the MP+F reached an intermediated level.

3.2. Operating Characteristics of Pruning Treatments

During the mechanical pruning, to obtain a regular and accurate cut, a maximum cutting bar frequency was set (90 cuts/min) while keeping a limited forward speed of the tractor (Table 5). For the MP, the average mean speed adopted during the five years of the trial was 1.5 km/h, while for the mechanical pruning followed by hand-finishing, the machinery speed was reduced to 1.2 km/h to allow the hand pruners to realize a proper spur-thinning. Under these conditions, the first worker operated 45 cuts per minute, while the second one, engaged in a more careful selection of the spurs to be eliminated, was able to keep a mean of 35 cuts per minute. In MAN, the pruners working from the ground maintained a speed of 66 m/h, with an average frequency of 25 cuts per minute.

Table 5. Operating characteristics of winter pruning treatments applied on cv. Trebbiano Romagnolo vines (data averaged over 2011–2015).

Treatment	Mechanical Pruning Unit Speed (km/h)	Worker Speed (m/h)	Workers Cutting Frequency (Cuts/min)	Field Working Capacity (ha/h)	Worker Hours per Hectare (h/ha)
MAN	-	66 ± 3.2	25.0 ± 1.8	-	75.8 ± 4.0
MP + F	1.2 ± 0.04	-	40.0 ± 1.6 *	0.22 ± 0.01	13.8 ± 0.6 **
MP	1.5 ± 0.05	-		0.27 ± 0.01	3.7 ± 0.1 **

Values are means ±standard errors of measures in five different years (2011–2015). MAN, manual pruning; MP+F, mechanical pre-pruning and simultaneous manual follow up; MP, mechanical pruning; * mean values of the two operators located on the tractor-drawn platform; ** the work hours of the tractor driver are included in the value.

Table 5 also shows the working capacities for the three pruning treatments, calculated according to the mean speeds and considering a field efficiency of 90%, mainly due to the turning and maneuvering phases. These values indicate that pruning was completed in 3.70 and 4.55 h/ha in the MP and MP+F (in the latter case with three operators) vs. the 75.8 h/ha required for hand pruning. Comparing the worker hours saved (which included the working time of the driver), the two mechanized pruning treatments made it possible to reduce the worker time employed by 82% and 91%, respectively, for the MP+F and MP compared to MAN.

3.3. Economic Evaluation of Pruning Treatments

The operating cost of each pruning treatment was determined by considering different levels of the machine's annual use, referring to different vineyard sizes (Figure 9). Compared to manual pruning, which determines a cost of 1137 €/ha, the two mechanized treatments were less expensive, even if applied on vineyards of a few hectares. On these bases, the convenience of introducing mechanical pruning was achieved, with a surface of 1.5 hectares with the application of the MP, while the MP + F results were more advantageous compared to manual pruning when the vineyard surface was higher than 2.9 hectares.

The simulation of the pruning cost, assuming the management of 5 and 30 ha of the vineyard, is shown in Figure 10. In the first case, the cost of the MP + F and MP allows for saving compared to the manual pruning of 29% and 58%, corresponding to 326 €/ha and 664 €/ha, respectively. Even more evident are the savings if the pruning is carried out on a 30-ha vineyard, with a cost reduction of 61% and 80%, corresponding to 693 €/ha and 908 €/ha for the two levels of mechanization.

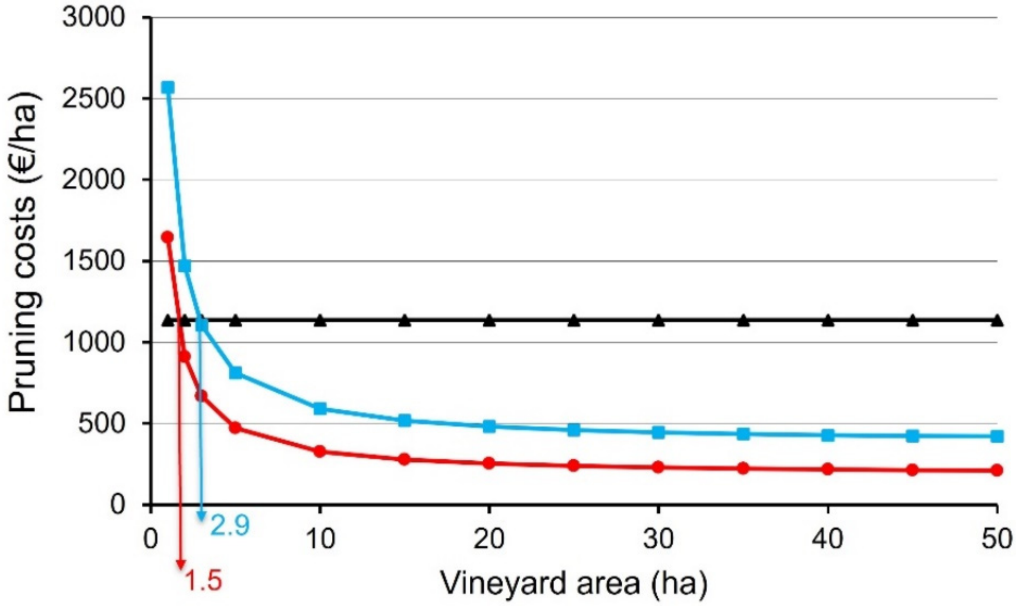

Figure 9. Pruning costs based on the area managed. MAN, manual pruning (▲); MP+F, mechanical pre-pruning and simultaneous manual follow up (■); MP, mechanical pruning (●). Means values of data recorded over 2011–2015. The arrows indicate the break-even point corresponding to the cost indifference area; MAN vs. MP (1.5 ha) and MAN vs. MP + F (2.9 ha).

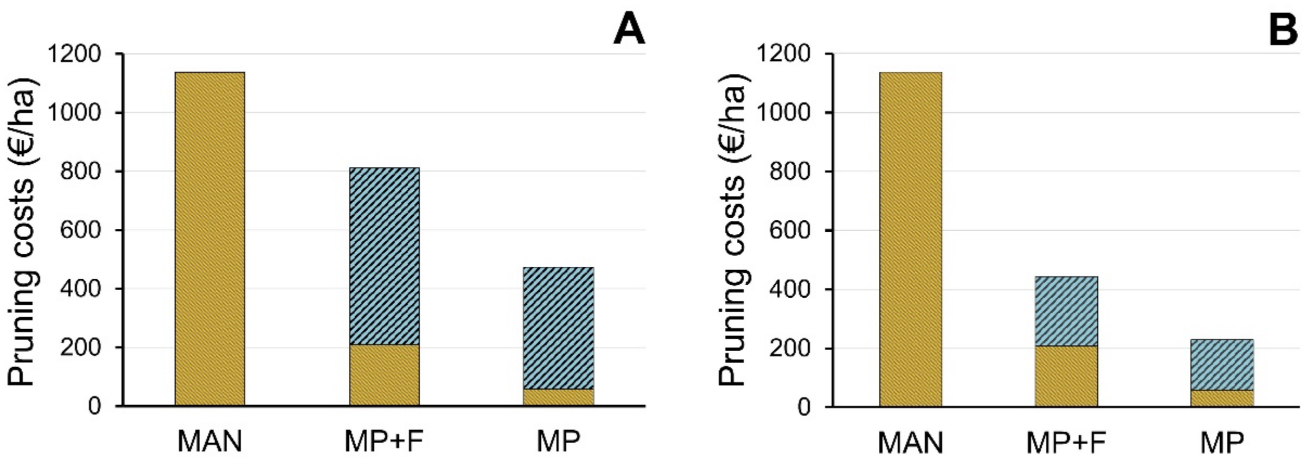

Figure 10. Labor (■) and machinery (■) pruning costs, referred to 5 hectares (**A**) and 30 hectares (**B**) of managed vineyard. MAN, manual pruning; MP+F, mechanical pre-pruning and simultaneous manual follow up; MP, mechanical pruning.

The evaluation reported in Figure 11 was performed assuming various workers' wages, which may broadly change in different viticultural countries. The graph shows that the difference between the surfaces of the economic indifference regarding the "MP+F vs. MAN" and "MP vs. MAN" decreases as the cost increases. As shown, even considering the lowest wage (9 €/h), mechanical pruning becomes convenient if applied on at least 6 and 2.9 hectares for the MP+F and MP, respectively. Considering the highest labor cost (18 €/h), the minimum vineyard surface to economically justify the introduction of mechanical pruning is 1.2 (MP) and 2.3 (MP + F) hectares.

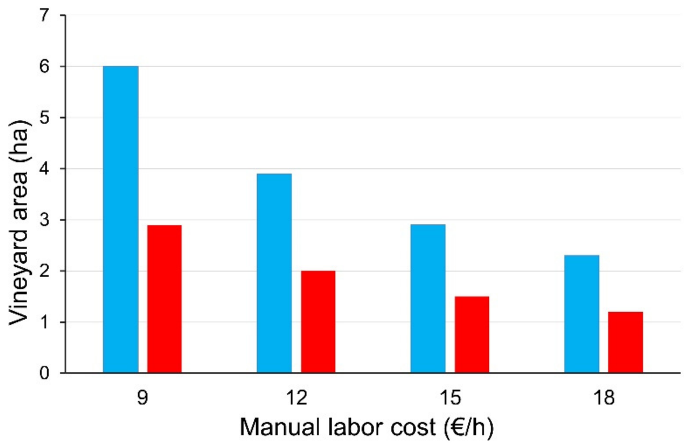

Figure 11. Surface (ha) of economic indifference between the MP+F vs. MAN (■) and MP vs. MAN (■) for pruning mechanization related to different levels of labor cost.

4. Discussion

The trial was conducted on vines trained to the GDC with horizontal and self-supporting arms, which allows a suitable integration with the tractor-mounted cutter bar unit [11].

As expected, the number of nodes increased dramatically in MP vines, while the manual follow-up limited the increase to 60%, as found with a 'light' manual follow-up on cv. Croatina [12]. As previously described, the latter operation, which was conducted with pneumatic shears from the tractor-drawn platform moving forward at 1.2 km/h, allowed the operators to apply only a few cuts per vine, mainly removing the overlapped spurs and those grown towards the inside of the trellis structure. Therefore, most of the spurs were not shortened by the manual follow-up, and this is the reason why some five- and six-node spurs were retained.

Despite the rise in the node number, the increase of the yield in both the mechanical pruning treatments was lower than 15% as compared to hand pruning, indicating that different self-regulation mechanisms set a partial yield compensation. In our study, the shoot fruitfulness (inflorescences/shoot) and cluster weight decreased as the node number increased, while no difference was noted in the bud break rate (shoots/node), which was reported to be a powerful 'tool' to influence the yield [29] and which, however, responded mainly in the first years of the mechanical pruning [12]. Considering that in our Trebbiano vineyard, mechanical pruning had been applied since 2005, the latter finding may explain why during the experiment (2011–2015), the vines did not respond to the bud break adjustment. On the other hand, the decrease in shoot fruitfulness in the mechanically pruned vines was the most effective self-regulation mechanism, as also reported by Clingeleffer [30]. A pioneering study conducted on Montuni grapevines [31], a cultivar characterized by low fruitful basal buds, demonstrated that the decrease in shoot fruitfulness in mechanically pruned vines was caused by the higher number of shorter spurs left by the cutting bars as compared to manual pruning, which featured less fruitful nodes. Considering that also the basal buds of Trebbiano Romagnolo exhibit low fruitfulness, this factor may have contributed to the decrease of shoot fruitfulness in the MP and MP+F vines. Besides that, some limitations on the induction and differentiation processes, such as the excessive shading of the basal nodes [32] due to the higher density of the shoots in the mechanically pruned vines, may have also affected negative shoot fruitfulness.

The decrease of the cluster weight in response to the increase of the nodes was the second yield compensation factor that occurred in our trial, and it was partially due to the reduction of the berry weight, which, in previous studies, was reported to be not very sensitive to mechanical pruning [4,33]. Furthermore, the decrease in the cluster weight might have been caused also by the impaired flower formation and/or the reduced fruit set due to the source limitation, as suggested by Intrieri and Poni [2].

The cluster rot was not affected by mechanical pruning because no difference was found regarding the cluster compactness, the morphologic trait which plays a key role in the development of Botrytis cinerea and sour rot [34].

Considering that the yield increase of the mechanical pruning treatments was limited (less than 15%), not surprisingly, the sugar concentration did not differ, as also reported by previous long-term trials [31,35]. However, the higher titratable acidity of the MP berries might be probably due to the higher number of shoots that shaded more intensely the clusters, reducing the degradation of malic acid [36].

Although in the MP vines, the number of shoots was the highest, the weight of the pruning wood recorded in the winter of the last year of the experiment resulted in the lowest, indicating that those shoots were thinner and lighter than those of the other treatments. Moreover, the lower pruning wood weight of the mechanically pruned vines suggests that those shoots contained fewer reserves for the following year, and it may explain the source limitation that might have impaired the induction and differentiation processes that caused the reduction of the shoot fruitfulness and cluster weight.

The results obtained by applying mechanical winter pruning have shown the possibility of limiting this highly relevant cost of vineyard management. The reduction of costs, increasing from an intermediate level of mechanization with hand finishing to full mechanization, is easy to achieve because only a few hectares of vineyards are enough to make cost-effective the purchasing of the machines. The economic assessment of mechanical pruning is substantially positive, even with low labor costs, and can represent a strategy for tackling the serious labor shortage that occurs on farms throughout Europe [17,18]. Although mechanized winter pruning allows significant cost reductions in vineyard management and has been shown not to adversely affect grape quality [19], this technique has not yet been widely adopted in Italy [5,9]. However, the progressive reduction in the number of farms that leads to the increase in the average size of the vineyard recorded by the latest ISTAT census [37] will certainly promote a strong incentive for the diffusion of mechanical pruning.

5. Conclusions

The agronomic and economic results obtained in this five-year study support our hypothesis and confirm that mechanical pruning may be profitably applied also on grapevine varieties characterized by low basal bud fruitfulness, such as Trebbiano romagnolo. Our data indicate that even with a dramatic increase in the node number, the yield compensation factors limited the increase of productivity to less than 15%, allowing the harvest of grapes with a similar composition as that of manual pruning. It is worthy of notice that these remarkable results were achieved also because the vines had been pruned by applying the same treatments for five years before the beginning of the experiment, avoiding yield alternation that usually occurs in the first 2–3 years and that, in turn, mislead the results on the grape composition. The data reported in this research indicate that also mechanical pruning without any manual follow-up is feasible on Trebbiano romagnolo and that the vine performances are very similar to those of the vines subjected to a light manual follow-up. Moreover, our results demonstrated that economic sustainability might also be achieved in vineyards of about three hectares.

In conclusion, taking into account also the grape composition, the results of the present study reveal that the pruning mechanization may be applied successfully under the current global warming conditions, in viticultural areas characterized by flat land or gentle hills, and even in small viticultural farms, aimed to produce high-value sparkling wines, which may be able to benefit from the moderate sugar concentration and the quite high level of acidity characterizing the grapes from mechanically pruned vines.

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