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Influence of vineyard inter-row management and clone on 'Sauvignon Blanc' performance in Friuli Venezia Giulia (north-eastern Italy)

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Summary

The vineyard inter-row management affects grapevine vegetative and bunch health status, as well as yield and grape quality parameters. Several studies assessed that cover-cropped inter-row in place of soil tillage often reduced plant vigour and yield but positively contributed to vineyard ecosystem services and, to a lower extent, to grape quality. In 2013 and 2014, two inter-row management strategies, *i.e.* soil tillage and mowing of spontaneous cover crops, were compared in an organic vineyard in north-eastern Italy and cultivated with 'Sauvignon Blanc' (*Vitis vinifera* L.), clones R3 and 297. In particular, the effects of tillage and mowing treatments on grapevine vegetative and bunch health status, yield and grape quality were evaluated. The vegetative parameters were lower in the mowing treatment than in the tillage one and in clone R3 compared to 297. The incidence of *Botrytis cinerea* was higher in the tillage treatment than in the mowing one and in clone 297 compared to R3. A significant reduction of the yield and bunch weight was ascertained in the mowing treatment, and these parameters were higher for clone 297 compared to clone R3. Titratable acidity was significantly higher in the tillage treatment than in the mowing one and in clone 297 compared to R3. Moreover, hue of berry skin was qualitatively better in the tillage treatment than in the mowing one. In the pedo-climatic conditions of Friuli Venezia Giulia (north-eastern Italy), the management of the vineyard inter-row with spontaneous cover crops proved to be effective to manage grapevine vigour, reducing yield and improving quality of the grapes during maturation.

Key words: 'Sauvignon Blanc'; clones; soil tillage; permanent green cover; *Botrytis cinerea*; hue of berry skin.

Introduction

Managing inter-rows with or without spontaneous cover crops influence vegetative and productive parameters, as well as bunch health status (Abad *et al.* 2021). Moreover, inter-row management impacts on biodiversity and ecosystem services, as tillage and herbicide applications affect soil erosion rate, soil fertility degradation and groundwater contamination (Winter *et al.* 2018).

Spontaneous cover crops can compete with grapevines for water and nutrients, compromising plant vigour and, as a consequence, yield (Tan and Crabtree 1990, Carsoulle 1995, Rodriguez-Lovelle *et al.* 2000, David *et al.* 2001, Pardini *et al.* 2002, Ingels *et al.* 2005, Wheeler *et al.* 2005, Tesic *et al.* 2007, Celette *et al.* 2009, Guerra and Steenwerth 2012). The adverse effects of spontaneous cover crops on grapevine yield increase in rainfall-deficient climates when irrigation is unavailable (Morlat and Geoffrion 2000, Marques *et al.* 2010, Ripoche *et al.* 2011, Ruiz-Colmenero *et al.* 2011, Winter *et al.* 2018). However, in too vigorous vineyards, inter-row mowing represents an effective tool to control vegetative growth (Beslic *et al.* 2015). Benefits can also be observed on must quality, with increased total soluble solids and polyphenolic compounds, lower titratable acidity and higher pH (Carsoulle 1995, Morlat and Geoffrion 2000, David *et al.* 2001, Morlat and Jacquet 2003, Wheeler *et al.* 2005, Beslic *et al.* 2015). Pathogens such as grey mould (*Botrytis cinerea* Pers.), downy mildew (*Plasmopara viticola* Berk. & M. A. Curtis, Berl. & De Toni) and powdery mildew (*Erysiphe necator* Schwein) are reduced in cover-cropped inter-row vineyards, primarily due to lower vigour of vines (Carsoulle 1995, Morlat and Geoffrion 2000, Morlat and Jacquet 2003, Valdés *et al.* 2005, Valdés-Gómez *et al.* 2011). Moreover, spontaneous cover crops can favour arthropod pest control (Berndt *et al.* 2006, Sanguankeo and Leòn 2011, Daane *et al.* 2018, Winter *et al.* 2018), mainly increasing the abundance of natural enemies. However, some polyphagous pests can be favoured by the availability of alternative host plants and shelters in cover-cropped inter-rows (Costello and Daane 1998, Landis *et al.* 2000, Danne *et al.* 2010, Judt *et al.* 2019). Selective cover crops maximised biological control of some pests in vineyards (Begum *et al.* 2006, Nboyine *et al.* 2018). As for the carpophagous moth *Lobesia botrana* (Den. & Schiff.) (Lepidoptera: Tortricidae), Hoffmann *et al.* (2017) did not observe significant effects of selective cover crops *vs* native ground vegetation on parasitisation and predation of eggs or pupae, whereas Serra

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et al. (2006) reported higher larval infestation in tilled plots than spontaneous cover crop plots.

Despite some difficulties, the farmers could be encouraged to adopt spontaneous cover crops management for marketing purposes, as wine consumers increasingly appreciate eco-friendly farming practices (Viers *et al.* 2013). In addition, the agri-environmental measures adopted by the Friuli Venezia Giulia region encourage cover-cropped inter-row management through public subsidies considering this practice beneficial for the community as it promotes biodiversity and other ecosystem services.

In an organic vineyard, periodical soil tillage-based inter-row management, normal soil management adopted in the past in this grape-growing area, was replaced with periodical cover-crops mowing. The purpose of this study was to evaluate the effects of the management modification on (i) grapevine vegetative status, (ii) bunch health status, (iii) grape yield and (iv) grape quality.

Material and Methods

Vineyard site: The study was carried out during two consecutive years (*i.e.* 2013 and 2014) in an organic vineyard located in north-eastern Italy (locality Cormons, Gorizia district, 45°56'56"N, 13°27'11"E, 46 m a.s.l.). The vineyard was planted in 1980 with two clones of 'Sauvignon Blanc' (*Vitis vinifera* L.), *i.e.* clones R3 and 297 grafted on SO4. The vineyard consisted of 16 rows 140 m long and N48°E oriented. The first nine rows (south side) were planted with clone 297 and the following seven with clone R3 (Fig. 1). The vine spacing was 1.7 m between vines and 2.7 m between rows and trained to the Guyot training system. The soil was of alluvial origin, with moderately high gravel content (20-30 % in the first 50 cm of soil) and loam texture. In the years prior to the study, every second inter-row was tilled. Fertilisation and irrigation were set up according to the farm schedule. As for the canopy management, standard agronomical practices have been carried out during the trial

Fig. 1: Experimental design of the trial carried out in a vineyard of north-eastern Italy (Cormons, Gorizia), planted with two clones of 'Sauvignon Blanc', where two different inter-row management strategies (*i.e.* tillage-TT and mowing-MT) were compared (aerial image modified with QGIS; QGIS.org, 2021; QGIS Geographic Information System; QGIS Association; http://www.qgis.org).

with manual vertical shoot positioning and mechanical trimming during the summer. The timing and intensity of these cultural practices were the same for each plot. As regards plant protection, no insecticide and only sulphur- and copper-based fungicides were applied on grapevines.

Treatments: In early spring 2013, two inter-row management strategies were established in the vineyard: mowing, with spontaneous cover crops between rows, and tillage, with the periodical restoration of bare soil between rows (Fig. 1). In the mowing treatment (hereafter "MT"), every second inter-row was mowed when flowering began in the next inter-row. This management technique was adopted to maintain flowering plants at least on one side of the grapevine rows. Thus, nectar and pollen for natural enemies were guaranteed throughout the whole vegetative season. In the tillage treatment (hereafter "TT"), all the inter-rows were ploughed to avoid flowering of newly emerged herbaceous plants. To achieve this result, twice per year (6 May and 1 July 2013, 5 May and 5 July 2014), inter-rows of MT were mowed, and those of TT were cultivated, using a shredding machine and a tractor-mounted tiller, respectively. Each treatment was replicated in two plots for each clone (block) (Fig. 1). Plot size was ca 550 m^2 (about 120 vines) for clone R3 block and 750 m^2 (about 160 vines) for clone 297 block.

Weather data and *Lobesia botrana* phenology: The temperature and rainfall data were obtained from a weather station (Gradisca d'Isonzo, Gorizia, ARPA FVG–OSMER, http://www.meteo.fvg.it/) located at 6 km from the study vineyard. Male flight phenology of *L. botrana* and the grapevine phenology were provided by the Consorzio Tutela Vini DOC Friuli Isonzo (Cormons, Gorizia).

Sampling: During the two-year trial, samplings were carried out to assess (i) grapevine vegetative status, (ii) bunch health status, (iii) yield and (iv) grape quality. Unless otherwise specified, samplings were performed in the two central rows of each plot, excluding the five plants next to the plot border.

Grapevine health status: Normalised Difference Vegetation Index (NDVI) and pruning weight were used to determine the grapevine vegetative status.

Rouse *et al.* (1974) introduced the NDVI index as the first multispectral index related to the plants vigour. Vigorous grapevines, characterised by large and dense canopies, are associated with high NDVI values, whereas less vigorous grapevines have low NDVI. Thus, in some studies NDVI has been adopted to evaluate within-vineyard vigour differences (Bigot *et al.* 2013, Hall *et al.* 2002).

The NDVI was calculated by processing the data collected on 6 September 2013 and 16 August 2014 using two ACS-210 optical sensors (Holland scientific Inc., Lincoln, Nebraska) laterally installed on a four-wheeler (All-Terrain Vehicle). Measurements were recorded every 0.5 m with a PC data logger mounted aboard. Data processing was then performed using FarmWorks® software (Farm Works Information Management - Hamilton, Indiana) to exclude outliers. Furthermore, QGIS software (https://www.qgis.org/) was used to calculate mean NDVI values for each plot with spatial statistical analysis. Pruning weight was collected on 13 January 2014 and 18 March 2015. One-year-old canes of five plants per plot were weighed (kg per plant) with a digital dynamometer.

B u n c h h e a l t h s t a t u s : *Lobesia botrana*, downy mildew (*P. viticola*) and bunch rots were considered agents of bunch damages. The larval infestation of the *L. botrana* second generation was estimated at about 40 d after the beginning of the second flight, whereas the larval infestation of the moth third generation was estimated at harvest time (August 2 and September 4, 2013; August 1 and September 9, 2014). At each sampling time, 50 bunches per plot were examined on 10 different plants. Five bunches were chosen alternately from each grapevine based on an a priori scheme to avoid subjective choice (Pavan *et al.* 1998). On each bunch, the number of larval nests was counted. A larval nest consists of a group of berries with feeding and webbing damages caused by a single larva.

At harvest time, on the same bunches sampled for larval nests of *L. botrana*, third generation, the percentage of berries with downy mildew (*P. viticola*), grey mould (*B. cinerea*), sour rot and black aspergilli rot (*Aspergillus* section *Nigri*) was also assessed. For this purpose, disease severity was estimated according to eight classes (0, 1, 5, 10, 25, 50, 75, and 100 % of rotten berries) by visually rating individual bunch.

G r a p e y i e l d a n d q u a l i t y : At harvest time, the number of bunches was counted on five vines per plot, and the yield was weighted. Then, the average bunch weight was calculated by rating the two parameters.

As grape quality parameters, the hue of berry skin, total soluble solids (TSS), sugar loading (SS), titratable acidity (TA) and pH value were evaluated.

In each plot, 200 berries were randomly collected to measure the hue of berry skin on the colour wheel (H°) in the analysis laboratory. The berries were evaluated for colour with a chroma meter CR-400 (Konica Minolta, Japan) using the CIELAB colour system. For 'Sauvignon Blanc' berries, the evolution of H° from 85 to 70 (*i.e.* the evolution of colour from green to yellow) is associated with an evolution of berry aromatic sequence during ripening (*i.e.* 85-80 = asparagus/citrus aromatic profile; 80-75 = asparagus/tropical fruit/citrus aromatic profile; 75-70 = tropical fruit aromatic profile) (Deloire 2013).

Then, the 200 berries were mechanically homogenised at room temperature, and the juice, separated from the solid fraction pomace, was used to determine TSS (°Brix) using a digital refractometer (Quick-Brix 60 Mettler-Toledo Inc.). Moreover, TA ($g \cdot L^{-1}$ tartaric acid equivalent) was assessed by titration with NaOH 0.1 N until pH 8.2 and pH value by a pH-meter (HI2211 Hanna Instruments, USA). Sugar loading (SS; mg per berry) was computed based on TSS and average berry weight.

D a t a a n a l y s i s : A general linear ANOVA model, considering as sources of variation "year" (*i.e.* data collected both in 2013 and 2014), "treatment" (*i.e.* TT and MT), 'Sauvignon Blanc' "clone" (*i.e.* R3 and 297) and their interactions, was used to compare grapevine vegetative status, *L. botrana* infestation, infections by downy mildew and bunch rots, and productive parameters. When the interaction year × treatment or year × clone was significant, the two years were analysed through ANOVA separately.

Results

W e a t h e r c o n d i t i o n s : The vegetative season 2013 was characterised by three periods (Fig. 2). From early May to mid-June (46 d), a rainy period occurred with 389 mm of rain distributed in 27 d and average daily temperatures almost always below 20 °C. From mid-June to mid-August (61 d), a dry period occurred with only 63 mm of rain distributed in seven days and average daily temperatures almost constantly above 25 °C. Finally, from mid-August to harvest (19 d), 67 mm of rain distributed in 8 d fell, and temperatures remained between 20 and 25 °C.

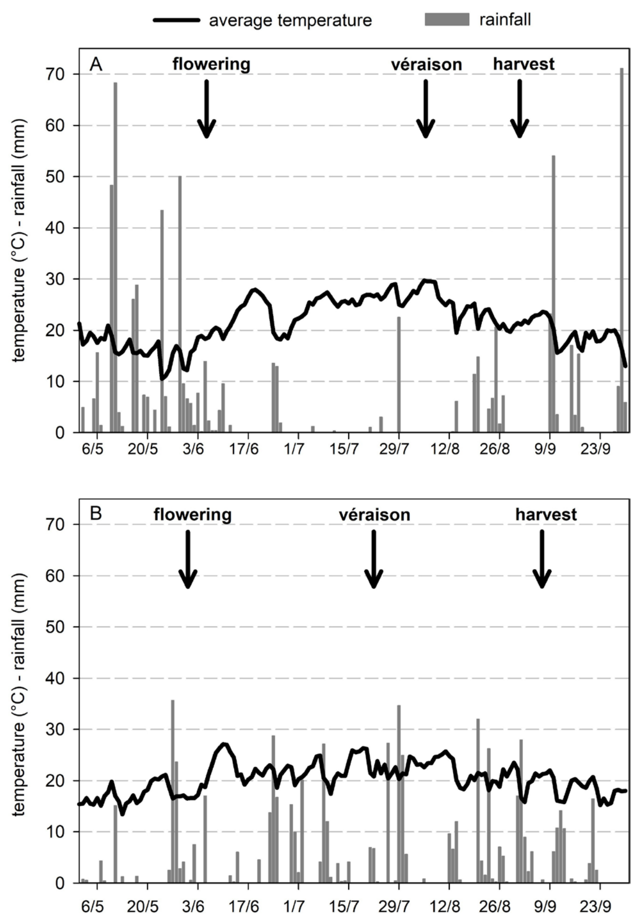

Fig. 2: Weather condition and main growth stages recorded over the 2013 (**A**) and 2014 (**B**) vegetative seasons in the grape-growing area where the study vineyard is located.

The vegetative season 2014 was characterised by two different periods (Fig. 2). Up to the first decade of June (41 d), rainfall was moderate (118 mm of rain distributed in 15 d), and average daily temperatures were almost always below 20 °C. Then, from the first decade of June to harvest time (86 d), rainfall was more abundant (448 mm of rain distributed in 37 d), and the average daily temperatures were almost always between 20 and 25 °C, with only 6 d below 20 °C and 7 d above 25 °C.

G r a p e v i n e v e g e t a t i v e s t a t u s : Both the vegetative parameters examined revealed significant differences between years and treatments (Tab. 1). The NDVI was significantly higher in 2013 than in 2014 ($P < 0.001$) and in TT than in MT ($P < 0.001$). Accordingly, pruning weight was significantly higher in the first year ($P = 0.004$)

Table 1

Grape vegetative parameters recorded in 2013 and 2014 in the two treatments and clones in comparison. NDVI was measured on 6 September 2013 and 16 August 2014, while pruning was weighted on 13 January 2014 and 18 March 2015

Factor		NDVI	Pruning weight (kg·vine^{-1})
Year (Y)	2013	0.703 ± 0.008	0.478 ± 0.047
	2014	0.635 ± 0.009	0.299 ± 0.054
		***	**
Treatment (T)	Tillage (TT)	0.689 ± 0.014	0.469 ± 0.060
	Mowing (MT)	0.650 ± 0.013	0.308 ± 0.044
		***	**
Clone (C)	R3	0.665 ± 0.016	0.316 ± 0.045
	297	0.673 ± 0.015	0.460 ± 0.067
		ns	*
Interactions	Y × T	ns	ns
	Y × C	ns	ns
	T × C	ns	ns

* Data were analysed through three-way general linear ANOVA model (ns, not significant; *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$), considering as sources of variation 'year', 'treatment' and 'clone'.

than the second one and in TT (P = 0.007) than in MT. Moreover, significantly higher values were found for clone 297 compared to clone R3 (P = 0.012).

Grapevine health status: Larval infestation of *L. botrana*, both during the second and third generations, was higher in 2013 than in 2014 (second generation: P < 0.001; third generation: P = 0.007) (Tab. 2). For both generations, the infestation level was influenced neither by the treatment (second generation: P = 0.80; third generation: P = 0.35) nor by the clone (second generation: P = 0.09; third generation: P = 0.65). The interaction year × clone was significant (P = 0.05) because the infestation was higher for clones 297 and R3 in the 2013 and 2014, respectively.

The percentage of berries infected by *P. viticola* was not significantly influenced by the year (P = 0.20), neither by the treatment (P = 0.25) nor by the clone (P = 0.53). However, the fungus incidence was on average higher in 2014 (*i.e.* the wettest year) than in 2013, in TT than in MT, and for clone R3 than clone 297 (Tab. 2). The percentage of berries infected by *B. cinerea* was influenced by the year (P < 0.001), the treatment (P = 0.002) and the clone (P < 0.001) (Tab. 2). In particular, the incidence was four times higher in 2014

Table 2

Bunch health parameters recorded in 2013 and 2014 in the two treatments and clones in comparison

Factor		Number of larval nests of *Lobesia botrana* / 50 bunches		Percentage of berries infected by			
		Second generation	Third generation	Downy mildew	Grey mould	Sour rots	Black aspergilli rot *Aspergillus* section *Nigri*
Year (Y)	2013	48.5 ± 3.08	143.3 ± 22.5	0.24 ± 0.09	14.3 ± 5.6	3.1 ± 0.8	0.36 ± 0.13
	2014	5.25 ± 0.90	61.50 ± 8.08	0.59 ± 0.25	57.8 ± 13.0	69.5 ± 18.9	0.00 ± 0.00
		***	**	ns	***	***	**
Treatment (T)	Tillage (TT)	27.25 ± 8.73	113.6 ± 22.9	0.57 ± 0.26	53.0 ± 14.9	42.2 ± 20.3	0.19 ± 0.11
	Mowing (MT)	26.50 ± 8.23	91.1 ± 22.1	0.26 ± 0.07	19.1 ± 5.5	30.5 ± 15.8	0.18 ± 0.12
		ns	ns	ns	**	*	ns
Clone (C)	R3	24.13 ± 7.25	113.6 ± 22.9	0.49 ± 0.25	23.1 ± 9.9	12.4 ± 3.7	0.03 ± 0.02
	297	29.63 ± 9.44	91.1 ± 22.1	0.33 ± 0.12	49.0 ± 13.8	60.2 ± 22.3	0.33 ± 0.14
		ns	ns	ns	*	***	**
Interactions (Sign. F)	Y × T	ns	ns	ns	*	ns	ns
	Y × C	*	ns	ns	ns	***	**
	T × C	ns	ns	ns	ns	ns	ns

* Data were analysed through three-way general linear ANOVA model (ns, not significant; *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$), considering as sources of variation 'year', 'treatment' and 'clone'.

than in 2013, three times higher in TT than in MT and twice as high in clone 297 than clone R3. The interaction year × treatment was significant ($P < 0.001$) as the differences between the treatments were wider in 2013 than in 2014. The percentage of berries infected by sour rot was negligible in 2013 and high in 2014 ($P < 0.001$) (Tab. 2). The incidence of this disease was almost three times higher in TT than in MT ($P = 0.042$). Clone 297 was twice more susceptible than clone R3 ($P < 0.001$). The interaction year × clone was significant ($P < 0.001$) as the differences between clones were wider in 2014 than in 2013. The black aspergilli rot was identified only in 2013 (Tab. 2). The treatment did not influence the percentage of berries infected by the fungus ($P = 0.93$). As for sour rot, the incidence of this disease was strongly influenced by the clone, being 10 times higher in clone 297 than clone R3 ($P = 0.023$).

Grape yield and quality: The number of bunches per vine was significantly higher in 2013 than in 2014 ($P < 0.001$) and in clone 297 than in clone R3 ($P < 0.0001$), while the treatment did not affect this parameter ($P = 0.510$) (Tab. 3). However, the interaction year × treatment was significant ($P = 0.022$). Analysing the years separately, in 2014, the number of bunches was significantly higher in TT than in MT ($P = 0.047$), whereas in 2013, this parameter was slightly higher in MT than in TT ($P = 0.260$). The interaction year × clone was also significant ($P = 0.034$), as the number of bunches was significantly higher in clone 297 than in clone R3 in 2014 ($P = 0.003$) but not in 2013 ($P = 0.074$).

The second yield parameter evaluated, the average bunch weight, was significantly influenced by the year ($P = 0.022$), the treatment ($P = 0.010$) and the clone ($P < 0.001$). In particular, this latter parameter was significantly higher in 2013 than in 2014, in TT than in MT and for clone 297 compared to clone R3. The interaction year × clone was also significant ($P = 0.013$), as the difference between clones was wider in 2013 than in 2014. All factors significantly affected grapevine yield; thus, the yield was significantly higher in 2013 than in 2014 ($P < 0.001$), in TT than in MT ($P = 0.024$) and for clone 297 in comparison with clone R3 ($P < 0.001$). This result was the consequence of the different number of bunches and bunch weight. The average berry weight was significantly influenced by both years ($P < 0.001$) and the treatment ($P = 0.004$), being higher in 2014 than in 2013 and in TT than in MT. However, berry weight was not different between clones ($P = 0.84$) (Tab. 3).

With regard to the grape quality parameters, the hue of berry skin was significantly higher in the TT than in MT ($P = 0.037$), *i.e.* closer to green in the former treatment and yellow in the latter. Consequently, the aromatic profile was closer to asparagus/citrus and asparagus/tropical fruit/citrus in the former and latter treatment, respectively (Tab. 4). No significant influence of the year ($P = 0.17$) and the clone ($P = 0.81$) was observed on the hue of the berry.

TSS were higher in 2013 than in 2014 ($P < 0.001$), without reaching the significance level for the treatment ($P = 0.06$) and the clone ($P = 0.12$) (Tab. 4). However, the interaction year × treatment was significant ($P = 0.014$), as TSS were significantly higher in MT than in TT in 2014 ($P = 0.048$), but not in 2013 ($P = 0.24$). In contrast, SS was higher in 2014 than in 2013 ($P < 0.001$), while did not reach the significance level for the treatment ($P = 0.051$) and the clone ($P = 0.210$).

TA was significantly higher in 2014 than in 2013 ($P < 0.001$), in TT than in MT ($P = 0.001$) and in clone 297 than clone R3 ($P < 0.001$) (Tab. 4). The interaction year × treatment was significant ($P = 0.001$), as TA was significantly different between the two treatments in 2014 ($P < 0.001$), while it was negligible in 2013 ($P = 0.81$). The pH was significantly lower in 2014 than in 2013 ($P < 0.001$) and in clone R3 than clone 297 ($P = 0.033$). The treatment did not affect the pH ($P = 0.55$) (Tab. 4).

Table 3

Grapevine yield parameters recorded in 2013 and 2014 in the two treatments and clones in comparison

Factor		Number of bunches/vine	Average bunch weight (g)	Yield (kg·vine^{-1})	Average berry weight (g)
Year (Y)	2013	22.4 ± 1.0	82.4 ± 9.2	1.9 ± 0.3	1.334 ± 0.033
	2014	15.7 ± 81.7	72.6 ± 3.9	1.2 ± 0.2	1.725 ± 0.030
		***	*	***	***
Treatment (T)	Tillage (TT)	19.4 ± 1.7	83.3 ± 6.0	1.7 ± 0.3	1.588 ± 0.069
	Mowing (MT)	18.7 ± 2.0	71.6 ± 7.8	1.4 ± 0.3	1.471 ± 0.086
		ns	*	*	**
Clone (C)	R3	16.2 ± 1.9	62.3 ± 4.3	1.0 ± 0.1	1.526 ± 0.088
	297	21.9 ± 1.1	92.7 ± 4.7	2.1 ± 0.2	1.533 ± 0.073
		***	***	***	ns
Interactions	Y × T	*	ns	ns	ns
	Y × C	*	*	ns	ns
	T × C	ns	ns	ns	ns

* Data were analysed through three-way general linear ANOVA model (ns, not significant; *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$), considering as sources of variation 'year', ‘treatment' and 'clone'.

Table 4

Grape quality parameters recorded in 2013 and 2014 in the two treatments and clones in comparison

Factor		Total soluble solid (°Brix)	Sugar loading (mg·berry^{-1})	Titratable acidity (g·L^{-1})	pH	Hue of berry skin (H°)
Year (Y)	2013	18.69 ± 0.08	292.8 ± 7.4	8.75 ± 0.38	3.21 ± 0.02	73.38 ± 2.11
	2014	16.54 ± 0.28	382.3 ± 6.6	15.76 ± 0.54	2.89 ± 0.01	79.25 ± 1.66
		***	***	***	***	ns
Treatment (T)	Tillage (TT)	17.39 ± 0.54	347.9 ± 16.7	12.77 ± 1.58	3.06 ± 0.06	80.50 ± 2.12
	Mowing (MT)	17.84 ± 0.33	327.13 ± 19.0	11.74 ± 1.17	3.05 ± 0.06	74.512 ± 0.9
		ns	ns	**	ns	*
Clone (C)	R3	17.79 ± 0.46	343.8 ± 8.6	11.32 ± 1.36	3.03 ± 0.06	77.00 ± 2.06
	297	17.43 ± 0.44	331.3 ± 10.9	13.19 ± 1.36	3.08 ± 0.06	77.62 ± 1.73
		ns	ns	***	*	ns
Interactions	Y × T	*	ns	**	ns	ns
	Y × C	ns	ns	ns	ns	ns
	T × C	ns	ns	ns	ns	ns

* Data were analysed through three-way general linear ANOVA model (ns, not significant; *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$), considering as sources of variation 'year', 'treatment' and 'clone'.

Discussion

Effect of inter-row management: The main effects of the conversion of the inter-row management from periodical soil tillage to periodical mowing of spontaneous cover crops were: (i) reduced grapevine vigour, (ii) decreased grey mould and sour rot severity, (iii) lower yield, (iv) higher TSS (only in the second year) and lower TA, (v) improved berry colour and, as a consequence, berry aromatic profile.

The reduction of grapevine vigour in the MT may be due to the competition for water or nutrients between grasses and grapevines, as already widely reported in the literature (Tan and Crabtree 1990, Carsoulle 1995, Rodriguez-Lovelle *et al.* 2000, David *et al.* 2001, Pardini *et al.* 2002, Ingels *et al.* 2005, Wheeler *et al.* 2005, Tesic *et al.* 2007, Celette *et al.* 2009, Guerra and Steenwerth 2012, Abad *et al.* 2021). Although increased pruning weight when cover crops are adopted has not been ever observed, most studies revealed a reduction in this parameter to a different extent based on grapevine variety and climate.

The introduction in the vineyard of permanent cover crops in 2013 replacing periodical tillage (continuously adopted from 1980), without any supplementary fertilisers, drastically reduced the available nitrogen. Therefore, lower vegetative development occurred, even though up to mid-June there was no shortage of water. It is well-known that grasses are nitrogen scavengers, competing with vines to absorb this mineral element from soil (Varga *et al.* 2012). This study assessed a close relationship between vine vigour and bunch rots; as a rule of the thumb, the higher the rainfall at preharvest time, the more severe the infection of bunch rots, as observed in the second year (2014). In TT, the higher vigour of grapevines favoured the development of bunch rots (*i.e.*, grey mould and sour rot), as the wider leaf area around the fruit zone led to prolonged wetting of the bunches after the rain fallen before harvest time (R'Houma *et al.* 1998, Muckensturm and Decoin 2000, Valdés-Gómez *et al.* 2008). This effect was more evident in the second year.

The transition from tillage to mowing of the inter-rows also resulted in a contraction of grape yield. The decreased yield in MT was due to the lower average berry weight and, in the second year of permanent cover crops, also to fewer bunches. Most of the studies on cover-cropped vineyards revealed lower yields than bare or tilled soils (e.g. Wheeler *et al.* 2005, Palliotti *et al.* 2007, Varga *et al.* 2012, Coniberti *et al.* 2017). Only a few trials showed opposite results (Fourie *et al.* 2007, Steenwerth *et al.* 2013, Abad *et al.* 2021). The reduced berry weight can be associated with the lower availability of water and nutrients, as already discussed for plant vigour, and could be compensated with irrigation and fertilisation practices (Morlat and Geoffrion 2000, Guerra and Steenwerth 2012). Moreover, bud differentiation could have been negatively affected by the poor availability of water and nutrients; thus, fewer cluster primordia have been developed (Alleweldt and Ilter 1969). In this study, the number of bunches in 2014 was lower, and this fact could be explained by reduced flower differentiation in 2013. In the first part of the season of 2013, until berry-set, low temperatures combined with heavy rains likely interfered with the development of cluster primordia (Buttrose 1969). Spontaneous cover crops are a more profitable inter-row management strategy in wine areas where (i) grapevines are not subject to water stress (Tesic *et al.* 2007), (ii) grapevines are too vigorous (Beslic *et al.* 2015) and (iii) water stagnation could compromise early firm footing for cultural practices, especially the spraying against downy mildew (Guerra and Steenwerth 2012). When cover crops in the inter-rows were eliminated in the summer months to avoid severe competition with the vines, the negative effect on plant vigour and yield could have been mitigated (Guerra and Steenwerth 2012).

Quality viticulture does not promote high yield; thus, cover crops are a suitable inter-row management strategy improving grape quality (*i.e.* increase of total soluble solid and polyphenolic compounds, decrease of titratable acidity and pH, improving of aromatic profile) (Carsoulle 1995, Morlat and Geoffrion 2000, David *et al.* 2001, Morlat and Jacquet 2003, Wheeler *et al.* 2005, Beslic *et al.* 2015, this study). Considering the productive parameters, it is worth noting that, despite the reduction in average berry weight observed in MT, TSS per berry was not significantly different between the two treatments. However, TSS were slightly higher in MT. Most of the studies carried out on cover-cropped vineyards agree with the presented results, and no effects on TSS were ascertained. Only a few studies showed an increase in TSS, essentially due to the reduction in yield and berry weight, as reviewed by Abad *et al.* (2021). In this study, permanent cover crops caused a decrease in TA. Literature reports different effects of cover crops on TA (Carsoulle 1995, Morlat and Geoffrion 2000, David *et al.* 2001, Morlat and Jacquet 2003, Wheeler *et al.* 2005, Beslic *et al.* 2015). Most of these studies did not report significant modification, except for some cases where a reduction was observed, e.g. for 'Sauvignon Blanc' (Caspari *et al.* 1997). We can speculate that the decrease of yield observed in our study, promoted an advanced maturation of the grapes, with higher accumulation of TSS and more intense degradation of malic acid that resulted in lower titratable acidity.

Deloire (2013) demonstrated that the aromatic maturation of 'Sauvignon Blanc' grapes could be easily monitored by examining the hue of berry skin (H°); yellowish berry colour (lower values of H°) is associated with a higher concentration of thiols, while greenish colour (higher values of H°) is correlated with higher pyrazines. In this study, MT significantly decreased the hue of berry skin; this result could be the consequence of higher sun exposure of the bunches promoted by reducing both vigour and yield. As already shown by Ryona *et al.* (2008) and Mosetti *et al.* (2016), there is a positive correlation between vegetal-like aroma compounds and malic acid concentration. Thus, bunch sun exposure has a direct effect on methoxypyrazines. The tendency of a higher hue of berry skin in 2014 could be due to the delay of ripening caused by the unfavourable weather conditions, rainy and with relatively low temperatures right before the harvest. Moreover, the reduced biosynthesis of polyphenols triggered by UV-wavelengths, that are well-known to contribute to the orange nuances of the berry skin (Haselgrove *et al.* 2000), may have resulted in higher hue.

In integrated pest management, permanent cover crops in vineyards are preferable to tillage, as they contribute to reduce diseases (*i.e.* downy mildew, powdery mildew and bunch rots) and pests levels (Carsoulle 1995, Nicholls *et al.* 2000, Costello and Daane 2003, Hanna *et al.* 2003, Morlat and Jacquet 2003, Valdés *et al.* 2005, Serra *et al.* 2006, Valdés-Gómez *et al.* 2011, this study). Plant protection can take advantage of cover-cropped inter-rows, such as lower damage by diseases and pests, lower spraying, and the possibility of postponing harvest due to lower incidence of bunch rots. Moreover, the indirect damage by *L. botrana* is lower (*i.e.* reduced susceptibility to the grey mould of both bored berries and the contiguous ones; Pavan *et al.* 2014), allowing higher economic injury acceptance levels. However, in this study, permanent cover crops did not reduce *L. botrana* infestation, as previously observed in Serra *et al.* (2006). Furthermore, the third generation of the moth was on average lower in MT than in TT, likely due to lower grapevine vigour, and consequent greater exposure of bunches to sunlight, in MT. In fact, the higher temperature recorded on sun-exposed berries compared to shaded ones negatively affected egg-hatching and mostly larval settlement (Kiaeian Moosavi *et al.* 2018).

Effect of clone: The clone affects plant vigour and yield and interferes with inter-row management. Comparing 297 and R3 clones, the former revealed a higher vigour, and replacing tillage with the periodical mowing of spontaneous cover crops determined a higher reduction of vigour in the more vigorous clone (43 % vs 20 % for clones 297 and R3, respectively). In addition, the vines of clone 297 had bigger and more compact bunches, which caused higher incidence of bunch rots. In a compacted bunch, the internal berries suffer high humidity conditions; thus higher probability of microcrackings can cause leakage of juice, favouring the growth of moulds (Marois *et al.* 1986). Moreover, dry flower debris trapped inside the bunches could serve as a nutrient supply synergistically enhancing the development of moulds (Hed *et al.* 2009). The tight distribution of the berries in more compact bunches also reduces airflow, and the consequent higher relative humidity may favour moulds (Sternad Lemut *et al.* 2015).

Bunch number was larger in the case of the more vigorous clone 297 and accounted for a significantly higher yield than clone R3. It is well-known among winegrowers that clone R3 has less bud fertility, but no scientific contributions report differences between 'Sauvignon Blanc' clones. Information regarding some clones is reported in the Italian "Registro Nazionale delle Varietà di Vite" (http://catalogoviti.politicheagricole.it/catalogo.php), but the clones compared herein are missing. However, the transition of the inter-row management from tillage to mowing allowed clone 297 to maintain a good yield level (7.5 $t \cdot ha^{-1}$ instead of 9.0 $t \cdot ha^{-1}$). Interestingly, the higher yield per plant of clone 297 compared to clone R3 was not associated with a reduction of TSS, whereas higher TA and a lower pH were observed compared to the clone R3. This delayed maturation for clone 297, masked by a similar accumulation of TSS but confirmed by the higher value of the hue of berry skin. Thus, the grapes of clone 297 could have the potential to be harvested later if weather conditions are unfavourable to the development of bunch rots. Therefore, the transition from tillage to mowing as an alternative inter-row management strategy could be advantageous for the more vigorous clone 297, as the yield reduction is acceptable. Moreover, high-quality musts can be produced, postponing harvest until the optimal ripeness, as the risk of bunch rots is reduced. On the contrary, the less productive clone R3 could not be favoured by tillage, as increased vigour could further increase the competition between vegetative and reproductive development. Thus, bud fertility and grape yield may be reduced without positive effects on TA or aromatic profile.

Conclusions

Replacing vineyard inter-row tillage with permanent cover crops reduced the vegetative growth and grapevine yield and improved the health status of the bunches. The differences observed were conditioned by both the meteorological conditions of the two investigated seasons and the peculiar characteristics of the vineyard site. The scarce water in 2013, combined with the high percentage of coarse and loam texture of the soil, emphasised the effects of inter-row management in that year. Also, berry qualitative parameters were affected by cover-cropped inter-rows that reduced titratable acidity and the hue of berry skin, with a more yellowish colour of the berry skins and more advanced maturation.

As regards the 'Sauvignon Blanc' clones, a higher yield and higher sensitivity to bunch rots were shown for clone 297, characterised by more compacted bunches, which also reported a significantly higher titratable acidity at harvest. The effects of the inter-row management were similar for both the clones, but the more productive clone 297, exhibited more severe yield reduction and promoted improved grape quality, mainly in the hue of berry skin.

The adoption of permanent green cover or soil tillage in vineyards should be decided according to the environmental conditions, the clonal characteristics and the oenological purposes. Lastly, in the pedo-climatic conditions of Friuli Venezia Giulia (north-eastern Italy), managing the vineyard inter-row with permanent green cover proved to be a powerful tool to control the vigour, reduce grape yield and improve the quality of the grapes at maturation.

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References

Abad, J.; de Mendoza, I. H.; Marín, D.; Orcaray, L.; Santesteban, L. G.; 2021: Cover crops in viticulture. A systematic review (2): Implications on vineyard agronomic performance. Oeno One **55**, 1-27. DOI: https://doi.org/10.20870/oeno-one.2021.55.2.4481

Alleweldt, G.; Ilter, E.; 1969: Untersuchungen über die Beziehungen zwischen Blütenbildung und Triebwachstum bei Reben. Vitis **8**, 286-313. DOI: https://doi.org/10.5073/vitis.1969.8.286-313

Begum, M.; Gurr, G. M.; Wratten, S. D.; Hedberg, P. R.; Nicol, H. I.; 2006: Using selective food plants to maximize biological control of vineyard pests. J. Appl. Ecol. **43**, 547-554. DOI: https://doi.org/https://doi.org/10.1111/j.1365-2664.2006.01168.x

Berndt, L. A.; Wratten, S. D.; Scarratt, S. L.; 2006: The influence of floral resource subsidies on parasitism rates of leafrollers (Lepidoptera: Tortricidae) in New Zealand vineyards. Biol. Control **37**, 50-55. DOI: https://doi.org/10.1016/j.biocontrol.2005.12.005

Beslic, Z.; Pantelic, M.; Dabic, D.; Todic, S.; Natic, M.; Tesic, Z.; 2015: Effect of vineyard floor management on water regime, growth response, yield and fruit quality in Cabernet Sauvignon. Sci. Hortic. (Amsterdam). **197**, 650-656. DOI: https://doi.org/https://doi.org/10.1016/j.scienta.2015.10.029

Bigot, L.; Bigot, G.; Bragato, G.; Mosetti, D.; Sivilotti, P.; 2013: "La Viarte" project: The knowledge of whole surface variability within a precision viticulture approach. In: S. Poni (Ed.): Proc. 1st Workshop on Vineyard Mechanization and Grape and Wine Quality, 55-62. Piacenza, Italy. (ISHS: Leuven, Belgium). DOI: https://doi.org/10.17660/ActaHortic.2013.978.4

Buttrose, M. S.; 1969: Fruitfulness in grapevines: effects of light intensity and temperature. Bot. Gaz. **130**, 166-173.

Carsoulle, J.; 1995: L'enherbement permanent du vignoble. Influence sur la production viticole et son environment. Phytoma **478**, 38-41.

Caspari, H. W.; Neal, S.; Naylor, A.; 1997: Cover crop management in vineyards to enhance deficit irrigation in a humid climate. Acta Hortic. **449**, 313-320. DOI: https://doi.org/10.17660/ActaHortic.1997.449.44

Celette, F.; Findeling, A.; Gary, C.; 2009: Competition for nitrogen in an unfertilized intercropping system: The case of an association of grapevine and grass cover in a Mediterranean climate. Eur. J. Agron. **30**, 41-51. DOI: https://doi.org/https://doi.org/10.1016/j.eja.2008.07.003

Coniberti, A.; Ferrari, V.; Disegna, E.; Lakso, A. N.; García Petillo, M.; 2017: Interactions of under-trellis cover crops and planting density to achieve vine balance in a temperate humid climate. In: T. Robinson (Ed.): Proc. International Symposium on Physiological Principles and Their Application to Fruit Production, 339-348. Geneva, USA (ISHS: Leuven, Belgium). DOI: https://doi.org/10.17660/ActaHortic.2017.1177.49

Costello, M. J.; Daane, K. M.; 2003: Spider and leafhopper (*Erythroneura* spp.) response to vineyard ground cover. Environ. Entomol. **32**, 1085-1098. DOI: https://doi.org/10.1603/0046-225X-32.5.1085

Costello, M. J.; Daane, K. M.; 1998: Influence of ground cover on spider populations in a table grape vineyard. Ecol. Entomol. **12**, 33-40. DOI: https://doi.org/10.1046/j.1365-2311.1998.00108.x

Daane, K. M.; Hogg, B. N.; Wilson, H.; Yokota, G. Y.; 2018: Native grass ground covers provide multiple ecosystem services in Californian vineyards. J. Appl. Ecol. **55**, 2473-2483. DOI: https://doi.org/https://doi.org/10.1111/1365-2664.13145

Danne, A.; Thomson, L. J.; Sharley, D. J.; Penfold, C. M.; Hoffmann, A. A.; 2010: Effects of native grass cover crops on beneficial and pest invertebrates in Australian vineyards. Environ. Entomol. **39**, 970-978. DOI: https://doi.org/10.1603/EN09144

David, N. E.; Serrano, E.; Renard, R.; 2001: Vigne et qualité de vendage: effect de l'enherbeement semé. Synthèse de sept année d'essais sur cèpage Colombard. Phytoma **544**, 46-47.

Deloire, A.; 2013: A new method to determine optimal ripeness for different white wine styles. PW J. **201**, 75-79.

Fourie, J. C.; Louw, P. J. E.; Agenbag, G. A.; 2007: Cover crop management in a Sauvignon blanc/Ramsey vineyard in the semi-arid Olifants River Valley, South Africa. 2. Effect of different cover crops and cover crop management practices on grapevine performance. South Afr. J. Enol. Vitic. **28**, 81-91. DOI: https://doi.org/10.21548/28-2-1463

Guerra, B.; Steenwerth, K.; 2012: Influence of floor management technique on grapevine growth, disease pressure, and juice and wine composition: a review. Am. J. Enol. Vitic. **63**, 149-164. DOI: https://doi.org/10.5344/ajev.2011.10001

Hall, A.; Lamb, D. W.; Holzapfel, B.; Louis, J.; 2002: Optical remote sensing applications in viticulture - a review. Aust. J. Grape Wine Res. **8**, 36-47. DOI: https://doi.org/10.1111/j.1755-0238.2002.tb00209.x

Hanna, R.; Zalom, F. G.; Roltsch, W. J.; 2003: Relative impact of spider predation and cover crop on population dynamics of *Erythroneura variabilis* in a raisin grape vineyard. Entomol. Exp. Appl. **107**, 177-191. DOI: https://doi.org/10.1046/j.1570-7458.2003.00051.x

Haselgrove, L.; Botting, D.; van Heeswijck, R.; Hoj, P. B.; Dry, P. R.; Ford, C.; Land, P. G. I.; 2000: Canopy microclimate and berry composition: The effect of bunch exposure on the phenolic composition of *Vitis vinifera* L. cv. Shiraz grape berries. Aust. J. Grape Wine Res. **6**, 141-149. DOI: https://doi.org/10.1111/j.1755-0238.2000.tb00173.x

Hed, B.; Ngugi, H. K.; Travis, J. W.; 2009: Relationship between cluster compactness and Bunch rot in vignoles grapes. Plant Dis. **93**, 1195-1201. DOI: https://doi.org/10.1094/PDIS-93-11-1195

Hoffmann, C.; Köckerling, J.; Biancu, S.; Gramm, T.; Michl, G.; Entling, M. H.; 2017: Can flowering greencover crops promote biological control in German vineyards? Insects **8**, 121. DOI: https://doi.org/10.3390/insects8040121

Ingels, C. A.; Scow, K. M.; Whisson, D. A.; Drenovsky, R. E.; 2005: Effects of cover crops on grapevines, yield, juice composition, soil microbial ecology, and gopher activity. Am. J. Enol. Vitic. **56**, 19-29.

Judt, C.; Guzmán, G.; Gómez, J. A.; Cabezas, J. M.; Entrenas, J. A.; Winter, S.; Zaller, J. G.; Paredes, D.; 2019: Diverging effects of landscape factors and inter-row management on the abundance of beneficial and herbivorous arthropods in Andalusian vineyards (Spain). Insects **10**, 320. DOI: https://doi.org/10.3390/insects10100320

Kiaeian Moosavi, F.; Cargnus, E.; Pavan, F.; Zandigiacomo, P.; 2018: Effects of grapevine bunch exposure to sunlight on berry surface temperature and *Lobesia botrana* (Lepidoptera: Tortricidae) egg laying, hatching and larval settlement. Agric. For. Entomol. **20**, 420-432. DOI: https://doi.org/10.1111/afe.12274

Landis, D. A.; Wratten, S. D.; Gurr, G. M.; 2000: Habitat management to conserve natural enemies of arthropod pests in agriculture. Annu. Rev. Entomol. **45**, 175-201. DOI: https://doi.org/10.1146/annurev.ento.45.1.175

Marois, J. J.; Nelson, J. K.; Morrison, J. C.; Lile, L. S.; Bledsoe, A. M.; 1986: The influence of berry contact within grape clusters on the development of *Botrytis cinerea* and epicuticular wax. Am. J. Enol. Vitic. **37**, 293-296.

Marques, M. J.; García-Muñoz, S.; Muñoz-Organero, G.; Bienes, R.; 2010: Soil conservation beneath grass cover in hillside vineyards under Mediterranean Climatic conditions (Madrid, Spain). L. Degrad. Dev. **21**, 122-131. DOI: https://doi.org/https://doi.org/10.1002/ldr.915

Morlat, R.; Geoffrion, R.; 2000: L'enherbement permanent contrôlé des sols viticoles. Vingt ans de recherches sur le terrain en Anjou. Phytoma **530**, 28-31.

Morlat, R.; Jacquet, A.; 2003: Grapevine root system and soil characteristics in a vineyard maintained long-term with or without interrow sward. Am. J. Enol. Vitic. **54**, 1-17.

Mosetti, D.; Herrera, J.C.; Sabbatini, P.; Green, A.; Alberti, G.; Peterlunger, E.; Lisjak, K.; Castellarin, S. D.; 2016: Impact of leaf removal after berry set on fruit composition and bunch rot in "Sauvignon blanc". Vitis **55**, 57-64. DOI: https://doi.org/10.5073/vitis.2016.55.57-64

Muckensturm, N.; Decoin, M.; 2000: La pourriture grise de la vigne. Pourquoi la lutte échoue parfois, et comment la faire réussir. Phytoma **525**, 50-52.

Nboyine, J. A.; Boyer, S.; Saville, D. J.; Wratten, S. D.; 2018: Agroecological management of a soil-dwelling orthopteran pest in vineyards. Insect Sci. **25**, 475-486. DOI: https://doi.org/10.1111/1744-7917.12425

Nicholls, C. I.; Parrella, M. P.; Altieri, M. A.; 2000: Reducing the abundance of leafhoppers and thrips in a northern California organic vineyard through maintenance of full season floral diversity with summer cover crops. Agric. For. Entomol. **2**, 107-113. DOI: https://doi.org/10.1046/j.1461-9563.2000.00054.x

Palliotti, A.; Cartechini, A.; Petoumenou, D.; Silvestroni, O.; Mattioli, S.; Berrios, J. G.; 2007: Long-term effects of seeded cover-crop on vegetative characteristics, yield and grape and wine composition of "Grechetto" grapevines in Central Italy. In: V. Nuzzo, P. Giorio, C. Giulivo (Eds): Proc. Int. Workshop on Advances in Grapevine and Wine Research, 515-521. Venosa, Italy (ISHS: Leuven, Belgium). DOI: https://doi.org/10.17660/ActaHortic.2007.754.69

Pardini, A.; Faiello, C.; Longhi, F.; Mancuso, S.; Snowball, R.; 2002: Cover crop species and their management in vineyards and olive groves. Adv. Hortic. Sci. **16**, 225-234.

Pavan, F.; Bigot, G.; Cargnus, E.; Zandigiacomo, P.; 2014: Influence of the carpophagous generations of the European grapevine moth *Lobesia botrana* on grape bunch rots. Phytoparasitica **42**, 61-69. DOI: https://doi.org/10.1007/s12600-013-0338-5

Pavan, F.; Girolami, V.; Sacilotto, G.; 1998: Second generation of grape berry moths, *Lobesia botrana* (Den. & Schiff.) (Lep.; Tortricidae) and *Eupoecilia ambiguella* (Hb.) (Lep.; Cochylidae): spatial and frequency distributions of larvae, weight loss and economic injury level. J. Appl. Entomol. **122**, 361-368. DOI: https://doi.org/10.1111/j.1439-0418.1998.tb01513.x

R'Houma, A.; Chérif, M.; Boubaker, A.; 1998: Effect of nitrogen fertilization, green pruning and fungicide treatments on Botrytis bunch rot of grapes. J. Plant Pathol. **80**, 115-124.

Ripoche, A.; Rellier, J. P.; Martin-Clouaire, R.; Paré, N.; Biarnès, A.; Gary, C.; 2011: Modelling adaptive management of intercropping in vineyards to satisfy agronomic and environmental performances under Mediterranean climate. Environ. Model. Softw. **26**, 1467-1480. DOI: https://doi.org/10.1016/j.envsoft.2011.08.003

Rodriguez-Lovelle, B.; Soyer, J.; Molot, C.; 2000: Nitrogen availability in vineyard soils according to sil management practices. Effects on vine. In: B. A. Bravdo (Ed.): Proc. V Int. Symposium on Grapevine Physiology, 277-286. Jerusalem, Israel (ISHS: Leuven, Belgium). DOI: https://doi.org/10.17660/ActaHortic.2000.526.29

Rouse, J. W.; Haas, R. H.; Schell, J. A.; Deering, D. W.; 1974: Monitoring vegetation systems in the Great Plains with ERTS. In: C. Fraden, E. P. Marcanti, M. A. Becker (Eds): Proc. Third ERTS-1 Symposium, 309-317. Washington D. C., USA.

Ruiz-Colmenero, M.; Bienes, R.; Marques, M. J.; 2011: Soil and water conservation dilemmas associated with the use of green cover in steep vineyards. Soil Tillage Res. **117**, 211-223. DOI: https://doi.org/https://doi.org/10.1016/j.still.2011.10.004

Ryona, I.; Pan, B. S.; Intrigliolo, D. S.; Lakso, A. N.; Sacks, G. L.; 2008: Effects of cluster light exposure on 3-Isobutyl-2-methoxypyrazine accumulation and degradation patterns in red wine grapes (*Vitis vinifera* L. cv. Cabernet Franc). J. Agric. Food Chem. **56**, 10838-10846. DOI: https://doi.org/10.1021/jf801877y

Sanguankeo, P. P.; Leòn, R. G.; 2011: Weed management practices determine plant and arthropod diversity and seed predation in vineyards. Weed Res. **51**, 404-412. DOI: https://doi.org/https://doi.org/10.1111/j.1365-3180.2011.00853.x

Serra, G.; Lentini, A.; Verdinelli, M.; Delrio, G.; 2006: Effects of cover crop management on grape pests in a Mediterranean environment. IOBC/wprs Bull. **29**, 209-214.

Steenwerth, K. L.; Mcelrone, A. J.; Calderón-orellana, A.; Hanifin, R.C.; Storm, C.; Collatz, W.; Manuck, C.; 2013: Cover crops and tillage in a mature Merlot vineyard show few effects on grapevines. Am. J. Enol. Vitic. 64, 515-521. DOI: https://doi.org/10.5344/ajev.2013.12119

Sternad Lemut, M.; Sivilotti, P.; Butinar, L.; Laganis, J.; Vrhovsek, U.; 2015: Pre-flowering leaf removal alters grape microbial population and offers good potential for a more sustainable and cost-effective management of a Pinot Noir vineyard. Aust. J. Grape Wine Res. **21**, 439-450. DOI: https://doi.org/10.1111/ajgw.12148

Tan, S.; Crabtree, G. D.; 1990: Competition between perennial ryegrass sod and 'Chardonnay' wine grapes for mineral nutrients. HortScience **25**, 533-535.

Tesic, D.; Keller, M.; Hutton, R. J.; 2007: Influence of vineyard floor management practices on grapevine vegetative growth, yield, and fruit composition. Am. J. Enol. Vitic. **58**, 1-11.

Valdés-Gómez, H.; Fermaud, M.; Roudet, J.; Calonnec, A.; Gary, C.; 2008: Grey mould incidence is reduced on grapevines with lower vegetative and reproductive growth. Crop Prot. **27**, 1174-1186. DOI: https://doi.org/10.1016/j.cropro.2008.02.003

Valdés-Gómez, H.; Gary, C.; Cartolaro, P.; Lolas-Caneo, M.; Calonnec, A.; 2011: Powdery mildew development is positively influenced by grapevine vegetative growth induced by different soil management strategies. Crop Prot. **30**, 1168-1177. DOI: https://doi.org/10.1016/j.cropro.2011.05.014

Valdés, H.; Celette, F.; Fermaud, M.; Cartolaro, P.; Clerjeau, M.; Gary, C.; 2005: How to evaluate the influence of vegetative vigour in vine sensitivity to cryptogamic diseases?. In: Proc. XIV International GESCO Viticulture Congress, 832-838. Geisenheim, Germany.

Varga, P.; Májer, J.; Győrffyné Jahnke, G.; Németh, C.; Szőke, B.; Sárdi, K.; Varga, Z.; Kocsis, L.; Salamon, B.; 2012: Adaptive nutrient supply and soil cultivation methods in the upper zone of hillside vineyards. Commun. Soil Sci. Plant Anal. **13**, 334-340. DOI: https://doi.org/10.1080/00103624.2012.641463

Viers, J. H.; Williams, J. N.; Nicholas, K. A.; Barbosa, O.; Kotzé, I.; Spence, L.; Webb, L. B.; Merenlender, A.; Reynolds, M.; 2013: Vinecology: pairing wine with nature. Conserv. Lett. **6**, 287-299. DOI: https://doi.org/https://doi.org/10.1111/conl.12011

Wheeler, S. J.; Black, A. S.; Pickering, G. J.; 2005: Vineyard floor management improves wine quality in highly vigorous *Vitis vinifera* 'Cabernet Sauvignon' in New Zealand. New Zeal. J. Crop Hortic. Sci. **33**, 317-328. DOI: https://doi.org/10.1080/01140671.2005.9514365

Winter, S.; Bauer, T.; Strauss, P.; Kratschmer, S.; Paredes, D.; Popescu, D.; Landa, B.; Guzmán, G.; Gómez, J. A.; Guernion, M.; Zaller, J. G.; Batáry, P.; 2018: Effects of vegetation management intensity on biodiversity and ecosystem services in vineyards: A meta-analysis. J. Appl. Ecol. **55**, 2484-2495. DOI: https://doi.org/10.1111/1365-2664.13124

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