

Effects of vineyard floor cover crops on grapevine vigor, yield, and fruit quality, and the development of the vine mealybug under a Mediterranean climate

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1 **Effects of vineyard floor cover crops on grapevine vigor, yield, and fruit quality, and the**  
2 **development of the vine mealybug under a Mediterranean climate**

3

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13

14

15 **ABSTRACT**

16

17 The influence of complete cover cropping (inter- and intra-row) on grapevine growth, yield  
18 and must quality was evaluated in a three-year field trial in a commercial vineyard in  
19 northwestern Sardinia (Italy). Effects on developmental and reproductive parameters of the  
20 vine mealybug, *Planococcus ficus* (Signoret) (Hemiptera: Pseudococcidae), were also  
21 investigated. The cover crop treatments were: natural covering, legume mixture, grass  
22 mixture, and conventional soil tillage, which was included as the reference treatment. Relative  
23 to soil tillage, cover crops reduced grape production by modifying yield components in  
24 different ways: legume mixture reduced the cluster weight, whereas grass mixture led to a  
25 lower number of clusters per vine coupled with a lower cluster weight. Cover crops also  
26 altered the must qualities relative to soil tillage. Grass mixture increased the content of sugar,  
27 anthocyanins and polyphenols, whereas legume mixture and natural covering reduced total  
28 polyphenols and anthocyanin content, respectively. All the *P. ficus* biological parameters  
29 examined were affected by the floor management practices. Mealybugs reared on grapevines  
30 subjected to soil tillage and legume covering showed a faster development time and higher  
31 survival, fecundity and fertility than those developed on natural covering and grass plots. The  
32 vine mealybug showed a higher performance on grapevines with a higher nitrogen content  
33 and vigor. Effects of cover crop treatments appear to be mediated through nutrient availability  
34 and content in grape plants. Consequently, utilizing competitive cover crops, while reducing  
35 yields, would improve must quality and reduce pest development.

36

37 **Keywords:** *Vitis vinifera*; Cover crops; Grape quality; *Planococcus ficus*; Mealybug  
38 development; Mealybug fecundity.

39

## 40 **1. Introduction**

41

42 Cover crops are important ecological vineyard management tools, which improve the soil  
43 structure and soil erosion control, enrich nitrogen and organic matter content, and regulate  
44 excessive grapevine vigor (Pardini et al., 2002). Many experiments have been carried out to  
45 better identify the influence of different floor covers in grapevine vegetative growth, yield,  
46 berry and wine quality (Monteiro and Lopes, 2007; Guerra and Steenwerth, 2012; Mercenaro  
47 et al., 2014). Today, cover crops are widely used in vineyard inter-rows combined with  
48 herbicide strips under the vines.

49 Cover cropping the entire vineyard floor (intra and inter-row) may increase the control of  
50 excessive vine vigor, with consequent changes in grape quality, and reduce the herbicide use  
51 and associated risks, such as plant injury by spray drift, evolution of weed resistance (Powles  
52 et al., 1997), contamination of groundwater (Thurman et al., 1996), and reduction in agro-  
53 ecosystem biodiversity (Danne et al., 2010; Sanguaneko and León, 2011). The reduction in  
54 herbicide use would also facilitate compliance with EU directives and regulations that restrict  
55 or ban the use of several pesticides and promote the development of integrated control  
56 techniques and the use of environmentally friendly tools (European Union, 2009a, 2009b).

57 Few studies have investigated the influence of complete floor cover crops (inter- and intra-  
58 row) on grapevine, especially when cultivated in semi-arid conditions. In a Chenin blanc  
59 vineyard under dryland conditions in South Africa, weeds and cover crops competed with  
60 grapevines during the growing season, thus decreasing vegetative growth and yield (Van  
61 Huyssteen and Weber, 1980). Other studies found similar effects, but alterations in the canopy  
62 architecture and reductions in grapevine vigor and crop yield were only observed after several  
63 years (Testic et al., 2007; Gontier et al., 2011).

64 In order to reduce the excessive grape vigor and crop yield and thus improve the grape  
65 quality, several crop regulation techniques, such as shoot and cluster thinning (Naor et al.,  
66 2002; Calderon-Orellana et al., 2014; Gamero et al., 2014) and early defoliation (Poni et al.,  
67 2006; Silvestroni et al., 2016) have been evaluated. Inter-row cover crops have also been  
68 tested in multi-year experiments for regulating grape production. The overall results showed  
69 no influence on crop yield, while changes in the must composition were observed after 2-3  
70 years (Lopes et al., 2008; Mercenaro et al., 2014). One of the aims of the present work was to  
71 study various complete floor cover crops as a cultural practice to reduce excessive grape vigor  
72 and productivity by evaluating grapevine growth, yield and fruit composition parameters.

73 Cover crops can also alter vineyard insect pest dynamics and may play a role in integrated  
74 pest management programs. Cover crops can affect pest dynamics through altering plant and  
75 natural enemy diversity (top-down effects) as well as modifying nutrient status and vigor of  
76 vines (bottom-up effects) (Landis et al., 2000; Thomson and Hoffmann, 2013; Veres et al.,  
77 2013). However, increasing plant diversity does not always increase pest control (Bone et al.,  
78 2009; D'Alberto et al., 2012). Evidence suggests that when cover crops reduce the nitrogen  
79 content in crops, the growth and development of plant-feeding insects are reduced as  
80 individual and population growth of these insects is typically N-limited (Wilson et al., 1988;  
81 Hunt et al., 1992; Cocco et al., 2015).

82 In vineyards, cover crops have had variable effects on pest densities. For example,  
83 competition for water and nutrients caused lower plant vigor and reduced leafhopper density  
84 due to a poorer host quality (Costello and Daane, 2003). On the other hand, a higher  
85 abundance of the vine mealybug, *Planococcus ficus* Signoret (Hemiptera: Pseudococcidae),  
86 was observed as a consequence of the suppression of tillage which promoted the development  
87 of ant populations and, therefore, the disruption of its natural enemies (Serra et al., 2006;  
88 Mgocheki and Addison, 2010; Mansour et al., 2012). *P. ficus* is a key widespread pest in the

89 main grape growing areas which severely reduces the economic yield of table grape and the  
90 quality of wine grape, in addition to being a vector of several viruses and diseases (Daane et  
91 al., 2012).

92 From the perspective of a more sustainable viticulture oriented towards high-quality  
93 production with a reduced use of insecticides and herbicides, we investigated the influence of  
94 different complete floor covers on the grapevine yield and must quality, and the bottom-up  
95 effects of cover crops on development and reproduction of the vine mealybug in a three-year  
96 survey conducted in a commercial vineyard under Mediterranean climatic conditions.

97

## 98 **2. Materials and methods**

99

### 100 *2.1 Study site and experimental design*

101

102 The experiment was carried out between 2013 and 2015, in a 17-year-old vineyard, cv.  
103 Carignano, located at 40 m a.s.l. in northwestern Sardinia (Italy, 40°33'28"44 N;  
104 08°19'19"56 E). Prior to this study, the site was used for a separate cover crop trial  
105 (Mercenaro et al., 2014). The cultivar Carignano is widely cultivated in Sardinia, Spain  
106 (known as Cariñena and Mazuela) and southern France (Carignan noir), and it is a highly  
107 productive and vigorous cultivar when cultivated in fertile soils (Christensen et al., 2003).  
108 Vines were grafted onto 779 P rootstock, trained by a spur-pruned cordon (commonly with  
109 five spurs with two buds each) and spaced 2.7 m between rows and 1.0 m within rows. The  
110 site has a relatively uniform calcareous alluvial soil, with an average depth of 60-70 cm, and  
111 the following physico-chemical characteristics: sand 51.0%, clay 24.9%, silt 24.1%; pH =  
112 7.44; organic matter content = 16 g kg<sup>-1</sup>. Vines were drip-irrigated three times per year from  
113 late June to mid August (corresponding to about 700 m<sup>3</sup> ha<sup>-1</sup> year<sup>-1</sup>). The experimental

114 vineyard is characterized by a typical central Mediterranean climate, with mild winters and  
115 hot dry summers, and precipitations concentrated between October and May (560 mm average  
116 total annual rainfall). Daily temperature, relative humidity and rainfall during the survey were  
117 recorded by a weather station positioned in the vineyard. In 2013, annual and spring rainfall  
118 were higher compared with 2014 and 2015, while summer precipitations were generally  
119 scarce, especially in 2014 when the dry season lasted from June to October. Temperatures  
120 varied among years. 2015 had a relatively colder winter and hotter summer, resulting in  
121 increased abiotic stress for plant growth.

122 The present study was conducted in a randomized complete block design with four  
123 replications. Each plot was 32 m long and 5.4 m wide (width of two inter-rows) and consisted  
124 of a central experimental row of 32 grapevines and two adjacent inter-rows on either side of  
125 the study row. Plots were separated by a single border row. The following floor management  
126 systems were compared: natural covering (NC) with a dominance of annual grasses (*Bromus*  
127 *hordeaceus* L., *Avena sterilis* L. and *Vulpia myuros* L.); cover crop of an annual self-  
128 reseeded legume mixture (LM): *Medicago polymorpha* L. cv Anglona (50%) and *Trifolium*  
129 *yanninicum* Katzn. and Morley cv Gosse (50%); grass mixture (GM) cover consisting of a  
130 summer semi-dormant perennial grass, *Dactylis glomerata* L. cv Currie (80%) and an annual  
131 self-reseeded grass, *Lolium rigidum* Gaud. cv Nurra (20%); soil tillage (ST) as the reference  
132 treatment. Grass and legume mixtures are expressed by the percentage of viable seed number  
133 m<sup>-2</sup>. LM was over-seeded by hand in the inter-rows, whereas a full covering of *D. glomerata*  
134 was present in the GM inter-rows from the previous trial.

135 Cover crops were seeded along LM and GM rows in mid November 2012 at a rate of 30 kg  
136 ha<sup>-1</sup>, and plots were rolled immediately afterwards. Since the re-establishment of LM in  
137 autumn 2013 was unsatisfactory due to adverse weather conditions, an over-sowing was  
138 performed in mid February 2014 at the rate of 20 kg ha<sup>-1</sup>. No herbicides or fertilizers were

139 used on cover crop plots during the trial. The only exception was on LM plots where the non-  
140 residual herbicide glyphosate (Roundup Power 2.0, Monsanto, Milano, Italy) was sprayed  
141 once in late October 2012 at the rate of 2.5 L ha<sup>-1</sup> before LM sowing in order to remove a  
142 severe infestation of annual and perennial grasses. Glyphosate is most effective against  
143 perennial weeds and less costly than pre-emergence herbicides or soil tillage (Monteiro and  
144 Moreira, 2004; Tourte et al., 2008).

145

## 146 *2.2 Cover crop assessment*

147

148 In each cover crop plot, the following parameters were observed:

- 149 - establishment and re-establishment of autumn swards by counting in each plot the number of  
150 seedlings (annuals) or plants (*D. glomerata*) in four sampling areas (25 × 50 cm) when  
151 legumes reached the third trifoliate leaf stage;
- 152 - seasonal sward covering rate (%) and presence of unsown species by monthly visual  
153 estimation of the whole plots;
- 154 - dry matter yield (DMY) and its botanical composition in four sampling areas of 100 × 50 cm  
155 in each plot. Swards were mowed when their height reached 10-15 cm in order to control the  
156 cover crop vegetative growth and ensure a proper establishment and self-reseeding of annuals.  
157 Plant samples were oven-dried at 60 °C to constant weight and then weighed to determine the  
158 above-ground dry matter yield.

159

## 160 *2.3 Grapevine leaf nitrogen content, vegetative growth and crop yield*

161

162 The content of nitrogen on leaves was estimated with the SPAD 502 Chlorophyll Meter  
163 (Minolta, Osaka, Japan), which is a non-destructive portable tool to measure the chlorophyll

164 concentration in leaves (Shaahan et al., 1999; Porro et al., 2001). The nitrogen content in  
165 grapevine leaves is closely related with SPAD readings ( $r^2 = 0.989$ ) (Cocco et al., 2015). The  
166 leaf nitrogen content was estimated on six dates in spring-summer 2013 and 2014 and eight  
167 times in 2015 by measuring the SPAD values in five leaves opposite to basal clusters on each  
168 plant artificially-infested with *P. ficus* mealybugs.

169 The grapevine growth and productivity was evaluated in the central 20 vines of each  
170 experimental row. The supernumerary shoots were thinned after bud break, and the number of  
171 shoots per vine was then determined. Each year, the evolution of fruit composition was  
172 assessed from veraison to harvest in 600 berries per plot randomly collected approximately  
173 every two weeks starting from the stage of ‘50% veraison’, corresponding to 60, 72 and 74  
174 days after anthesis (DAA) in 2013, 2014 and 2015, respectively. Berries were weighed and  
175 crushed, and total soluble solids (°Brix), pH and titratable acidity of juice were determined in  
176 accordance with the procedures of the Organisation Internationale de la Vigne et du Vin  
177 (O.I.V., 2006). Total anthocyanins and polyphenols were evaluated by spectrophotometry,  
178 measuring ultraviolet absorption at 520 nm and 700 nm, respectively (Di Stefano and  
179 Cravero, 1991). All the grapevines investigated were harvested on the same dates: 3 October  
180 2013 (130 DAA), 7 October 2014 (127 DAA) and 12 October 2015 (137 DAA). Vine yield  
181 and yield composition (cluster and berry weights, and number of clusters per vine) were  
182 determined by weighing ten clusters randomly chosen for each replicate and ten berries  
183 randomly picked from each cluster. The weight of the dry pruning wood was recorded during  
184 the dormant season in order to estimate the vegetative growth and calculate the Ravaz index  
185 (determined as the ratio between crop yield and pruning wood).

186

#### 187 *2.4 Vine mealybug biological parameters*

188

189 The response of *P. ficus* to different floor management systems was investigated in artificial  
190 cohorts established on grapevines. Mealybugs were obtained from a mass-rearing colony  
191 maintained on sprouted potato placed inside Plexiglas cages (30 × 30 × 30 cm) with two sides  
192 covered with mesh for ventilation. The culture was maintained at 26 ± 1 °C, 60-70% RH, in  
193 constant darkness. In order to obtain eggs of the same age, a number of ovipositing females  
194 were placed with a sable-hair brush (gauge 000) in 2 × 2 cm strips of cardboard and allowed  
195 to oviposit for 24 hours, after which females were removed. Eggs were counted under a  
196 dissecting microscope and held in a growth chamber at 25 °C for seven days. Batches of 500  
197 hatching eggs were used to infest one shoot from each of three separate plants per plot by  
198 securing the cardboard strips to the abaxial surface of a median leaf in order to minimize *P.*  
199 *ficus* handling.

200 Experimental plants were inspected before the study to ensure the absence of wild populations  
201 of mealybugs in the canopy and under the bark. Trials started on 14 June 2013, 30 May 2014  
202 and 3 June 2015 (egg release) and ended on 5 August 2013, 16 July 2014 and 20 July 2015  
203 (count of remaining females). During their development, mealybugs were confined by  
204 covering 3-4 leaves of the artificially-infested shoot with a cage of spun-bonded  
205 polypropylene fabric (Agribon AG-15, 18.65 g m<sup>-2</sup>, 90% light transmission) secured at both  
206 ends with elastic bands. Cages protected mealybugs from natural enemies and prevented the  
207 spread of *P. ficus* immatures within the canopy, which would have dramatically increased the  
208 time and effort required for a daily check of the experimental plants.

209 Starting three weeks after egg release, all leaves, petioles and stems inside the cages were  
210 inspected daily, and the first 20 females at the onset of oviposition were collected with a  
211 sable-hair brush (gauge 00) and placed inside plastic containers. Ovipositing females were  
212 stored in a cooler at ~10 °C during the transport back to the laboratory. The dates of collection  
213 were recorded in order to determine the development time from egg eclosion to ovipositing

214 female. All the mealybugs from the different treatments were stored under the same  
215 laboratory conditions and allowed to complete oviposition inside the containers, upon which  
216 the fecundity was determined under a dissecting microscope by counting the number of first  
217 instar nymphs and unhatched eggs. In 2014 and 2015, the fertility was also calculated as the  
218 percentage of hatched first-instar nymphs. The survival to adulthood was estimated in each  
219 plant by counting adult females since males could not be counted due to their small size and  
220 short lifespan. The mealybug survival was estimated as follows: [adult females/(released eggs  
221  $\times$  percentage of female eggs released)]  $\times$  100, assuming a percentage of female eggs of 60.3%  
222 (Cocco et al., 2015).

223

## 224 *2.5 Data analysis*

225

226 The cover crop dry matter yield, the grapevine growth and yield variables, and the mealybug  
227 development and reproductive parameters were compared using a generalized linear mixed  
228 model (PROC GLIMMIX, SAS Institute 2008) with cover crops as fixed and blocks as  
229 random effects. In order to compare parameters among years, the treatment factor 'year' was  
230 included as a fixed effect (Giese et al., 2014). In the model, numerical and percentage data  
231 were assumed to follow normal and binomial distributions, respectively. The patterns of  
232 SPAD values and cover crop soil covering rates during the experiments were compared with  
233 the same treatment factors previously described (i.e. cover crops and year) and separated  
234 among treatments by analysis of variance with a repeated-measures design (PROC MIXED,  
235 SAS Institute 2008). Treatments and treatment interactions were compared by Tukey's post  
236 hoc test at the significance level of 0.05. When the interaction was significant, differences  
237 among cover crops were further investigated within each year. When needed, letter displays  
238 indicating significant treatment difference were generated with the %MULT macro within

239 PROC GLIMMIX (Piepho, 2012). Data from plants affected by esca disease were not  
240 included in the statistical analyses.

241

### 242 **3. Results**

243

#### 244 *3.1 Cover crop covering and composition*

245

246 Both NC and GM cover crops established quickly and provided consistent and similar cover  
247 through seasons and among years (>77%) (Fig. 1). On the other hand, LM failed to re-  
248 establish in the autumn of the first year, resulting in a significantly lower covering rate than  
249 NC and GM in 2013. After the over-sowing in February 2014, LM had similar covering rate  
250 to other treatments.

251 Growth of cover crops, and thus the mowing frequency, varied by year due to climate  
252 conditions. Plots were mowed once in 2013 and 2014 and three times in 2015 (Fig. 2). The  
253 production of dry matter differed significantly by mowing date and year, and main effect  
254 interactions were also significant. NC produced significantly less dry matter than LM in 2013  
255 and less than both LM and GM in 2014. In the last year of the study, LM and NC were in  
256 general more productive than GM. Seeded species dominated the stands of LM and GM with  
257 >61% and >85% of DMY, respectively. The most common weeds were: *Plantago lanceolata*  
258 L., *Conyza canadensis* (L.) Cronq., *Senecio vulgaris* L., *Avena sterilis* L., *Poa annua* L.,  
259 *Sonchus oleraceus* L.

260

#### 261 *3.2 Grapevine leaf nitrogen content, vegetative growth and crop yield*

262

263 The different floor management systems significantly affected the leaf nitrogen content of  
264 grapevines, assessed as SPAD values, in all three years of the survey (Table 1). In 2013 and  
265 2015, ST and LM treatments exhibited higher leaf nitrogen content (averaged across season)  
266 than GM and NC, while the nitrogen concentration in 2014 differed in all treatment groups  
267 (ST>LM>GM>NC,  $P < 0.05$ ).

268 The number of shoots per vine did not vary across treatments in any of the years (Table 2) as  
269 a consequence of the removal of supernumerary shoots. Relative to the grapevine vigor, the  
270 GM treatment in the first year showed statistically lower pruning weights than all the other  
271 treatments. In 2014 and 2015, ST grapevines produced significantly more pruning wood than  
272 other treatments, while GM vines exhibited the lowest values confirming the observation of  
273 the first year. The Ravaz index varied significantly by year but it was not affected by the  
274 different floor management systems (Table 2).

275 Grapevine yield differed significantly among treatments during the trial. Soil tillage promoted  
276 higher grape production than cover crops in all experimental years except in 2013 (Table 3).  
277 Focusing on the various floor covers, yield in GM was consistently lower than that in NC and  
278 LM plots in all three years of observations. Regardless of the treatment, the yield harvested in  
279 2013 was higher and almost twice that of the following year, while in 2015 the production  
280 was intermediate compared with 2013 and 2014 (Table 3).

281 In relation to yield components, the number of clusters per vine was lower in GM plots than  
282 in other treatments, with significant differences in 2014 and 2015, suggesting that the lower  
283 production depended on a lower number of clusters per vine (Table 3). Relative to ST, cover  
284 crop effects on cluster weight were not consistent among years (cover crop  $\times$  year interaction  
285  $P < 0.05$ ), but tended to reduce the weight of clusters. These effects were most consistent in  
286 GM plots. In 2013, cluster weight was similar in ST, NC and LM and greater than GM. ST  
287 produced heavier clusters than GM and LM in 2014 and than all other treatments in 2015.

288 Berry weight was not affected by either soil tillage or cover crops in 2013, while it tended to  
289 be lower in LM and higher in NC vines in the following years.

290 The floor management significantly influenced most of the fruit composition parameters at  
291 harvest (Figs. 3 and 4), except for total acidity and pH (data not shown). However, the must  
292 quality changed significantly from vintage to vintage. Overall, the 2013 vintage was  
293 characterized by grapes with lower soluble solids content and higher acidity than the other  
294 two vintages, while the highest sugar levels at harvest were achieved in 2014 regardless of  
295 soil management. Focusing on differences in the phenolic component among vintages, the  
296 total anthocyanins were the lowest in 2013 and highest in 2015. Conversely, the total  
297 polyphenols were less influenced by vintage, and were significantly lower than in previous  
298 years only in 2015.

299 Effects of cover crop treatments on the sugar content were not consistent among years (cover  
300 crop  $\times$  year interaction  $P < 0.05$ ). No effects were observed at harvest in the first year of the  
301 study but significant differences were found among treatments in the final two years. In 2014,  
302 the sugar level detected on GM vines (22.7 °Brix) was higher than on LM vines (20.7 °Brix),  
303 while soluble solids in 2015 were significantly higher on GM than on ST vines (20.8 and 18.9  
304 °Brix, respectively) (Fig. 3). The total acidity was influenced by treatments only in the first  
305 sampling dates of each season, while at harvest no differences among cover crops were  
306 recorded (Fig. 3).

307 The color intensity, measured as total anthocyanins, generally increased along with the  
308 ripening process in all treatments (Fig. 4). At harvest, the anthocyanin content of grapes in  
309 NC was consistently the lowest, while other treatments had similar concentrations to each  
310 other in the first two years. In 2015, anthocyanins in GM were higher than in LM and ST. The  
311 concentration of total polyphenols in NC, LM and GM plots increased in the first weeks of  
312 ripening and then declined slowly until harvest, except in 2013 on LM vines (Fig. 4).

313 Conversely, vines subjected to traditional soil tillage showed a steady increase in total  
314 polyphenols from veraison to harvest in 2013 and 2014. The statistical analysis indicates that  
315 at harvest 2013, the polyphenol content was higher in ST and LM grapes than GM, which in  
316 turn was higher than NC. In 2014, LM showed a lower concentration of polyphenols at  
317 harvest compared to the other treatments. In the last harvest, a higher accumulation of  
318 polyphenols was observed on GM and ST than NC berries, with LM grapes showing the  
319 lowest polyphenol content.

320

### 321 *3.3 Vine mealybug biological parameters*

322

323 All the vine mealybug biological parameters investigated were significantly affected by  
324 ground covers, especially in 2014 and 2015 (Table 4). In 2013, the development time from  
325 egg hatching to ovipositing female was shorter in mealybugs collected in ST and LM plots  
326 than in NC plots, while ST values in 2014 differed from all cover crop treatments. In 2015,  
327 mealybugs on ST and LM plants developed faster than those in NC and GM plots. The pest  
328 survival was highly variable in the first two years of the survey, when differences were not  
329 significant. Conversely, mealybug survival was higher in LM plots than in other treatments in  
330 2015. In 2013, the floor management systems did not affect the fecundity of *P. ficus* females,  
331 while the fecundity in 2014 was higher in mealybugs developed in ST and LM grapevines  
332 compared with those reared in NC. In 2015, the number of eggs oviposited by mealybugs in  
333 LM was higher than that observed in ST treatment, which in turn was higher than that  
334 recorded in NC and GM plots. The fertility was statistically higher in LM (2014 and 2015)  
335 and in ST plots (2015) compared to NC and GM.

336

## 337 **4. Discussion**

338

339 Control of fruit composition during ripening can be achieved through oenological and cultural  
340 practices. The increase of sugar content and color intensity is commonly obtained through  
341 cluster thinning, especially for ‘appellation of origin’ wines that require crop yield limits.  
342 Although undoubtedly effective, thinning is also time consuming and expensive (Berkey et  
343 al., 2011; Preszler et al., 2013). Other practices that increase nutritional and water  
344 competition, such as cover crops, are also effective in avoiding excessive crop yield and are  
345 more economically sustainable compared to cluster thinning. In addition, cover crops have a  
346 number of beneficial effects on the vineyard agro-ecosystem, including all-year-round  
347 accessibility for time-sensitive cultural practices (e.g. harvest, fungicide applications) (Pardini  
348 et al., 2002).

349 In our experiment, all the complete floor cover crops investigated promoted lower yields  
350 compared to conventional soil tillage from the second year of the study, most likely due to the  
351 competition for water and nutrients. However, not all cover crops competed in the same  
352 manner with vines, as only grass cover crop (GM) had a negative impact on the following  
353 year's grape production. Conversely, in our previous experiment carried out for five years in  
354 the same vineyard, inter-row GM did not affect grape yield and its components (Mercenaro et  
355 al., 2014). This was probably due to insufficient competition of grass in inter-rows since the  
356 soil areas of maximum root water and nutrient uptake are located near the vine trunk (Fuentes  
357 et al., 2008).

358 Few studies have been conducted to evaluate complete floor cover crops in vineyards. Our  
359 results confirm the findings of a four-year experiment carried out in France by Gontier et al.  
360 (2011), all of which observed a reduced crop yield and vigor and an increased sugar and  
361 polyphenolic content in grapevines subjected to complete grass cover cropping. In contrast,  
362 Giese et al. (2014a, 2014b) found no depressive effect on productivity caused by complete

363 floor covers in a Cabernet Sauvignon vineyard located in North Carolina. Giese et al. (2014a)  
364 also reported a significant effect of complete grass cover on reducing canopy density as well  
365 as pruning weight. The latter outcome is in accordance with our trial, in which a general  
366 reduction in the weight of pruning wood was observed during the three experimental years in  
367 all cover crop plots compared with traditional floor management. All cover crops except  
368 legume mixture (LM) established well in the first year. However, the over-sowing in LM  
369 plots in early 2014 ensured a satisfactory soil covering similar to GM and natural covering  
370 (NC). Afterwards, the density of all the investigated ground covers ensured a good control of  
371 the grapevine vigor, in accordance with findings of Pou et al. (2011) in a Manto negro  
372 vineyard in the Balearic Islands (Spain). Therefore, changes in vegetative growth and yield in  
373 2014 and 2015 represent the response of grapevines to mature complete floor covers.

374 Floor management may also contribute to improve the must quality. In the present study, GM  
375 increased sugar concentrations at harvest relative to ST in the final year of the study. Cover  
376 crop treatments also affected concentrations of anthocyanins and polyphenols relative to  
377 standard tillage, but effects were most consistent in the final two years. Grass cover produced  
378 concentrations that were higher than or similar to ST, while NC reduced anthocyanin  
379 concentrations and LM reduced polyphenol concentrations relative to ST in most years. In our  
380 previous study (Mercenaro et al., 2014), the only significant change in the must composition  
381 involved the total anthocyanin content, with higher values in the grass treatment. Several  
382 studies have tested the between-row cover crop strategy, showing that the choice of an  
383 appropriate cover crop led to, for instance, higher sugar (Lavezzi et al., 2005) and total  
384 polyphenol (Lopes et al., 2008) content in the berries and improved wine quality (Xi et al.,  
385 2011). Conversely, cover crops did not influence the must composition over a three-year  
386 period in an intercropped vineyard (Ingels et al., 2005), whereas grape ripeness improved  
387 from the fourth year of observations on vines managed with a permanent complete floor cover

388 (Tescic et al., 2007). These results suggest a greater influence of cover crops on vegetative  
389 growth and yield than on must quality, especially in the first years of ground cover  
390 establishment, and indicate the importance of long-term studies to highlight changes in the  
391 grape composition due to floor management practices.

392 Currently, the vine mealybug control mostly relies on chemical applications, although this  
393 method is often unsatisfactory as mealybugs prefer concealed locations under the bark or in  
394 the roots. From the perspective of a more sustainable agriculture and integrated pest  
395 management, active ingredients with novel modes of action and more sustainable control  
396 strategies have been tested with promising results (Mansour et al., 2010; Karamaouna et al.,  
397 2013; Cocco et al., 2014). Cover crops should additionally be considered in integrated pest  
398 management programs. In fact, floor management systems affected all the investigated  
399 biological parameters of *P. ficus*, in particular development time, fecundity and fertility.  
400 Development and reproductive performances of mealybugs developed on LM grapevines  
401 were overall similar to the reference treatment (ST) and higher than those of mealybugs  
402 reared on GM and NC plots. Differences among treatments became more evident in 2014 and  
403 2015 and were generally consistent in both years. Because the ovipositing mealybugs  
404 collected from the experimental plots were kept under the same conditions of temperature,  
405 relative humidity and photoperiod, differences in the reproductive output of mealybugs are  
406 attributable to their nutritional status and feeding history at the time of the onset of  
407 oviposition.

408 Our findings show that all the tested floor cover treatments affected - through a bottom-up  
409 regulation process - the development and reproductive parameters of *P. ficus*. In particular,  
410 GM and NC reduced grape growth and nitrogen content relative to ST, resulting in a negative  
411 effect on mealybug performance. Improved *P. ficus* development and reproduction was  
412 consistently observed in grapevines with a higher leaf nitrogen content and vigor (ST and

413 LM), in accordance with prior studies on mealybugs (Hogendorp et al., 2006; Cocco et al.,  
414 2015). Competition of cover crops for water and nutrients can alter the phenology of host  
415 plants, reducing their nutritional quality and, thereby, pest development (Costello and Daane  
416 2003; Schmidt et al., 2007). However, response of pests to changes in host quality cannot be  
417 generalized, as stressed plants can enhance the performance of some pests and in contrast  
418 reduce the density of others (Bukovinszky et al., 2004). The effectiveness of a bottom-up  
419 integrated pest management program based on habitat management, cultural practices and  
420 minimum use of pesticides was also demonstrated in a long-term trial conducted in a  
421 commercial apple orchard (Prokopy, 2003).

422 Further aspects need to be considered in order to fully understand the influence of cover crops  
423 in regulating mealybug populations, such as the top-down effects that could help to reduce  
424 pest density via the enhancement of the natural enemy complex (Landis et al., 2000). In fact,  
425 cover crops also play an important ecological role, as they can influence the development of  
426 insect populations by harboring and sheltering beneficials, such as generalist predators (Daane  
427 and Costello, 1998; Nicholls et al., 2000) or pests (Meagher and Meyer, 1990; Bone et al.,  
428 2009). Moreover, untilled soil in vineyards indirectly favors higher *P. ficus* infestation by  
429 promoting the establishment of ant colonies that disrupt the activity of the vine mealybug  
430 parasitoid complex (Serra et al., 2006; Mgocheki and Addison, 2010). Finally, the choice of  
431 cover crop species should also consider their potential harboring of stolbur phytoplasma (bois  
432 noir), as a number of potential cover crop species have been successfully inoculated by the  
433 vector *Hyaletthes obsoletus* Signoret (Hemiptera: Cixiidae) (Maixner et al., 2001).  
434 Conversely, competitive cover crops could suppress *H. obsoletus* host species, hence reducing  
435 the pest population density (Maixner, 2007).

436

## 437 **5. Conclusions**

438

439 Our findings highlight that complete vineyard floor cover cropping significantly influences  
440 grapevine growth, yield and must composition and, when optimized, represents a sustainable  
441 tool to improve the quality of wines. Making generalizations about the most suitable floor  
442 management system in vineyards is difficult, as response to cover crop is site-specific and  
443 variety-dependent due to differences in terms of soil, plant vigor, level of production and  
444 oenological objectives. Therefore, the choice of cover crops strongly depends on the wine  
445 grape cultivar and cultivation site. The viticultural terroir investigated in this study was  
446 characterized by a Mediterranean climate, fertile soil and a productive and vigorous cultivar  
447 (Carignano). In this context, complete grass cover is recommended in order to limit excessive  
448 vegetative growth and improve must quality, especially the phenolic content.

449 In addition, complete grass mixture and natural covering negatively influenced the vine  
450 mealybug development, creating unfavorable conditions for pest development. However, total  
451 ground cover does not effectively reduce *P. ficus* populations as a stand-alone control strategy  
452 but should instead be integrated in sustainable control programs. This study indicates the  
453 importance of floor management systems for the trophic system grapevine – *P. ficus* and  
454 suggests, in addition to other factors, the inclusion of cover cropping in pest management  
455 programs.

456

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463 **References**

464

465 Berkey, T.G., Mansfield, A.K., Lerch, S.D., Meyers, J.M., Heuvel, J.E.V. 2011. Crop load  
466 adjustment in ‘Seyval Blanc’ winegrape: impacts on yield components, fruit  
467 composition, consumer wine preferences, and economics of production. HortTech. 21,  
468 593–598.

469 Bone, N.J., Thomson, L.J., Ridland, P.M., Cole, P., Hoffmann, A.A., 2009. Cover crops in  
470 Victorian apple orchards: effects on production, natural enemies and pests across a  
471 season. Crop Prot. 28 675–683.

472 Bukovinszky, T., Tréfás, H., van Lenteren J.C., Vet, L.E.M., Fremont, J., 2004. Plant  
473 competition in pest-suppressive intercropping systems complicates evaluation of  
474 herbivore responses. Agric. Ecosyst. Environ. 102, 185–196.

475 Calderon-Orellana, A., Mercenaro, L., Shackel, K.A., Willits, N., Matthews, M. A. 2014.  
476 Responses of fruit uniformity to deficit irrigation and cluster thinning in commercial  
477 winegrape production. Am. J. Enol. Vitic. DOI: 10.5344/ajev.2014.13135.

478 Christensen, L.P., Dokoozlian, N.K., Walker, M.A., Wolpert, J.A., 2003. Wine grape varieties  
479 in California. UC Agriculture and Natural Resources, Publication 3419, Oakland, CA,  
480 USA.

481 Cocco, A., Lentini, A., Serra, G., 2014. Mating disruption of the vine mealybug, *Planococcus*  
482 *ficus*, in vineyards using reservoir pheromone dispensers. J. Insect Sci. 14, 144. DOI:  
483 <http://dx.doi.org/10.1093/jisesa/ieu006>.

484 Cocco, A., Marras, P.M., Muscas, E., Mura, A., Lentini, A., 2015. Variation of life-history  
485 parameters of *Planococcus ficus* (Hemiptera: Pseudococcidae) in response to grapevine  
486 nitrogen fertilization. J. Appl. Entomol. 139, 519–528.

487 Costello, M.J., Daane, K.M., 2003. Spider and leafhopper (*Erythroneura* spp.) response to  
488 vineyard ground cover. *Environ. Entomol.* 32, 1085–1098.

489 D’Alberto, C.F., Hoffmann, A.A., Thomson, L.J., 2012. Limited benefits of non-crop  
490 vegetation on spiders in Australian vineyards: regional or crop differences?. *Biocontrol*  
491 57, 541–552.

492 Daane, K.M., Costello, M.J., 1998. Can cover crops reduce leafhoppers abundance in  
493 vineyard? *California Agric.* 52, 27–33.

494 Daane, K.M., Almeida, R.P.P., Bell, V.A., Walker, J.T.S., Botton, M., Fallahzadeh, M., Mani,  
495 M., Miano, J.L., Sforza, R., Walton, V.M., Zaviezo, T., 2012. Biology and management  
496 of mealybugs in vineyards, in: Bostanian, N.J., Charles, V., Isaacs, R. (Eds.), *Arthropod*  
497 *management in vineyards: pests, approaches, and future directions*. Springer, Dordrecht,  
498 pp. 271–307.

499 Danne, A., Thomson, L.J., Sharley, D.J., Penfold, C.M., Hoffmann, A.A., 2010. Effects of  
500 native grass cover crops on beneficial and pest invertebrates in Australian vineyards.  
501 *Environ. Entomol.* 39, 970–978.

502 Di Stefano, R., Cravero, M.C., 1991. The grape phenolic determination. *Riv. Vitic. Enol.*  
503 49(2), 37–45.

504 European Union, 2009a. Directive 2009/128/EC of the European Parliament and of the  
505 Council of 21 October 2009 establishing a framework for Community action to achieve  
506 the sustainable use of pesticides. *Off. J. Eur. Commun.* L 309, 71–86.

507 European Union, 2009b. Regulation (EC) No 1107/2009 of the European Parliament and of  
508 the Council of 21 October 2009 concerning the placing of plant protection products on  
509 the market and repealing Council Directives 79/117/EEC and 91/414/EEC. *Off. J. Eur.*  
510 *Commun.* L 309, 1–50.

511 Fuentes, S., Rogers, G., Jobling, J., Conroy, J., Camus, C., Dalton, M. Mercenaro, L. 2008. A  
512 soil-plant-atmosphere approach to evaluate the effect of irrigation/fertigation strategy on  
513 grapevine water and nutrient uptake, grape quality and yield. *Acta Hortic.* 792, 297–  
514 303.

515 Gamero, E., Moreno, D., Talaverano, I., Prieto, M.H., Guerra, M.T., Valdés, M.E. 2014.  
516 Effects of irrigation and cluster thinning on Tempranillo grape and wine composition. *S.*  
517 *Afr. J. Enol. Vitic.* 35, 196–204.

518 Giese, W.G, Velasco-Cruz, C., Roberts, L., Heitman, J., Wolf, T.K., 2014a. Complete  
519 vineyard floor cover crops favorably limit grapevine vegetative growth. *Scientia Hort.*  
520 170, 256–266.

521 Giese, W.G, Wolf, T.K., Velasco-Cruz, C., Roberts, L., Heitman, J., 2014b. Cover crop and  
522 root pruning impacts on vegetative growth, crop yield components, and grape  
523 composition of Cabernet Sauvignon. *Am. J. Enol. Vitic.* DOI:  
524 10.5344/ajev.2014.14100.

525 Gontier, L., Dufourcq, T., Gaviglio, C., 2011. Total grass cover in vineyards: an innovating  
526 and promising soil management alternative to reduce the use of herbicides. In: 17<sup>th</sup>  
527 International GiESCO Symposium, Asti-Alba, Italy, 29 August–2 September, 2011, pp.  
528 95–98.

529 Guerra, B., Steenwerth, K., 2012. Influence of floor management technique on grapevine  
530 growth, disease pressure, and juice and wine composition: a review. *Am. J. Enol. Vitic.*  
531 63, 149–164.

532 Hogendorp, B.K., Cloyd, R.A., Swiader, J.M., 2006. Effect of nitrogen fertility on  
533 reproduction and development of citrus mealybug, *Planococcus citri* Risso (Homoptera:  
534 Pseudococcidae), feeding on two colors of coleus, *Solenostemon scutellarioides* L.  
535 Codd. *Environ. Entomol.* 35, 201–211.

536 Hunt, D.W.A., Drury, C.F., Maw, H.E.L., 1992. Influence of nitrogen on the performance of  
537 Colorado potato beetle (Coleoptera: Chrysomelidae) on tomato. *Environ. Entomol.* 21,  
538 817–821.

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

542 Karamaouna, F., Kimbaris, A., Michaelakis, A., Papachristos, D., Polissiou, M., Papatsakona,  
543 P., Tsora, E., 2013. Insecticidal activity of plant essential oils against the vine  
544 mealybug, *Planococcus ficus*. *J. Insect Sci.* 13, 142.

545 Landis, D.A., Wratten, S.D., Gurr, G.M., 2000. Habitat management to conserve natural  
546 enemies of arthropod pests in agriculture. *Annu. Rev. Entomol.* 45, 175–201.

547 Lavezzi, A., Pascarella, G., Sivilotti, P., Tomasi, D., Altissimo, A., 2005. Cover cropping  
548 systems in vineyard: grass species and row management as affecting grapevine  
549 performance. In: 14<sup>th</sup> International GESCO Viticulture Congress, Geisenheim,  
550 Germany, 23-27 August, 2005, pp. 635–641.

551 Lopes, C.M., Monteiro, A., Machado, J.P., Fernandes, N., Araújo, A., 2008. Cover cropping  
552 in a sloping non-irrigated vineyard: II – Effects on vegetative growth, yield, berry and  
553 wine quality of ‘Cabernet Sauvignon’ grapevines. *Ciência Téc. Vitiv.* 23, 37–43.

554 Maixner, M., 2007. Biology of *Hyalesthes obsoletus* and approaches to control this soilborne  
555 vector of Bois noir disease. *IOBC/WPRS Bull.* 30(7), 3–9.

556 Maixner, M., Darimont, H., Mohr, H.D., 2001. Studies on the transmission of Bois noir to  
557 weeds and potential ground-cover plants by *Hyalesthes obsoletus* Signoret  
558 (Auchenorrhyncha: Cixiidae). *IOBC/WPRS Bull.* 24(7), 249-251.

559 Mansour, R., Grissa Lebdi, K., Rezgui, S., 2010. Assessment of the performance of some new  
560 insecticides for the control of the vine mealybug *Planococcus ficus* in a Tunisian  
561 vineyard. Entomol. Hell. 19, 21–33.

562 Mansour, R., Suma, P., Mazzeo, G., La Pergola, A., Pappalardo, V., Grissa Lebdi, K., Russo,  
563 A., 2012. Interactions between the ant *Tapinoma nigerrimum* (Hymenoptera:  
564 Formicidae) and the main natural enemies of the vine and citrus mealybugs (Hemiptera:  
565 Pseudococcidae). Biocon. Sci. Tech. 22, 527–537.

566 Meagher, R.L., Meyer, J.R., 1990. Effect of ground cover management on certain abiotic and  
567 biotic interactions in peach orchard ecosystems. Crop Prot. 9, 65–72.

568 Mercenaro, L., Nieddu, G., Pulina, P., Porqueddu, C., 2014. Sustainable management of an  
569 intercropped Mediterranean vineyard. Agric. Ecosyst. Environ. 192, 95–104.

570 Mgocheki, N., Addison, P., 2010. Spatial distribution of ants (Hymenoptera: Formicidae),  
571 vine mealybugs and mealybug parasitoids in vineyards. J. Appl. Entomol. 134, 285–  
572 295.

573 Monteiro, A., Lopes, C.M., 2007. Influence of cover crop on water use and performance of  
574 vineyard in Mediterranean Portugal. Agric. Ecosyst. Environ. 121, 336–342.

575 Monteiro, A., Moreira, I., 2004. Reduced rates of residual and post-emergence herbicides for  
576 weed control in vineyards. Weed Res. 44 117–128.

577 Naor, A., Gal, Y., Bravdo, B. 2002. Shoot and cluster thinning influence vegetative growth,  
578 fruit yield, and wine quality of ‘Sauvignon blanc’ grapevines. J. Amer. Soc. Hort. Sci.  
579 127, 628–634.

580 Nicholls, C.I., Parrella, M.P., Altieri, M.A., 2000. Reducing the abundance of leafhoppers and  
581 thrips in a northern California organic vineyard through maintenance of full season  
582 floral diversity with summer cover crops. Agric. For. Entomol. 2, 107–113.

583 O.I.V., 2006. Recueil international des methodes d'analyses des vins et des moutes, vol. 2.  
584 Organisation Internationale de la Vigne et du Vin, Paris, France.

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

587 Piepho, H.P., 2012. A SAS macro for generating letter displays of pairwise mean  
588 comparisons. *Commun. Biometry Crop Sci.* 7, 4–13.

589 Poni, S., Casalini, L., Bernizzoni, F., Civardi, S., Intrieri, C. 2006. Effects of early defoliation  
590 on shoot photosynthesis, yield components, and grape composition. *Amer. J. Enol.*  
591 *Vitic.* 57, 397–407.

592 Porro, D., Dorigatti, C., Stefanini, M., Ceschini, A., 2001. Use of SPAD meter in diagnosis of  
593 nutritional status in apple and grapevine. *Acta Hortic.* 564, 243–252.

594 Pou, A., Gulías, J., Moreno, M.M., Tomás, M., Medrano, H., Cifre, J., 2011. Cover cropping  
595 in *Vitis vinifera* L. cv. Manto negro vineyards under Mediterranean conditions: effects  
596 on plant vigour, yield and grape quality. *J. Int. Sci. Vigne Vin.* 45, 223–234.

597 Powles, S.B., Preston, C., Bryan, I.B., Jutsum, A.R., 1997. Herbicide resistance: impact and  
598 management. *Adv. Agron.* 58, 57–93.

599 Preszler, T., Schmit, T.M., Heuvel, J.E.V. 2013. Cluster thinning reduces the economic  
600 sustainability of Riesling production. *Amer. J. Enol. Vitic.* DOI:  
601 10.5344/ajev.2013.12123.

602 Prokopy, R.J., 2003. Two decades of bottom-up, ecologically based pest management in a  
603 small commercial apple orchard in Massachusetts. *Agric. Ecosyst. Environ.* 94, 299–  
604 309.

605 Sanguankeo, P.P., León, R.G., 2011. Weed management practices determine plant and  
606 arthropod diversity and seed predation in vineyards. *Weed Res.* 51, 404–412.

607 SAS Institute, 2008. SAS/ETS® 9.2 user's guide. SAS Institute Inc, Cary, NC, USA.

608 Serra, G., Lentini, A., Verdinelli, M., Delrio, G., 2006. Effects of cover crop management on  
609 grape pests in a Mediterranean environment. *IOBC/WPRS Bull.* 29(11), 209–214.

610 Shaahan, M.M., El-Sayed, A.A., Abou El-Nour, E.A.A., 1999. Predicting nitrogen,  
611 magnesium and iron nutritional status in some perennial crops using a portable  
612 chlorophyll meter. *Sci. Hortic.* 82, 339–348.

613 Silvestroni, O., Lanari, V., Lattanzi, T., Palliotti, A., Sabbatini, P. 2016. Impact of crop  
614 control strategies on the performance of high-yielding Sangiovese grapevines. *Amer. J.*  
615 *Enol. Vitic.* DOI: 10.5344/ajev.2016.15093.

616 Schmidt, N.P., O’Neal, M.E., Singer, J.W., 2007. Alfalfa living mulch advances biological  
617 control of soybean aphid. *Environ. Entomol.* 36, 416–424.

618 Tesic, D., Keller, M., Hutton, R.J., 2007. Influence of vineyard floor management practices  
619 on grapevine vegetative growth, yield, and fruit composition. *Amer. J. Enol. Vitic.* 58,  
620 1–11.

621 Thomson, L.J., Hoffmann, A.A., 2013. Spatial scale of benefits from adjacent woody  
622 vegetation on natural enemies within vineyards. *Biol. Control* 64, 57–65.

623 Thurman, E.M., Goolsby, D.A., Aga, D.S., Pomes, M.L., Meyer, M.T., 1996. Occurrence of  
624 alachlor and its sulfonated metabolite in rivers and reservoirs of the Midwestern United  
625 States: the importance of sulfonation in the transport of chloroacetanilide herbicides.  
626 *Environ. Sci. Technol.* 30, 569–574.

627 Tourte, L., Smith, R., Bettiga, L., Bensen, T., Smith, J., Salm, D., 2008. Post-emergence  
628 herbicides are cost effective for vineyard floor management on the Central Coast.  
629 *California Agric.* 62, 19–23.

630 Van Huyssteen, L., Weber, H.W., 1980. The effect of selected minimum and conventional  
631 tillage practices in vineyard cultivation on vine performance. *S. Afr. J. Enol. Vitic.* 1,  
632 77–83.

- 633 Veres, A., Petit, S., Conord, C., Lavigne, C., 2013. Does landscape composition affect pest  
634 abundance and their control by natural enemies? A review. *Agric. Ecosyst. Environ.*  
635 166, 110–117.
- 636 Wilson, L.T., Smilanick, J.M., Hoffmann, M.P., Flaherty, D.L., Ruiz, S.M., 1988. Leaf  
637 nitrogen and position in relation to population parameters of Pacific spider mite,  
638 *Tetranychus pacificus* (Acari: Tetranychidae) on grapes. *Environ. Entomol.* 17, 964–  
639 968.
- 640 Xi, Z.M., Tao, Y.S., Zhang, L., Li, H., 2011. Impact of cover crops in vineyard on the aroma  
641 compounds of *Vitis vinifera* L. cv Cabernet Sauvignon wine. *Food Chem.* 127, 516–  
642 522.

643 **Table and figure captions**

644

645 **Table 1**

646 SPAD values (mean  $\pm$  SE) on grapevine leaves in spring-summer under different floor  
 647 management systems: soil tillage (ST); natural covering (NC); grass mixture (GM); legume  
 648 mixture (LM).

Year	SPAD value <sup>a</sup>			
	ST	NC	GM	LM
2013	41.62 $\pm$ 0.81 a	35.11 $\pm$ 0.86 b	36.48 $\pm$ 0.61 b	42.06 $\pm$ 1.09 a
2014	45.71 $\pm$ 0.82 a	37.13 $\pm$ 0.80 d	40.86 $\pm$ 1.08 c	43.71 $\pm$ 0.83 b
2015	47.54 $\pm$ 0.72 a	43.23 $\pm$ 0.71 b	43.82 $\pm$ 0.85 b	47.71 $\pm$ 0.56 a
Significance <sup>b</sup>				
Cover crop		**		
Year		**		
Cover crop $\times$ year		**		

649 <sup>a</sup> Values within rows followed by different letters are not significantly different ( $P < 0.05$ ) by

650 Tukey's test.

651 <sup>b</sup> \* =  $P < 0.05$ ; \*\* =  $P < 0.01$ ; ns = not significant

652

653 **Table 2**654 Grapevine growth parameters (mean  $\pm$  SE) under different floor management systems: soil

655 tillage (ST); natural covering (NC); grass mixture (GM); legume mixture (LM).

Year	Shoots/vine (no.) <sup>a</sup>			
	ST	NC	GM	LM
2013	9.8 $\pm$ 1.4	10.4 $\pm$ 1.2	9.9 $\pm$ 1.4	10.5 $\pm$ 0.9
2014	9.3 $\pm$ 1.2	9.1 $\pm$ 0.6	9.3 $\pm$ 0.9	10.6 $\pm$ 0.9
2015	10.5 $\pm$ 0.6	9.7 $\pm$ 1.2	9.7 $\pm$ 0.8	9.2 $\pm$ 1.3
Significance <sup>b</sup>				
Cover crop		ns		
Year		ns		
Cover crop $\times$ year		ns		
Year	Pruning weight/vine (kg) <sup>a</sup>			
	ST	NC	GM	LM
2013	1.04 $\pm$ 0.19 a	1.00 $\pm$ 0.13 a	0.85 $\pm$ 0.18 b	1.06 $\pm$ 0.16 a
2014	0.80 $\pm$ 0.14 a	0.62 $\pm$ 0.07 b	0.52 $\pm$ 0.09 c	0.68 $\pm$ 0.11 b
2015	1.05 $\pm$ 0.04 a	0.97 $\pm$ 0.25 b	0.72 $\pm$ 0.22 c	0.93 $\pm$ 0.20 b
Significance <sup>b</sup>				
Cover crop		*		
Year		**		
Cover crop $\times$ year		**		
Year	Ravaz index (kg yield/kg pruning weight) <sup>a</sup>			
	ST	NC	GM	LM
2013	5.5 $\pm$ 1.0	6.3 $\pm$ 0.6	4.9 $\pm$ 0.7	5.4 $\pm$ 0.9
2014	4.4 $\pm$ 0.5	4.3 $\pm$ 1.1	3.8 $\pm$ 0.9	3.8 $\pm$ 0.4
2015	4.7 $\pm$ 0.3	3.7 $\pm$ 0.3	4.2 $\pm$ 0.5	3.9 $\pm$ 0.4
Significance <sup>b</sup>				
Cover crop		ns		
Year		**		
Cover crop $\times$ year		*		

656 <sup>a</sup> Values within rows followed by different letters are not significantly different ( $P < 0.05$ ) by

657 Tukey's test.

658 <sup>b</sup> \* =  $P < 0.05$ ; \*\* =  $P < 0.01$ ; ns = not significant

659 **Table 3**

660 Grapevine yield parameters (mean  $\pm$  SE) under different floor management systems: soil  
 661 tillage (ST); natural covering (NC); grass mixture (GM); legume mixture (LM).

Year	Yield/vine (kg) <sup>a</sup>			
	ST	NC	GM	LM
2013	5.7 $\pm$ 0.6 a	6.3 $\pm$ 0.4 a	4.2 $\pm$ 0.2 b	5.7 $\pm$ 0.6 a
2014	3.6 $\pm$ 0.5 a	2.7 $\pm$ 0.5 b	2.0 $\pm$ 0.3 c	2.6 $\pm$ 0.7 b
2015	4.9 $\pm$ 0.4 a	3.6 $\pm$ 0.3 b	3.0 $\pm$ 0.3 c	3.6 $\pm$ 0.4 b
Significance <sup>b</sup>				
Cover crop		*		
Year		**		
Cover crop $\times$ year		*		
Year	Clusters/vine (no.) <sup>a</sup>			
	ST	NC	GM	LM
2013	16.9 $\pm$ 1.9	19.0 $\pm$ 1.2	14.6 $\pm$ 1.9	17.8 $\pm$ 1.3
2014	9.0 $\pm$ 0.9 a	9.4 $\pm$ 0.6 a	7.3 $\pm$ 0.6 b	9.1 $\pm$ 0.3 a
2015	14.0 $\pm$ 0.8 a	13.7 $\pm$ 0.7 a	10.2 $\pm$ 0.8 b	13.8 $\pm$ 0.6 a
Significance <sup>b</sup>				
Cover crop		*		
Year		**		
Cover crop $\times$ year		**		
Year	Cluster weight (g) <sup>a</sup>			
	ST	NC	GM	LM
2013	442.1 $\pm$ 29.5 a	420.4 $\pm$ 50.5 a	361.4 $\pm$ 36.9 b	414.0 $\pm$ 31.0 a
2014	365.0 $\pm$ 24.8 a	328.0 $\pm$ 56.4 ab	269.7 $\pm$ 49.8 b	266.0 $\pm$ 38.0 b
2015	339.0 $\pm$ 13.5 a	277.8 $\pm$ 39.5 b	262.8 $\pm$ 45.1 b	264.0 $\pm$ 31.7 b
Significance <sup>b</sup>				
Cover crop		*		
Year		**		
Cover crop $\times$ year		**		
Year	Berry weight (g) <sup>a</sup>			
	ST	NC	GM	LM
2013	2.94 $\pm$ 0.25	2.63 $\pm$ 0.34	2.59 $\pm$ 0.18	2.88 $\pm$ 0.11
2014	2.36 $\pm$ 0.30 b	2.83 $\pm$ 0.22 a	2.30 $\pm$ 0.27 b	1.96 $\pm$ 0.19 c
2015	2.62 $\pm$ 0.12 ab	2.82 $\pm$ 0.09 a	2.62 $\pm$ 0.12 ab	2.49 $\pm$ 0.10 b

Significance<sup>b</sup>

Cover crop \*

Year \*

Cover crop × year \*

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662 <sup>a</sup> Values within rows followed by different letters are significantly different ( $P < 0.05$ ) by

663 Tukey's test.

664 <sup>b</sup> \* =  $P < 0.05$ ; \*\* =  $P < 0.01$ ; ns = not significant

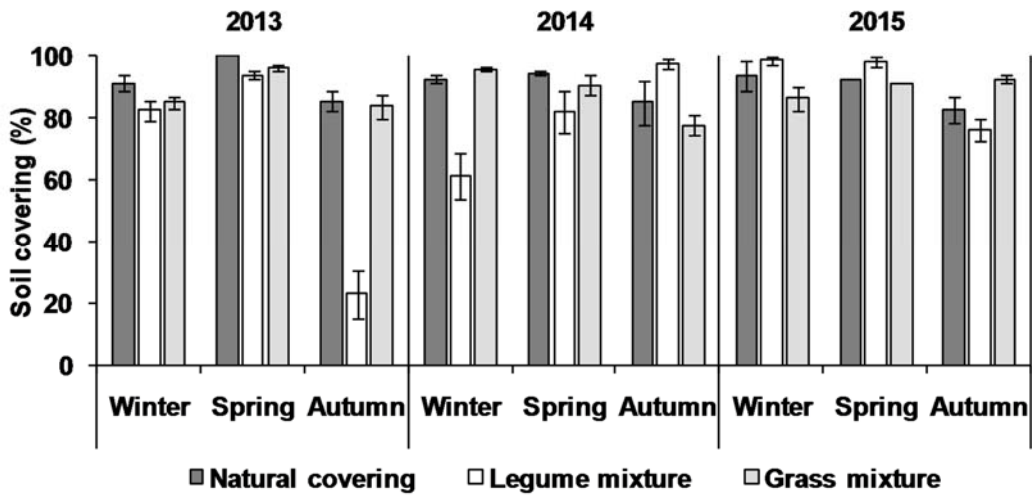
665

666 **Table 4**

667 Biological parameters (mean  $\pm$  SE) of *Planococcus ficus* on vines under different floor  
 668 management systems: soil tillage (ST); natural covering (NC); grass mixture (GM); legume  
 669 mixture (LM).

Year	Development time (d) <sup>a</sup>			
	ST	NC	GM	LM
2013	34.07 $\pm$ 0.23 b	35.71 $\pm$ 0.27 a	34.62 $\pm$ 0.24 ab	33.82 $\pm$ 0.22 b
2014	33.82 $\pm$ 0.16 c	35.57 $\pm$ 0.20 a	34.95 $\pm$ 0.23 ab	34.82 $\pm$ 0.18 b
2015	33.26 $\pm$ 0.15 b	34.36 $\pm$ 0.15 a	34.52 $\pm$ 0.16 a	32.96 $\pm$ 0.17 b
Significance <sup>b</sup>				
Cover crop		**		
Year		**		
Cover crop $\times$ year		**		
Year	Survival (%) <sup>a</sup>			
	ST	NC	GM	LM
2013	13.93 $\pm$ 6.13	12.84 $\pm$ 5.31	14.60 $\pm$ 8.68	12.03 $\pm$ 4.77
2014	26.85 $\pm$ 2.91	26.52 $\pm$ 2.01	28.87 $\pm$ 2.04	26.37 $\pm$ 2.82
2015	26.66 $\pm$ 2.71 b	27.24 $\pm$ 2.44 b	27.03 $\pm$ 2.23 b	30.49 $\pm$ 3.39 a
Significance <sup>b</sup>				
Cover crop		*		
Year		**		
Cover crop $\times$ year		**		
Year	Fecundity (no. eggs) <sup>a</sup>			
	ST	NC	GM	LM
2013	133.66 $\pm$ 6.55	124.57 $\pm$ 6.53	119.76 $\pm$ 4.91	133.52 $\pm$ 7.19
2014	178.95 $\pm$ 4.55 a	138.57 $\pm$ 3.14 c	162.69 $\pm$ 4.95 b	172.34 $\pm$ 4.67 ab
2015	126.89 $\pm$ 2.52 b	116.18 $\pm$ 2.68 c	108.00 $\pm$ 2.44 c	141.82 $\pm$ 3.47 a
Significance <sup>b</sup>				
Cover crop		**		
Year		**		
Cover crop $\times$ year		**		
Year	Fertility (%) <sup>a</sup>			
	ST	NC	GM	LM
2014	97.12 $\pm$ 0.20 b	96.23 $\pm$ 0.28 c	96.18 $\pm$ 0.32 c	97.32 $\pm$ 0.21 a
2015	91.81 $\pm$ 0.69 a	90.18 $\pm$ 0.71 b	90.47 $\pm$ 0.71 b	92.39 $\pm$ 0.58 a

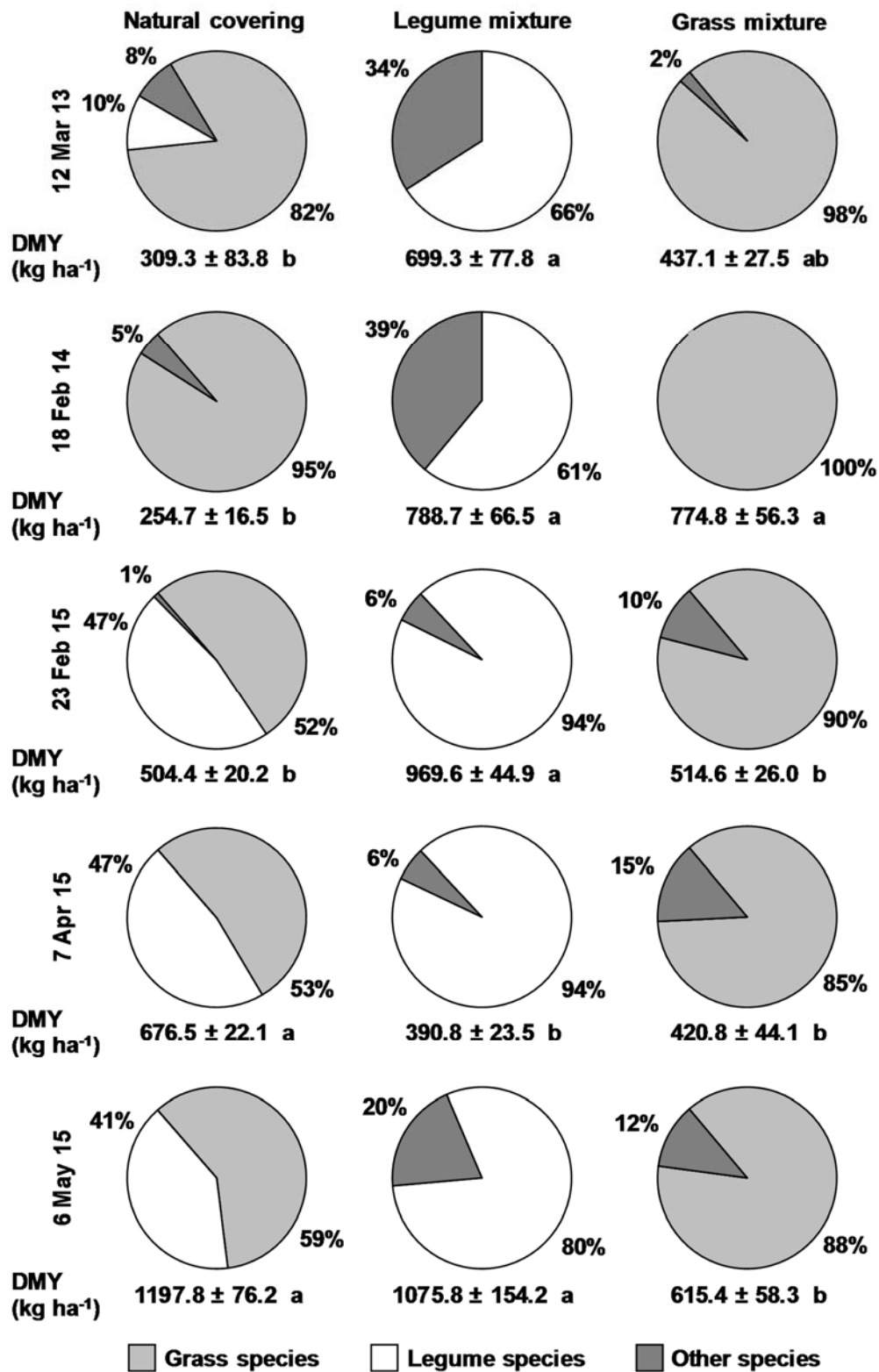




674

675 **Fig. 1.** Percentage soil cover by natural covering legume mixture and grass mixture during the  
 676 survey (2013-2015).

677

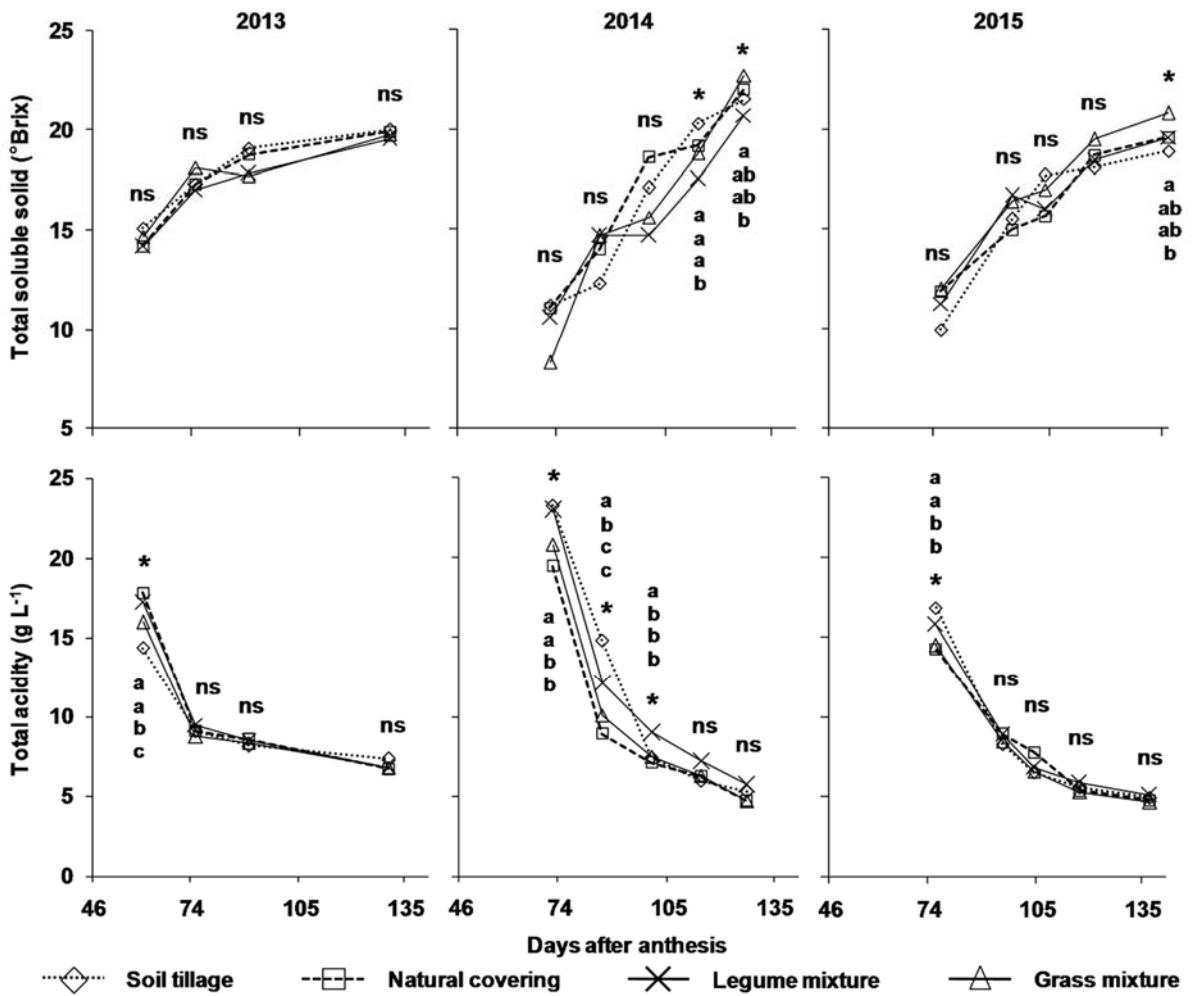


678

679 **Fig. 2.** Dry matter yield (DMY) and percentage species contribution to dry matter production

680 for each cut during the survey. DMY values within each cut bearing the same letters were not

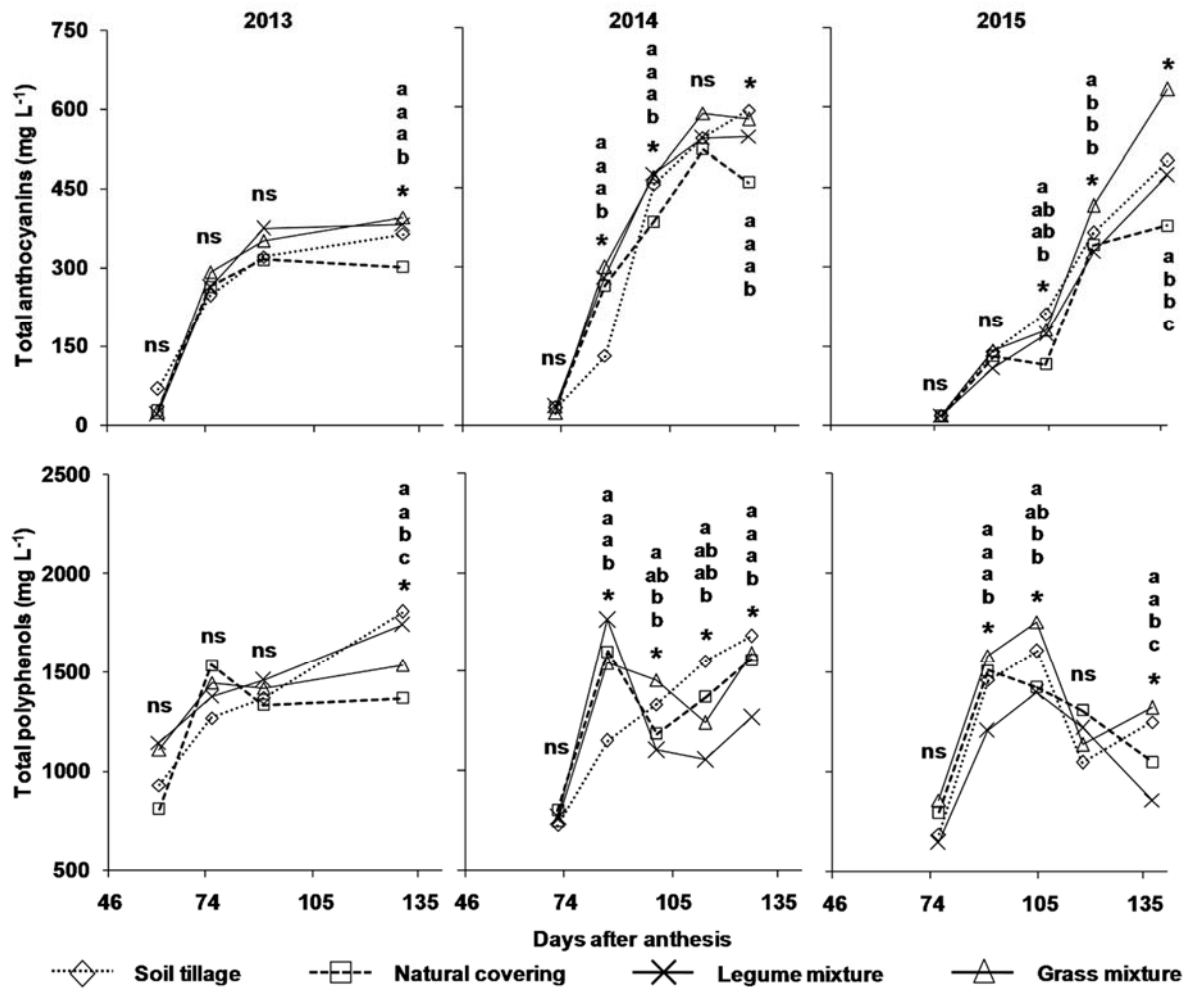
681 significantly different ( $P < 0.05$ ) by Tukey's test.



682

683 **Fig. 3.** Total soluble solids and total acidity of must from veraison to harvest under different  
 684 floor management systems. Levels of significance are denoted by \* =  $P < 0.05$  or ns = not  
 685 significant. Different letters within each sampling date indicate significant differences among  
 686 means by Tukey's test. Note the different axis scales.

687



688

689 **Fig. 4.** Total polyphenol and total anthocyanin content on must from veraison to harvest under  
 690 different floor management systems. Levels of significance are denoted by \* =  $P < 0.05$  or ns  
 691 = not significant. Different letters within each sampling date indicate significant differences  
 692 among means by Tukey's test. Note the different axis scales.