The effects of management regime on arthropod communities in Argentinian vineyards

MASTER THESIS

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ABSTRACT

Vineyards are located in climatically favourable areas such as low-altitude, xerothermophile slopes, where the relatively high proportion of uncultivated surface may create favourable habitats to host rare, endangered plants and invertebrate species. Different management practices are likely to provide very different biodiversity outcomes. Beside differences in the use of certain pesticides, management practices differ in the treatment of the vegetation in the uncultivated surface between the vine rows. As a consequence, the vegetation cover on this surface varies substantially among parcels, which may have a significant impact on plant and animal communities within the vineyards. With this study we investigate how different management practices of vineyards in the Mendoza province of Argentina influence arthropod communities. Biodynamic management of the vineyard, more than organic, presented higher abundance, biomass and richness compared to conventional. Abundance, biomass and richness of arthropods showed a curvilinear positive relationship with vegetation structure, peaking at 70% ground vegetation cover. There was a significant interaction between ground vegetation cover and management practice: the positive effect of ground vegetation cover on arthropod communities was significantly higher in organic and biodynamic parcels than in conventional parcels. Possibly, pesticide applications in conventional parcels have detrimental effects on non-target arthropod communities. Our results indicate that arthropod diversity can be efficiently promoted by a considerate management of the vineyard uncultivated surface. They also suggest that the type of management may affect entire trophic chains, from pollinators and herbivore populations up to generalist pest-controlling beetles and spiders.

INTRODUCTION

Vineyards are typically cultivated in intensively managed monocultures, where the perennial grape vines are arranged in rows. This spatial arrangement leaves considerable uncultivated space between the rows; this space, which may either consist of bare soil, or be covered with vegetation, needs to be managed to prevent the growth of weed. In addition, grape vineyards require a substantial use of fungicide due to the susceptibility of most varieties to fungal diseases, as well as artificial irrigation in particularly xeric regions. Currently 7.5 million hectares worldwide are used for wine grape production, and this surface is rapidly expanding (OIV report on vitiviniculture, 2017). Consequently, vitiviniculture has important, negative effects on biodiversity due to the destruction and fragmentation of natural habitats, intensive use of pesticides, removal of overwintering sites and food sources (Nicholls, Parrella & Altieri 2001; Altieri, Ponti & Nicholls 2005). On the one hand, these impacts on biodiversity are thought to degrade key ecosystem functions important for agriculture such as pest control, which is highly dependent on arthropod species richness (Nicholls, Parrella & Altieri 2001; Tilman et al. 2002). For example, the loss of generalist, arthropod predators such as carabid beetles and wolf-spiders reduces the population control over leafhoppers (*Cicadellidae*, grape disease-vectors) in agricultural fields (Lang, Filser & Henschel 1999). On the other hand, in numerous regions as for example Central Europe, where grape wines are at the limit of their natural distribution, vineyards are located in climatically favourable areas such as low-altitude, xerothermophile slopes, which are also the only habitats of numerous specialized plant and animal species.

A common solution to counter-act the habitat simplification is to increase the floral diversity of the agricultural landscape by implementation of field margins to enhance beneficial species within crops and reduce pesticide use (Marshall & Moonen 2002). In vineyards, the relatively high proportion of uncultivated surface may also create favourable habitats for plants and insects by letting vegetation grow between the rows (Nicholls, Parrella & Altieri 2001). A vegetational corridor connected to the surrounding natural habitat might channel insect biodiversity into the vineyard and eventually enhance biological control of leafhoppers and thrips (Altieri, Ponti & Nicholls 2005). Lastly, it has been shown that organic farming has a positive effect on both species richness and abundance of carabid beetles (Bengtsson, Ahnstrom & Weibull 2005); biodiversity is enhanced compared to conventional farming systems because of the reduced disturbance and chemical applications (Nascimbene, Marini

& Paoletti 2012), but that enhancement also depends on the surrounding vegetation structure and landscape composition (Benton, Vickery & Wilson 2003; Caprio et al. 2015).

Vineyard management practices can be divided into conventional, organic and biodynamic. In conventional production, synthetic fertilizers as well as different types of pesticides (herbicides, fungicides and insecticides) may be used. For the control of weed between the rows of vine grapes, different practices may be implemented, such as herbicide treatment, mechanic ploughing or mowing of the vegetation. In contrast, the organic production applies natural fertilizers and fungicides only and the use of herbicide for the control of weeds is prohibited (Caprio et al. 2015). Biodynamic management can be understood as a modification of organic agriculture, with for example the additional application of fermented manure, mineral or plant preparations and the use of an astrological sowing and planting calendar (Döring et al. 2015). The control of weed in particular thus varies considerably between management practices. Limited available data suggest that the best management regime for both arthropod communities and agricultural production in vineyard is to control competitive weed while maintaining floral diversity to promote favourable conditions for beneficial organisms (Sanguankeo & Leon 2011). In addition, regional differences in weed control techniques are also known, depending on topographic or climatic conditions.

In the present study we assess the influence of different vineyard management regimes on arthropod communities in the Mendoza province of Argentina. We investigated and quantified whether differences in arthropod abundance, biomass and richness are better explained by management type (conventional, organic and biodynamic) or by the structure of the vegetation in the surface between vine rows. Additionally, we compared arthropod abundance and biomass between vineyards and natural habitat. Our hypotheses were that parcels with biodynamic and organic managements host the highest arthropod abundance and biomass; and that increased ground vegetation cover yields higher biodiversity (Genini 2000) in every vineyard management regime. We also expected that the effect of vegetation cover on arthropod communities occurs as a positive, curvilinear relationship reaching abundance peaks at around 50% ground vegetation cover (Arlettaz et al. 2012). As for natural habitat, we expected to find higher abundance and biomass compared to vineyard parcels.

MATERIAL AND METHODS

Study sites and experimental design

The study was carried out between September 2016 and February 2017 in the Mendoza province around Valle de Uco (Argentina, austral summer). Mendoza is situated in a semi-arid territory, under the dry slope of the High Andes, where the climate is temperate warm with an average 25° C temperature in summer and 7° C in winter (Canziani & Scarel 2009). Argentina ranks as the seventh country by surface area used for grape production, and the first overall in the southern hemisphere, with 224 thousand hectares under vines. Mendoza's foothills of the Andes are the main wine region of Argentina, accounting for more than 70% of the country's wine production (OIV report on vitiniculture 2017). In the region, biodynamic parcels are less common than organic or conventional. Overall, organic and conventional parcels share a similar vegetation structure while biodynamic vineyards outstand by ground vegetation cover and mean vegetation height. Biodynamic vineyards often have flowering plants between vine rows as cover crops, more than in organic vineyards, to improve soil structure and reduce pest damage.

Based on our contacts with local vine-growers, we selected a total of N=30 vineyard parcels. These 30 parcels included 13 parcels with conventional management regime, 9 organic and 8 biodynamic, all sites being at a minimal distance of 1 km between each other. The vineyard parcels were chosen to reflect a gradient of ground vegetation cover for each management type and uniformly distributed across the sampling area, to avoid spatial aggregation of same management types or vegetation cover levels. All parcels had grape vines planted according to the 'espaldero' system (high trellis) and were located on horizontal terrain. Moreover, an irrigation system factor was assessed for each parcel, either by drip irrigation under the vine plants ('drop') or by canal irrigation and flooding of the vine lines ('flood').

Lastly, we sampled N=8 (i.e. not more than the least represented management regime, biodynamic parcels) different natural habitats located near the selected parcels. Sampling of these habitats was performed to obtain background knowledge on the composition of the local, natural arthropod communities and to enable comparisons with vineyards. The natural habitat sites were selected for their accessibility and were homogenously distributed to cover our entire vineyard sampling area. All of them consist of semi-arid shrubland. The GPS coordinates of the sampled sites and their characteristics are presented in Suppl. Table 1.

Arthropod sampling

Ground-dwelling and vegetation arthropods were sampled using pitfall traps (PF) and sweep-netting (SN). For each vineyard parcel, 3 pitfall traps consisting of 500 ml white plastic cups were buried between adjacent individual plants of vine grape (and not between the rows, to avoid machine passage) at a minimal distance of 10 meters between each other and more than 10 meters away from the parcel's border (all of the selected parcels were large enough to respect these distances). The plastic cups contained a mixture of odourless soapy water and propylenglycol (1:1) and were left with the opening at the very ground level for one week. The sweepnet sampling (20 swings, one every footstep; Bruggisser, Schmidt-Entling & Bacher 2010) was performed along one transect line in the same row used for the pitfall traps; the most vegetated sections in the row was selected. Vegetation structure for both vineyard parcels and natural habitats was measured by taking the mean of ten repeated vegetation height measurements across the transect line (VegH) and by visual estimation of ground vegetation cover (in percent) at the entire parcel scale (GVC). The samplings were performed in November 2016, December 2016 and January 2017 (austral spring and summer) i.e. three sampling sessions separated by at least three weeks between each other. Considering both natural and vineyard habitats, we placed a total of 343 pitfall traps (3 traps x 38 sites x 3 sessions), from which only 299 traps were taken for arthropod identification (44 traps were removed by dogs), and collected 114 sweepnet samples (1 sweep-netting x 38 sites x 3 sessions).

Identification of arthropods was performed to order level for each individual; for Hemiptera, we identified each individual at the suborder level, thus distinguishing between leafhoppers (*Auchenorrhyncha*), aphids (*Sternorrhyncha*) and heteropterans (*Heteroptera*). In addition, beetles (*Coleoptera*) and spiders (*Araneae*) were identified to family level due to their high abundance found in a similar study previously done in Valais vineyards, Switzerland, and their use as biodiversity indicators in several previous studies (Diehl et al. 2013, Pearce & Vernier 2006, Riano & Niemelä 2003). A few poorly represented arthropods groups such as cockroaches (*Blattodea*), mites (*Acari*), silverfishes (*Zygentoma*) and springtails (*Collembola*) were categorized as "others". Once collected and identified, the pitfall traps and sweepnet specimens were stored in 98% ethanol and their biomass weighted after drying for 48 hours at 40°C and 30% relative humidity. To make sure that arthropods with different body size were homogenously dry, we measured three of the heaviest samples and plotted their mass over drying period, until reaching the minimal weight (asymptote of water loss over time).

Data processing

Ants (Formicidae) were not counted for the total abundance due to their eusocial lifestyle and their dominant presence in all types of habitat; their presence in traps is likely strongly influenced by the proximity to a colony, and their abundance would have masked the results for the remaining arthropod groups. Two raw datasets were produced from the sampling sessions: pitfall traps (PF) sampling (N=298; 234 from vineyard parcels, 64 from natural habitat) and sweepnet (SN) sampling (N=114; 90 from vineyard parcels and 64 from natural habitat). Natural habitat sampling was discarded from all analyses except when explicitly comparing vineyard to natural habitat arthropod abundance, biomass and richness.

For arthropod abundance (and biomass), response variables were always computed from PF and SN dataset separately and we computed the following variables (Fig. 1): PF arthropod abundance (and biomass), and SN abundance (and biomass). Data from PF and SN were analysed separately because of the different sampling units covered by these two techniques (mean abundance per pitfall trap and mean abundance per transect line, for pitfall and sweepnet sampling, respectively). PF abundance (and biomass) was calculated as the average of the abundances in the 3 PF per each parcel and session in order to avoid pseudoreplication. Pitfall traps accidentally flooded by irrigation, filled with soil by mechanic ploughing or lifted from ground level (hereafter "inadequate pitfall traps", in total N=47) were excluded to compute abundance (and biomass) since the values are given "per trap" and thus representative of a standardized sampling technique.

For arthropod richness, response variables were calculated both from the individual PF and SN datasets, and from combined PF and SN datasets. Richness in PF consists of the richness found in the three pitfall traps per parcel-session combined. The following variables were computed (Fig. 1; Table 1): arthropod order richness (including the sub-orders mentioned above and thus referred to hereafter as ‘group richness’), beetle family richness, spider family richness.

Data analysis and model selection

All the statistical tests and linear models were performed with R programming language, version 3.3.3 (R Core Team 2014) and RStudio interface software, version 1.0.153 (RStudio Team 2015). Generalized linear mixed models were built with ‘*lme4*’ (Bates et al. 2015) and analysed with ‘*MuMIn*’ (Barton 2016) and ‘*lmerTest*’ (Kuznetsova et al. 2016) R packages.

Boxplots and residual plots were produced with the R packages ‘*ggplot2*’ (Wickham 2009) and ‘*car’* (Weisberg 2011).

We built mixed linear models with Gaussian distribution for arthropod abundance, biomass and group richness. Preliminary bivariate analyses indicated that, in addition to management regime and vegetation structure (Suppl. Figs. 1-8); the sampling session and irrigation systems had a significant effect on the arthropod abundance and diversity (Suppl. Figs. 9-10). Consequently, the full model (Table 1 and Equation 1) included fixed effects (vineyard vegetation structures characteristics, management regime, and irrigation systems), the interactions between them, and two random effects (the sampling session and the parcel’s owner, as a few parcels were owned by the same private, thus suggesting similar management techniques). We then ran the model selection function ‘*dredge*’ (package ‘*MuMIn*’, Barton 2016) for each response variable and compared the resulting best candidate models, ranked by corrected Aikake information criteria (AICc). This ranking method was preferred over plain AIC because using AICc decreases the probability of selecting models that have too many parameters, i.e. overfitting. This probability can be substantial when the sample size N is not many times larger than the squared number of predictors k. Our full model was built on N = 75-90 sample size and k = 8 predictors (N just slightly bigger than k^2), so that the best solution was to rank our models by AICc.

The ‘*dredge*’ function takes the full model previously defined and builds a list of models with every possible fixed effects (including explicit interactions) combination, while keeping the same random effects. When AICc values difference between two model candidates was small enough (ΔAICc < 2), the selected best model was the one with greater Akaike weight (if 1.5 to 2 times bigger). When Akaike weights were of similar amplitude, the selected model was the one showing greater conditional R^2 (i.e. most explained variance by both fixed and random effects), which was computed with the ‘*r.squaredGLMM*’ function from the R package ‘*MuMIn*’ (Barton 2016). When even conditional R^2 were similar, by the law of parsimony, we selected the model containing less predictors. Finally, to compare arthropod abundance in vineyard parcels to natural habitat, we built a linear mixed model on the predictor ‘*habitat*’ (2 levels: ‘*natural*’ and ‘*vineyard*’) and included the following random effects: ‘*vineyard management regime*’ (4 levels: C, O, BD and N = natural), sampling session and parcel’s owner. As previously done in the abundance data management for vineyard habitats, we excluded all the inadequate PF traps and averaged the three traps per parcel and session.

Model's p-values ($P>|t|$) were found with Satterthwaite approximations to degrees of freedom of the corresponding predictor. Fixed effect's F-values were calculated by ANOVA performed on the candidate model with the '*anova*' function from the R package '*lmerTest*' (Kuznetsova et al. 2016). The models followed a Gaussian distribution (even abundance models, as the median was large enough to prefer a Gaussian over a Poisson distribution) and were checked for normality by looking at the histogram distribution of the residuals and homoscedasticity with their quantile-quantile plots.

RESULTS

Differences in vegetation structure

Biodynamic vineyards had significantly higher ground vegetation cover compared to organic vineyards (BD > O, $p = 0.003$). They also showed higher mean vegetation height compared to both organic and conventional vineyards (BD > O, $p = 0.04$ and BD > C, $p < 0.001$), see Suppl. Fig. 4.

Arthropod groups sampling

In PF sampling, the most abundant arthropod groups (*Formicidae* excluded) were isopods (*Isopoda*, N=3430), beetles (*Coleoptera*, N=3130) and spiders (*Araneae*, N=1993); the most abundant beetle families were carabids *(Carabaidae)*, rove beetles *(Staphylinidae)* and ant-like beetles *(Anthicidae);* the most abundant spider families were wolf spiders *(Lycosidae)*, sheet weavers *(Linyphiidae)* and ground spiders *(Gnaphosidae)*. Sorting index and sampling details are shown in Suppl. Table 2.

In SN sampling, the most abundant arthropod groups were aphids (*Sternorrhyncha*, N=6598), heteropterans (*Heteroptera*, N=4008) and dipterans (*Diptera*, N=2749); the most abundant beetle families were true weevils *(Curculionidae)*, ladybird beetles *(Coccinellidae)* and leaf beetles *(Chrysomelidae)*; the most abundant spider families were crab-spiders *(Thomisidae)*, orb-weaver spiders *(Araneidae)* and dwarf-sheet spiders *(Hahniidae)*. Sorting index and sampling details are shown in Suppl. Table 2.

Statistical modelling

Arthropod abundance in vineyards

A comprehensive list of all examined models is presented in Table 2. Overall arthropod abundance in PF did not show any significant difference between management regimes nor irrigation system, the only two predictors included in the best model. The best model for overall abundance model in SN included all the predictors but again, none had a significant effect (estimates, standard errors, p-values and F-values can be found in Table 2).

With respect to specific arthropod group, the following significant relationships were found (Suppl. Table 3). Beetle abundance in PF was higher in biodynamic ‘BD’ and organic ‘O’ parcels compared to conventional ‘C’ (p = 0.039 and p = 0.019, respectively). Beetle abundance in SN was found to have a positive relationship with GVC ($p < 0.001$, Fig. 2A and Suppl. Table 3) and with the interaction ‘GVC : irrigation’ (GVC:flood > GVC:drip, $p < 0.001$). Spider abundance in SN was lower in organic compared to conventional parcels (p = 0.043) and increased with vegH (p = 0.009, Fig. 2B and Table 2). Pollinator abundance in SN was lower in organic compared to biodynamic (p = 0.006), increasing with GVC ($p < 0.001$) and depending on the interaction ‘management : vegH’ (O > C, p = 0.001; O > BD, $p < 0.001$). In particular, dipteran abundance in SN was higher in biodynamic compared to conventional (p = 0.038, Fig. 2C and Table 2), for which also ground vegetation cover and vegetation height were found to be significant (respectively, $p < 0.001$ and p = 0.015). Dipteran abundance in PF was also higher in biodynamic compared to conventional (p = 0.049). Hymenopteran abundance in SN had a strong positive relationship with GVC ($p < 0.001$). Heteropteran abundance in SN was higher in conventional and biodynamic compared to organic parcels (respectively, $p < 0.001$ and p = 0.02), and additionally showed a negative relationship with vegetation height (p = 0.043) and the following significant interactions: ‘vegH : irrigation’ (vegH:drop > vegH:flood, $p < 0.001$) and ‘vegH : management’ (vegH:O > vegH:C, $p < 0.001$; vegH:O > vegH:BD, $p < 0.001$). Aphids abundance in SN had a positive relationship with vegetation height (p = 0.006) and the interaction ‘vegH : management’ was significant (vegH:BD < vegH:C, p = 0.014; vegH:O < vegH:C, p = 0.028). Finally, carabid beetles abundance in PF was higher in organic compared to conventional parcels (p = 0.045, Fig. 2D and Table 2).

Arthropod biomass in vineyards

A comprehensive list of all examined models is presented in the Table 3. In linear models with biomass variables, total biomass in PF had a significant relationship with the interaction ‘GVC : management’, i.e. the most vegetated organic parcels had higher biomass than the most vegetated conventional and biodynamic parcels (p = 0.008 and p = 0.005, respectively). The interaction ‘GVC : irrigation’ showed that drip watering combined with taller vegetation resulted in significantly increased biomass in PF compared to canal flooding with taller vegetation (p = 0.013). As for total biomass in SN, we found that biodynamic parcels showed significantly higher values compared to conventional parcels (p = 0.038, Fig. 3B and Table 3) and that these values increased with both GVC (Fig. 3A and Table 3) and vegetation height (respectively, p = 0.017 and p = 0.004).

Arthropod group/family richness in vineyards

A comprehensive list of all examined models is presented in Table 4. From the combined PF+SN group/family richness none of the selected explanatory variables showed significant difference. However, by analysing PF and SN separately, we found that beetle family richness and arthropod group richness in SN had a strongly significant positive relationship with GVC (both $p < 0.001$, Fig. 4A and Table 4). Arthropod group richness in PF showed significantly higher values in biodynamic compared to conventional parcels (BD > C, $p = 0.026$, Fig. 4B and Table 4).

Arthropod abundance, biomass and group richness in natural habitat

Heteropteran abundance in SN was higher in natural habitats (Suppl. Fig. 1) when compared to vineyard parcels ($p = 0.003$). Spider and hymenopteran abundance in SN were higher in natural habitats (respectively, $p < 0.001$ and $p = 0.005$). Camel spiders (*Solifugae*) as well as mantises (*Mantodea*) were almost exclusively found in PF from natural habitats (respectively, $p = 0.015$ and $p = 0.004$ higher abundance than in vineyard parcels). On the other hand, vineyards hosted on average more than thrice the amount of aphids, even though this difference was not significant ($p = 0.398$ in PF, and $p = 0.524$ in SN). Smaller, non-significant, variations were also observed within dipterans and isopods (vineyard > habitat, SN dipterans $p = 0.496$ and PF isopods $p = 0.723$). Lastly, SN and PF overall arthropod group richness were not significantly lower in vineyards compared to natural habitat (respectively, $p = 0.193$ and $p = 0.095$); on the other hand arthropod biomass in SN was significantly higher in vineyards compared to natural habitat ($p < 0.001$).

DISCUSSION

We successfully demonstrate how vegetation structure promotes arthropod diversity in vineyards. Increased ground vegetation cover between vine rows has clear, positive effects on arthropod abundance, biomass and group richness. These effects are exemplified by the increase in overall biomass, group richness, beetle family richness and abundance of pollinating insect orders such as coleopterans, dipterans and hymenopterans. An increase in vegetation height yields conflicting results: increased biomass, higher spider and aphid abundance, but lower dipteran and heteropteran abundance. Biodynamic vineyards show the highest diversity, followed by organic and conventional. Differences in arthropod diversity between biodynamic and organic management regimes are seldom significant. However, biodynamic vineyards are more vegetated, resulting in increased biodiversity more consistently than organic vineyards when compared to conventional. Comparisons with natural habitats showed that vineyards host less heteropterans, spiders and hymenopterans but present more overall arthropod biomass. This study confirms the key role of a considerate management of vineyards' uncultivated surface in favouring agricultural landscapes' biodiversity.

Effects of vegetation on arthropod diversity

Differences in arthropod diversity due to vegetation structures were only significant with respect to sweepnet sampling. While Mendoza's organic and conventional parcels share comparable vegetation structures due to similar vine rows ploughing and mowing regimes, biodynamic vineyards standout by larger vegetation structures and particular care for between-row floral diversity. Species richness of web-building spiders and order richness of prey increases with plant diversity (Greenstone 1984, Diehl et al. 2013) and increased vegetation complexity is a result of less intensive mowing regime. Accordingly, we found that spider abundance increases with vegetation height. Overall biomass and the overrepresented aphid abundance also increase with vegetation height. Aphid abundance however presents additional significant differences when considering the interaction between vegetation structure and management. With an increasing vegetation height, conventional vineyards host more aphids than organic and biodynamic. These results match with Diehl et al. 2013, in which web-building spiders at low management intensity contribute to aphid suppression.

Ground vegetation cover directly contributes to the increase in the abundances of coleopterans, dipterans, hymenopterans, coleopteran family richness and total biomass.

Effects of management regime on arthropod diversity

Carabid beetle abundance wash higher in organic vineyards but did not increase with ground vegetation cover. The reason that limits higher abundance to organic and not biodynamic (more vegetated) parcels might be that ground vegetation impedes carabids' movement and reduces pitfall catches (Greenslade 1964). Total arthropod biomass and carabid abundance were lower in conventional parcels: an intensively tilled soil may lead to a reduced diversity of carabid beetles (Miñarro & Dapena 2003) and herbicide applications could result in fewer large carabid individuals (Brust 1990). Accordingly, ground-dwelling spiders (mostly *Lycosidae* and *Gnaphosidae*) are more abundant in conventional than organic parcels, maybe due to competition with carabid beetles (similarly to the results of Shochat et al. 2004). Dipteran abundance, group richness and overall biomass increase in biodynamic vineyards compared to other management regimes, but these are more likely to be consequences of the increased vegetation cover. The irrigation system parameter was included in many best candidate models even though its significant effects barely appeared, i.e. only in terms of interactions with management regime or vegetation structures, making it difficult to interpret. The canal flooding technique favours the abundance of ground-dwelling wolf-spiders and isopods, but requires constant mechanic ploughing of the vine rows, which removes large sections of ground vegetation; hence the water-dripping system yields higher richness of vegetation insect groups and specific spider families (coleopterans, aphids, flower crab spiders and web-building spiders).

Comparison of arthropods in natural habitats and vineyards

The semi-arid shrubland of the Andean foothills, known as 'Monte', hosts a high proportion of endemic insect genera and species (Roig-Juñent et al. 2005). These natural habitats present drastically different arthropod community compositions compared to vineyards, which are persistently irrigated and plough, increasing soil disturbance. On the one hand, large amounts of heteropterans were collected across the natural habitats; these numbers were probably inflated by unintentional sampling during insects' reproductive peaks, resulting in high densities at very specific locations. Further differences consisted in higher abundance of hymenopterans (mostly solitary bees), spiders (mostly *Lycosidae* juveniles), orthopterans, lepidopterans and additional arthropod orders, virtually absent in vineyards: camel spiders

(*Solifugae*), scorpions (*Scorpiones*), cockroaches (*Blattodea*), silverfishes (*Thysanura*). On the other hand, in vineyards we sampled more aphids (*Sternorrhyncha*), leafhoopers (*Auchenorrhyncha*) and flies (*Diptera*): many species of these insect groups being known as common vineyard pests (e.g. the grape phylloxera *Daktulosphaira vitifoliae*, the glassy-winged sharpshooter *Homalodisca vitripennis* and the spotted wing fly *Drosophila suzukii*). Total arthropod biomass in pitfall traps was higher in vineyards, probably due to the higher abundance of isopods, which were often the bulkiest organisms in the samples, or due to vineyards' higher primary production which correlates with species diversity (Haberl et al. 2004). Isopods settle more densely in soil with added water and artificial holes (Baker, Sachal & Brand 1998). The higher isopod abundance in vineyards might thus be explained by the common canal flooding irrigation system used in the region.

Recommendations

Mean vegetation height yielded contrasting results for biomass, heteropteran and dipteran abundance in sweepnet sampling. Its effect was significant mostly within interactions with other predictors (management or irrigation system) and of challenging interpretation. The reasons might be: 1) the unpredictability of mowing activity, in contrast with ground vegetation cover (which tends to be more stable throughout the sampling session and more specific to each parcel and management regime), and 2) the inefficacity of our measurement method, i.e. we considered only one transect line to be representative of the whole parcel's mean vegetation height. For these reasons, vegetation height effects and interactions need to be interpreted carefully and a variable showing mowing frequency should be added to the full model. Herbicide application was not quantified but it might be an interesting parameter to better understand variations in vegetation structure across the sampling sessions. Lastly, identifying arthropod community changes with better precision might require a detrended correspondence analysis of beetle and spider families over management and vegetation factors, which is highly recommended for future studies.

Conclusion

Arthropod abundance in vineyards is strongly dependent on vegetation structure between vine lines. That is, better biodiversity yields can be obtained by a considerate management of the parcel's uncultivated surface even in conventional vineyards where herbicide application is limited to a small area surrounding the vine stock. Higher arthropod abundance is correlated with higher ground vegetation cover and vegetation height, for which Mendoza's biodynamic vineyards outstand both organic and conventional parcels. Arthropod abundance, biomass and richness linear mixed models successfully confirmed our curvilinear relationship with vegetation cover hypothesis, demonstrating that abundance peaks were reached at around 70% ground vegetation cover. This suggests that recurrent, intensive weed control affects entire trophic chains: from pollinators (in particular dipterans and hymenopterans) and herbivore populations, up to beneficial organisms, generalist predator carabid beetles and web-building spiders. Arthropod diversity can be efficiently promoted in every management regime by a less intensive management of the vineyard uncultivated surface and increasing vegetation cover, as exemplified by the particular care of biodynamic parcels' floral diversity between vine rows. Ultimately, this approach might favour species conservation opportunities within the agricultural context of grape production. By combining a moderate mowing activity with increased ground vegetation cover, biodynamic management demonstrates to effectively promote arthropod biodiversity more than in organic and conventional vineyards.

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TABLES & EQUATIONS

Table 1 Full model's explanatory variables with each tested response variable for vineyard parcels data *(ab. = abundance, PF = pitfall, SN = sweepnet; C = conventional, BD = biodynamic, O = organic*). *SN Pollinators were defined as the sum of the abundances of lepidopterans, dipterans, heteropterans, hymenopterans and coleopterans. Sampling Unit = PF/SN per parcel.session; N = 75 for PF abundance and biomass; N = 90 for SN abundance and biomass; N = 83 for combined richness.

Response variables	Explanatory variables		
	Fixed effects	**Interactions**	**Random effects**
Combined PF & SN beetle family richness	a) Management regime (mgmt) *categorical [C, BD, O]*	e) gvc : mgmt	i) Sampling session *categorical [Nov, Dec, Jan]*
Combined PF & SN group richness		f) vegH : mgmt	j) Parcel owner *categorical with 23 levels*
Combined PF & SN spider family richness	b) Ground vegetation cover (gvc) *continuous [0 - 100 %]*	g) irr : gvc	
PF aphid ab.		h) irr : vegH	
PF beetle ab.			
PF carabid ab.	c) Vegetation height (vegH) *continuous [cm]*		
PF dipteran ab.			
PF grasshopper ab.			
PF group richness			
PF heteropteran ab.			
PF hymenopteran ab.	d) Irrigation system (irr) *categorical [drop, flood]*		
PF isopod ab.			
PF spider ab.			
PF total ab.			
PF total biomass [mg]			
PF true weevil ab.			
PF wolf spider ab.			
SN aphid ab.			
SN beetle ab.			
SN beetle family richness			
SN spider family richness			
SN dipteran ab.			
SN heteropteran ab.			
SN hymenopteran ab.			
SN ladybird beetle ab.			
SN leaf beetle ab.			
SN leafhopper ab.			
SN orb-weaver ab.			
SN group richness			
SN pollinator* ab.			
SN total ab.			
SN total biomass [mg]			

Table 2 Outputs of the best linear mixed models of arthropod abundance in vineyard parcels. PF = pitfall, SN = sweepnet, GVC = ground vegetation cover, VegH = vegetation height, BD = biodynamic, O = organic, C = conventional, A : B = interaction between predictors. *Pollinators = sum of dipterans, heteropterans, lepidopterans, hymenopterans and coleopterans (without carabids) abundances. Specific arthropod groups and families models which had no significant effects or very low overall abundances are not showed. Significant differences (*P* < 0.05) are presented in bold.

Response variable	**Abundance best models**				
(abundance)	**Predictors**	**Estimate**	**SE**	**P(>|t|)**	**F-value**
PF total	**Management**				0.327
(cond. R^2 = 0.166)	BD vs. C	2.452	19.457	0.901	
	O vs. C	12.56	16.16	0.447	
	O vs. BD	10.107	19.374	0.609	
	Irrigation				0.054
	drop vs. flood	-4.850	20.879	0.82	
SN total	**Management**				0.453
(cond. R^2 = 0.336)	BD vs. C	-29.082	77.832	0.710	
	O vs. C	-59.596	63.064	0.348	
	O vs. BD	-30.514	71.775	0.672	
	Irrigation				0.315
	drop vs. flood	-43.279	20.879	0.577	
	GVC	-0.403	0.973	0.680	0.608
	VegH	-2.066	2.852	0.471	<0.001
	Irrigation : VegH				
	drop vs. flood	3.038	2.295	0.189	1.752
	GVC : Management				0.620
	BD vs. C	0.852	1.238	0.494	
	O vs. C	1.630	1.485	0.276	
	O vs. BD	0.778	1.409	0.582	
	VegH : Management				0.178
	BD vs. C	0.211	2.620	0.936	
	O vs. C	1.476	2.666	0.581	
	O vs. BD	1.266	2.658	0.635	
PF beetles	**Management**				4.124
(cond. R^2 = 0.503)	BD vs. C	10.935	4.914	**0.039**	
	O vs. C	10.359	4.039	**0.019**	
	O vs. BD	-0.577	4.927	0.908	
	Irrigation				1.441
	drop vs. flood	6.553	5.459	0.247	
PF spiders	**Management**				0.624

(cond. R^2 = 0.238)	BD vs. C	-2.601	2.627	0.335	
	O vs. C	0.101	4.039	0.964	
	O vs. BD	2.702	2.608	0.315	
	Irrigation				0.414
	drop vs. flood	-1.760	2.736	0.532	
SN beetles	**GVC**	0.075	0.014	**<0.001**	19.196
(cond. R^2 = 0.384)	**Irrigation**				0.775
	drop vs. flood	0.741	0.842	0.381	
	Irrigation : GVC				16.229
	drop vs. flood	-0.071	0.018	**<0.001**	
SN spiders	**Management**				2.619
(cond. R^2 = 0.336)	BD vs. C	-0.903	0.623	0.176	
	O vs. C	-1.13	0.504	**0.043**	
	O vs. BD	-0.227	0.593	0.711	
	Irrigation				0.141
	drop vs. flood	0.223	0.595	0.720	
	VegH	0.048	0.018	**0.009**	7.263
PF pollinators*	**Management**				4.56
(cond. R^2 = 0.266)	BD vs. C	18.186	7.328	**0.024**	
	O vs. C	15.883	6.093	**0.018**	
	O vs. BD	-2.303	7.292	0.756	
	Irrigation				0.522
	drop vs. flood	5.633	7.797	0.484	
SN pollinators*	**Management**				4.457
(cond. R^2 = 0.469)	BD vs. C	15.849	13.375	0.242	
	O vs. C	-23.213	11.776	0.053	
	O vs. BD	-39.063	13.526	**0.006**	
	Irrigation				0.077
	drop vs. flood	1.702	6.119	0.787	
	GVC	0.390	0.106	**<0.001**	13.589
	VegH	-0.199	0.349	0.570	2.608
	VegH : Management				8.229
	BD vs. C	-0.003	0.456	0.994	
	O vs. C	1.622	0.483	**0.001**	
	O vs. BD	1.625	0.441	**<0.001**	
PF dipterans	**Management**				2.196
(cond. R^2 = 0.144)	BD vs. C	7.814	3.904	**0.049**	
	O vs. C	4.685	3.276	0.157	
	O vs. BD	-3.129	3.852	0.419	

	Irrigation				0.063
	drop vs. flood	-0.999	3.991	0.803	
SN dipterans	**Management**				2.319
(cond. R^2 = 0.351)	BD vs. C	9.191	4.366	**0.038**	
	O vs. C	5.074	3.659	0.169	
	O vs. BD	-4.117	4.170	0.328	
	Irrigation				3.147
	drop vs. flood	-7.398	4.170	0.080	
	GVC	0.301	0.073	**<0.001**	17.207
	VegH	-0.362	0.146	**0.015**	6.189
SN hymenopterans	**Management**				1.509
(cond. R^2 = 0.291)	BD vs. C	0.589	0.878	0.504	
	O vs. C	1.331	0.767	0.086	
	O vs. BD	0.741	0.884	0.404	
	Irrigation				0.250
	drop vs. flood	-0.447	0.894	0.618	
	GVC	0.068	0.014	**<0.001**	24.825
SN heteroptera	**Management**				8.647
(cond. R^2 = 0.649)	BD vs. C	-9.031	9.954	0.369	
	O vs. C	-31.735	7.888	**<0.001**	
	O vs. BD	-22.705	9.453	**0.020**	
	Irrigation				4.011
	drop vs. flood	-20.015	9.993	0.051	
	VegH	-0.719	0.349	**0.043**	12.746
	VegH : Irrigation				14.033
	drop vs. flood	1.052	0.281	**<0.001**	
	VegH : Management				18.312
	BD vs. C	0.356	0.305	0.247	
	O vs. C	1.659	0.304	**<0.001**	
	O vs. BD	1.302	0.273	**<0.001**	
SN aphids	**Management**				1.636
(cond. R^2 = 0.337)	BD vs. C	38.843	23.796	0.107	
	O vs. C	26.073	19.155	0.178	
	O vs. BD	-12.771	23.930	0.595	
	Irrigation				0.639
	drop vs. flood	8.607	10.769	0.427	
	VegH	1.615	0.778	**0.006**	1.367

	VegH : Management				3.708
	BD vs. C	-1.953	0.778	**0.014**	
	O vs. C	-1.789	0.794	**0.028**	
	O vs. BD	-0.164	0.751	0.827	
PF carabids	**Management**				2.336
(cond. R^2 = 0.738)	BD vs. C	2.683	2.383	0.274	
	O vs. C	4.168	1.946	**0.045**	
	O vs. BD	1.485	2.399	0.543	
	Irrigation				1.598
	drop vs. flood	3.415	2.702	0.222	

Table 3 Outputs of the best linear mixed models of arthropod biomass in vineyard parcels. PF = pitfall, SN = sweepnet, GVC = ground vegetation cover, VegH = vegetation height, BD = biodynamic, O = organic, C = conventional, A : B = interaction between predictors. Significant differences (*P* < 0.05) are presented in bold.

Response variable (biomass)	Biomass best models Predictors	Estimate	SE	P(>|t|)	F-value
PF total biomass [mg]	**Management**				0.841
(cond. R^2 = 0.603)	BD vs. C	-447.780	377.187	0.240	
	O vs. C	-308.699	304.973	0.316	
	O vs. BD	139.081	359.093	0.700	
	Irrigation				1.584
	drop vs. flood	-389.275	309.258	0.219	
	GVC	-13.385	6.867	0.056	0.199
	VegH	-9.479	7.952	0.238	2.611
	GVC : Management				4.999
	BD vs. C	3.066	6.289	0.628	
	O vs. C	21.438	7.800	**0.008**	
	O vs. BD	18.372	6.271	**0.005**	
	VegH : Management				1.797
	BD vs. C	13.282	10.97	0.231	
	O vs. C	-8.374	12.119	0.492	
	O vs. BD	-21.656	11.772	0.071	
	GVC : Irrigation				6.534
	drop vs. flood	12.769	4.995	**0.013**	
SN total biomass [mg]	**Management**				2.401
(cond. R^2 = 0.370)	BD vs. C	47.303	22.283	**0.038**	
	O vs. C	7.210	19.207	0.709	
	O vs. BD	-40.303	22.677	0.083	
	Irrigation				2.054
	drop vs. flood	17.251	12.038	0.179	
	GVC	0.418	0.171	**0.017**	6.000
	VegH	1.626	0.554	**0.004**	7.725
	VegH : Management				4.348
	BD vs. C	-1.864	0.717	**0.011**	
	O vs. C	-0.224	0.760	0.769	
	O vs. BD	1.640	0.696	**0.021**	

Table 4 Outputs of the best linear mixed models of arthropod group/family richness in vineyard parcels. PF = pitfall, SN = sweepnet, BD = biodynamic, O = organic, C = conventional. Significant differences (*P* < 0.05) are presented in bold.

Response variable (richness)	**Group/family richness best models**				
	Predictors	**Estimate**	**SE**	**P(>|t|)**	**F-value**
Combined group richness	**Management**				0.8413
(cond. R^2 = 0.603)	BD vs. C	-447.78	377.187	0.240	
	O vs. C	-308.699	304.973	0.316	
	O vs. BD	139.081	359.093	0.700	
	Irrigation				1.584
	drop vs. flood	-389.275	309.258	0.219	
Combined beetle family richness	**Management**				2.313
(cond. R^2 = 0.497)	BD vs. C	2.286	1.151	0.063	
	O vs. C	1.500	0.955	0.133	
	O vs. BD	-0.786	1.154	0.505	
	Irrigation				0.666
	drop vs. flood	1.046	1.282	0.427	
Combined spider family richness	**Management**				1.242
(cond. R^2 = 0.276)	BD vs. C	-0.004	0.809	0.996	
	O vs. C	-0.981	0.690	0.171	
	O vs. BD	-0.976	0.802	0.242	
	Irrigation				2.054
	drop vs. flood	0.445	0.858	0.614	
SN group richness	**GVC**	0.040	0.007	**<0.001**	3.591
(cond. R^2 = 0.360)					
SN beetle family richness	**GVC**	0.013	0.003	**<0.001**	14.901
(cond. R^2 = 0.273)					
PF group richness	**Management**				2.961
(cond. R^2 = 0.292)	BD vs. C	1.667	0.685	**0.026**	
	O vs. C	0.623	0.570	0.289	
	O vs. BD	-1.045	0.683	0.146	
	Irrigation				2.621
	drop vs. flood	1.179	0.728	0.131	

$$Full\,model = \boldsymbol{abudance/biomass/richness} \sim mgmt + gvc + vegH + irr + gvc{:}mgmt + vegH : mgmt + irr : mgmt + irr : vegH + (1 \mid session) + (1 \mid owner)$$

Equation 1 Full linear mixed model equation. Three types of response variable were tested: arthropod abundance, arthropod biomass and group/family richness. Fixed effects: mgmt = management regime; gvc = ground vegetation cover; vegH = mean vegetation height; irr = irrigation system. Interactions: P1:P2 = interaction between P1 and P2. Random effects: session = sampling session; owner = parcel owner.

FIGURES

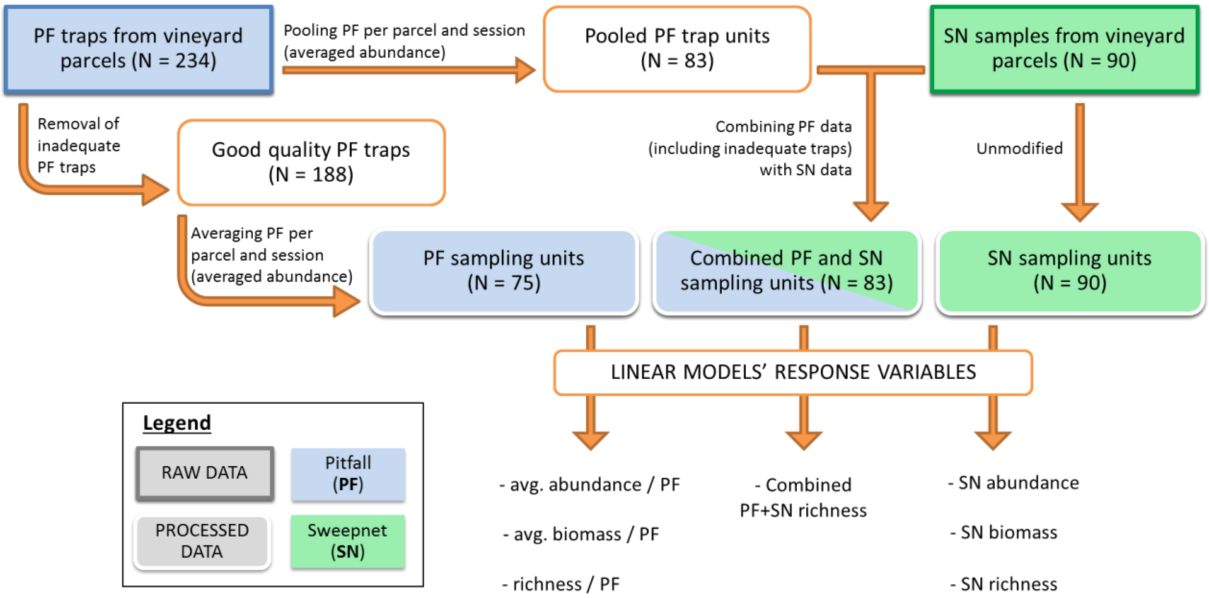


Figure 1 Data processing organigram presenting the arthropod sampling protocol in 30 vineyard parcels using two different techniques: pitfall sampling and sweepnet samplings. "Richness" refers to three separate variables: beetle family richness, spider family richness and arthropod group richness (orders and some suborders; see text for details).

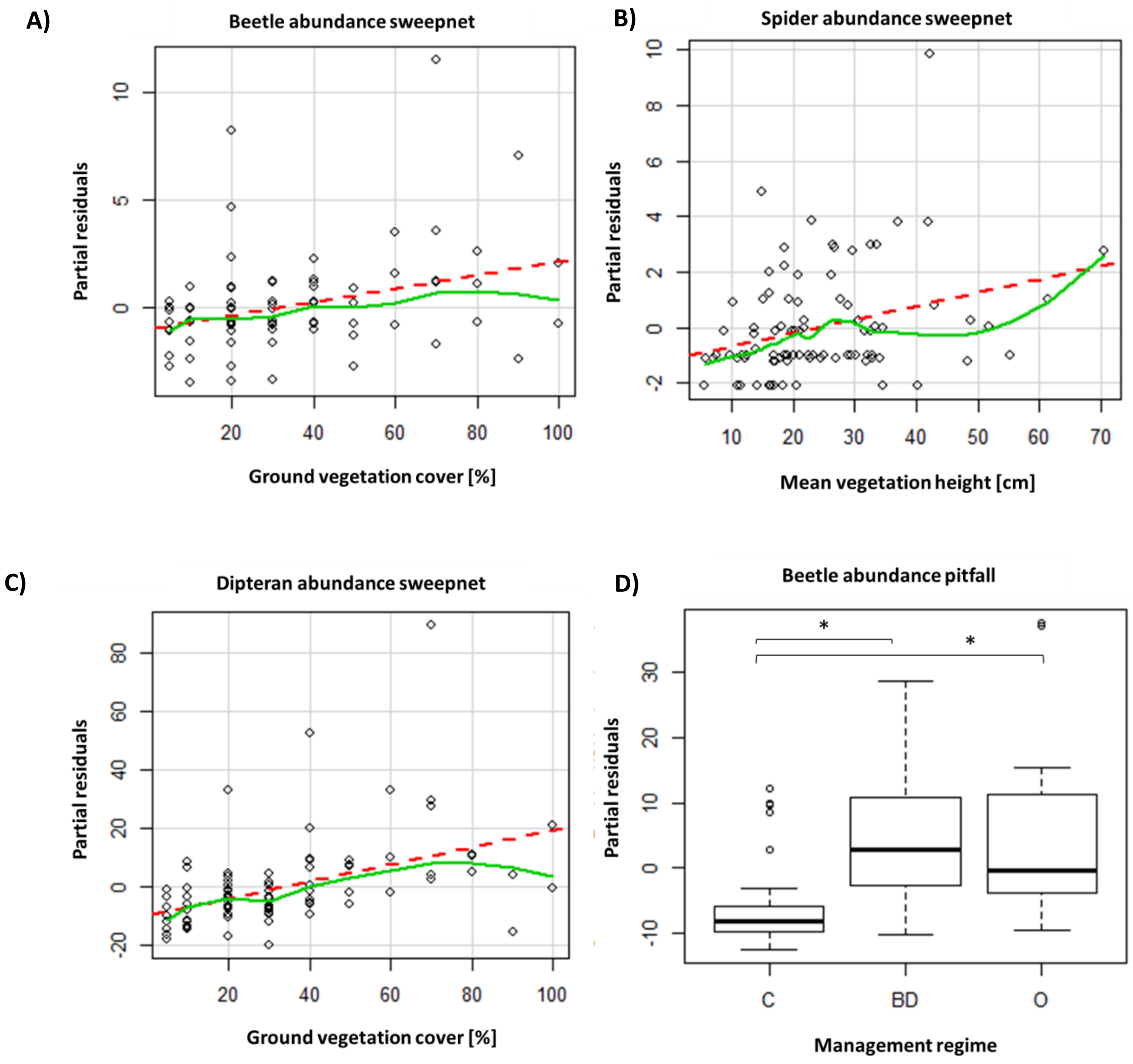


Figure 2 Partial residual plots of linear models examining arthropod abundance in Argentinian vineyards, see Suppl. Table 3 for model details. **A)** Beetles abundance in sweepnet (SN) sampling over ground vegetation cover ($p < 0.001$). **B)** Spiders abundance in SN sampling over mean vegetation height ($p = 0.009$). **C)** Dipterans abundance in SN sampling over ground vegetation cover ($p < 0.001$). **D)** Beetles abundance in pitfall (PF) traps over management regime (C = conventional, BD = biodynamic, O = organic; BD > C, $p = 0.039$; O > C, $p = 0.019$).

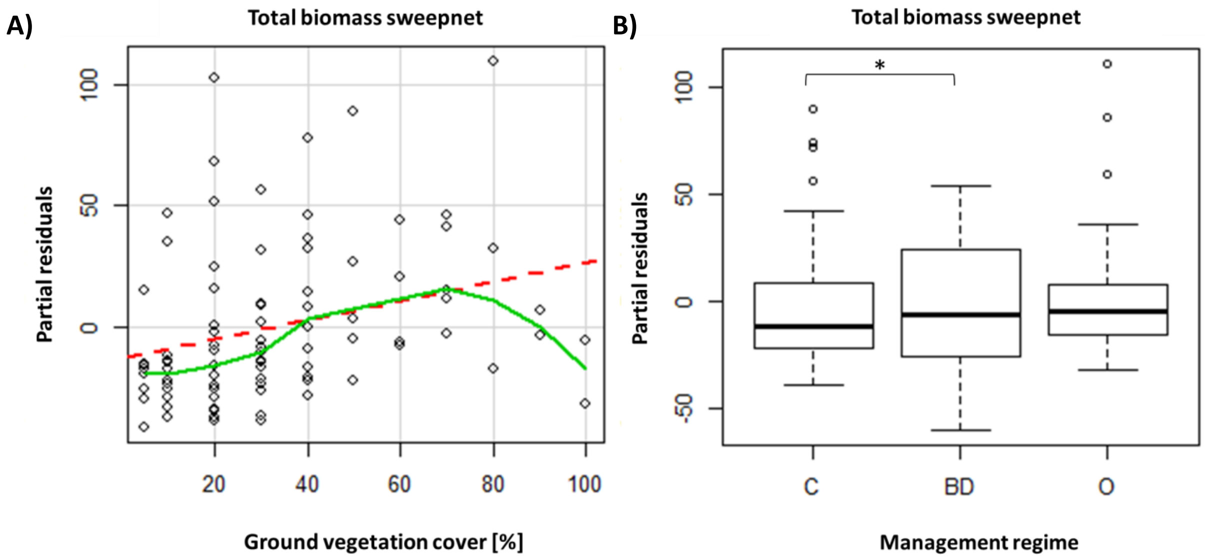


Figure 3 Partial residual plots of linear models examining arthropod biomass in Argentinian vineyards, see Supplementary Table 4 for model details. **A)** Total biomass in sweepnet (SN) sampling over ground vegetation cover ($p = 0.017$). **B)** Total biomass in SN sampling over management regime (C = conventional, BD = biodynamic, O = organic; BD > C, $p = 0.038$).

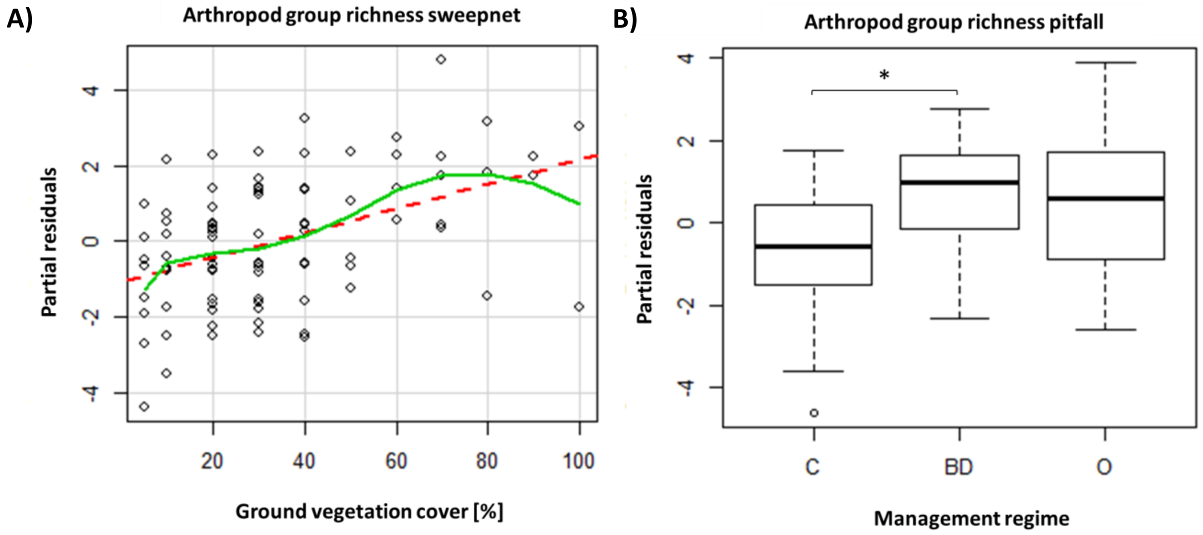


Figure 4 Partial residual plots of linear models examining arthropod group richness in Argentinian vineyards, see Supplementary Table 5 for model details. **A)** Arthropod group richness from sweepnet (SN) sampling over ground vegetation cover ($p < 0.001$). **B)** Arthropod group richness from PF sampling over management regime (C = conventional, BD = biodynamic, O = organic; BD > C, $p = 0.026$).

SUPPLEMENTARY MATERIAL

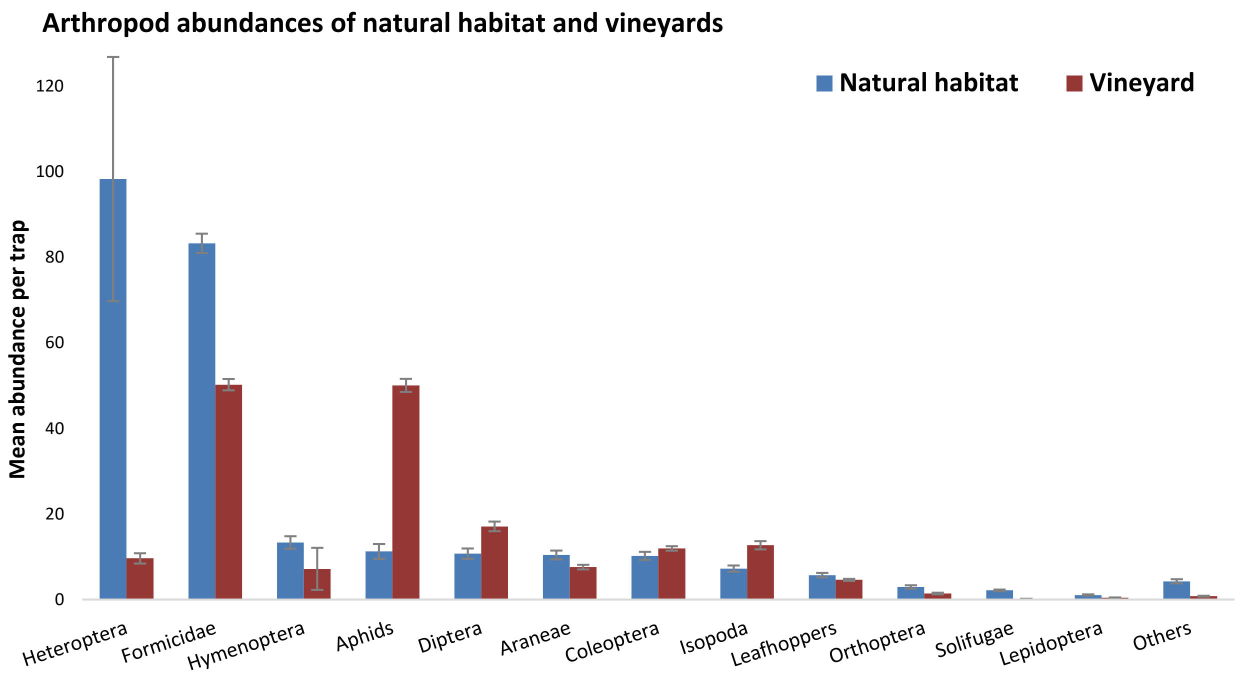
Supplementary Table 1 GPS coordinates, management and vegetation characteristics of the sampling sites. Management regime: BD = biodynamic, O = organic, C = conventional, N = Natural habitat. Irrigation system: drop = drip irrigation, flood = canal flooding.

Parcel ID	GPS coordinates [DD]	Municipality	Sampling date	Management regime	Mean vegetation height [cm]	Ground vegetation cover (gvc) [%]	Irrigation system
Alpamanta	-33.2325, -68.925	Luján de Cuyo	01.11.2016	BD	48.3	100	drop
Alpamanta	-33.2325, -68.925	Luján de Cuyo	07.12.2016	BD	70.6	100	drop
Alpamanta	-33.2325, -68.925	Luján de Cuyo	10.01.2017	BD	28.9	20	drop
Andalhue	-33.19361, -68.94194	Ugarteche	01.11.2016	O	26.5	10	drop
Andalhue	-33.19361, -68.94194	Ugarteche	07.12.2016	O	61.4	50	drop
Andalhue	-33.19361, -68.94194	Ugarteche	10.01.2017	O	21.8	10	drop
Argento	-33.75611, -69.1525	La Consulta	02.11.2016	O	7.5	5	drop
Argento	-33.75611, -69.1525	La Consulta	12.12.2016	O	18.6	20	drop
Argento	-33.75611, -69.1525	La Consulta	11.01.2017	O	13.7	40	drop
Aurea	-33.76722, -69.08916	La Consulta	02.11.2016	BD	55.2	10	flood
Aurea	-33.76722, -69.08916	La Consulta	12.12.2016	BD	33.6	10	flood
Aurea	-33.76722, -69.08916	La Consulta	11.01.2017	BD	9.9	5	flood
Caelum	-33.08833, -68.94333	Luján de Cuyo	31.10.2016	C	32.8	20	drop
Caelum	-33.08833, -68.94333	Luján de Cuyo	06.12.2016	C	26.3	20	drop
Caelum	-33.08833, -68.94333	Luján de Cuyo	09.01.2017	C	19.9	30	drop
Caligiore	-33.19944, -68.90055	Luján de Cuyo	01.11.2016	O	20	30	drop
Caligiore	-33.19944, -68.90055	Luján de Cuyo	07.12.2016	O	30.3	5	drop
Caligiore	-33.19944, -68.90055	Luján de Cuyo	10.01.2017	O	23.4	20	drop
Cecchin 1	-33.00881, -68.80424	Maipú	03.11.2016	O	48.8	90	flood
Cecchin 1	-33.00881, -68.80424	Maipú	10.12.2016	O	30.7	60	flood
Cecchin 1	-33.00881, -68.80424	Maipú	12.01.2017	O	16.2	50	flood
Cecchin 2	-33.01244, -68.80778	Maipú	03.11.2016	O	21.9	5	flood
Cecchin 2	-33.01244, -68.80778	Maipú	10.12.2016	O	13.9	5	flood
Cecchin 2	-33.01244, -68.80778	Maipú	12.01.2017	O	18.6	20	flood
Chakana 1	-33.17916, -68.90578	Ugarteche	01.11.2016	BD	17.1	10	drop
Chakana 1	-33.17916, -68.90578	Ugarteche	07.12.2016	BD	37	40	drop
Chakana 1	-33.17916, -68.90578	Ugarteche	10.01.2017	BD	16.8	10	drop
Chakana 2	-33.17642, -68.91878	Ugarteche	01.11.2016	BD	19	30	drop
Chakana 2	-33.17642, -68.91878	Ugarteche	07.12.2016	BD	29.6	20	drop
Chakana 2	-33.17642, -68.91878	Ugarteche	10.01.2017	BD	13.8	30	drop
Decero	-33.12055, -68.94305	Luján de Cuyo	31.10.2016	C	26.9	30	drop
Decero	-33.12055, -68.94305	Luján de Cuyo	06.12.2016	C	40.2	30	drop
Decero	-33.12055, -68.94305	Luján de Cuyo	09.01.2017	C	21	30	drop
Del Campo	-33.1798, -68.90195	Ugarteche	01.11.2016	C	22.9	20	drop
Del Campo	-33.1798, -68.90195	Ugarteche	07.12.2016	C	10.9	10	drop
Del Campo	-33.1798, -68.90195	Ugarteche	10.01.2017	C	20.8	30	drop
Ernesto Catena	-33.66694, -69.16722	Vistas Flores	02.11.2016	BD	31.9	70	drop
Ernesto Catena	-33.66694, -69.16722	Vistas Flores	12.12.2016	BD	42	70	drop
Ernesto Catena	-33.66694, -69.16722	Vistas Flores	11.01.2017	BD	42.9	30	drop
Finca del Inca	-33.19609, -68.99004	Agrelo	01.11.2016	C	17.2	40	drop
Finca del Inca	-33.19609, -68.99004	Agrelo	07.12.2016	C	34.5	30	drop
Finca del Inca	-33.19609, -68.99004	Agrelo	10.01.2017	C	18.7	20	drop
Jean Bousquet	-33.43858, -69.19943	Tupungato	02.11.2016	O	16.8	10	drop
Jean Bousquet	-33.43858, -69.19943	Tupungato	12.12.2016	O	12.5	5	drop
Jean Bousquet	-33.43858, -69.19943	Tupungato	11.01.2017	O	29	5	drop
Kontriras 1	-33.0665, -68.84365	Perdriel	03.11.2016	BD	32.7	60	flood
Kontriras 1	-33.0665, -68.84365	Perdriel	10.12.2016	BD	18.2	20	flood
Kontriras 1	-33.0665, -68.84365	Perdriel	12.01.2017	BD	24.9	80	flood
Kontriras 2	-33.06379, -68.8408	Perdriel	03.11.2016	BD	51.8	60	flood
Kontriras 2	-33.06379, -68.8408	Perdriel	10.12.2016	BD	32.2	70	flood
Kontriras 2	-33.06379, -68.8408	Perdriel	12.01.2017	BD	33.4	90	flood
Kontriras 3	-33.0113, -68.71003	Maipú	03.11.2016	BD	32.9	20	flood
Kontriras 3	-33.0113, -68.71003	Maipú	10.12.2016	BD	27.7	70	flood
Kontriras 3	-33.0113, -68.71003	Maipú	12.01.2017	BD	25	30	flood
La Clyde 1	-33.75944, -69.10019	La Consulta	02.11.2016	C	14.9	30	drop
La Clyde 1	-33.75944, -69.10019	La Consulta	12.12.2016	C	18.5	30	drop
La Clyde 1	-33.75944, -69.10019	La Consulta	11.01.2017	C	16.9	20	drop
La Clyde 2	-33.76209, -69.0955	La Consulta	02.11.2016	C	12.3	30	drop

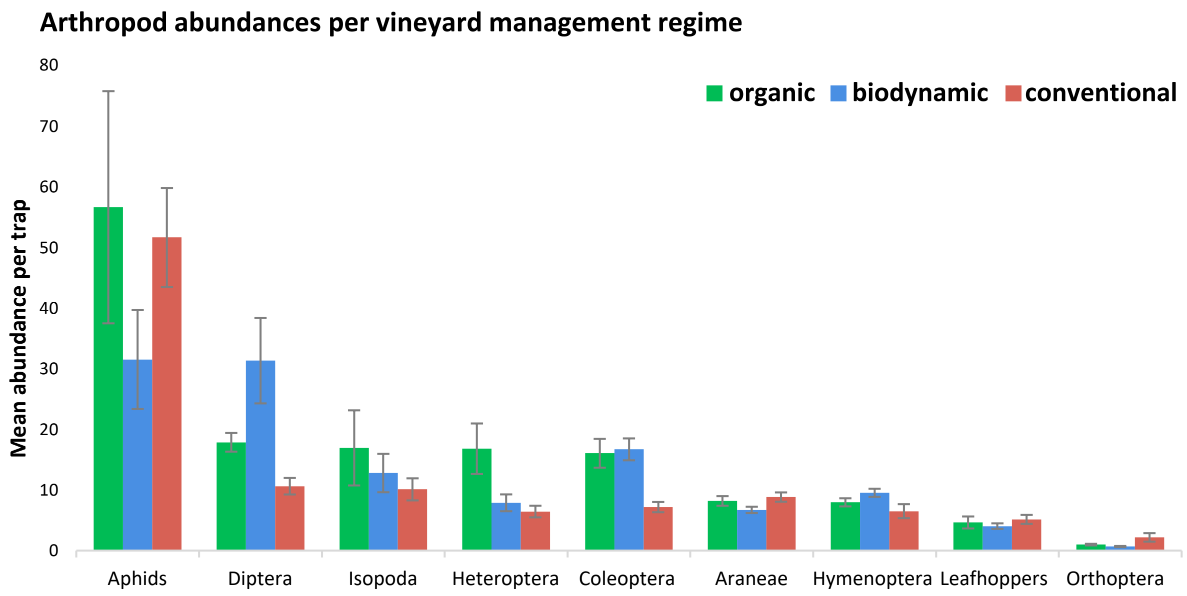
La Clyde 2	-33.76209, -69.0955	La Consulta	12.12.2016	C	17.9	40	drop
La Clyde 2	-33.76209, -69.0955	La Consulta	11.01.2017	C	34.1	30	drop
Las Yeguas	-33.08444, -69.00694	Luján de Cuyo	31.10.2016	O	19.3	40	drop
Las Yeguas	-33.08444, -69.00694	Luján de Cuyo	06.12.2016	O	34.6	50	drop
Las Yeguas	-33.08444, -69.00694	Luján de Cuyo	09.01.2017	O	21	20	drop
Margarita	-33.41632, -69.17146	Tupungato	02.11.2016	C	16.5	30	drop
Margarita	-33.41632, -69.17146	Tupungato	12.12.2016	C	24.6	20	drop
Margarita	-33.41632, -69.17146	Tupungato	11.01.2017	C	11	20	drop
N habitat 1	-33.08981, -68.98577	Luján de Cuyo	31.10.2016	N	52.6	80	none
N habitat 1	-33.08981, -68.98577	Luján de Cuyo	06.12.2016	N	34	70	none
N habitat 1	-33.08981, -68.98577	Luján de Cuyo	09.01.2017	N	43.5	70	none
N habitat 2	-33.06858, -68.84423	Perdriel	03.11.2016	N	30	50	none
N habitat 2	-33.06858, -68.84423	Perdriel	10.12.2016	N	39.6	70	none
N habitat 2	-33.06858, -68.84423	Perdriel	12.01.2017	N	32	70	none
N habitat 3	-33.17937, -68.8982	Ugarteche	01.11.2016	N	45.6	100	none
N habitat 3	-33.17937, -68.8982	Ugarteche	07.12.2016	N	61.1	100	none
N habitat 3	-33.17937, -68.8982	Ugarteche	10.01.2016	N	72.8	100	none
N habitat 4	-33.41567, -69.17389	Tupungato	02.11.2016	N	53	70	none
N habitat 4	-33.41567, -69.17389	Tupungato	11.12.2016	N	38.6	70	none
N habitat 4	-33.41567, -69.17389	Tupungato	11.01.2017	N	36.6	60	none
N habitat 5	-33.04839, -68.82112	Maipú	03.11.2016	N	42.6	70	none
N habitat 5	-33.04839, -68.82112	Maipú	10.12.2016	N	32.6	80	none
N habitat 5	-33.04839, -68.82112	Maipú	12.01.2017	N	35.6	70	none
N habitat 6	-33.1979, -68.99727	Agrelo	01.11.2016	N	42.5	50	none
N habitat 6	-33.1979, -68.99727	Agrelo	07.12.2016	N	39.7	50	none
N habitat 6	-33.1979, -68.99727	Agrelo	10.01.2017	N	38.7	60	none
N habitat 7	-33.78613, -69.11413	La Consulta	02.11.2016	N	39.5	70	none
N habitat 7	-33.78613, -69.11413	La Consulta	12.12.2016	N	35.2	70	none
N habitat 7	-33.78613, -69.11413	La Consulta	11.01.2017	N	33.5	70	none
N habitat 8	-33.11131, -68.94066	Luján de Cuyo	31.10.2016	N	24.3	60	none
N habitat 8	-33.11131, -68.94066	Luján de Cuyo	06.12.2016	N	45.2	70	none
N habitat 8	-33.11131, -68.94066	Luján de Cuyo	09.01.2017	N	29.7	70	none
Ojo de Vino 1	-33.12972, -68.96416	Luján de Cuyo	31.10.2016	O	22.6	30	drop
Ojo de Vino 1	-33.12972, -68.96416	Luján de Cuyo	06.12.2016	O	15.2	20	drop
Ojo de Vino 1	-33.12972, -68.96416	Luján de Cuyo	09.01.2017	O	29.5	20	drop
Ojo de Vino 2	-33.12526, -68.9695	Luján de Cuyo	31.10.2016	O	19.2	10	drop
Ojo de Vino 2	-33.12526, -68.9695	Luján de Cuyo	06.12.2016	O	11.7	10	drop
Ojo de Vino 2	-33.12526, -68.9695	Luján de Cuyo	09.01.2017	O	16.1	10	drop
Palumbo	-33.38833, -69.18805	Tupungato	02.11.2016	C	10.2	5	drop
Palumbo	-33.38833, -69.18805	Tupungato	12.12.2016	C	7.1	10	drop
Palumbo	-33.38833, -69.18805	Tupungato	11.01.2017	C	26.8	40	drop
San Diego	-33.05107, -68.8214	Maipú	03.11.2016	C	5.8	80	drop
San Diego	-33.05107, -68.8214	Maipú	10.12.2016	C	5.7	40	drop
San Diego	-33.05107, -68.8214	Maipú	12.01.2017	C	11.6	40	drop
Septima	-33.09351, -68.94396	Luján de Cuyo	31.10.2016	C	14.3	40	drop
Septima	-33.09351, -68.94396	Luján de Cuyo	06.12.2016	C	42.1	80	drop
Septima	-33.09351, -68.94396	Luján de Cuyo	09.01.2017	C	23	50	drop
Sophenia 1	-33.46171, -69.21761	Tupungato	02.11.2016	C	20.5	40	drop
Sophenia 1	-33.46171, -69.21761	Tupungato	12.12.2016	C	16.1	30	drop
Sophenia 1	-33.46171, -69.21761	Tupungato	11.01.2017	C	20.8	40	drop
Sophenia 2	-33.45781, -69.22386	Tupungato	02.11.2016	C	32.6	70	drop
Sophenia 2	-33.45781, -69.22386	Tupungato	12.12.2016	C	11	40	drop
Sophenia 2	-33.45781, -69.22386	Tupungato	11.01.2017	C	31.6	60	drop
Trapezio	-33.13861, -68.93444	Agrelo	31.10.2016	C	17.2	20	drop
Trapezio	-33.13861, -68.93444	Agrelo	06.12.2016	C	8.9	5	drop
Trapezio	-33.13861, -68.93444	Agrelo	09.01.2017	C	20.3	50	drop

Supplementary Table 2 Abundance data for arthropods sampled in the 38 sites (30 vineyard parcels, 8 natural habitats). Two sampling techniques have been used, pitfall traps (PF) and sweepnet sampling (SN).

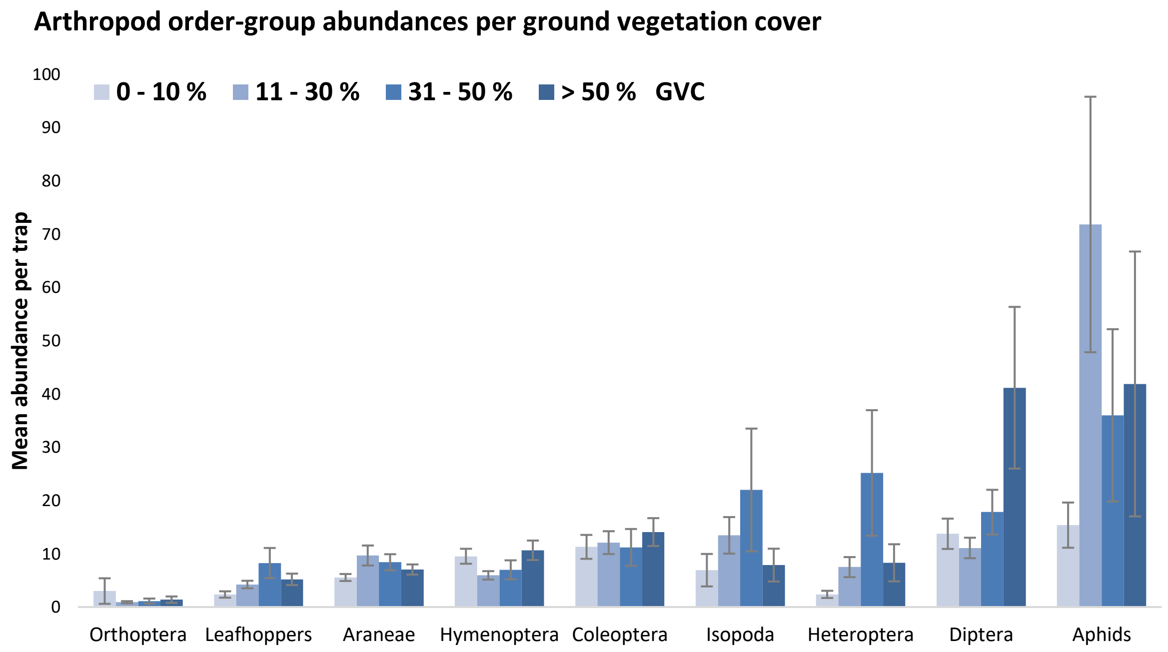
Arthropod groups				**Beetle families**				**Spider families**			
N=18	**PF**	**SN**	**Total**	**N=21**	**PF**	**SN**	**Total**	**N=25**	**PF**	**SN**	**Total**
Formicidae	16381	266	16647	*Carabidae*	722	2	724	*Lycosidae*	786	1	787
Aphids	2963	3635	6598	*Staphylinidae*	490	4	494	*Linyphiidae*	273	7	280
Heteroptera	1261	2747	4008	*Anthicidae*	446	5	451	*Thomisidae*	44	108	152
Isopoda	3430	1	3431	*Buprestidae*	282	1	283	*Araneidae*	62	81	143
Coleoptera	2934	196	3130	*Curculionidae*	169	33	202	*Gnaphosidae*	130	1	131
Diptera	1544	1205	2749	*Coccinellidae*	90	84	174	*Hahniidae*	72	28	100
Araneae	1719	274	1993	*Chrysomelidae*	119	47	166	*Corinnidae*	73	3	76
Hymenoptera	1511	389	1900	*Elateridae*	151	0	151	*Philodromidae*	67	7	74
Leafhoppers	219	467	686	*Tenebrionidae*	142	0	142	*Salticidae*	37	27	64
Larvae	448	97	545	*Scarabaeidae*	131	0	131	*Zodariidae*	34	8	42
Orthoptera	445	28	473	*Cryptophagidae*	82	1	83	*Clubionidae*	35	1	36
Others	298	61	359	*Histeridae*	56	0	56	*Tetragnathidae*	33	0	33
Solifugae	174	0	174	*Mordellidae*	22	3	25	*Dictynidae*	31	0	31
Chilopoda	165	3	168	*Cantharidae*	6	13	19	*Amaurobiidae*	14	0	14
Lepidoptera	114	22	136	*Latridiidae*	14	3	17	*Miturgidae*	12	0	12
Diplopoda	115	0	115	*Dermestidae*	3	0	3	*Theridiidae*	8	0	8
Scorpiones	10	0	10	*Lampyridae*	3	0	3	*Titanoecidae*	2	0	2
Mantodea	6	2	8	*Leiodidae*	2	0	2	*Anyphaenidae*	0	1	1
				Meloidae	2	0	2	*Dysderidae*	1	0	1
				Cerambycidae	1	0	1	*Oecobiidae*	1	0	1
				Mycetophagidae	1	0	1	*Oxyopidae*	0	1	1
								Pholcidae	1	0	1
								Sparassidae	1	0	1
								Theraphosidae	1	0	1
								Uloboridae	1	0	1



Supplementary Figure 1 Differences in PF+SN combined abundance per trap with standard errors, between natural and vineyard habitat.



Supplementary Figure 2 Differences in PF+SN combined avg. abundance per trap with standard errors, between different vineyard management.

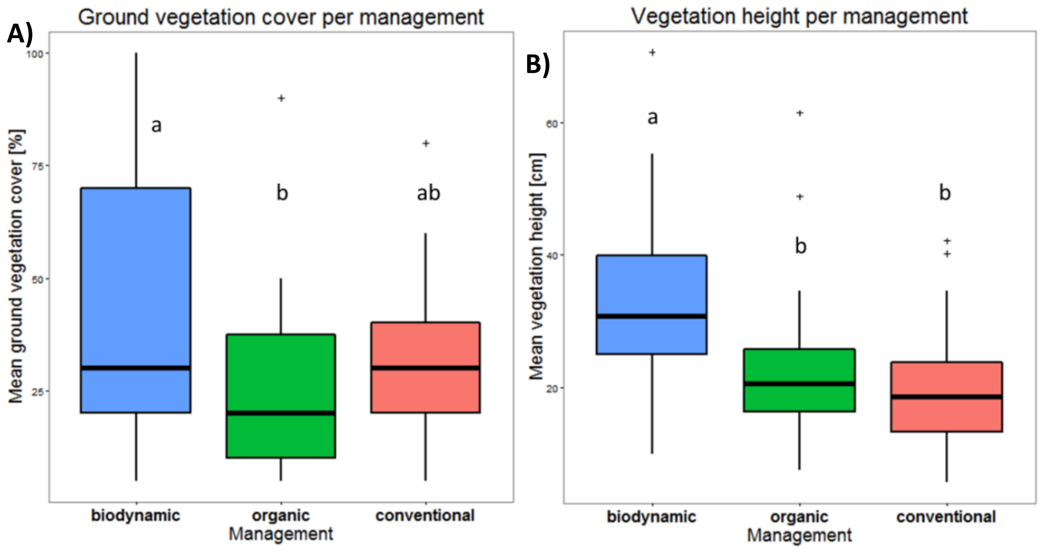


Supplementary Figure 3 Differences in PF+SN combined avg. abundance per trap with standard errors, between different ground vegetation cover percentages (GVC), here grouped in 4 distinct classes for graphical representation.

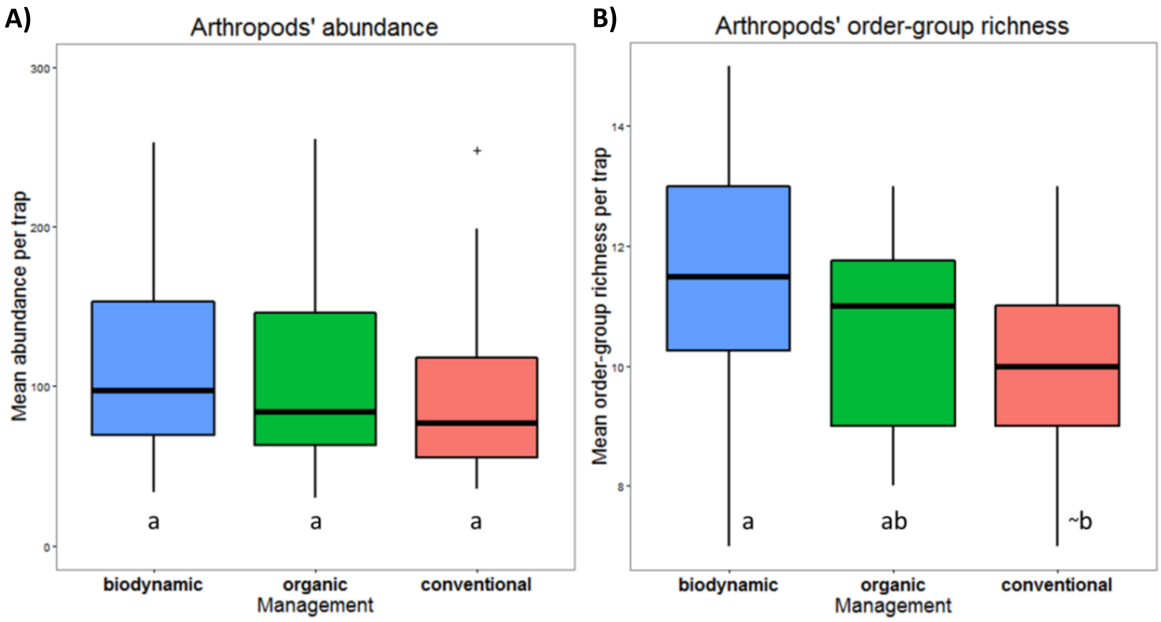
Bivariate comparison: effects of vineyard parcel characteristics

Further vineyard parcel characteristic were analysed and here briefly summarized. All of the following boxplots show non-significant differences between groups (same group *a*) obtained with a Tukey multiple comparisons of means at a 95% family-wise confidence level.

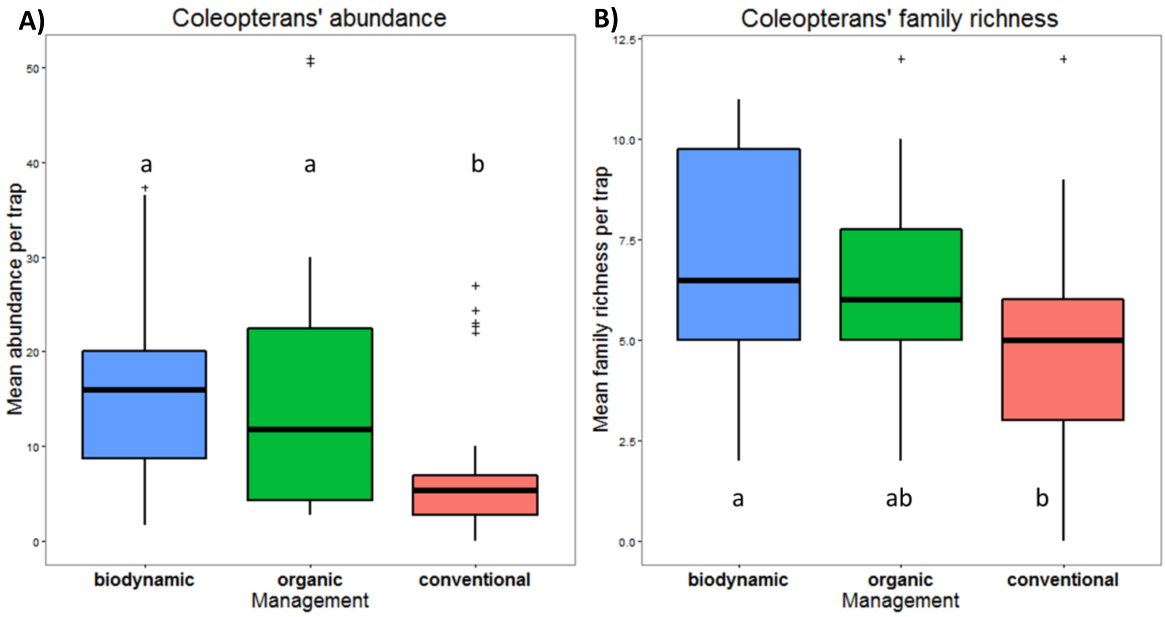
Management regime



Supplementary Figure 4 Differences in overall ground vegetation cover and vegetation height across the three sampling sessions for each management regime. **A)** organic parcels ground vegetation cover gradient significantly differed from biodynamic parcels but not conventional (BD > O, p = 0.003); **B)** Vegetation height was significantly differing in biodynamic parcels with respect to both organic and conventional managements (BD > O, p = 0.04; BD > C, p < 0.001).



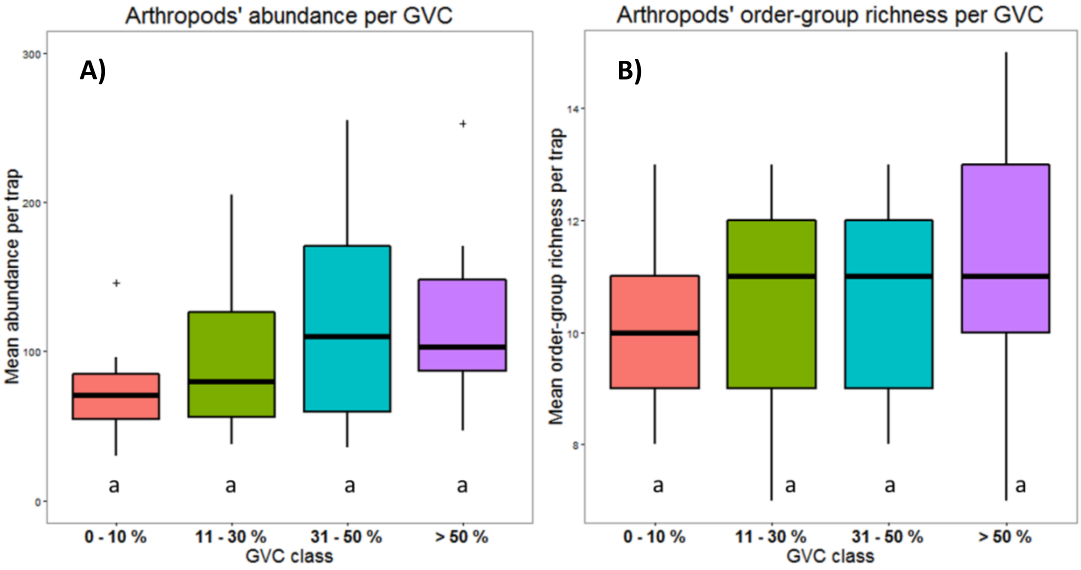
Supplementary Figure 5 Arthropod abundance and group richness for each management regime. **A)** no significant difference was found for abundance; **B)** for group richness, an almost significant difference (p=0.06) was found between biodynamic and conventional management regime.



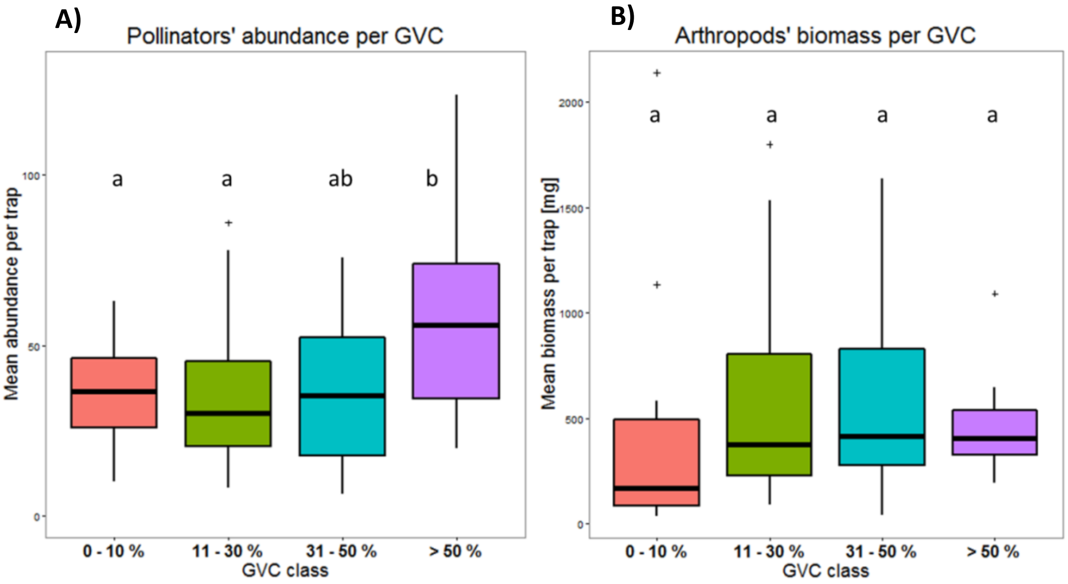
Supplementary Figure 6 **A)** Coleopteran abundance is significantly lower in conventional parcels compared to both organic and biodynamic management; **B)** on the other hand, richness is significantly different only between biodynamic and conventional regimes.

Ground vegetation cover

Ground vegetation cover values were grouped in 4 distinct classes (only for bivariate comparison but not the full model selection) to better represent the differences.



Supplementary Figure 7 A) no significant difference was found for arthropod abundance solely with respect to different ground vegetation classes. A tendency towards positive relationship is however present both in mean and variance. **B)** The same result appears when looking at overall group richness, with an even less defined contrast.

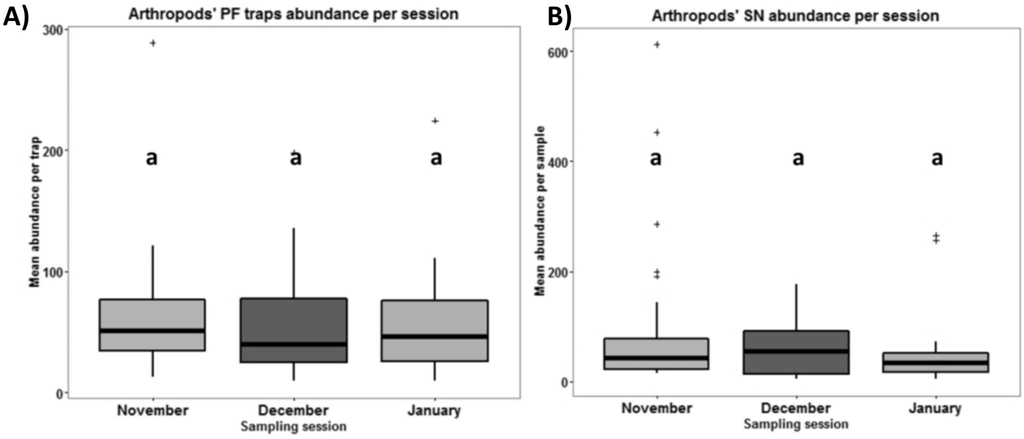


Supplementary Figure 8 A) We computed the overall abundance of pollinators by adding abundances from Diptera, Hymenopterans, Lepidoptera, Heteroptera and Coleoptera (without Carabidae, the most abundant non-pollinating beetle family) and finally obtained a significant difference between highly vegetated parcels (gvc class 4) and poorly vegetated ones (gvc classes 1 and 2); **B)** arthropod biomass didn't show significant differences between vegetation classes.

Irrigation system and sampling session parameters

Sampling sessions

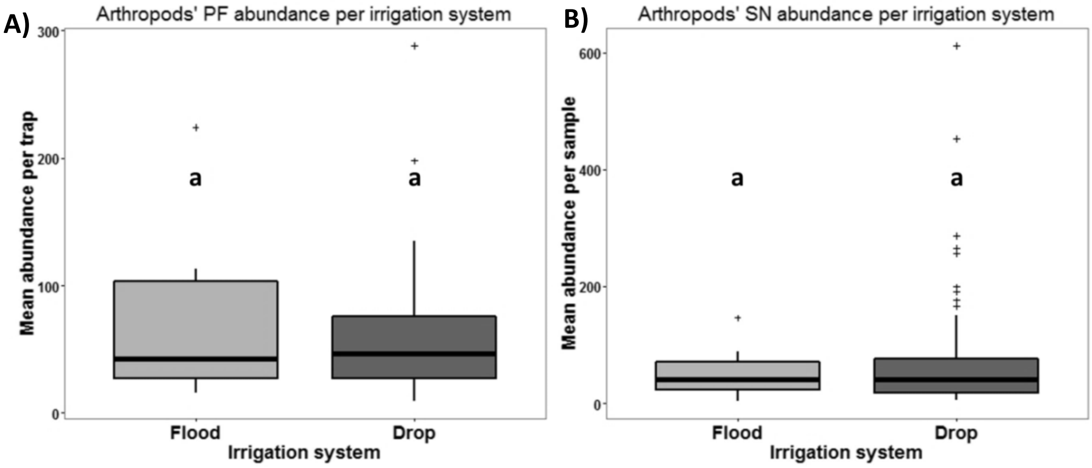
We noticed that the sampling session had an effect on the sweepnet arthropod abundances (even though not significant) but not on pitfall traps abundances nor group richness. These were assumptions which still needed to be accounted by our model selection so that the 'sampling session' explanatory variable was introduced as a random effect in our full linear model.



Supplementary Figure 9 Differences between sampling sessions for **A)** Pitfall traps (PF) arthropod abundance; and **B)** Sweepnet samples (SN) arthropod abundance.

Irrigation system

The differences in the irrigation system in use showed to be an important explanatory variable which was thus introduced in the full linear model as a fixed effect.



Supplementary Figure 10 A) arthropod pitfall traps (PF) abundance differences between canal-flooded parcels and drip irrigation; B) arthropod sweepnet samples (SN) abundance differences.