Organic farming increases functional diversity and ecosystem service provision of spontaneous vegetation in Mediterranean vineyards

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Abstract

Spontaneous plant species in agricultural systems (i.e., weeds) are bound to become key ecological indicators of agroecosystem resilience as they show high sensitivity to management, while they ensure the assembly of multiple ecological functions. Here we used the response-effect functional framework on spontaneous plant species growing in both organic and conventional vineyards, to assess whether their plant communities respond to contrasted farming systems and to soil conditions according to its competitive response and the provisioning of pollination services.

The results show that the spontaneous plant communities and its functions better reflected the effects of management -when considering the dichotomy organic-conventional farming- rather than soil conditions. Organic management in vineyards promoted higher plant species richness, with varied competitive response strategies to deal with different environmental conditions and management disturbances. Organic vineyards held more diverse and resilient plant communities for the provisioning of pollinator services than the conventional ones, which is expected to enhance pollinator communities with diverse feeding guilds. In contrast, conventional farming systems selected anemophilous plants or those with flower attributes related to generalist pollinators.

Such results highlight the significance of organic farming for the sustainment of the local accompanying plant diversity but also for the provisioning of ecosystem services in these agricultural landscapes. Besides, the study reinforces the applicability of the response-effect framework to identify the effects of vineyard management on the spontaneous plant communities and its potential impacts on the pollinator communities.

Key-words

Organic vs. conventional farming; Response traits; Effect traits; Species diversity; Weeds; Mediterranean croplands

1. Introduction

Organic farming is rapidly expanding in the Mediterranean vineyards of southern Europe linked with an increasing social interest and a legislation that encourage the implementation of more environmentally-friendly and sustainable production systems (EC, 2021). For instance, the area of vineyards under organic farming has remarkably increased in Catalonia (Spain) over the last two decades, from 455 ha in 2000 to 23 758 ha in 2020 (CCPAE, 2021). However, conventionally managed vineyards, mostly relying on external no-renewable inputs and high use of fossil fuel energy to rise crop production, are still the most common. Such more intensive agricultural systems are acknowledged to achieve higher crop yields, but at the expense of significant environmental impacts such as reducing water and soil quality, increasing greenhouse gas emissions and altering biodiversity (Stoate et al., 2009), which in turn involve important societal costs (Tscharntke et al., 2012). Instead, organic farming have been proved to provide acceptable crop yields without compromising the environmental quality, enhancing biodiversity and the provisioning of ecosystem services and functions (Tscharntke et al., 2005). Hence, the focus of agricultural systems is no longer only the provisioning of goods but also the sustainability in the delivery of supporting, regulatory and cultural ecosystem services (Montoya et al., 2019).

The spontaneous plant species growing in agricultural systems (i.e., the so-called weeds) have been traditionally considered as a constraint of crop production, as they compete with crop for the same resources and may limit its production (Oerke, 2006). However, biodiversity associated to agroecosystems represent an essential part of our natural heritage related to land use history and, apart from its own conservation value, plant diversity plays a key functional role providing alternative resources for pollinators, herbivores and granivorous animals, and are habitat and refuge for some crop-associated fauna (Marshall et al., 2006; Storkey et al., 2013). Farm management is determinant at assembling the associated plant communities in agroecosystems (José-María et al., 2010; Roschewitz et al., 2005) but also other environmental factors such as climate, landscape structure or soil characteristics may be important drivers of the spontaneous plant diversity (Roschewitz et al., 2005). Therefore, spontaneous plant species represent key ecological indicators because of their high sensitivity to management (Bengtsson et al., 2005) at the same time that they represent the link to other organism groups and multiple ecological functions, such as soil quality and pollination support (Albrecht, 2003; David et al., 2019).

Spontaneous plant species also act as a supply for pollinators and herbivorous arthropods and, thus, exert a bottom-up control on the assemblages and functioning of pollinator and phytophagous communities (Gaba et al., 2017). Therefore, the structure of weed communities through the functional pollination trait diversity shapes the insect community, with the consequent knock-on effects on higher trophic groups, while entailing the maintenance of plant communities

(Fornoff et al., 2017). Understanding how floral trait syndromes change in agricultural systems may underpin the provisioning of resources for pollinators, and, thus infer in the pollination ecosystem service provisioning (Solé-Senan et al., 2018).

Beyond the evaluation of plant diversity and composition from a taxonomic perspective, a functional approach may allow capturing a wider interpretation of the shifts in community composition and diversity responding to particular environmental filters and management pressures (through the plant response traits), while predicting the role of these plant species community impacting the environment in multitrophic systems (through the plant effect traits; Gaba et al., 2017; Solé-Senan et al., 2018). Therefore, the response-effect trait approach represents a promising framework for quantifying the arable species responses to the environmental factors and farming systems and for predicting the role of such species at providing ecosystem services (Lavorel and Grigulis, 2012). Competitive response traits such as life-span, growth form or plant height reflect the filtering effects of environmental and management conditions as well as the competition effect of other plants at assembling the community (Navas and Violle, 2009).

In short, spontaneous plants can have a clear benefit in agroecological systems, for instance by improving pollination and pest control, but they can also compete with crops in the availability of water and nutrients. Thus, the management of these spontaneous plant communities must be done rigorously. Therefore, the use of indicators of specific and functional diversities of spontaneous plant species in vineyards can be of great relevance to assess how contrasting agricultural management determine differences in the functioning of Mediterranean agroecosystems and the provisioning of ecosystem services. This would help to properly define more sustainable and resilient agroecosystems for a near future (MacLaren et al., 2020). Besides, despite the importance of vineyards in Mediterranean agroecosystems and the interest from the administration to promote organic vineyards in Catalonia, little is known about the effects of organic management at enhancing biodiversity within these systems (Puig-Montserrat et al., 2017).

The aim of this study was, thus, to evaluate the response of spontaneous arable plant species associated with vineyards with contrasting farming systems and its effects on the agroecosystem functioning (Figure 1). Specifically, the study aimed to: 1) determine the contrasting effects of conventional and organic farming systems on the species diversity components and on the community composition of the spontaneous arable plant species; 2) assess whether the shifts in the functional diversity and composition of plant competitive response traits act as indicators of the contrasted management systems; 3) evaluate whether the effects of contrasted management determined shifts in the functional diversity and composition of plant provisioning of pollination

services, and, lastly, 4) determine whether the components of plant species and functional diversity and composition were more linked to soil conditions rather than to the farming systems.
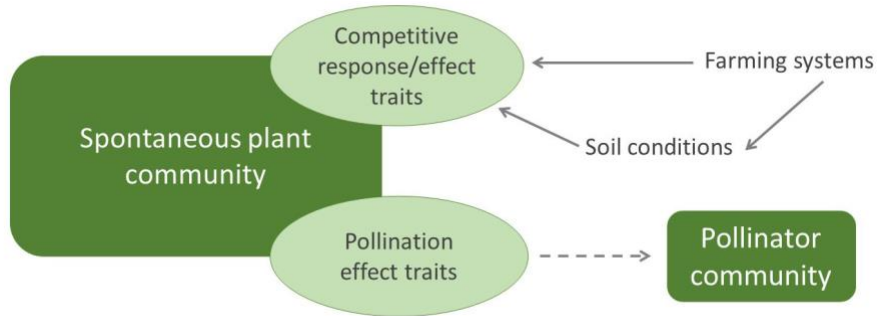

Figure 1. Framework for the functional response-effect approach used in the study.

2. Material and Methods

2.1. Study area

Sampling was conducted in 2021 in an area within the Alt Penedès county (1.740º E, 41.459º N – 1.782º E, 41.412º N), Catalonia (Spain) (Figure 2). The whole area lies on marls and calcareous sandstones, which create mainly basic soils, and the climate is typically Mediterranean, with mean annual temperatures of 14-15ºC and mean annual precipitation between 550 and 600 mm (Ninyerola et al., 2005).
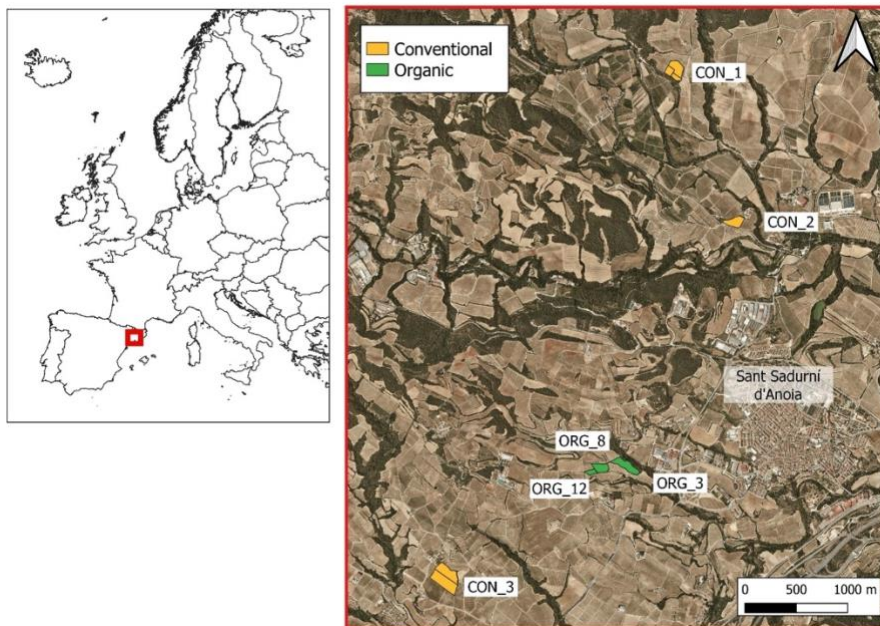

Figure 2. Location of the sampled fields under conventional (CON) and organic (ORG) management within the Penedès county, Catalonia (Spain).

Within this agriculturally dominated land, we selected two commercial vineyard farms with long-term contrasted farming systems, i.e., one under conventional management and the other one under organic management for more than 10 years. Management practices mainly differed in weed control and fertilization strategies. While conventional farmers mainly used mechanical weed control (only in one field herbicides were used), organic vineyard farmers used a combination of cover crops, mowing and summer tillage, with occasional grazing or horse-powered tillage. Conventional vineyards were amended with organo-mineral fertilizers (4-6-10 % OM) whereas organic vineyards were amended with composted cow manure and biodynamic amendments. The average yields during the previous 3 years were 6 548-8 697 kg/ha in conventional vineyards and 8 079-9 194 kg/ha in organic vineyards.

In three fields within each of the two farms (conventional and organic, Figure 2) we set up 5 sampling plots (crop lines) where surveys were conducted. The sampling plots were placed with the aim to capture all possible variability within each field. This represented a total of 30 plots being surveyed, 15 under conventional and 15 under organic management. Characteristics of planted crops and soil properties dependent on lithology (i.e., texture) for each field are indicated in Table 1. No significant differences were found among farming systems for the soil texture properties (Table S1 in Supplementary materials).

Table 1. Characteristics of each field within the two contrasted farming systems.

Farming type	Field	Area (ha)	Year	Variety	Planting frame	Soil texture		
						Clay (%) Average ± SE	Silt (%) Average ± SE	Sand (%) Average ± SE
Conventional	CON_1	2.47	1994 (0.59ha) 1996 (1.46ha) 2000 (0.42ha)	Xarel·lo	2.8 × 1.2 m	17.82 ± 1.42	41.66 ± 4.63	40.52 ± 5.70
	CON_2	0.99	1996	Macabeu	3.0 × 1.4 m	20.76 ± 1.40	38.94 ± 3.44	40.30 ± 4.57
	CON_3	4.97	2010	Xarel·lo	2.8 × 1.2 m	13.98 ± 2.29	29.00 ± 4.90	57.02 ± 7.10
Organic	ORG_3	1.80	2008	Xarel·lo	2.6 × 1.2 m	18.96 ± 2.45	36.88 ± 1.79	44.16 ± 4.22
	ORG_8	1.14	1996	Macabeu	3.0 × 1.2 m	28.32 ± 1.64	49.44 ± 4.01	22.24 ± 5.21
	ORG_12	0.67	1989	Xarel·lo	2.6 × 1.2 m	25.10 ± 2.74	39.38 ± 3.87	35.52 ± 5.87

2.2. Plant species and soil surveys

Plant species surveys were conducted during Spring (May) and Autumn (October) 2021, corresponding to the two phenological optimums of weeds in the Mediterranean region. These surveys were performed in each plot through 10 sampling quadrats of 0.25 m^2 placed 5 m apart from each other along the crop line that corresponded to a plot. Within each sampling quadrat, we listed all spontaneous plant species that appeared and recorded its cover using the Braun-Blanquet (1964) scale. The nomenclature of plant species followed de Bolòs et al. (2005).

Four soil samples were taken around a grapevine at a depth of 5 to 20 cm and 20 to 40 cm in the middle of each plot (between the 5th and the 6th sampling quadrat). The four samples were homogenized to get a composited sample, which was chilled to 4-8ºC during the sampling time and air-dried to analyse the physico-chemical soil characteristics of each plot. The variables analysed were soil texture (as percentage of clay, fine silt, coarse silt and sand), organic matter content from 5 to 20 cm and 20 to 40 cm, conductivity, pH, and nutrient content (as mg of Ammonium, N nitric, N Kjeldhal, Phosphorous, Potassium, Magnesium, Calcium, Sulphates, Sulphur, Copper and Iron over dry weight).

2.3. Species and functional diversity indices

For each plot, several measures of plant diversity and composition were calculated for the spring and autumn communities. Plant species cover was obtained by averaging the species cover (as percentage extracted from the Braun-Blanquet scale) at each sampling quadrat and calculating the mean cover among the 10 quadrats per plot. Species richness was calculated as the average number of observed species at each sampling quadrat per plot. Shannon diversity index (H') and Pielou evenness index (E) were also calculated as the average indices among sampling quadrats per plot to compare similarity of communities (Pielou, 1966).

For the functional diversity indices, a set of functional traits related to plant responses to the environment (mainly competitive ability traits) and to the provisioning of pollination services were considered. Competitive ability traits of plants can be used as proxies of plant competitive response being directly related to the tolerance to resource availability due to environmental conditions and depletion from neighbours, but also as proxies of plant competitive effects related to the capacity of a plant community to deplete resources (Navas and Violle, 2009). Pollination is one of the most studied ecosystem services in agroecosystems, because it involves both the maintenance of plant communities and the structuring of pollinator communities (Fornoff et al., 2017). The selected traits considered for the computation of competitive functional diversities and pollination service provision are detailed in Table 2.

Table 2. Functional traits, categories or values considered and explanations for the functional diversity components calculated to characterise the plant competitive ability functioning and the provision of pollination services functioning.

Plant trait	Trait Categories/Values	Trait explanation	Source*
a) Plant competitive traits			
Plant height (cm)	Mean value	Indicates species reaction to environament and management and competitive ability	1; 2
Raunkiær life form	Therophyte Hemicryptophyte Geophyte Chamaephyte	Type and position of propagules in the most adverse season; indicates potential to adapt to disturbance regime and infere with crop	1; 2, 3; 4
Growth form	Ascending herb Creeping herb Rosette Graminoid (grass-like plant)	Indicates species potential to capture resources (light, space) and interfere with crop	2
Vegetative reproduction	None Stolons Rhizomes	Indicates potential to adapt to disturbance regime and infere with crop	1
Affinity to soil nutrient conditions (N Ellenberg)	1 to 10 being 1 oligotrophic and 10 in nutrient-rich soils	Indicates species potential to adapt to nutrient soil conditions and compete with crop under a given set of conditions	1; 4
b) Plant provision of pollination services			
Start of flowering	Month (1-12) when flowering usually starts	Indicates potential to adapt to environmental and management conditions and to attract pollinators	1; 4
Flowering length	Number of months of duration of flowering	Indicates potential to adapt to environmental and management conditions and to provide resources to pollinators	1; 4
Flower colour	White/Yellow Blue/Violet Pink/Red Green/Brown	Indicates potential to attract pollinators	5
Flower morphology (simetry)	Actinomorphic Zygomorphic Non visible flowers	Indicates potential to attract pollinators	3
Pollen vector	Mainly self-pollinated Mainly insect-pollinated Mainly wind-pollinated	Indicates potential to attract pollinators	1; 3

* Sources of information obtained from the TR8 package (Bocci, 2020), f or R 4.1.1. (R Core Team, 2021) as: 1) ECOFLORA (Fitter and Peat, 1994); 2) LEDA traitbase (Kleyer et al., 2008); 3) BiolFlor (Klotz et al., 2002); 4) Pignatti (Pignatti et al., 2005); 5) Catminat (Julve, 1998)

Functional diversity components (functional richness, evenness and dispersion) were computed based on the multiple trait matrix (Table 1) of the species recorded in each plot and farming system using the FD package (Laliberté et al., 2014) for R 4.1.1. (R Core Team, 2021). With this

package, a Principal Components Analysis (PCA) was performed based on the Gower dissimilarity matrix, as calculated for the species by traits matrices. The obtained axes were then used to compute functional richness and functional evenness. Functional richness expressed the multidimensional trait space occupied by species in each community. Functional evenness quantified how even individuals from a community are distributed over trait space. Functional dispersion was computed based on the trait dispersion per community (Laliberté et al., 2014). Functional dispersion is the abundance weighted mean distance -i.e., spread- in the multidimensional trait space to the centroid of functional space, and represents a measure of community specialisation (Laliberté et al., 2014). The multiple trait matrix was also used to calculate functional redundancy of plant species per plot using the SYNCSA package (Debastiani, 2018) for R 4.1.1. (R Core Team, 2021). The functional redundancy was calculated as the difference between the species diversity and the Rao's quadratic entropy based on their functional dissimilarity.

2.4. Analysis of vineyard management on species and functional diversities

The effects of vineyard management type (conventional *vs.* organic) on spontaneous plant species diversity indices and functional diversity components for the spring and autumn communities were analysed by using linear mixed-effects models (Pinheiro and Bates, 2000), with the inclusion of the nested sampling design of random factors (plot nested to field) to account for the non-independence of the samples. Normality of data and homogeneity of variances were checked visually and tested using the Shapiro–Wilk and the Levene test, respectively. When the assumptions were not met, squared-root transformation was applied to comply with normality and homoscedasticity assumptions. Statistical analyses were conducted under R 4.1.1. (R Core Team, 2021), using lme4 package (Bates et al., 2015) for mixed-effects models and lmerTest package for evaluating the p-values (Kuznetsova et al., 2017).

2.5. Species and functional composition analyses

To assess the species composition of the plots within contrasted farm management, a multivariate analysis using presence/absence data of species was conducted. Species that occurred only in one plot were removed because they did not add information for the ordination. The Jaccard dissimilarity index was computed between the lists of species of each plot. Since we used a non-Euclidean distance metric, we chose Non-metric Multidimensional Scaling (NMDS) for this ordination, using a stable solution by random starts with k = 2 dimensions to facilitate the graphical representation. Farm management type (i.e., organic or conventional management) was

fitted onto the ordination, and their significance was tested with random permutations of the data. Species with more than 20% of the total presence were also fitted onto the ordination. We carried out this analysis under R 4.1.1. (R Core Team, 2021) using the 'vegan' package (Oksanen et al., 2019).

The composition of functional traits and trait categories related to plant competitive ability and to the provision of pollination services were analysed through the community-weighted mean values (CWM) calculated from the multi-trait matrixes using the FD package (Laliberté et al., 2014) for R 4.1.1. (R Core Team, 2021). The effects of vineyard management type (conventional *vs.* organic) on the CWM values for each trait (for quantitative variables) and trait category (for qualitative variables) for the spring and autumn communities were analysed by using linear mixed-effects models (Pinheiro and Bates, 2000), with the inclusion of the nested sampling design of random factors (plot nested to field) to account for the non-independence of the samples. Normality of data and homogeneity of variances were checked visually and tested using the Shapiro–Wilk and the Levene test, respectively. When the assumptions were not met, differences in the CWM of traits in contrasted farming systems were assessed using Kruskal–Wallis rank sum test. An ordination of samples according to the functional composition (CWM vales) was also conducted by means of a PCA. The CWM trait matrix was used to perform a PCA to produce orthogonal axes of functional trait composition and reduce trait redundancy. The first two axes obtained were used to plot the plant community samples of each plot according to their functional trait composition values. The significance of these two first PCA axes on spreading the samples according to farm management type was analysed with random permutations of the data.

2.6. Analyses of soil characteristics on the species community indices

The effects of soil physical-chemical characteristics on species and functional community descriptors were analysed using mixed effects models to account for the nested design of the plot nested to field as a random factor. The soil texture parameters (i.e., clay, silt and sand proportions) were not considered in the analyses as they are not dependent on agricultural management. Farming system (conventional *vs.* organic) was also included in the models. Due to the large amount of explanatory variables considered, these analyses were performed using the multimodel inference method (Burnham and Anderson, 2004), which allows inference to be made on the basis of all models from an *a priori* set rather than based only on the best estimated model. There were 16 383 possible combinations of all explanatory variables. However, only 1199 models were performed because models considering two correlated variables (Pearson correlation index > 0.6, Figure S2 in Supplementary Materials) were excluded. However, as the different soil descriptors

were included in the same multimodel inference, the AIC can be used to evaluate which model and, therefore, which soil descriptor provided better fit. Models were compared using the adjusted Akaike information criterion (AIC; Burnham and Anderson, 2004), which allows direct comparison of the information loss of each model in relation to the estimated best model, which has the minimum AIC ($\Delta i = AIC_i - AIC_{min}$). Afterwards, the Akaike weight (wi) was calculated for each model. Then, to assess the effect of each variable, the multimodel inference from the selected best models (for which the sum of wi reached 0.9) was performed, which provides the model-averaged parameter estimates and their unconditional SEs weighted by their Akaike weights. The 95% confidence intervals were also computed to evaluate the breath of the likely magnitude of their contributions. These analyses were conducted for each species and functional diversity index.

To test for the effects of soil characteristics on species and functional composition of each community, Mantel tests for each soil variable were performed on the species dissimilarity matrices of spring and autumn communities and on the Community Weighted Mean (CWM) dissimilarity matrices for competitive ability and for pollination provisioning traits for both spring and autumn communities. Mantel tests were performed using the vegan package for R 4.1.1. (R Core Team, 2021).

3. Results

3.1. Overview

Within the fields, a total of 44 spontaneous plant species were found during the spring survey, 18 in conventional plots and 41 in organic plots. A total of 26 species were exclusively found in plots under organic management and only 3 were detected exclusively in conventional plots. In autumn, 42 spontaneous plant species were listed, 24 in conventional plots and 34 in organic plots. 18 species were found exclusively in plots under organic management and 8 exclusively in conventional plots.

3.2. Species diversity and composition in contrasting farming systems

Organic plots held significantly higher plant cover, species richness, and Shannon and Evenness indices than conventional plots for all comparisons but the evenness of autumn community, which did not show significant differences among farming systems (Figure 3).
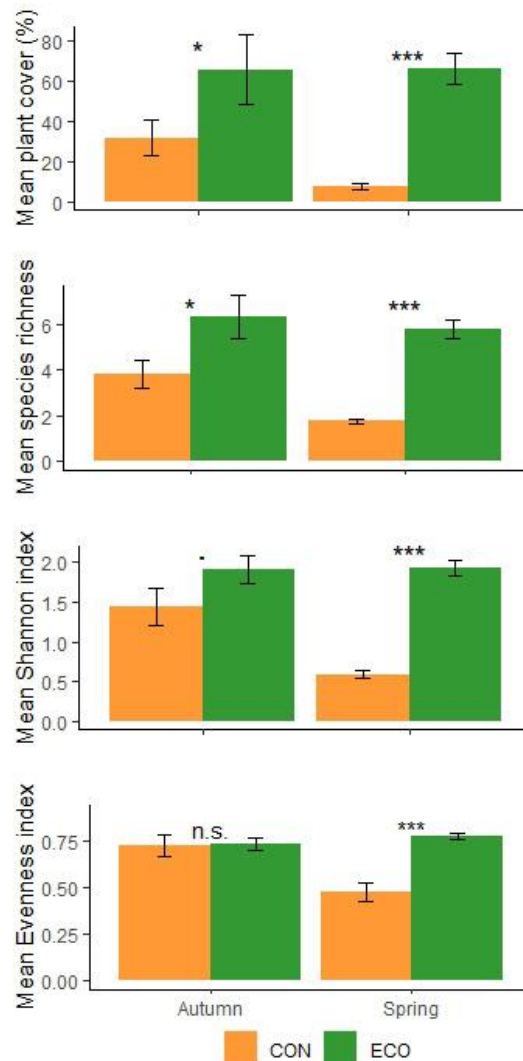
Figure 3. Species diversity descriptors (mean (± S.E.) plant species cover, richness, Shannon index and evenness index per plot) for the spring and autumn community comparing the conventional farming systems (CON) and the organic farming systems (ECO). Significance of the effects of the fixed factor farming system is indicated as *** when $p <$ .001; * when $p < .05$; · when $p < .1$; and n.s. when no significant differences were found.

Farm management determined shifts in the species composition of both spring and autumn plant communities of plots within vineyards (NMDS, K = 2, non-metric-fit for spring: $R^2 = 0.979$ and for autumn: $R^2 = 0.967$). The fit of farming systems onto the ordinations showed significant differences in the spring ($R^2 = 0.637$, p-val < 0.001) and in the autumn ($R^2 = 0.310$, p-val < 0.001) communities (Figure 3). Some species such as *Calendula arvensis* L., *Medicago polymorpha* L., *Medicago truncatula* Gaertn., *Avena barbata* Pott ex Link*, Poa annua* L. or *Hordeum murinum* L. were predominantly found in organic farming systems, while conventional farming systems do not seem to hold characteristic species but to share species with organic farming systems (Figure 4).
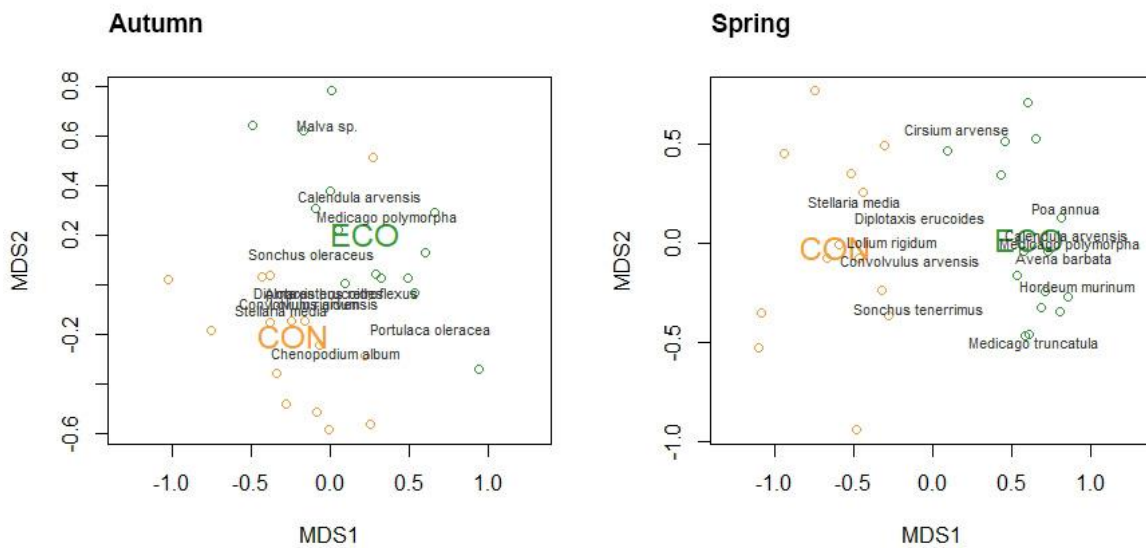
Figure 4. Plot ordination (NMDS) based on floristic similarities for spring (left) and autumn (right) communities. Plots under conventional farming system (CON) are represented as dark grey and plots under organic farming system (ORG) as light grey. Farming systems fitted onto the ordination, with an $R^2 = 0.637$, p-val < 0.001 for the spring community and $R^2 = 0.310$, p-val < 0.001 for the autumn community. The most common plant species were also fitted onto the ordination.

3.3. Functional diversity and composition under contrasted farming systems

3.3.1. Related to the plant competitive ability

Functional richness of competitive ability traits was significantly higher under organic farming systems for the spring community, but no differences were detected for the autumn community (Figure 4). No significant differences were detected on the functional evenness of competitive ability traits between farming systems neither for the spring nor the autumn community. Contrarily, higher functional dispersion of competitive ability traits was found under conventional management, while higher competitive trait redundancy was found under organic farming systems of both spring and autumn communities (Figure 5).
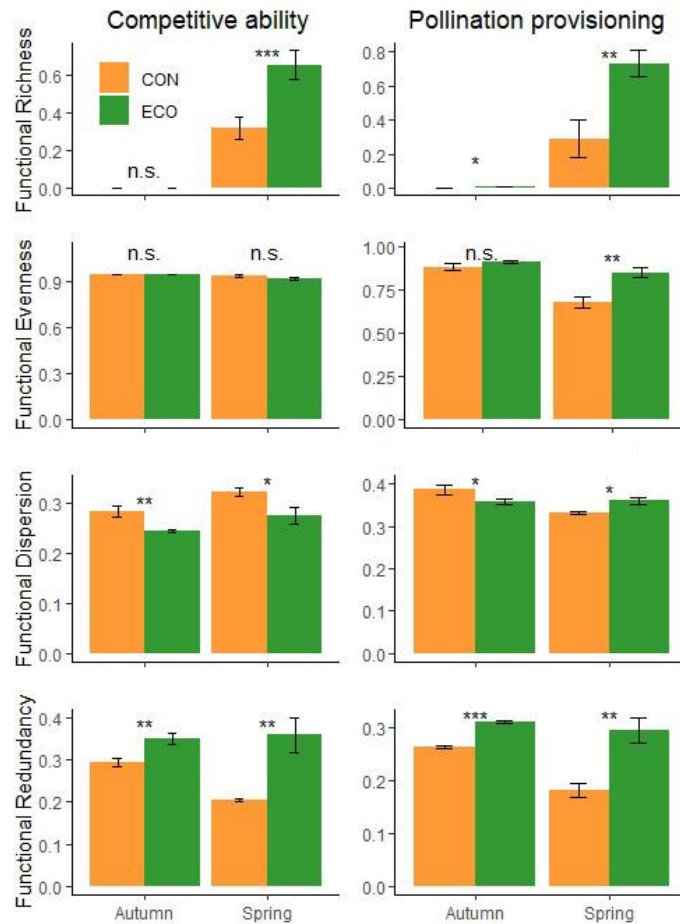
Figure 5. Functional diversity descriptors related to plant competitive ability and provisioning of pollination services (mean (± S.E.) functional richness, evenness, dispersion and redundancy per plot) for the spring and autumn community comparing the conventional farming systems (CON) and the organic farming systems (ECO). Significance of the effects of the fixed factor farming system is indicated as *** when $p < .001$; * when $p < .05$; · when $p < .1$; and n.s. when no significant differences were found.

The functional composition of communities according to the CWM of plant competitive ability traits differed between plots under contrasting farming systems for both the spring and autumn communities (Figure S1 in Supplementary Materials). The first two axes of the PCA run for the CWM data of plant competitive traits for the spring community explained 36.41 % and 21.68 % of the total variance, and the fit of farming systems resulted significant ($R^2 = 0.202$, p-val < 0.05). For the autumn community, the first two PCA axes explained 39.24 % and 18.85 % of the total variance, and the fit of farming systems was also significant ($R^2 = 0.473$, p-val < 0.001). Organic farming plots were dominated by therophyte and ascending growth form species, with no vegetative reproduction or with stolons. Contrarily, plots under conventional farming systems were characterised by taller plants more prone to nutrient availability, mainly geophyte species, with creeping growth forms and rhizomes as vegetative reproduction in the spring community; and chamaephyte or hemicryptophyte life forms, rosette or graminoid growing species, with

stolons as vegetative reproduction in the autumn community (Figure S1 in Supplementary Materials). Significant differences in the CWM of these traits between communities under contrasted farming systems are shown in Figure 6.
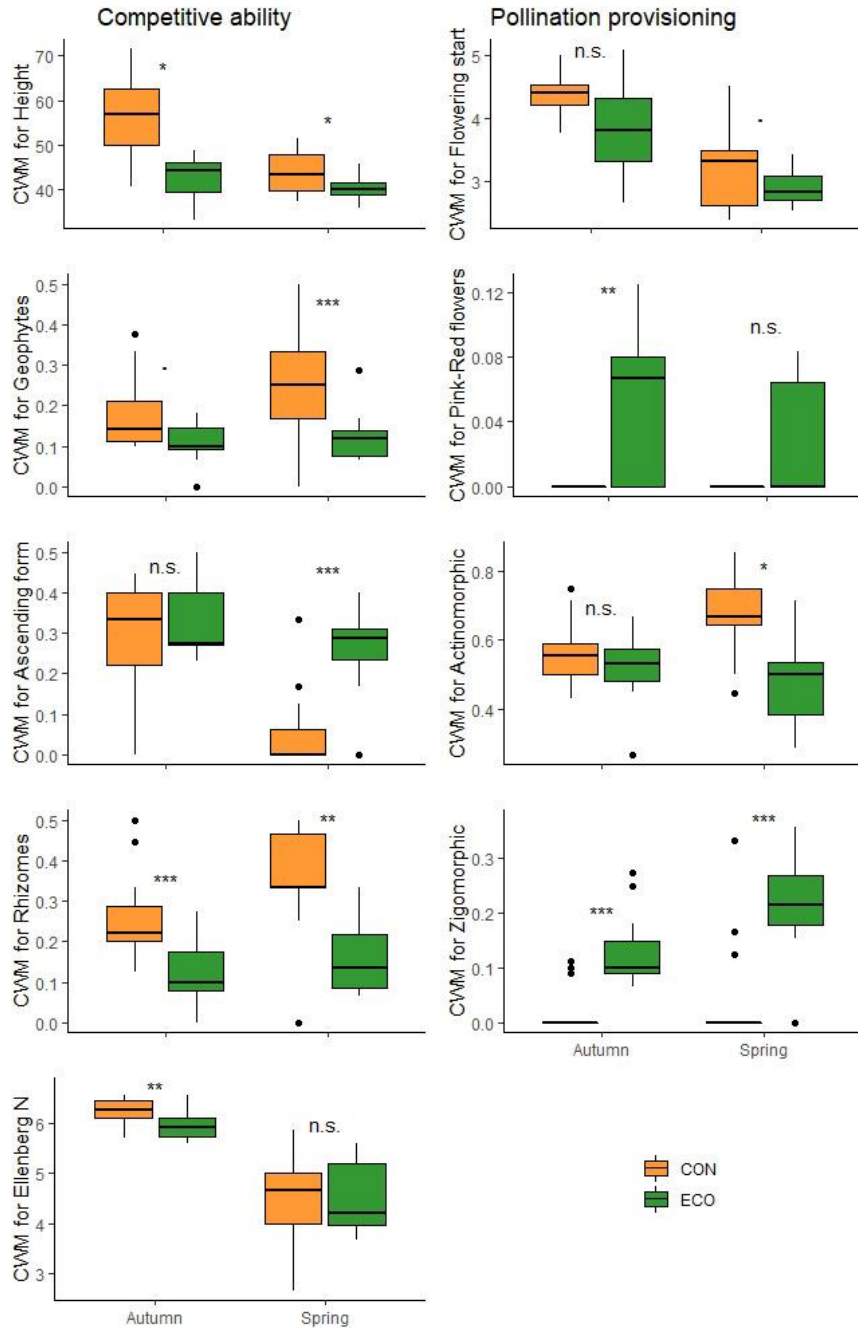
Figure 6. Boxplot of Community Weighted Mean (CWM) values of different functional traits (Plant height, Ellenberg index for nutrient tolerance and Month of flowering start) or trait categories (Geophyte life form, Ascending growth form, Vegetative reproduction with Rhyzomes, Pink-red coloured flowers, Actinomorphic or Zigomorphic flowers), related to plant competitive ability and provisioning of pollination services for the spring and autumn communities comparing the conventional farming systems (CON) and the organic farming systems (ECO). Only traits and trait categories with significant differences among farming systems are shown. Significance of the effects of the fixed factor farming system is indicated as *** when p < .001; ** when p < .01; * when p < .05; · when p < .1; and n.s. when no significant differences were found.

3.3.2. Related to the provision of pollination services

All functional diversity components of traits related to the provisioning of pollination services were significantly higher under organic farming systems in the spring community (Figure 4). Functional richness and redundancy of traits related to the provisioning of pollination services were also higher under organic management in the autumn community, while no significant differences were detected on the functional evenness (Figure 5). Instead, higher functional dispersion of traits related to the provisioning of pollination services was found under conventional management in the autumn communities (Figure 5).

The functional composition of communities according to the CWM of pollination provisioning traits differed between plots under contrasting farming systems, mainly for the spring community (Figure S1). The first two axes of the PCA run for the CWM data of pollination provisioning traits for the spring community explained 42.23 % and 18.93 % of the total variance, and the fit of farming systems resulted significant ($R^2 = 0.105$, p-val < 0.05). For the autumn community, the first two PCA axes explained 54.46 % and 14.63 % of the total variance, and the fit of farming systems was marginally significant ($R^2 = 0.092$, p-val $= 0.082$). Organic plots were characterised by insect-pollinated plants, with zygomorphic, pink/red flowers (Figure 5). Contrarily, conventional plots were characterised by self-pollinated plants, with actinomorphic, blue/violet-coloured flowers in the spring community; and wind-pollinated plants with green/brown flowers and with no visible flowers characterised the autumn community (Figures S1 and 6).

3.4. Associations between soil characteristics and plant species and functional diversity descriptors

Farm management type was the strongest driver of most plant species diversity descriptors of vineyard plots analysed when also considering the specific soil characteristics (Table S3 in Supplementary Materials). Nevertheless, some species diversity indices also responded to some soil physical-chemical characteristics. Plant cover and species richness of autumn community were related to the amount of different soil nutrients, such as copper, phosphorous, calcium and magnesium (Table S3 in Supplementary Materials). Shannon diversity indices in the autumn community also responded to copper content, apart from the farming system, and the evenness index for the autumn community was related to phosphorous content. The spring community diversity descriptors were mainly related to the farm management, with higher values under organic management, but the plant cover also responded positively to nitric content and organic

matter from 20 to 40 cm, and negatively to potassium content (Table S3 in Supplementary Materials).

As for the functional diversity components related to plant competitive ability, the farming system was still a strong determinant for the functional richness and redundancy of the spring community. No descriptors arose as being related to the functional richness of autumn community and to the functional evenness of both spring and autumn communities. Instead, the ammonium content was the main descriptor of plant competitive ability functional dispersion and potassium content was related to the functional redundancy of the autumn community (Table S4a in Supplementary Materials).

The functional richness related to the provision of pollination services was positively related to the organic farming systems in both spring and autumn communities. The functional evenness of the autumn community was negatively related to the sulphur content, while the functional dispersion of the spring community was mainly associated to the magnesium content in the soil (Table S4b in Supplementary Materials). Functional evenness for the spring community, functional dispersion for the autumn community and functional redundancy for both spring and autumn communities responded to farming systems (Table S4b in Supplementary Materials).

Several soil physical-chemical characteristics had significant effects on the community composition of both the species and the functional traits related to plant competitive ability and to provision of pollination services. Nitrogen content-related variables had significant impacts on determining the species composition and the composition of competitive ability traits of spring and autumn communities. Instead, the content of the other nutrients had different effects on the analysed community compositions (Table S4 in Supplementary Materials).

4. Discussion

4.1. Impacts of vineyard management on plant species community

Plant species diversity components within vineyards responded to farm management, showing the organically farmed plots higher species richness, Shannon's diversity and evenness indices (in the spring community), and higher plant cover than conventional ones. These results are found in previous studies and highlight the significance of organic farming at promoting the local plant diversity in agroecosystems (Puig-Montserrat et al., 2017), but also the risk that these species may outcompete with crop for resources (Albrecht, 2003). Autumn plant communities in conventional

systems were more equitable in abundance than the spring community in conventional systems, likely because the later held higher dominance of only few species.

Differences between organic and conventional farming systems not only hold true for the diversity indices, but also for species composition. Organic farming systems showed higher numbers of spontaneous plant species, but also higher numbers of species only growing in this system when compared to conventional farming systems. However, the species that only appeared in organic systems were common species in agricultural systems and they are not of particular conservation concern, what reduces the importance of these species singularity (José-María et al., 2010). Contrarily, conventional farming systems held fewer characteristic species only present in this system and, indeed, the majority of the species in conventional farming systems were also present in organic systems and considered common ruderal and arable weed species in agricultural systems (José-María et al., 2010), such as *Lolium rigidum* Gaudin, *Convolvulus arvensis* L. and *Stellaria media* (L.) Vill., among others.

4.2. Impacts of vineyard management on the competitive ability traits of plant community

Farm management filters the community composition of spontaneous species according to the functional traits rather than species (Gaba et al., 2017; Solé-Senan et al., 2018), thus suggesting that farming practices can affect functional rather than species diversities (Mouchet et al., 2010). Plant competitive response ability differed in communities within contrasting farming systems. The functional richness of plant competitive traits was higher in organic farming systems in the spring community, following trends of species richness. This reinforces the fact that less intensive vineyard management increase the ability of vegetation to respond to variable environmental conditions and disturbance regimes (Díaz and Cabido, 2001). However, no effects were detected on the competitive functional richness in the autumn community despite the differences detected in the species richness. This highlights that in the autumn communities, functional diversity might be lost at a higher rate than expected with decreasing species richness (Flynn et al., 2009).

Instead, the functional dispersion of competitive ability traits was significantly higher in conventional vineyards, highlighting that these farming systems offered certain environmental conditions, such as higher nutrient availability due to its fertilization regimes, which usually involve higher competition with neighbours, and this has been found to involve stronger trait divergence in plant communities (Laliberté et al., 2013). Such condition may have increased the space of successful ecological strategies and reduce the specialization of competitive functional traits and types (Laliberté and Legendre, 2010). These results reinforce trends found in previous studies confirming that plant communities tend to become more homogeneous under less

intensive agricultural practices (Guerra et al., 2022). However, these results differ from previous studies that pointed out that higher farming intensity constrains the number of successful ecological strategies and, thus, reduces the functional divergence (Solé-Senan et al., 2018, 2017).

Contrarily, organic farming showed higher functional redundancy of competitive ability traits than the conventional systems, reflecting a higher number of species contributing similarly to a specific ecosystem function. This trend reinforces the fact that less intensive farming systems hold less vulnerability of functional groups to future disturbances and, thus, the functional diversity could be maintained in case of species richness losses, which confers resilience to the associated plant diversity (Flynn et al., 2009; Laliberté et al., 2010). No differences were detected in the functional evenness of conventional and organic farming systems, both systems with pretty high values, indicating that both systems held species equally distant in the functional space (Villéger et al., 2008).

Spontaneous species appearing in arable land share similar functional syndromes mainly related to the habitat and the main management constraints (Bourgeois et al., 2019). However, diverging farming systems in vineyards determined clear shifts in the competitive ability trait assemblages in the differently managed communities. Both spring and autumn communities in organically farmed vineyards were characterised by therophyte and ascending herb plant species, clearly adapted to thrive the periodic disturbances of tilled vine inter-rows (Bourgeois et al., 2019). Instead, geophyte (in spring) and hemicryptophyte and chamaephyte (in autumn) life forms characterised the communities under conventional management. Conventional farming systems were also characterised by species producing rhizomes as vegetative reproduction (in spring), what highlights that community assemblies in conventional farming systems diverge from the characteristic arable species syndromes (Bourgeois et al., 2019) and show higher capacity to persist through different strategies the periodic disturbances and nutrient availability. Besides, such competitive traits selected in conventional management systems may represent better competitiveness affecting the performance of neighbour species (Gaba et al., 2017; Guerra et al., 2022), and somehow interfere with vineyard production.

4.3. Impacts of vineyard management on the provisioning of pollination services

Farming systems shaping the spontaneous plant communities had also its effects at arranging the available features of plant communities for the delivery of pollination services. The functional richness in spring and autumn communities under organic farming systems was higher than under conventional farming systems, indicating a higher availability of different traits related to the provision of pollination services (Villéger et al., 2008). This would likely involve a sustainment

of greater pollinator diversity, through the selection of a diverse feeding guilds' pollinator community (Rotchés-Ribalta et al., 2018; Scherber et al., 2010). However, this functional richness index is solely determined by the presence of species and, thus, the most extreme trait values account although they actually contribute little to ecosystem functioning (Winfree et al., 2015). Likewise, the spring community had also higher values of functional evenness, dispersion and redundancy for the provision of pollination service traits, highlighting that organically farmed vineyards held higher diversity of functional traits, equally represented in the community, with increased spread of ecological strategies and higher number of species contributing similarly to the provision of pollination services (Laliberté et al., 2010; Laliberté and Legendre, 2010). These results highlight, thus, the importance of organic farming systems for the sustainment of a rich, broad and more resilient plant communities for the provisioning of pollinator services at a local scale. This is expected to enhance a diverse pollinator community, as has been proved that the effects of local land-use on pollinator communities mainly act indirectly through the bottom-up effects of shifts in plant communities (Rotchés-Ribalta et al., 2018; Scherber et al., 2010).

Contrasting farming systems in vineyards not only determined shifts in the components of functional diversities but also in the functional composition of plant traits defining the provision of pollination services, with strong knock-on effects defining the potential pollinator communities (Fornoff et al., 2017). Organic farming systems defined plant communities characterised mainly by zygomorphic (and also actinomorphic in the autumn community) and pink/red (and blue/violet in autumn) coloured flowers and insect pollinated plants in the autumn community. These traits define a plant community highly reliant on a pollinator community and, thus, with the potential to enhance the abundance and richness of pollinators (Solé-Senan et al., 2017). Contrarily, plant pollination syndromes selected in plots under conventional farming systems were actinomorphic flowers in the spring communities, typically related to generalist pollinator species, or plants with no visible flowers or green/brown coloured flowers, which are traits not related to the attraction or the dependence on pollinators (Solé-Senan et al., 2018). Conventionally managed vineyards also held mainly self-pollinated (in spring) or wind-pollinated plants (in autumn) that reinforce the assemblage of a plant community not relying on pollinator community and, thus, likely involving less diverse pollinator communities (Fornoff et al., 2017). Therefore, these results highlight the great importance of less intensive agricultural systems for the promotion of plant diversity at a local scale with knock-on effects at supporting an associated diversity of other organisms such as pollinators, reinforcing trends found in previous studies (Solé-Senan et al., 2018, 2017).

4.4. Soil conditions influencing plant community

One of the most differentiating features between organic and conventional farming practices is the type and the amount of fertilization that these systems receive as well as the weed control strategies, both affecting the specific local soil variables (Hathaway-Jenkins et al., 2011). Therefore, the effects of contrasted farming systems at shaping the diversity and composition of spontaneous plant community may act through the indirect effects on soil conditions. Soil descriptors have been determined to affect the assemblies of plant species through its competitive response traits, while shape the plant effect traits that will determine the delivery of ecosystem services, such as the structure of networks, and pollinator communities (David et al., 2019). However, most plant species and functional descriptors considered in this study were more influenced by the farming system itself instead of by specific soil conditions. This highlights that the effects of agricultural management might be linked to factors other than the ones affecting the soil conditions and, thus, play a relevant role as a whole in determining the configuration of spontaneous plant species communities.

However, some soil physico-chemical characteristics of the soil arose as important direct determinants of species and functional plant diversity descriptors. The different species community descriptors for the autumn community responded to the content of some nutrients in the soil, such as copper, phosphorous, calcium, magnesium. Instead, higher nitrogen availability (as nitric) was related to higher species cover in the spring community.

The most important determinant of the functional dispersion of plant competitive traits in the spontaneous plant community was the ammonium content, and the effect of farming system was mitigated. This likely indicates that the greater functional dispersion found for competitive ability traits in conventional farming systems is mainly determined by the higher ammonium content typically found in conventional soils. Higher ammonium content in vineyard soils increased the space of successful strategies for nutrient caption and competition for resources and, thus, increased the spread of competitive ability-related functional traits and types.

Functional traits of plant communities related to plant provisioning of pollination services may be shaped by the response of plant communities to specific soil conditions, which, in turn, can inform us about the trends in pollinator communities (David et al., 2019). However, differences in functional diversity components for the provisioning of pollination services were not determined by the soil conditions in the experimental sites but were mainly determined by the contrasting farming practices in studied vineyards.

5. Conclusions

The response-effect framework has been used in the current study to identify the impacts of vineyard management on the spontaneous plant communities, considered as key indicator components of these agricultural systems. Although soil conditions influenced some spontaneous plant species diversity and functional diversity descriptors, the management effects on the spontaneous plant communities and its functions better reflected the effects of management when considering the dichotomy between organic and conventional farming.

The results of the study indicate that the organic management in vineyards promotes diverse local spontaneous plant communities, with varied competitive response strategies to deal with different environmental conditions and management disturbances, which increase the chances of the community to thrive different conditions. Besides, such communities in organically managed vineyards represented more rich, broad and resilient communities for the provisioning of pollinator services at a local scale, which is expected to enhance diverse pollinator communities with richer feeding guilds. Such results highlight the significance of organic farming for the sustainment of the local accompanying plant diversity but also for the provisioning of ecosystem services in these agricultural landscapes.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary Materials to the article:

Rotchés-Ribalta, R., Marull, J. & Pino, J. *Organic farming increases functional diversity and ecosystem service provision of spontaneous vegetation in Mediterranean vineyards*

Table S1. Effects of the farming system on the proportion (%) of clay, silt and sand in soils of the surveyed fields. Estimated coefficients and their standard errors for the linear mixed models and the P-values (*** when p-value <0.001; · <0.1 and n.s. >0.1) of the fixed effect factors; variance and their standard deviation of the field and plot (residual) random effect factors; and conditional (R^2 c) and marginal (R^2 m) coefficients of determination for each model are shown.

	Clay (%)			Silt (%)			Sand (%)		
	Estimate ± SE			Estimate ± SE			Estimate ± SE		
Fixed effects									
Intercept	17.520 ± 1.949		***	36.533 ± 3.138		***	45.947 ± 4.875		***
ORG (vs. CON)	6.607 ± 2.756		·	5.367 ± 4.438		n.s.	-11.973 ± 6.894		n.s.
	Variance ± Std.Dev			Variance ± Std.Dev			Variance ± Std.Dev		
Random effects									
Field	7.144 ± 2.673			14.270 ± 3.777			40.780 ± 6.386		
Residual	21.234 ± 4.608			76.360 ± 8.738			152.580 ± 12.352		
R^2 c	0.465			0.221			0.338		
R^2 m	0.285			0.076			0.161		

Figure S1. Plot ordination of the first two PCA axes based on the functional composition (Community-Weighted Mean, CWM) of traits related to plant competitive ability and plant provisioning of pollination services. Plots under conventional farming system (CON) are represented as dark grey and plots under organic farming system (ECO) as light grey. Farming systems fitted onto the ordination for the plant competitive ability, with an $R^2 = 0.202$, p-val < 0.05 for the spring community and $R^2 = 0.473$, p-val < 0.001 for the autumn community. Direction of the factors of the different competitive ability functional traits considered for the CWM index are also fitted as: "Height" for mean plant height, "GF_AscH" for ascending herb Growth Form; "GF_CreepH" for creeping herb Growth Form; "GF_Rosette" for Rosette Growth Form; "GF_Gram" for grass type Growth form; "LF_Ther" for therophyte life form; "LF_Cham" for chamephyte life form; "LF_Geo" for geophyte life form; "VR_None" for no vegetative reproduction known; "VR_Rhizome" for rhizome vegetative reproduction; "VR_Stolone" for stolones vegetative reproduction and "N_affinity" for Nitrogen Ellenberg index. Farming systems fitted onto the ordination for the plant provisioning of pollination services, with an $R^2 = 0.105$, p-val < 0.05 for the spring community and $R^2 = 0.092$, p-val $= 0.082$ for the autumn community. Direction of the factors of the different functional traits related to the provision of pollination services considered for the CWM index are also fitted as: "Fl_start" month when flowering starts, "Fl_length" duration of flowering; "Col_White/Yellow" for white-yellow flowers;"Col_Blue/Violet" for blue-violet flowers; "Col_Pink/Red" for pink-red flowers; "Col_Green/Brown" for greem-borwn flowers; "Shape_Actinom" for actinomorphic-shaped flowers; "Shape_Zigom" for zigomorphic-shaped flowers; "No visible flowers" when flowers were not visible; "Insect_pol" for insect-pollinated species; "Wind_pol" for wind-pollinated species and "Self_pol" for self-pollinated species.
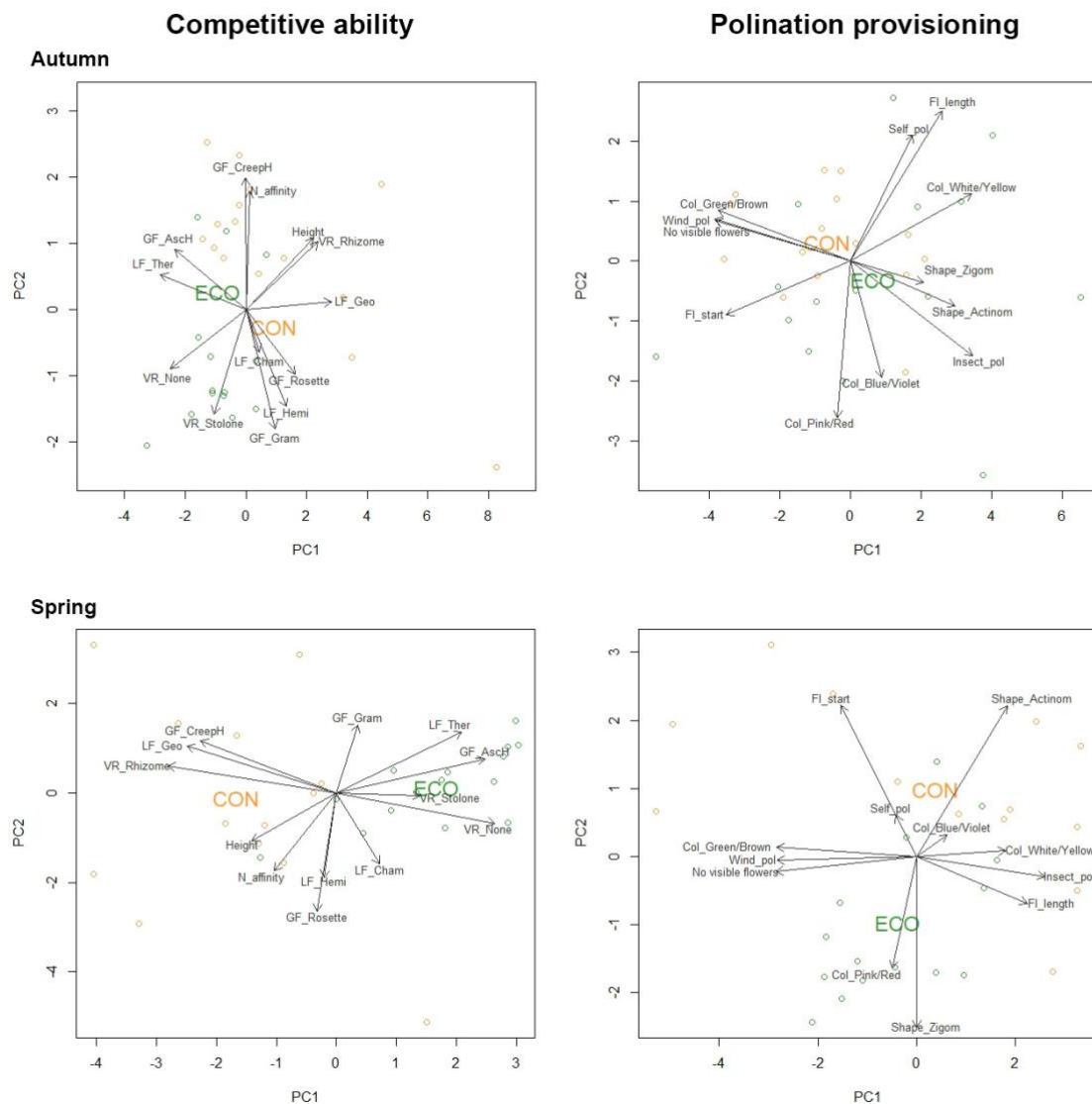
Figure S2. Pearson correlation matrix of soil physical-chemical characteristics.
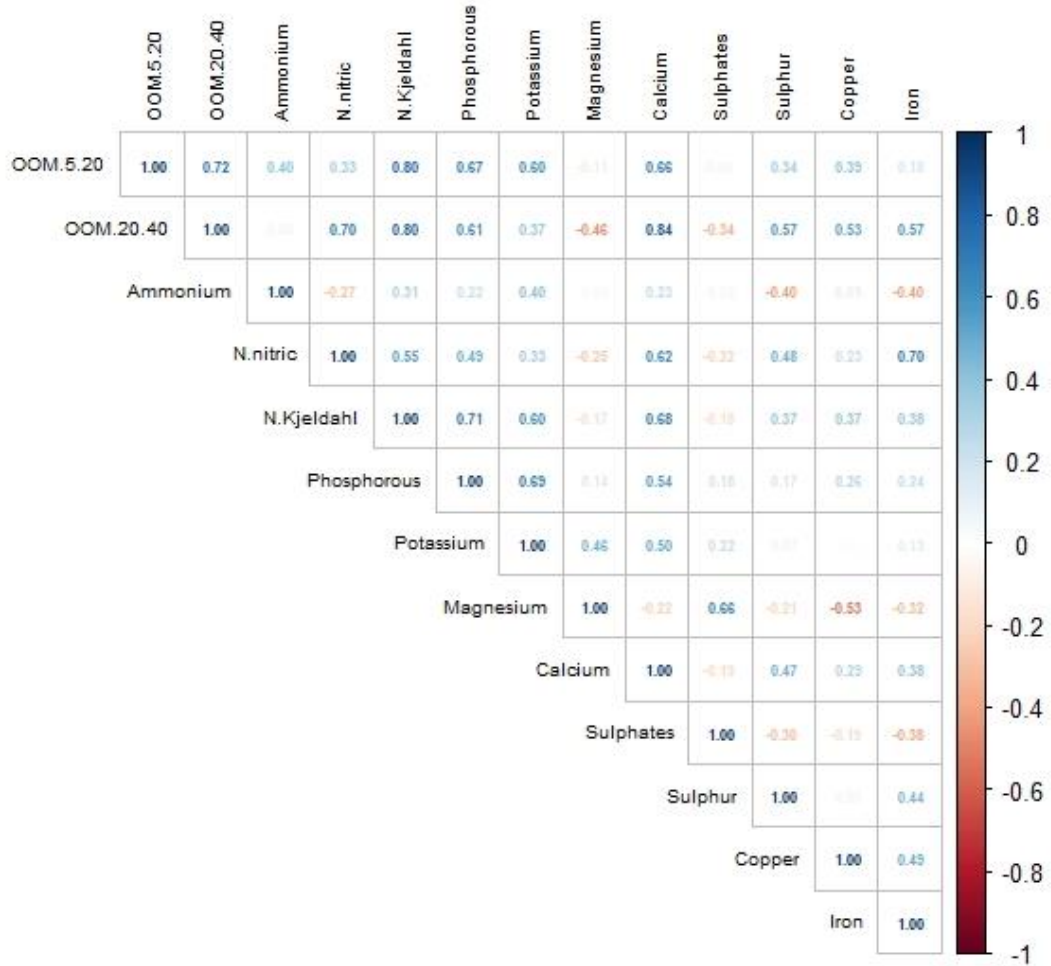
Table S3. Model averaged estimate ± unconditional SE (unSE) and relative importance (Rel. Imp.) of soil physical-chemical characteristics and farm management type (i.e., organic (ECO) vs. conventional (CON) farming systems) for the species diversity components of the spring and autumn communities in the studied vineyards. Only those variables for which the Rel. Imp > 0.3 and the 95 % confidence intervals did not include 0 are shown. + or – indicate the direction of the effect.

|	Spring community				Autumn community			
	Estimate	± unSE	Rel. Imp.		Estimate	± unSE	Rel. Imp.	
<u>Species Cover</u>								
Intercept	3.159	± 5.162	1.000		27.165	± 11.287	1.000	
ECO (vs. CON)	67.552	± 8.541	1.000	+	43.056	± 17.237	0.998	
Potassium (mg)	-5.702	± 2.086	0.880	-				
N nitric (mg)	5.576	± 1.008	0.459	+				
OOM 20-40 cm (mg)	5.880	± 1.084	0.400	+				
Copper (mg)					4.807	± 2.300	0.963	+
Magnesium (mg)					-6.580	± 2.389	0.878	-
Phosphorous (mg)					5.753	± 1.576	0.754	+
Calcium (mg)					-3.874	± 1.596	0.672	-
<u>Species richness</u>								
Intercept	1.652	± 0.324	1.000		3.199	± 0.519	1.000	
ECO (vs. CON)	4.237	± 0.520	1.000	+	3.763	± 0.883	1.000	+
Copper (mg)					1.094	± 0.299	1.000	+
Sulphates (mg)					-0.522	± 0.119	0.486	-
Sulphur (mg)					-0.400	± 0.112	0.333	-
Amonium (mg)					0.349	± 0.095	0.321	+
Iron (mg)					-0.384	± 0.119	0.300	-
<u>Shannon diversity</u>								
Intercept	0.578	± 0.095	1.000		1.422	± 0.217	1.000	
ECO (vs. CON)	1.353	± 0.143	1.000	+	0.676	± 0.187	0.740	+
Copper (mg)					0.264	± 0.072	0.848	+
<u>Species Evenness</u>								
Intercept	0.487	± 0.058	1.000		0.732	± 0.021	1.000	
ECO (vs. CON)	0.303	± 0.068	0.929	+				
Phosphorous (mg)					0.077	± 0.017	0.854	+

Table S4. Model averaged estimate ± unconditional SE (unSE) and relative importance (Rel. Imp.) of soil physical-chemical characteristics and farm management type (i.e., organic (ECO) vs. conventional (CON) farming systems) for the functional diversity components of the spring and autumn communities in the studied vineyards. Only those variables for which the Rel. Imp > 0.3 and the 95 % confidence intervals did not include 0 are shown. + or – indicate the direction of the effect.

Plant competitive ability traits

	Spring community				Autumn community			
	Estimate	± unSE	Rel. Imp.		Estimate	± unSE	Rel. Imp.	
Functional Richness								
Intercept	0.335 ±	0.090	1.000		0.000 ±	0.000	1.000	
ECO (vs. CON)	0.351 ±	0.095	0.857	+				
Functional Evenness								
Intercept	0.873 ±	0.050	1.000		0.944 ±	0.002	1.000	
Functional Dispersion								
Intercept	0.296 ±	0.006	1.000		0.269 ±	0.012	1.000	
Amonium (mg)	-0.025 ±	0.005	0.878	-	-0.019 ±	0.002	0.407	-
Functional Redundancy								
Intercept	0.210 ±	0.039	1.000		0.320 ±	0.011	1.000	
ECO (vs. CON)	0.167 ±	0.038	0.857					
Potassium (mg)					0.030 ±	0.006	1.000	+

Plant provisioning of pollination services

	Spring community				Autumn community			
	Estimate	± unSE	Rel. Imp.		Estimate	± unSE	Rel. Imp.	
Functional Richness								
Intercept	0.333 ±	0.128	1.000		0.003 ±	0.004	1.000	
ECO (vs. CON)	0.437 ±	0.120	0.813	+	0.008 ±	0.002	0.401	+
Functional Evenness								
Intercept	0.641 ±	0.057	1.000		0.891 ±	0.012	1.000	
ECO (vs. CON)	0.224 ±	0.061	0.877	+				
Sulphur (mg)					-0.027 ±	0.004	0.377	-
Functional Dispersion								
Intercept	0.343 ±	0.009	1.000		0.378 ±	0.011	1.000	
Magnesium (mg)	0.018 ±	0.002	0.410	+				
ECO (vs. CON)					-0.028 ±	0.005	0.382	-
Functional Redundancy								
Intercept	0.187 ±	0.023	1.000		0.265 ±	0.009	1.000	
ECO (vs. CON)	0.114 ±	0.026	0.919	+	0.047 ±	0.012	0.975	+

Table S5. Model estimate from the Mantel test (and p-values associated) performed for each soil descriptor variable on the species and functional composition of the spring and autumn communities.

	Species composition				Functional composition - Competitive ability traits				Functional composition - Pollination services provision			
	Spring community		Autumn community		Spring community		Autumn community		Spring community		Autumn community	
	Mantel R	p-val	Mantel R	p-val	Mantel R	p-val	Mantel R	p-val	Mantel R	p-val	Mantel R	p-val
Organic matter (mg) 5-20 cm	0.059	0.206	0.107	0.151	0.131	0.099 ·	0.136	0.085 ·	0.032	0.350	-0.150	0.934
Organic matter (mg) 20-40 cm	0.037	0.218	0.069	0.141	0.116	0.043 *	0.034	0.264	-0.001	0.471	0.079	0.122
Amonium (mg)	0.182	0.003 **	0.191	0.007 **	-0.031	0.631 ·	0.125	0.060 ·	0.001	0.450	-0.092	0.892
N nitric (mg)	0.341	0.000 **	0.230	0.007 **	0.196	0.024 *	0.064	0.207	0.191	0.036 *	0.047	0.286
N Kjeldahl (mg)	0.128	0.027 *	0.278	0.002 **	0.201	0.017 *	0.189	0.019 *	0.128	0.098 ·	0.059	0.252
Phosphorous (mg)	0.087	0.098 ·	0.304	0.000 **	0.022	0.356	0.292	0.001 **	0.135	0.081 ·	0.010	0.419
Potassium (mg)	0.147	0.017 *	0.335	0.000 **	0.051	0.252	0.395	0.000 **	0.104	0.136	0.137	0.084 ·
Magnesium (mg)	0.106	0.364	-0.001	0.483	0.012	0.406	-0.064	0.736	-0.180	0.989	0.470	0.000 *
Calcium (mg)	0.024	0.305	0.042	0.262	0.055	0.191	0.061	0.177	0.083	0.134	0.036	0.288
Sulphates (mg)	0.217	0.002 **	0.144	0.064 ·	0.324	0.002 *	0.030	0.340	-0.064	0.720	0.275	0.008 **
Sulphur (mg)	0.007	0.436	0.073	0.237	0.220	0.023 *	0.272	0.006 **	0.075	0.240	-0.055	0.661
Copper (mg)	0.124	0.026 *	0.060	0.208	0.069	0.157	-0.071	0.851	-0.067	0.790	0.079	0.159
Iron (mg)	0.327	0.000 *	0.152	0.052 ·	0.167	0.041 *	0.043	0.278	0.286	0.006 *	-0.035	0.594