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Organic Farming Benefits Local Plant Diversity in Vineyard Farms Located in Intensive Agricultural Landscapes

Juri Nascimbene · Lorenzo Marini · Maurizio G. Paoletti

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Abstract The majority of research on organic farming has considered arable and grassland farming systems in Central and Northern Europe, whilst only a few studies have been carried out in Mediterranean agro-systems, such as vineyards, despite their economic importance. The main aim of the study was to test whether organic farming enhances local plant species richness in both crop and non-crop areas of vineyard farms located in intensive conventional landscapes. Nine conventional and nine organic farms were selected in an intensively cultivated region (i.e. no gradient in landscape composition) in northern Italy. In each farm, vascular plants were sampled in one vineyard and in two non-crop linear habitats, grass strips and hedgerows, adjacent to vineyards and therefore potentially influenced by farming. We used linear mixed models to test the effect of farming, and species longevity (annual vs. perennial) separately for the three habitat types. In our intensive agricultural landscapes organic farming promoted local plant species richness in vineyard fields, and grassland strips while we found no effect for linear hedgerows. Differences in species richness were not associated to differences in species composition, indicating that similar plant communities were hosted in vineyard farms independently of the management type. This negative effect of conventional farming was probably due to the use of herbicides, while mechanical operations and mowing regime did not differ between organic and conventional farms. In grassland strips, and only marginally in vineyards, we found that the positive effect of organic farming was more pronounced for perennial than annual species.

Keywords Conventional farming · Disturbance · Grassland strip · Hedgerow · Herbicide · Semi-natural habitats

J. Nascimbene (✉) · M. G. Paoletti
Department of Biology, University of Padova,
via U. Bassi 58/B, 35121 Padova, Italy
e-mail: junasc@libero.it

L. Marini
DAFNAE, University of Padova, viale dell'Università 16, 35020 Legnaro, Padova, Italy

Introduction

Comparing biodiversity of organic and conventional farming has been a subject for research and debate for the last decades (Bengtsson and others 2005; Fuller and others 2005; Gomiero and others 2011; Hadjicharalampous and others 2002; Hole and others 2005; Hyvönen 2007; Paoletti and Pimentel 1992; Moreby and others 1994; Norton and others 2009; Stockdale and others 2001). Although in some cases the effectiveness of organic farming was not clear, large scale synthesizing studies suggest that organic farming is generally associated with higher levels of biodiversity of both plant and animal taxa (Bengtsson and others 2005; Caporali and others 2003; Clough and others 2007; Fuller and others 2005; Gabriel and others 2006, 2010; Hawesa and others 2010; Hole and others 2005; Hyvönen 2007; Mäder and others 2002; Moreby and others 1994; Roschewitz and others 2005). For instance the meta-analysis of Bengtsson and others (2005) showed that organic farming has positive effects on species richness and abundance in the 84% of the studies included in their review. These studies indicate that organic farming systems provide greater potential for biodiversity than their conventional counterparts, mainly because of reduced soil disturbance and chemical applications associated with management practices.

Although, at the local scale (i.e. within a field), biodiversity is often higher in organic farms, the benefits of organic farming also depends on the composition of the surrounding landscape (Ekroos and others 2010; Rundlöf and Smith 2006; Rundlöf and others 2008, 2010; Weibull and others 2003). This landscape dependence is particularly relevant for highly mobile organisms such as flying insects and birds, while plants usually exhibit lower dependence on landscape processes (Gabriel and others 2010; Marini and others 2008a, b; but see Rundlöf and others 2010). Plant species richness under organic farming is expected to be higher than under conventional farming in simple landscapes, while conventional farms might reach similar diversity levels to those of organic farms when the surrounding landscape is complex (Batáry and others 2011; Roschewitz and others 2005; Tscharntke and others 2005).

A large body of research has considered arable and grassland farming systems mostly in Central and Northern Europe, while only a few studies have been carried out in other economically important agro-ecosystems of the Mediterranean regions such as vineyards, citrus and olive orchards (Cárdenas and others 2006; Gago and others 2007). Despite the fact that in several countries vineyards are economically relevant cultivations, only a very few studies have evaluated the effects of management practices on biodiversity (Brittain and others 2010; Brugisser and others 2010; Paoletti and others 2007).

Hence, the main aim of this study was to test whether organic farming enhances local plant species richness in vineyard farms located in a homogenous intensive conventional landscape. Specifically, this study had two main objectives: (i) to compare plant species richness and composition in three habitat types (vineyard, grassland strip, and hedgerow) between conventional vs. organic vineyard farms located in intensively managed conventional landscape, and (ii) to explore whether species richness responses to farm management differ between annual and perennial species. Perennial species are expected to be more sensitive to mechanical disturbance (McIntyre and others 1999) than annual species. Frequent disturbance destroys in general both annuals and perennials established, but it creates more favourable conditions for new germinations of annuals (Gago and others 2007).

Materials and Methods

Study Area

The study was carried out in the administrative region of Veneto (Fig. 1). The region is one of the most important areas of north Italy for grape production with c. 71,360 ha cultivated as vineyards. In Veneto, vineyard farms are mainly managed with conventional practices, and only a small percentage is managed under organic farming (∼2%). Because of the dominance of conventional farming, the few organic farms are composed of scattered patches within a matrix of an intensively farmed landscape. In these areas, semi-natural habitats such as deciduous forests and semi-natural grasslands have been progressively converted to farmland, resulting in a relatively simplified landscape. Due to the dominance of conventional farming, it was not possible to include a gradient in landscape composition along with local management. We, therefore, kept constant landscape composition and tested only local farming practices. This was done by sampling farms in landscapes with more or less the same cover of semi-natural habitats (see below).

Sampling

Nine conventional and nine organic farms were selected to keep landscape composition constant and to test the effect of local management (Fig. 1). The farms were selected using a regional database to include the main productive districts of the region. Organic and conventional farms had 10.6% (SD = 15.3%) and 6.8% (SD = 7.5%) of cover of semi-natural habitats in the surroundings (quantified within a 1-km radius), respectively. There was no significant difference between the conventional and organic farms in the proportion of surrounding semi-natural habitats (unpaired t test, $n = 18$, $p = 0.514$). The landscape was characterized by a matrix of intensive conventional vineyards or arable lands where vineyard fields are usually located in a continuous matrix of vineyards and are sometimes bordered by grasslands strips and hedgerows.

Management information was obtained through farmer interviews. Sampled organic farms were converted to organic farming at least 10 years before sampling, except in the case of one farm which was converted in 2005. In organic farms, weeds are controlled only by mowing (3–4 times per year) whereas in conventional farms they are controlled both mechanically and chemically using herbicides (mainly glyphosate) 2–4 times per year, both on the rows and between them (Table 1). Mown vegetation is generally removed from the fields. Tillage on the rows is the main mechanical operation used in both organic and conventional farms. The number of fungicide and insecticide treatments is similar between organic and conventional farms, obviously differing in the type of product. Organic farms use only substances admitted by the management guidelines for organic farming (e.g., copper hydroxide, *Bacillus thuringiensis*, and pyrethroids), while conventional farms use various agrochemical (e.g., Fenamidone, Mancosin, Tebufenozide).

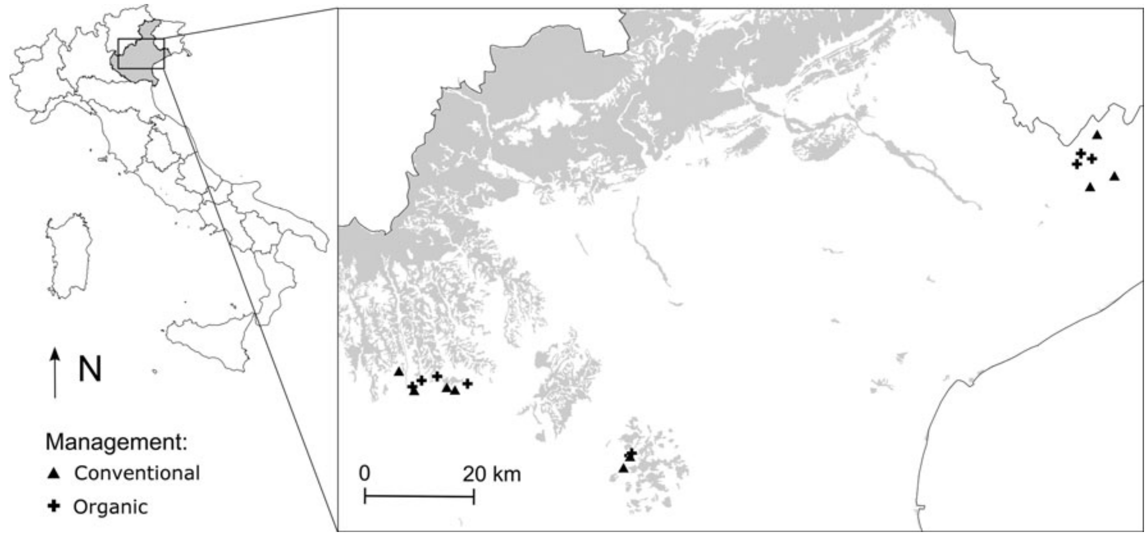


Fig. 1 Location of the study area and of the 9 organic and 9 conventional farms. The *grey* area in the panel on the right represents the cover of semi-natural habitats in the region

Table 1 Average ± SD (min–max) values of the main management treatments applied in organic versus conventional farms

	Organic ($n = 9$)	Conventional ($n = 9$)
Mean surface (ha)	22 ± 10 (12–39)	36 ± 35 (8–115)
Mean length of grass strips	55 ± 22 (35–90)	60 ± 35 (40–120)
Mean length hedgerows	45 ± 18 (20–90)	35 ± 10 (18–56)
Years of organic farming	16 ± 7 (5–25)	–
N herbicide treatments	0	2 ± 1.4 (1–4)
N fungicide treatments	15.3 ± 4.5 (9–21)	12.8 ± 4.2 (10–20)
N insecticide treatments	2 ± 2.4 (0–7)	1.4 ± 1.1 (0–3)
Use of mineral fertilizer	No	Yes
Use of organic fertilizer	Yes	Yes
N total (kg ha^{-1})	88 ± 36 (50–130)	82 ± 50 (36–160)
Tillage on the rows	Yes	Yes
Mowing frequency	3–4	3–4

In each farm, vascular plants (both herbaceous and woody species) were sampled in one randomly selected vineyard field and in the two linear habitats closest to the vineyard field: (i) grassland strips (~4 to 6 m width) dominated by herbaceous vegetation, used for tractors crossing and usually managed with the same criteria as for vineyard, being actually part of the "vineyard system", and (ii) single-row hedgerows with trees and shrubs, usually coppiced (~5 to 8 m width; ~6 to 8 m far from the vineyard). For the hedgerows, we placed the plot directly next to the hedgerows. In one farm and three farms there was no grassland strip and no linear hedgerow respectively. In each habitat, plant sampling was carried out once between April 15th and May 10th, 2010 before any management interventions. In each vineyard, plants were sampled within a single 10 × 10 m^2 plot placed in the centre of the cultivated area. For each species, the abundance was visually estimated using 5% cover classes. Plants in linear habitats (one grassland strip and one hedgerow in each farm) were recorded within 1 × 1 m^2 plots placed in the centre of the linear element. The abundance of each species was estimated using the same approach applied within vineyard fields.

Data Analysis

Plant species were classified into two groups on the basis of their longevity: (i) annual species, and (ii) perennial species (including biennial species). For each group, species richness was computed as the total number of species recorded in each plot. Linear mixed models were used to test the main effects on species richness of management (conventional vs. organic) and species longevity (annual, and perennial) and their interaction separately for the three habitats (vineyard, grassland strip, and hedgerow). We included farm and plot as random factors in the model. The plot as random factor was included to account for the fact that the numbers of species in each trait group were quantified at the same sites. A significant interaction between management and longevity would imply a differential response to management of annual versus perennial species. We used linear mixed model assuming normal error distribution using the lmer function implemented in the "nlme" package using a restricted maximum likelihood estimation procedure (Pinheiro and others 2009) in R (R Development Core Team 2008, version 2.8.0). We verified assumptions of linear mixed models by inspecting diagnostic plots of model residuals.

Differences in species composition between organic and conventional farms were evaluated for each habitat separately both by Multi-Response Permutation Procedures (MRPP) and Indicator Species Analysis (ISA; Dufrêne and Legendre 1997) as implemented in PC-ORD (McCune and Mefford 1999). MRPP was used to test the significance of differences in plant species composition between the two management types, using a Monte Carlo p-value which describes the likelihood of an equal or smaller effect size "A" than that measured by the procedure (McCune and Grace 2002). The effect size is the value 1–0 (within group heterogeneity/randomly expected heterogeneity). When $A = 1$, there is perfect agreement within the group, and when $A = 0$ the agreement within the group is equal to random probability. A significant effect size of 0.1 is commonly observed in community data (McCune and Grace 2002). The Sørensen distance measure and rank transformation of the distance matrices was used. ISA was used to determine how strongly each species was associated with each type of management. For each species, the Indicator Value (INDVAL) ranges from 0 (no indication) to 100 (maximum indication). Statistical significance of INDVAL was tested by means of a Monte Carlo test, based on 10,000 randomizations.

Results

A total of 211 species were found (50 annuals, and 161 perennials), 162 in conventional and 171 in organic farms. Regional species pool of vineyards and hedgerows in organic farms was richer than their conventional counterparts (Table 2).

Management type and longevity had different effects depending on the habitat (Table 3). Within the vineyard fields, we found a positive effect of organic farming on species richness. There was a tendency for a stronger effect of organic farming on perennial than annual species. Species richness did not differ between annual and perennial species (Fig. 2a). Within the grassland strips, we found a significant interaction between longevity and management, i.e. the number of perennial species was higher in the grassland strips under organic than conventional farming while annual species richness was not affected by management. Annual species richness was smaller than perennial species richness (Fig. 2b). Within the hedgerows, we did not find any effect of management. Plant assemblages of were mainly composed of perennial species both in conventional and organic farms (Fig. 2c).

The multi-response permutation procedure found no difference in overall species composition between farming types (MRPP: effect size $A < 0.003$, and $p > 0.3$ for all the habitats). Also no indicator species were detected by ISA as being linked to either organic or conventional farms in any of the three habitats.

Table 2 Total plant species richness in the three habitats in conventional and organic farms

Habitat	Management		Total
	Conventional	Organic	
Vineyards	71 (49.3% annual)	98 (38.8% annual)	106
Grassland strips	94 (38.3% annual)	89 (30.3% annual)	125
Hedgerows	78 (14.1% annual)	92 (17.4% annual)	128

The percentage of annual species is included in parenthesis for each habitat × management combination

Table 3 Results of the linear mixed model testing the main effects of management (organic vs. conventional), and longevity and their interaction on plant species richness within the three habitats in the 18 farms

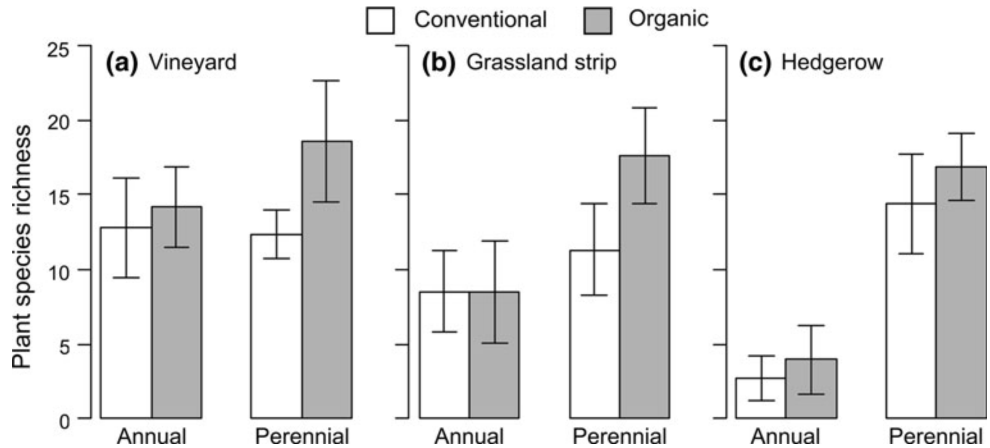
	d.f.	*F*	*P*
Vineyard			
Management	1, 16	6.00	<0.001
Longevity	1, 16	1.54	0.232
Management × Longevity	1, 16	2.33	0.146
Grassland			
Management	1, 15	3.88	0.067
Longevity	1, 15	13.32	0.002
Management × Longevity	1, 15	4.52	0.050
Hedgerow			
Management	1, 13	2.17	0.167
Longevity	1, 13	93.55	<0.001
Management x Longevity	1, 13	0.23	0.634

d.f. are different due to missing values, i.e. in some farms no semi-natural habitat was present

Discussion

Our study evaluated the effect of organic farming on plant species richness in both crop and non-crop areas of vineyard farms. In our intensive agricultural landscapes organic farming promoted local plant species richness in vineyard fields, and grassland strips while we found no effect for linear hedgerows. Differences in species richness were not associated with differences in species composition, indicating that similar plant communities grew in vineyard farms independently of the management type. However, the plant species pool was poorer in conventional than in organic farms.

Fig. 2 Mean annual and perennial plant species richness in conventional versus organic farms in **a** vineyards, **b** grassland strips, and **c** hedgerows. The *bars* indicate the 95% intervals of confidence



In vineyard fields, the main difference between the two farming regimes in terms of management practices potentially influencing plants was the use of herbicides under conventional farming, while mechanical operations and mowing regime did not differ between the two management regimes. The use of herbicides was probably the main cause of the reduced establishment of large species richness under conventional farming (Hald 1999; Rundlöf and others 2010).

Research on the evaluation of the effects on biodiversity of organic versus conventional farming has sometimes led to contrasting results even within the same agro-ecosystem, depending on the taxonomic groups and spatial scales considered. Our results contrast with those of Brugisser and others (2010) who found that in vineyards plant species richness was not enhanced by organic farming compared to conventional farming. They conclude that biodiversity in vineyards may not benefit to the same degree from organic farming as in annual arable systems. They interpreted their results in the light of the intermediate disturbance regime hypothesis applied to vineyards compared to the more intensive management regime applied to annual crops. In their study, the positive effect of the intermediate disturbance regime on species richness overrode the benefit provided by organic farming, allowing conventional vineyards to reach comparable richness levels to their organic counterparts. In our study, both conventional and organic farms were scattered in an intensive-dominated conventional landscape sometimes extending for thousands of hectares. Intensively farmed and homogenous landscapes dominated by few crops have been considered as those where organic farming should produce the best benefits to biodiversity (Roschewitz and others 2005; Rundlöf and others 2010; Tscharntke and others 2005). Consistently, in our study, the intensive landscape management at the regional level could explain the positive effect of organic farming on local plant species richness. However, this conclusion does not necessarily apply to more mobile organisms such as insects or birds which often depend on suitable habitats and resources at larger spatial scale (Brittain and others 2010).

We further investigated the effect of organic farming on plant species richness in two common semi-natural habitats associated with vineyard cropping systems finding a beneficial effect for grassland strips and no effect for linear hedgerows. Grassland strips are expected to be more directly influenced by crop management than hedgerows due to their position and use within the farm. While grassland strips are usually managed with the same criteria as for vineyard, being actually part of the "vineyard system", linear hedgerows are not expected to be managed differently in organic versus conventional farms. They are usually coppiced for wood fuel production and/or traditionally used to mark field boundaries. Moreover, hedgerows are located 6–10 m far from the vineyard reducing the potential negative effect of agro-chemical drifts from crop areas.

In grassland strips, and only marginally in vineyards, we found that the positive effect of organic farming was more pronounced for perennial than annual species. The use of herbicides was probably the main cause of the reduced establishment of perennial species under conventional farming. Accordingly, Gago and others (2007) found that weed control, tillage, and mowing allow annual species to complete their life cycle. On the contrary, the development of perennial species is effectively hindered by herbicides, whilst tillage and mowing have a lower impact. Boer and Stafford Smith (2003) also showed that annual species richness was enhanced by habitat degradation and disturbance removing perennial and biennial species (McIntyre and others 1999).

In both organic and conventional vineyard farms, our three habitats are distributed along a gradient of disturbance, being higher in vineyard fields, intermediate in grassland strips and lower in hedgerows. While in vineyards there is no difference between the number of annual and perennial species, in grassland strips and hedgerows perennial species richness was higher than annual species richness irrespectively of the management type. In the case of hedgerows this is an obvious result related to the features of the vegetation which is largely composed by shrubs and tree species. In the case of grassland strips this situation could be indicative of less disturbed and more stable conditions allowing this habitat to host a higher number of more ecologically sensitive species.

In conclusions, our results demonstrate that in vineyard farms located in intensive conventional landscapes, local plant species richness benefits from organic farming within vineyard fields, grassland strips but not within linear hedgerows. As studies on the effects of organic farming on biodiversity within vineyards are still limited to a very few single-region studies, larger scale synthesizing studies are urgently needed to clarify the response of other organisms occupying different trophic levels, and to monitor in the long term the effects of the conversion from conventional to organic farming.

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