Journal of Insect Conservation (2023) 27:729–741
https://doi.org/10.1007/s10841-023-00493-9

ORIGINAL PAPER

Differential responses of Orthoptera in vineyards to organic farming, pesticide reduction, and landscape heterogeneity

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Received: 25 November 2022 / Accepted: 30 June 2023 / Published online: 15 July 2023

Abstract

Conservation measures such as those under the European Green Deal aim to counteract the biodiversity loss by increasing the share of organic farming and reducing pesticide use, as well as increasing the proportion of semi-natural habitats (SNH) in agricultural landscapes. Given the large environmental impacts of agriculture, it is important to thoroughly understand effects of such measures on organisms to provide evidence-based and effective implications for conservation. In this study, we analysed how vineyard management, pesticide reduction, and landscape composition affect Orthoptera densities and species composition. Therefore, we sampled herb- and vine-dwelling orthopterans in a paired design of classic and fungus-resistant grape (FRG) varieties in conventionally and organically managed vineyards along a landscape heterogeneity gradient. Here, FRG varieties allowed us to study the effect of 44% reduced pesticide applications under real-world conditions. Total densities of herb-dwelling Orthoptera did not differ between grape varieties in conventional vineyards, but were 2.9 times higher in FRG varieties under organic management. In contrast, total densities of vine-dwelling Orthoptera, mainly driven by the dominant species *Phaneroptera falcata*, were similar between grape varieties in organic vineyards, but tended to be 1.4 times higher in classic grapes under conventional management. Furthermore, the management system and SNH in a radius of 500 m in the surrounding landscape influenced species composition.

Implications for insect conservation

Our work shows that the cultivation of FRG varieties, at least in organic viticulture, clearly benefits some orthopteran species. It appears that the reduction of non-specific pesticides such as copper and sulfur is important to mitigate negative effects and promote Orthoptera in viticulture.

Keywords Insects · Organic versus conventional farming · Fungus-resistant grape variety · Semi-natural habitat · Viticulture · Conservation measures

Introduction

Together with the impact of climate change, habitat destruction, and invasive species, intensified agriculture is considered one of the main drivers of the serious loss of biodiversity in recent decades, harming the environment through regular disturbance, clearing of semi-natural habitats (SNH), and high use of pesticides and fertilizers (Hallmann et al. 2017; Hochkirch 2016; Seibold et al. 2019; Wagner 2020). To counteract the negative impacts of agriculture on biodiversity, measures such as those under the European Green Deal, including the Farm to Fork Strategy, are intended to increase the proportion of organic farming in the upcoming years, as well as reducing the use of pesticides (European Commission 2019). Given the large environmental impacts of agriculture, it is important to thoroughly understand the effects of intensive crop management on organisms as well as the impacts of such measures.

In viticulture, where the use of pesticides, especially fungicides, is particularly high due to introduced fungal diseases such as powdery and downy mildew, large

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non-target effects, e.g. on arthropods, can be expected (Pertot et al. 2017). While organic farming promotes biodiversity in many cropping systems compared to conventional farming (Bengtsson et al. 2005; Hole et al. 2005; Tuck et al. 2014), the effect seems to be less clear in viticulture and vary between and even within organism groups (Bruggisser et al. 2010; Döring et al. 2019; Ostandie et al. 2021; Paiola et al. 2020; Schirmel et al. 2022, Kaczmarek et al. 2023). Since the use of synthetic chemicals is prohibited in organic management, non-synthetic components such as copper and sulfur are used in high quantities in viticulture to control pests, which, however, can also negatively impact non-target organisms (Biondi et al. 2012; Nash et al. 2010; Vogelweith and Thiéry 2018). The copper accumulates in the soil and thus may have long-term risks on the environment (Komárek et al. 2010). Further, an increased number of pesticide applications in organic viticulture leads to more tractor passages, and may affect non-target organisms by higher disturbance of the ground vegetation and increased soil compaction (Bruggisser et al. 2010).

Regardless of conventional or organic vineyard management, the impact of pesticides on biodiversity can be reduced by cultivating fungus-resistant grape (FRG) varieties, which are characterized by resistance traits to the major fungal diseases (Töpfer et al. 2011). While the first resistant grape varieties were developed in the late 19th and early 20th centuries, the first cultivars with convincing wine qualities were only developed by the end of the 20th century and nowadays, over 38 cultivars are available for winegrowers (Töpfer and Trapp 2022). However, despite that the resistances can reduce the need for pesticides by up to 80% for some multi-resistant varieties and increase the sustainability of viticulture (Töpfer and Trapp 2022), only about 2.7% of the area under cultivation is planted with FRG varieties in our study region (Statistisches Bundesamt (Destatis) 2023). Positive effects of the cultivation of such varieties are recently reported to benefit non-target organisms, including predatory mites and some spider families (Pennington et al. 2017, 2019; Reiff et al. 2021a, 2023), making the cultivation of FRG varieties a promising approach to promote biodiversity in viticulture. While this is of importance in the context of, e.g., the European efforts to reduce pesticides, evidence is lacking as there are only few recent research studies on the effects of the cultivation of FRG varieties on biodiversity.

Although organisms are usually exposed to high levels of pesticides due to the intensive management in viticulture, vineyards can provide a suitable habitat for species through the vines themselves, but especially through the vegetation in the inter-rows. Improved ground vegetation management may promote biodiversity by higher vegetation cover and species-rich cover crops providing habitat especially for typical grassland species (Blaise et al. 2022; Ortis et al. 2021; Paiola et al. 2020; Winter et al. 2018). In addition, biodiversity is usually enhanced by heterogeneous landscapes with a high proportion of SNH (Martin et al. 2019; Ostandie et al. 2021; Paiola et al. 2020). Forests, hedges, shrubs, and grasslands can provide habitat for shelter and overwintering as well as food and breeding resources for species for which such resources are not available in vineyards (Holland et al. 2017).

Orthopterans are an important arthropod group in terrestrial food webs and provide a food source for various predatory species (Belovsky and Slade 1993). However, agricultural land use intensification, including the use of pesticides, is considered one of the major threats to Orthoptera species (Zuna-Kratky et al. 2016). They may be highly exposed to pesticides through surface contact, their feeding behavior, and the egg-laying substrate (Bundschuh et al. 2012; Ingrisch and Köhler 1998), making them sensitive to environmental changes caused by management practices. In viticulture, the orthopteran fauna is further determined by tillage, cover crop management, the presence of habitat structures in the surrounding area, and the location of the vineyard in the landscape context (Detzel 1998). In Central Europe, vineyards can mainly be found in climatically favorable regions (Bruggisser et al. 2010) and can provide habitat for several Orthoptera species including both shrub-dwelling orthopterans (mainly species of the order Ensifera) in the vines and herb-dwelling orthopterans (mainly of the order Caelifera) in the inter-row vegetation (Detzel 1998). Hence, Orthoptera are appropriate indicators of the effects of pest, soil, and cover crop management practices and landscape heterogeneity in viticulture as they meet many of the criteria for effective ecological indicators (Noss 1990). In addition, density and species composition can be easily measured (Gardiner et al. 2005), which is why orthopterans are widely used as indicator species in ecological studies (Alignan et al. 2018; Bazelet and Samways 2011; Dvořák et al. 2022).

To assess how organic vineyard management, pesticide reduction, and landscape heterogeneity affect orthopteran densities and species composition, we sampled herb- and vine-dwelling orthopterans using box quadrats and transect walks with song detection, respectively. For this purpose, we used a paired design with classic and FRG varieties in either conventionally or organically managed vineyards along a gradient of landscape heterogeneity. In particular, we expected that (1) orthopterans are promoted by organic compared to conventional farming and (2) that they benefit from the cultivation of FRG varieties. Lastly, we investigated whether (3) SNH-rich compared to vineyard-dominated landscapes favor orthopterans.

Materials and methods

Study area and site selection

We conducted the study in the district Südliche Weinstraße and the district-free city Landau in der Pfalz (49.273280 °N, 8.020602 °E / 49.147516 °N, 8.175736 °E). The area is located in the wine-growing region Palatinate in the south of Rhineland-Palatinate in southwestern Germany with a temperate climate with an average annual temperature of 11.1 °C and a total annual precipitation of 687.5 mm (Agrarmeteorologie Rheinland-Pfalz 2022; Beck et al. 2018).

We chose 16 different landscapes along a gradient of landscape heterogeneity in the study region that differed in their proportion of SNH in the surrounding landscape (Fig. 1). In each landscape, we sampled in two vineyards planted with a FRG and a classic grape variety, respectively, while the management system was organic in half of the pairs of vineyards and conventional in the other half. Of the vineyards studied, those managed conventionally had 10 pesticide applications in classic grape varieties (SD = ± 2)

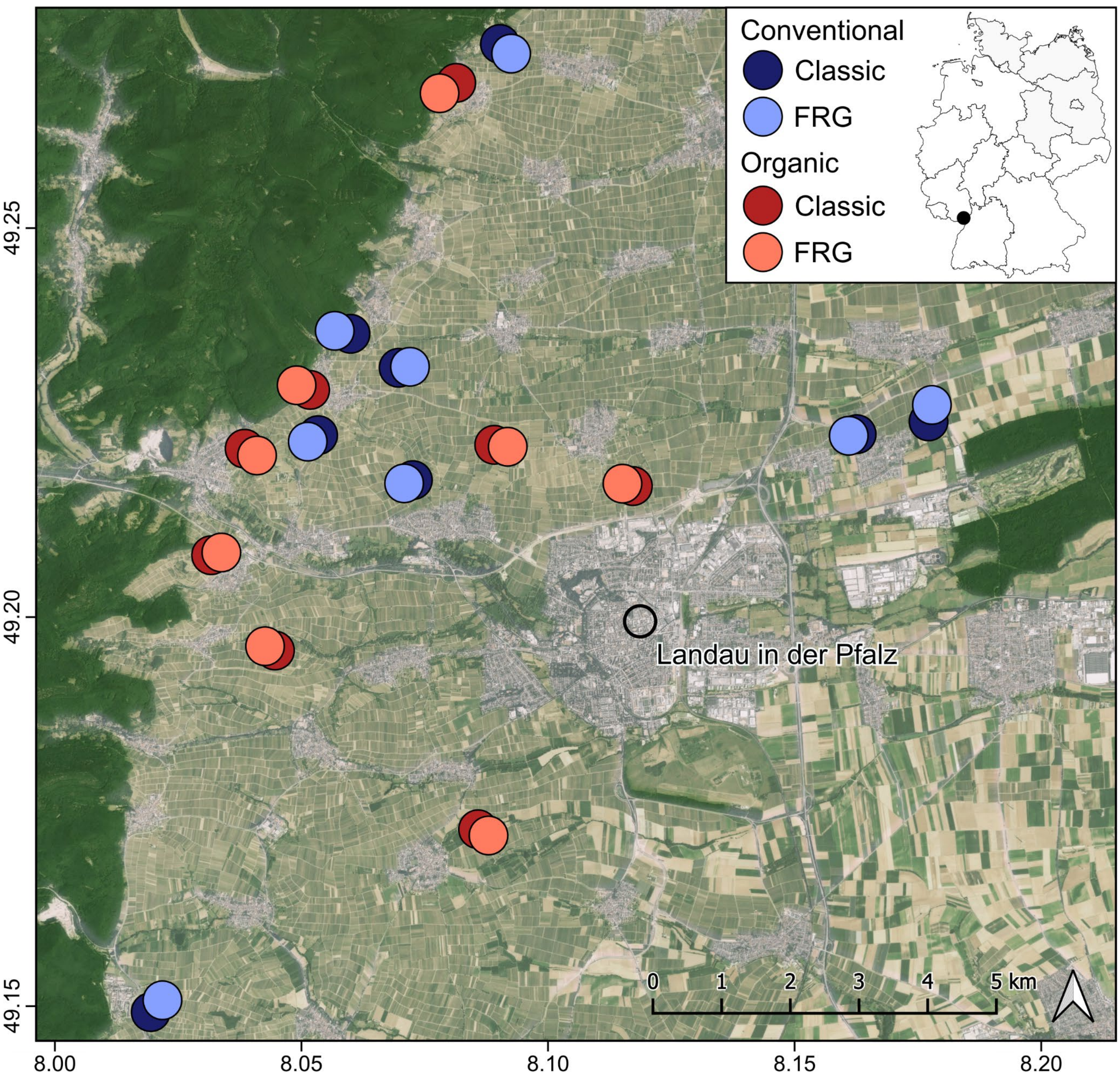

Fig. 1 Locations of the 16 landscapes in the south of Rhineland-Palatinate, Germany, with organic (red) and conventional (blue) management and fungus-resistant (FRG, brighter) and classic grape varieties (darker). Basic map data by © GeoBasis-DE/LVermGeoRP (2022)

and 7 in FRG varieties (SD = ± 3), while those managed organically had 13 pesticide applications in classic grape varieties (SD = ± 1) and 6 in FRG varieties (SD = ± 3; Table S1).

Sampling of herb-dwelling Orthoptera

In mid-August 2021, during dry and warm weather with temperatures ranging from 20 to 30 °C, a 40 m section was sampled in two randomly selected inter-rows in the center of each vineyard using a 1.96 m^2 box quadrat to assess the density of herb-dwelling Orthoptera. We sampled in two adjacent, differently tilled inter-rows and placed the isolation square on the ground seven times per inter-row. We identified orthopterans within the box quadrat (according to Fischer et al. 2020) and released individuals afterwards. Only adult individuals were analyzed.

Sampling of vine-dwelling Orthoptera

In early September 2021, after sunset and during dry weather with temperatures above 10 °C, we walked through two randomly selected inter-rows in the center of each vineyard to assess the density of vine-dwelling Orthoptera in the adjacent rows of grape vines. We detected individuals by their species-specific songs (according to Orthoptera.ch 2021) and additionally used a bat detector (Observer 2 HD², CIEL-electronique) to make calls in the high frequency range audible. We calculated the number of individuals per 100 m inter-row.

Vegetation and landscape parameters

We measured the vegetation height in two randomly selected inter-rows per vineyard by using a cardboard-disc with a diameter of 30 cm and a measuring stick. Further, we visually assessed the proportion of ground covered by vegetation in the two whole inter-rows. A mean value for vegetation height and cover was calculated out of all measurements for each vineyard (Table S1). For each landscape, we calculated the mean proportion of SNH, which we defined as forests, hedges, shrubs, and grassland, within a radius of 500 m of each vineyard using ATKIS data (Basis-DLM by ©GeoBasis-DE/BKG (2013)) with intersection of spatial data in an Oracle database 12c (Oracle 2017).

Data analysis

We used R 4.0.5 (R Core Team 2021) for statistical analyses and the R package *ggplot2* (Wickham 2016) for creating figures.

We used an information-theoretic approach to multi-model inference (Burnham and Anderson 2002) to analyze the effects of vineyard management and vegetation and landscape parameters on Orthoptera densities. We conducted linear mixed models (R command 'lmer' in the R package *lme4*, Bates et al. 2015) and used total density of herb-dwelling Orthoptera, total density of vine-dwelling Orthoptera, and densities of the three most frequent herb- and vine-dwelling Orthoptera, respectively, as dependent variables. In order to meet model assumptions, densities were log (x + 1) transformed. We standardized the regression predictors using the 'standardize' function (R package *arm*, Gelman and Su 2016). As explanatory variables we included vineyard management (factor with the two levels 'organic' and 'conventional'), grape variety (factor with the two levels 'FRG' and 'classic'), vegetation cover (continuous), vegetation height (continuous), and the amount of SNH in the surrounding landscape (continuous) in the full models. To assess whether the effect of grape variety differs among organic and conventional vineyards, we further included their interaction in the models. Due to our paired design, we included the site ID as a random effect in the models. For automated model selection, we used the 'dredge' function (R package *MuMln*, Bartoń 2020) and selected those top-ranked models within Δ AICc < 4. We used the AICc for small sample sizes. Conditional averaged parameter estimates from this top set of models were then produced using the 'model.avg' function. To check for correlations among the explanatory variables we calculated the variation inflation factors (VIF). In cases where an explanatory variable had a VIF > 2 (which was either vegetation height or vegetation cover), we excluded this variable in the full model which resulted in VIF < 2 of all remaining variables.

The species composition of Orthoptera was analyzed using redundancy analysis (command 'rda' in package *vegan*, Oksanen et al. 2020). For the multivariate analysis, we used binary data (presence / absence) because densities of herb- and vine-dwelling Orthoptera are not comparable due to the differently used sampling methods. We used the same explanatory variables as in the univariate models.

Results

General results

With the box quadrat, we sampled 271 adult individuals of five herb-dwelling Orthoptera species (Table S2). Most frequent species were *Chorthippus brunneus* (Thunberg, 1815; 126 individuals) followed by *C. biguttulus* (Linnaeus, 1758; 91 individuals) and *Pseudochorthippus parallelus*

(Zetterstedt, 1821; 50 individuals). Only one Ensifera individual of *Roeseliana roeselii* (Hagenbach, 1822) was found while all others belonged to Caelifera.

With the sound detection, we sampled 270 individuals of four vine-dwelling species (Table S3). By far the most frequent species was *Phaneroptera falcata* (Poda, 1761; 209 individuals) followed by *Leptophyes punctatissima* (Bosc, 1792; 31 individuals) and *Tettigonia viridissima* (Linnaeus, 1758; 23 individuals).

Effects of vineyard management, grape variety, and local and landscape parameters

Total density of herb-dwelling Orthoptera was significantly affected by grape variety and the interaction of management system and grape variety (Table 1). This indicates that total densities were not different between classic and FRG varieties in conventional vineyards, but were almost 3 times higher in FRG varieties under organic management (Fig. 2A). Management, vegetation cover, and the amount of SNH in the surrounding were included in the final model of total density of herb-dwelling Orthoptera but had no significant effects (Table 1). The two most common herb-dwelling species *C. brunneus* and *C. biguttulus* showed similar responses: Both species had higher densities in FRG varieties under organic management, while no such differences were observed in conventional vineyards. Furthermore, *C. brunneus* densities significantly increased with increasing vegetation height (Fig. 2B and C). Management, grape variety, and the amount of SNH in the surrounding were all not significantly related to densities of *C. brunneus* and *C. biguttulus* (Table 1). For *P. parallelus* we found a significant influence of the grape variety while all other parameters had no significant effect (Table 1). Densities were on average about two times higher in FRG compared to classic varieties (organic vineyards: three times higher, conventional vineyards: 1.7 times higher; Fig. 2D).

As a trend, total density of vine-dwelling Orthoptera was affected by the interaction of management and grape variety (Table 2). Densities were similar between classic and FRG varieties in organic vineyards, but 1.4 times higher in classic grapes under conventional management (Fig. 3A). Further, their density tended to increase with increasing vegetation cover. All other parameters included in the final model of total density of vine-dwelling Orthoptera had no significant effects (Table 2). For the density of the most frequent vine-dwelling Orthoptera *P. falcata*, we found no significant effects of the explanatory variables (Table 2). *P. falcata* densities were higher in conventional than in organic vineyards, but this pattern was statistically not significant and driven by two extreme values in classic and FRG varieties, respectively (Fig. 3B; Table 2). Organic management had

Table 1 Model-averaging results of the top-ranked models for total densities of herb-dwelling Orthoptera and the three most common species in vineyards with different management (conventional, organic) and grape varieties (classic, fungus-resistant). Indicated are the standardized coefficient (Coeff.), adjusted standard error (SE), z-score (z), and P-value (p) for management, grape variety, their interaction (Man:Var), semi-natural habitats (SNH), and vegetation cover and height. Significant P-values are in bold, P-values with a trend are in italics

Predictor	Total density				*Chorthippus brunneus*				*Chorthippus biguttulus*				*Pseudochorthippus parallelus*			
	Coeff.	SE	z	p	Coeff.	SE	z	p	Coeff.	SE	z	p	Coeff.	SE	z	p
Intercept	0.863	0.069	12.586	**< 0.001**	0.557	0.067	8.364	**< 0.001**	0.451	0.074	6.127	**< 0.001**	0.306	0.060	5.107	**< 0.001**
Management	-0.186	0.138	1.343	0.179	0.030	0.137	0.218	0.828	-0.166	0.146	1.139	0.255	-0.083	0.120	0.691	0.489
Grape variety	0.254	0.053	4.809	**< 0.001**	0.179	0.120	1.493	0.135	-0.081	0.068	1.201	0.230	0.189	0.090	2.101	**0.036**
Man:Var	0.456	0.106	4.285	**< 0.001**	0.374	0.195	1.916	*0.055*	0.363	0.128	2.830	**0.005**	*Not included in top-ranked model*			
SNH	0.093	0.141	0.659	0.510	0.027	0.136	0.026	0.844	0.037	0.161	0.277	0.820	0.101	0.121	0.836	0.403
Veg. cover	0.099	0.085	1.155	0.248	*Not included in full model*				-0.151	0.117	1.294	0.196	*Not included in full model*			
Veg. height	*Not included in full model*				0.272	0.129	2.104	**0.035**	*Not included in full model*				-0.117	0.111	1.058	0.290

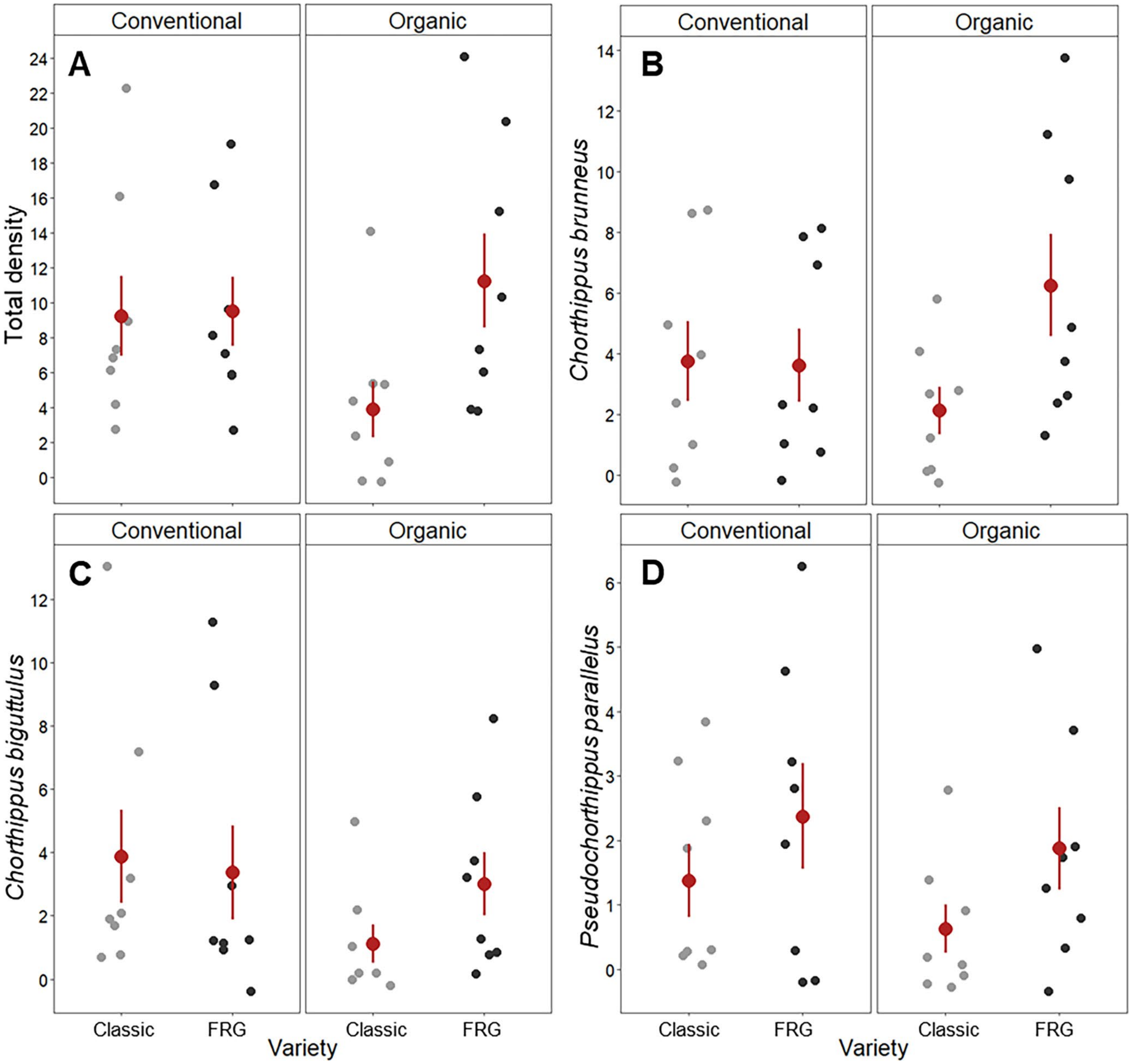

Fig. 2 Densities (mean ± SE and raw data points) of herb-dwelling Orthoptera (total and the three most common species) for classic and fungus-resistant grape (FRG) varieties under conventional and organic management

a significant negative effect on *T. viridissima* and densities were on average three times higher in conventional than in organic vineyards (Table 2; Fig. 3C). The amount of SNH in the surrounding landscape, grape variety, and its interaction with management as well as vegetation height had all no significant influence on the density of *T. viridissima* (Table 2). *L. punctatissima* densities increased significantly with increasing amount of SNH while no other explanatory variable had a significant effect (Table 2; Fig. 3D).

The Orthoptera species composition, based on presence-absence data, was significantly influenced by vineyard management and the amount of SNH in the surrounding of the vineyard (Table 3). However, it was not affected by the grape variety. Species related to conventional vineyards were *T. viridissima* and *C. biguttulus*, while *L. punctatissima* were more common in organic vineyards (Fig. 4). *L. punctatissima* was also related to vineyards with a higher amount of SNH in the surrounding landscape, while *P. falcata* was more common in vineyards with less SNH (Fig. 4).

Table 2 Model-averaging results of the top-ranked models for total densities of vine-dwelling Orthoptera and the three most common species in vineyards with different management (conventional, organic) and grape varieties (classic, fungus-resistant). Indicated are the standardized coefficient (Coeff.), adjusted standard error (SE), z-score (z), and P-value (p) for management, grape variety, their interaction (Man:Var), semi-natural habitats (SNH), and vegetation cover and height. Significant P-values are in bold, P-values with a trend are in italics

Predictor	Total density				*Phaneroptera falcata*				*Tettigonia viridissima*				*Leptophyes punctatissima*			
	Coeff.	SE	z	p	Coeff.	SE	z	p	Coeff.	SE	z	p	Coeff.	SE	z	p
Intercept	0.497	0.075	6.615	**<0.001**	0.311	0.085	3.673	**<0.001**	0.111	0.026	4.214	**<0.001**	0.144	0.032	4.537	**<0.001**
Management	-0.225	0.146	1.536	0.125	-0.258	0.164	1.575	0.115	-0.108	0.053	2.045	**0.041**	0.074	0.063	1.171	0.242
Grape variety	-0.018	0.056	0.331	0.741	0.008	0.060	0.129	0.898	-0.081	0.053	1.527	0.127	0.035	0.060	0.588	0.556
Man:Var	0.200	0.103	1.940	*0.053*	*Not included in top-ranked model*				0.089	0.100	0.864	0.386	*Not included in top-ranked model*			
SNH	0.012	0.165	0.678	0.498	-0.191	0.174	1.100	0.271	0.071	0.055	1.305	0.192	0.241	0.064	3.701	**0.002**
Veg. cover	0.149	0.091	1.650	*0.099*	0.100	0.099	1.009	0.313	*Not included in full model*				*Not included in full model*			
Veg. height	*Not included in full model*				*Not included in full model*				0.033	0.060	0.547	0.584	0.034	0.064	0.533	0.594

Discussion

We assessed how organic and conventional viticulture, reduced pesticide application by using FRG varieties, and the proportion of SNH in the landscape around vineyards affected the density and species composition of herb- and vine-dwelling Orthoptera. Our main findings were that total densities of herb-dwelling Orthoptera were greatly enhanced in FRG varieties under organic management, while total densities of vine-dwelling Orthoptera tended to be higher in classic grapes under conventional management. Further, the management system and SNH in the surrounding landscape influenced species composition.

In contrast to our first hypothesis, we did not find any general effects of organic viticulture on total densities of Orthoptera. The only species where we found an effect was *T. viridissima*, being even three times less abundant in organically managed vineyards than in conventional ones. Thus, a conversion from conventional to organic viticulture, such as that aimed for by the European Green Deal to counteract the loss of biodiversity (European Commission 2019), does not seem to increase Orthoptera densities in our study. However, it is important to note that the diversity and conservation value of orthopterans that we found was rather low compared to some areas with different soil and relief, such as in the Middle Rhine valley (Wersebeckmann et al. 2023). Similarly, other studies showed that general effects of organic farming in viticulture on biodiversity are less clear then in other cropping systems, where both positive and negative effects were reported (Bengtsson et al. 2005; Bruggisser et al. 2010; Ostandie et al. 2021; Paiola et al. 2020). In organic viticulture, non-synthetic compounds (mainly copper and sulfur) are used instead of synthetic chemicals, but they can have strong effects on non-target organisms, too (Biondi et al. 2012; Nash et al. 2010; Vogelweith and Thiéry 2018). Möth et al. (2021) found higher toxicity levels in organic vineyards, where high concentrations of copper accumulate in the soil (Mackie et al. 2012). The effects of management and fungicide reduction observed in our study could have been weakened by pesticide drift from neighboring fields (Druart et al. 2011), because vineyards of our region are often small and adjacent vineyards are frequently managed differently. However, the observed differences in species abundances and species composition confirm that our study design was suitable to detect local management effects on Orthoptera. Vineyard management influenced species and taxonomic groups differently, and thus, may affect species interactions (Caprio et al. 2015; Ostandie et al. 2021; Pedneault and Provost 2016; Vogelweith and Thiéry 2018). Further research is needed to determine the extent to which species relevant to nature conservation or

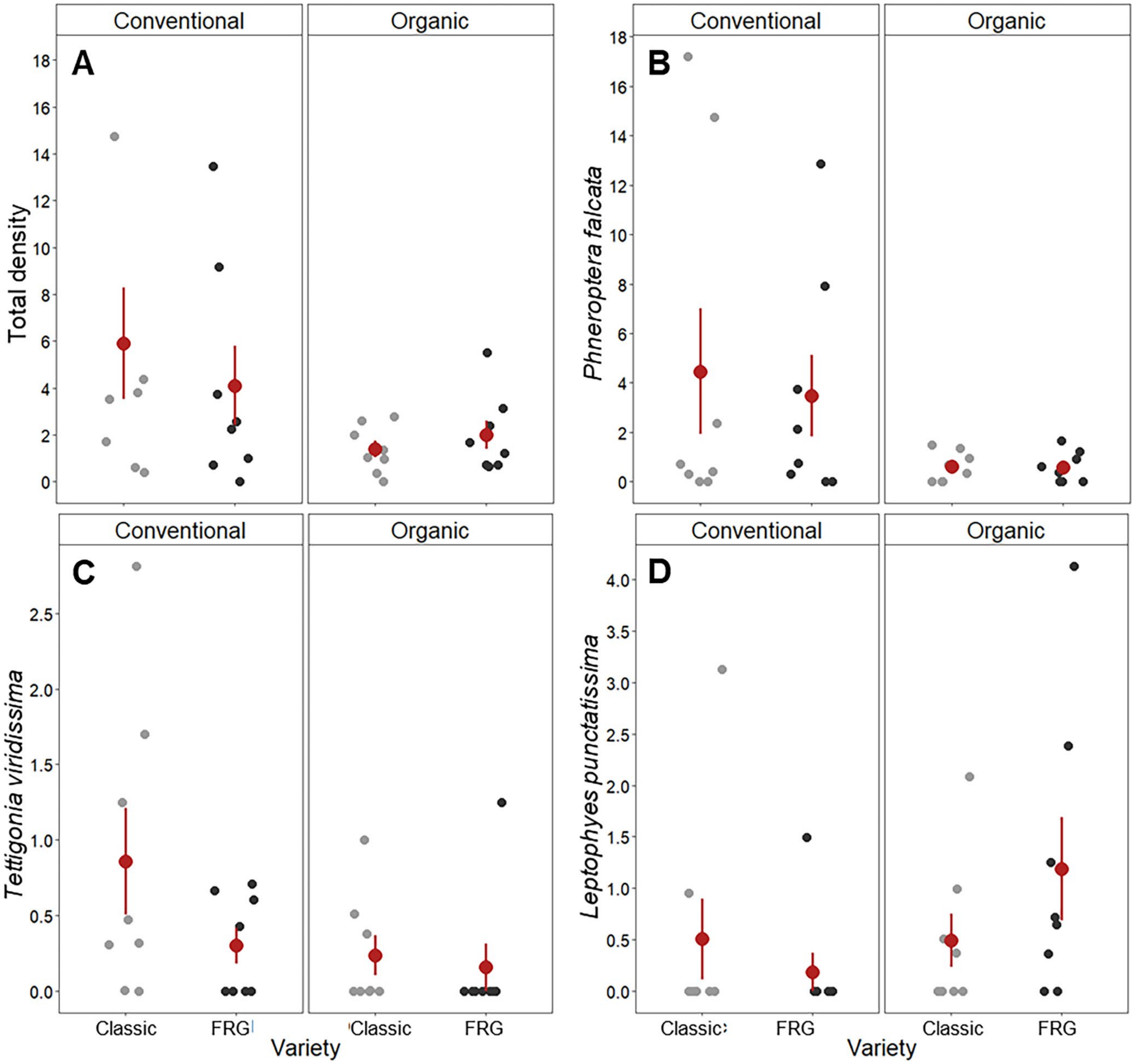

Fig. 3 Densities (mean ± SE and raw data points) of vine-dwelling Orthoptera (total and the three most common species) for classic and fungus-resistant grape (FRG) varieties under conventional and organic management

Table 3 Effect of vineyard management (conventional, organic), grape varieties (classic, fungus-resistant), vegetation height and cover, and the proportion of semi-natural habitats in the surrounding landscape on the species composition of Orthoptera in vineyards analyzed using redundancy analysis on presence-absence data. Indicated are the F-value (F) and P-value (p). Significant P-values are in bold

Predictor	F	p
Management	2.576	**0.009**
Grape variety	1.265	0.267
Vegetation height	1.463	0.159
Vegetation cover	1.615	0.122
Semi-natural habitats	2.177	**0.028**
Management:Grape variety	0.708	0.670

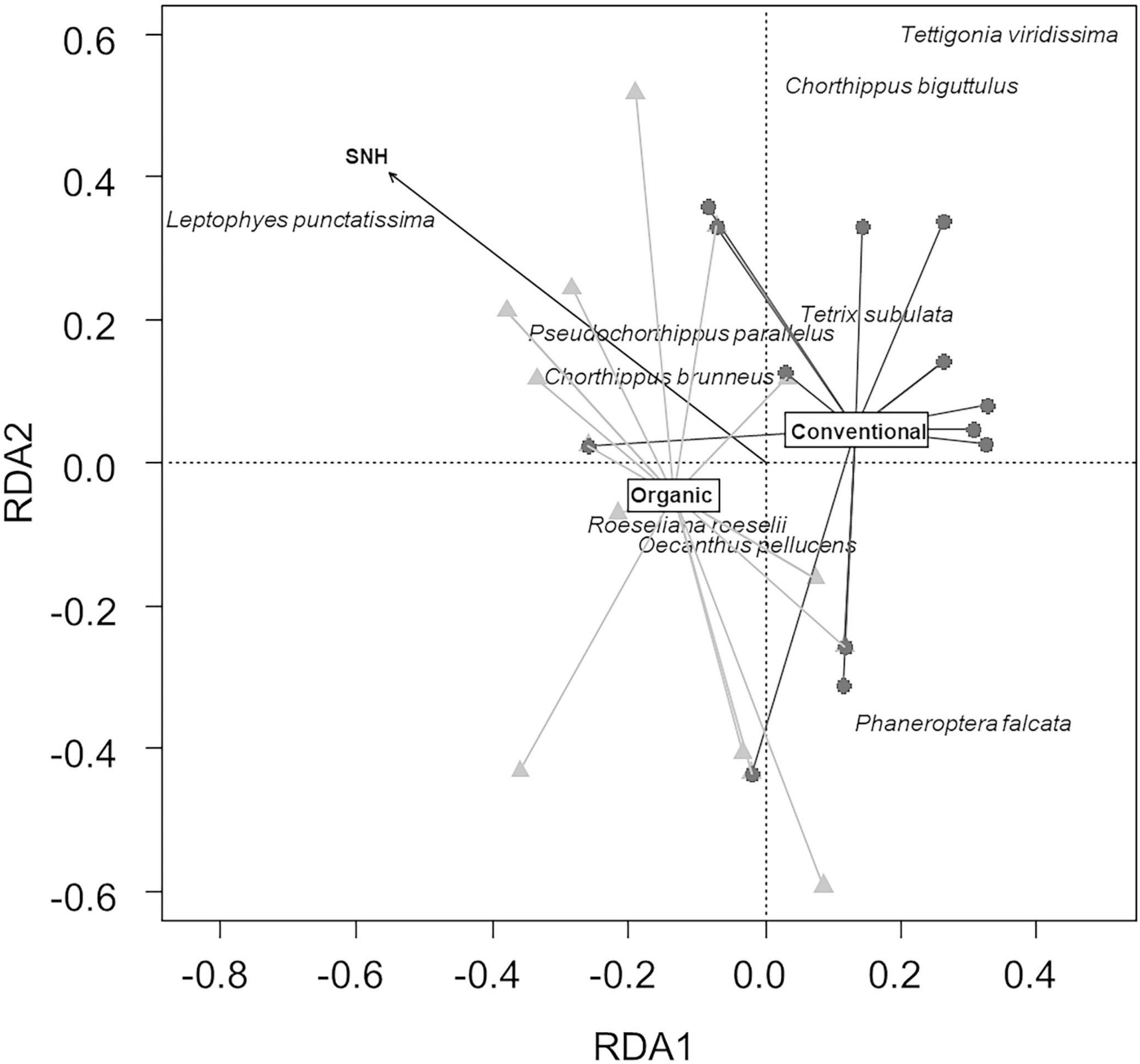

Fig. 4 Biplot based on redundancy analysis (presence-absence data) of the species composition of Orthoptera in vineyards. Species composition was significantly affected by vineyard management (organic, conventional) and the proportion of semi-natural habitats in the surrounding landscape. For statistics see Table 3

beneficial insects are harmed or benefited by conversion to organic viticulture.

Herb-dwelling orthopterans were, in accordance with our second hypothesis, more common in FRG varieties with fewer pesticide applications compared to classic grape varieties. However, a positive effect of reduced pesticide application, with the exception of *P. parallelus*, was only present in organically managed vineyards, where copper and sulfur are used for plant protection. Since both the herb-dwelling Orthoptera and *T. viridissima*, which was affected by organic management as we discussed before, lay their eggs in the soil (Ingrisch and Köhler 1998), the eggs and hatching larvae, respectively, may be comparatively affected by accumulating copper in the topsoil (Karimi et al. 2021), which could explain the stronger negative effect. Furthermore, orthopterans can be exposed to copper through surface contact and their feeding behavior (Ingrisch and Köhler 1998). In a microcosm experiment, however, Karimi et al. (2021) have determined that the effects of copper on soil biodiversity are only measurable at annual concentrations far above those authorized by the European commission, while in toxicity tests, Duque et al. (2023) found that concentrations also found in regional vineyards could have lethal effects on earthworms. However, Karimi et al. (2021) also point out that there is still a lack of field experiments that provide information on community dynamics under in situ conditions. In addition to the negative effects of copper, the use of dusting sulfur, which is used particularly in organic viticulture as fungicide but acts as a broad-spectrum pesticide, may also negatively affect non-target organisms in the inter-rows, potentially leading to a positive effect of reduced plant protection on herb-dwelling orthopterans. A negative effect of sulfur on non-target organisms such as parasitoids, predatory thrips and mites, and grapevine moths has been shown in earlier studies (Hanna et al. 1997; Jepsen et al. 2007; Tacoli et al. 2020). In addition to negative effects of pesticides in organic and conventional viticulture, the fact that *P. parallelus* is similarly affected by the cultivation of FRG varieties in both organic and conventional management may be also due to a lower overall workload in those vineyards. A reduced number of pesticide applications leads to less tractor traffic, resulting in less disturbance of the ground vegetation and reduced soil compaction likely enhancing orthopterans (Bruggisser et al. 2010). This could be particularly relevant in flightless species such as *P. parallelus*. Less intensive tillage may also be beneficial for egg pods development (Detzel 1998).

Vine-dwelling Orthoptera had similar densities in organic managed vineyards, but tended to be 1.4 times more abundant in classic than in FRG varieties in conventional managed vineyards. However, the total density of vine-dwelling Orthoptera was driven by high densities of *P. falcata*. *T. viridissima* seems to be more affected by pesticides used under organic management, where it occurs generally less common compared to conventional management. This may be because the larval stage lives in the herb layer (Detzel 1998), where it may come into contact with copper more intensively. Although copper also accumulates in the leaves of grapevines throughout the season (Angelova et al. 1999), species appear to be less affected here. One reason for this could be that copper on leaves is washed off by precipitation (Angelova et al. 1999). Furthermore, the use of sulfur as a widely used pesticide in organic viticulture may play a role here, too. Thus, reducing high toxicity levels in organic viticulture by cultivating FRG varieties can have a particularly large effect on promoting such affected species and may be a promising approach to reduce the pressure of intensified agriculture on biodiversity, as it was also reported to have positive effects on mites, spiders, and certain insects (Pennington et al. 2017, 2019; Reiff et al. 2021a, 2023; Kaczmarek et al. 2023). Furthermore, the trend for higher densities of vine-dwelling Orthoptera in classic grape varieties compared to FRG varieties in conventionally managed vineyards, driven by *P. falcata*, could possibly be explained by changes in species composition. For example, vine-dwelling Orthoptera could benefit from increased pesticide use if their predators or competitors are affected negatively. Further research would be needed to substantiate such possible indirect effects. Regardless of the exact mechanisms, our results highlight how the use of pesticides can affect species abundance differently and how these differential effects can alter species composition.

While a strong positive effect of landscape heterogeneity on biodiversity has been reported in various studies (Barbaro et al. 2021; Kolb et al. 2020; Martin et al. 2019; Schmidt et al. 2005), the influence of landscape is comparatively low in our study. One reason for this rather low positive effect on Orthoptera could be that orthopterans tend to be sedentary species with a small range of action and the entire life cycle of the observed herb- and vine-dwelling species can take place in the vineyards or the immediate surroundings (Detzel 1998; Ingrisch and Köhler 1998). Only the species *L. punctatissima* occurs more frequently with a higher proportion of SNH. *L. punctatissima* prefers forest edges and is dependent on woody structures with adjacent grass and herbaceous areas (Detzel 1998; Schlumprecht 2003), so a higher abundance is expected here, as a higher proportion of SNH in our study is often associated with a higher proportion of forest in the surrounding area and thus a shorter distance to forest edges (Fig. S1).

Biodiversity is usually influenced by local practices besides pesticide use, such as tillage and cover crop management (Blaise et al. 2022; Ostandie et al. 2021; Reiff et al. 2021b). In line with this, we found that vegetation positively affected *C. brunneus*, which became more abundant with increasing vegetation height. Additionally, the total density of vine-dwelling Orthoptera tended to increase with higher ground vegetation cover, possibly being influenced by the inter-row vegetation during larval stages that live in the herb layer (Detzel 1998). Increased densities of Orthoptera with increasing vegetation height and vegetation cover might be linked to higher food supply, suitable microclimate, and the provision of hiding places. Further, more intensive tillage may harm egg pods development (Detzel 1998). Adapted management of vineyard inter-rows, such as grazing or less intensive mowing and tillage, can thus be another effective measure to promote the biodiversity of herb-dwelling species, in addition to the measures previously discussed (Blaise et al. 2022; Bosco et al. 2022; Detzel 1998).

Conclusion

According to our results, organic viticulture had no general positive effect on Orthoptera. Rather, reducing the number of pesticide applications and associated tractor passages, at least in organic viticulture, is important and shows a clear benefit to some orthopterans. Effects of the proportion of semi-natural habitats in the surrounding landscape on Orthoptera in vineyards were weak, while other studies showed strong positive effects for other taxonomic groups of insects as well as for spiders and birds. We conclude that under organic viticulture, reducing the use of non-specific pesticides is important to promote biodiversity and that the cultivation of fungus-resistant grape varieties can have a significant part to this progress.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10841-023-00493-9.

Acknowledgements We thank the winegrowers for their cooperation and permission to work on their properties and acknowledge Peter Horney for providing the data of semi-natural habitats in the study area.

Authors' contributions M.K., M.G., M.H.E., C.H., and J.S. conceptualized the study and designed methodology. M.G. collected data of herb-dwelling orthopterans while M.K. collected data of vine-dwelling orthopterans. J.S. analyzed the data. M.K. led the writing of the manuscript with M.G. and J.S. under supervision of M.H.E. and C.H. C.H. administered the project and acquired funding. All authors contributed critically to the study and have read and agreed to the final version of the manuscript.

Funding Open Access funding enabled and organized by Projekt DEAL. The presented study, financed by Julius Kühn Institute funds, is part of the joint project 'Farmland biodiversity Monitoring' (MonViA) that has been funded by the German Federal Ministry of Food and Agriculture.

Declarations

Conflict of Interest The authors declare no conflict of interest.

Competing interests The authors declare no competing interests.

References

Agrarmeteorologie Rheinland-Pfalz (2022) Weatherstation Siebeldingen: Mean values 2008–2020. https://www.wetter.rlp.de/Internet/AM/NotesAM.nsf/amweb/752dce127578072cc12572eb0020c16c?OpenDocument&TableRow=2.1.2,2.6#2.1. Accessed 18 November 2022

Alignan J-F, Debras J-F, Dutoit T (2018) Orthoptera prove good indicators of grassland rehabilitation success in the first french natural Asset Reserve. J Nat Conserv 44:1–11. https://doi.org/10.1016/j.jnc.2018.04.002

Angelova VR, Ivanov AS, Braikov DM (1999) Heavy metals (pb, Cu, Zn and Cd) in the system soil - grapevine - grape. J Sci Food Agric 79:713–721. https://doi.org/10.1002/(SICI)1097-0010(199904)79:5<713:AID-JSFA229>3.0.CO;2-F

Barbaro L, Assandri G, Brambilla M, Castagneyrol B, Froidevaux J, Giffard B, Pithon J, Puig-Montserrat X, Torre I, Calatayud F, Gaüzère P, Guenser J, Macià-Valverde F-X, Mary S, Raison L, Sirami C, Rusch A (2021) Organic management and landscape heterogeneity combine to sustain multifunctional bird communities in european vineyards. J Appl Ecol 58:1261–1271. https://doi.org/10.1111/1365-2664.13885

Bartoń K (2020) MuMIn: Multi-Model Inference. R package version 1.43.17. https://cran.r-project.org/web/packages/MuMIn/index.html

Bates D, Mächler M, Bolker B, Walker S (2015) Fitting linear mixed-effects models using lme4. J Stat Softw 67:1–48. https://doi.org/10.18637/jss.v067.i01

Bazelet CS, Samways MJ (2011) Identifying grasshopper bioindicators for habitat quality assessment of ecological networks. Ecol Indic 11:1259–1269. https://doi.org/10.1016/j.ecolind.2011.01.005

Beck HE, Zimmermann NE, McVicar TR, Vergopolan N, Berg A, Wood EF (2018) Present and future Köppen-Geiger climate classification maps at 1-km resolution. Sci Data 5:180214. https://doi.org/10.1038/sdata.2018.214

Belovsky GE, Slade JB (1993) The role of vertebrate and invertebrate predators in a grasshopper community. Oikos 68:193. https://doi.org/10.2307/3544830

Bengtsson J, Ahnström J, Weibull A-C (2005) The effects of organic agriculture on biodiversity and abundance: a meta-analysis. J Appl Ecol 42:261–269. https://doi.org/10.1111/j.1365-2664.2005.01005.x

Biondi A, Desneux N, Siscaro G, Zappalà L (2012) Using organic-certified rather than synthetic pesticides may not be safer for biological control agents: selectivity and side effects of 14 pesticides on the predator Orius laevigatus. Chemosphere 87:803–812. https://doi.org/10.1016/j.chemosphere.2011.12.082

Blaise C, Mazzia C, Bischoff A, Millon A, Ponel P, Blight O (2022) Vegetation increases abundances of ground and canopy arthropods in Mediterranean vineyards. Sci Rep 12:3680. https://doi.org/10.1038/s41598-022-07529-1

Bosco L, Siegenthaler D, Ruzzante L, Jacot A, Arlettaz R (2022) Varying responses of invertebrates to biodynamic, organic and conventional viticulture. Front Conserv Sci 3. https://doi.org/10.3389/fcosc.2022.837551

Bruggisser OT, Schmidt-Entling MH, Bacher S (2010) Effects of vineyard management on biodiversity at three trophic levels. Biol Conserv 143:1521–1528. https://doi.org/10.1016/j.biocon.2010.03.034

Bundschuh R, Schmitz J, Bundschuh M, Brühl CA (2012) Does insecticide drift adversely affect grasshoppers (Orthoptera: Saltatoria) in field margins? A case study combining laboratory acute toxicity testing with field monitoring data. Environ Toxicol Chem 31:1874–1879. https://doi.org/10.1002/etc.1895

Burnham KP, Anderson DR (2002) Model selection and multi-model inference: a practical information-theoretic approach, 2nd edn. Springer New York, New York

Caprio E, Nervo B, Isaia M, Allegro G, Rolando A (2015) Organic versus conventional systems in viticulture: comparative effects on spiders and carabids in vineyards and adjacent forests. Agric Syst 136:61–69. https://doi.org/10.1016/j.agsy.2015.02.009

Detzel P (ed) (1998) Die Heuschrecken Baden-Württembergs: [im Rahmen des Artenschutzprogrammes Baden-Württemberg]; 51 Tabellen. Ulmer, Stuttgart. (Hohenheim)

Döring J, Collins C, Frisch M, Kauer R (2019) Organic and biodynamic viticulture affect biodiversity and properties of vine and wine: a systematic quantitative review. Am J Enol Vitic 70:221–242. https://doi.org/10.5344/ajev.2019.18047

Druart C, Millet M, Scheifler R, Delhomme O, Raeppel C, de Vaufleury A (2011) Snails as indicators of pesticide drift, deposit, transfer and effects in the vineyard. Sci Total Environ 409(20):4280–4288. https://doi.org/10.1016/j.scitotenv.2011.07.006

Duque T, Nuriyev R, Römbke J, Schäfer RB, Entling MH (2023) Variation in the chemical sensitivity of earthworms from field populations to imidacloprid and copper. Environ Toxicol Chem 42:939–947. https://doi.org/10.1002/etc.5589

Dvořák T, Hadrava J, Knapp M (2022) The ecological niche and conservation value of central european grassland orthopterans: a quantitative approach. Biol Conserv 265:109406. https://doi.org/10.1016/j.biocon.2021.109406

European Commission (2019) The European Green Deal. Communication from the commission, Brussels, Belgium

Fischer J, Steinlechner D, Zehm A, Poniatowski D, Fartmann T, Beckmann A, Stettmer C (2020) Die Heuschrecken Deutschlands und Nordtirols: Bestimmen – Beobachten – Schützen, 2nd edn. Quelle & Meyer, Wiebelsheim

Gardiner T, Hill J, Chesmore D (2005) Review of the methods frequently used to estimate the abundance of orthoptera in grassland ecosystems. J Insect Conserv 9:151–173. https://doi.org/10.1007/s10841-005-2854-1

Gelman G, Su YS (2016) arm: Data analysis using regression and multilevel/hierarchical models. R package version 1.9-3. https://CRAN.Rproject.org/package=arm

Hallmann CA, Sorg M, Jongejans E, Siepel H, Hofland N, Schwan H, Stenmans W, Müller A, Sumser H, Hörren T, Goulson D, de Kroon H (2017) More than 75% decline over 27 years in total flying insect biomass in protected areas. PLoS ONE 12:e0185809. https://doi.org/10.1371/journal.pone.0185809

Hanna R, Zalom FG, Wilson LT, Leavitt GM (1997) Sulfur can suppress mite predators in vineyards. Calif Agric 51:19–21. https://doi.org/10.3733/ca.v051n01p19

Hochkirch A (2016) The insect crisis we can't ignore. Nature 539:141. https://doi.org/10.1038/539141a

Hole DG, Perkins AJ, Wilson JD, Alexander IH, Grice PV, Evans AD (2005) Does organic farming benefit biodiversity? Biol Conserv 122:113–130. https://doi.org/10.1016/j.biocon.2004.07.018

Holland JM, Douma JC, Crowley L, James L, Kor L, Stevenson DR, Smith BM (2017) Semi-natural habitats support biological control, pollination and soil conservation in Europe. A review. Agron Sustain Dev 37. https://doi.org/10.1007/s13593-017-0434-x

Ingrisch S, Köhler G (1998) Die Heuschrecken Mitteleuropas. Die Neue Brehm-Bücherei, vol 629. Westarp Wissenschaften, Magdeburg

Jepsen SJ, Rosenheim JA, Bench ME (2007) The effect of sulfur on biological control of the grape leafhopper, Erythroneura elegantula, by the egg parasitoid Anagrus erythroneurae. Biocontrol 52:721–732. https://doi.org/10.1007/s10526-006-9058-9

Kaczmarek M, Entling MH, Hoffmann C (2023) Differentiating the effects of organic management, pesticide reduction, and landscape diversification for arthropod conservation in viticulture. Biodivers Conserv. https://doi.org/10.1007/s10531-023-02621-y

Karimi B, Masson V, Guilland C, Leroy E, Pellegrinelli S, Giboulot E, Maron P-A, Ranjard L (2021) Ecotoxicity of copper input and accumulation for soil biodiversity in vineyards. Environ Chem Lett 19:2013–2030. https://doi.org/10.1007/s10311-020-01155-x

Kolb S, Uzman D, Leyer I, Reineke A, Entling MH (2020) Differential effects of semi-natural habitats and organic management on spiders in viticultural landscapes. Agric Ecosyst Environ 287:106695. https://doi.org/10.1016/j.agee.2019.106695

Komárek M, Čadková E, Chrastný V, Bordas F, Bollinger J-C (2010) Contamination of vineyard soils with fungicides: a review of environmental and toxicological aspects. Environ Int 36:138–151. https://doi.org/10.1016/j.envint.2009.10.005

Mackie KA, Müller T, Kandeler E (2012) Remediation of copper in vineyards–a mini review. Environ Pollut 167:16–26. https://doi.org/10.1016/j.envpol.2012.03.023

Martin EA, Dainese M, Clough Y, Báldi A, Bommarco R, Gagic V, Garratt MPD, Holzschuh A, Kleijn D, Kovács-Hostyánszki A, Marini L, Potts SG, Smith HG, Al Hassan D, Albrecht M, Andersson GKS, Asís JD, Aviron S, Balzan MV, Baños-Picón L, Bartomeus I, Batáry P, Burel F, Caballero-López B, Concepción ED, Coudrain V, Dänhardt J, Diaz M, Diekötter T, Dormann CF, Duflot R, Entling MH, Farwig N, Fischer C, Frank T, Garibaldi LA, Hermann J, Herzog F, Inclán D, Jacot K, Jauker F, Jeanneret P, Kaiser M, Krauss J, Le Féon V, Marshall J, Moonen A-C, Moreno G, Riedinger V, Rundlöf M, Rusch A, Scheper J, Schneider G, Schüepp C, Stutz S, Sutter L, Tamburini G, Thies C, Tormos J, Tscharntke T, Tschumi M, Uzman D, Wagner C, Zubair-Anjum M, Steffan-Dewenter I (2019) The interplay of landscape composition and configuration: new pathways to manage functional biodiversity and agroecosystem services across Europe. Ecol Lett 22:1083–1094. https://doi.org/10.1111/ele.13265

Möth S, Walzer A, Redl M, Petrović B, Hoffmann C, Winter S (2021) Unexpected effects of local management and landscape composition on predatory mites and their food resources in vineyards. Insects 12. https://doi.org/10.3390/insects12020180

Nash MA, Hoffmann AA, Thomson LJ (2010) Identifying signature of chemical applications on indigenous and invasive nontarget arthropod communities in vineyards. Ecol Appl 20:1693–1703. https://doi.org/10.1890/09-1065.1

Noss RF (1990) Indicators for monitoring biodiversity: a hierarchical approach. Conserv Biol 4:355–364. https://doi.org/10.1111/j.1523-1739.1990.tb00309.x

Oksanen J, Blanchet FG, Friendly M, Kindt R, Legendre P, McGlinn D, Minchin PR, O'Hara RB, Simpson GL, Solymos P, Stevens MHH, Szoecs E, Wagner H (2020) vegan: Community ecology package. https://CRAN.R-project.org/package=vegan

Oracle (2017) Oracle Database 12c. https://www.oracle.com/database/index.html

Orthoptera.ch (2021) Heuschrecken-Plattform für die Schweiz und Europa. https://www.orthoptera.ch/. Accessed 01 September 2022

Ortis G, Mazzon L, Cavaletto G, Marangoni F, Marini L (2021) Can extensively managed perennial crops serve as surrogate habitat for orthopterans typical of dry calcareous grasslands? Agric Ecosyst Environ 319:107536. https://doi.org/10.1016/j.agee.2021.107536

Ostandie N, Giffard B, Bonnard O, Joubard B, Richart-Cervera S, Thiéry D, Rusch A (2021) Multi-community effects of organic and conventional farming practices in vineyards. Sci Rep 11:11979. https://doi.org/10.1038/s41598-021-91095-5

Paiola A, Assandri G, Brambilla M, Zottini M, Pedrini P, Nascimbene J (2020) Exploring the potential of vineyards for biodiversity conservation and delivery of biodiversity-mediated ecosystem services: a global-scale systematic review. Sci Total Environ 706:135839. https://doi.org/10.1016/j.scitotenv.2019.135839

Pedneault K, Provost C (2016) Fungus resistant grape varieties as a suitable alternative for organic wine production: benefits, limits, and challenges. Sci Hortic 208:57–77. https://doi.org/10.1016/j.scienta.2016.03.016

Pennington T, Kolb S, Kaiser J, Hoffmann C, Entling MH (2019) Does minimal pruning and reduced fungicide use impact spiders in the grapevine canopy? J Arachnol 47:381. https://doi.org/10.1636/0161-8202-47.3.381

Pennington T, Kraus C, Alakina E, Entling MH, Hoffmann C (2017) Minimal pruning and reduced plant protection promote predatory mites in grapevine. Insects 8:86. https://doi.org/10.3390/insects8030086

Pertot I, Caffi T, Rossi V, Mugnai L, Hoffmann C, Grando MS, Gary C, Lafond D, Duso C, Thiery D, Mazzoni V, Anfora G (2017)

A critical review of plant protection tools for reducing pesticide use on grapevine and new perspectives for the implementation of IPM in viticulture. Crop Prot 97:70–84. https://doi.org/10.1016/j.cropro.2016.11.025

R Core Team (2021) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

Reiff JM, Ehringer M, Hoffmann C, Entling MH (2021a) Fungicide reduction favors the control of phytophagous mites under both organic and conventional viticulture. Agric Ecosyst Environ 305:107172. https://doi.org/10.1016/j.agee.2020.107172

Reiff JM, Kolb S, Entling MH, Herndl T, Möth S, Walzer A, Kropf M, Hoffmann C, Winter S (2021b) Organic farming and cover-crop management reduce pest predation in austrian vineyards. Insects 12:220. https://doi.org/10.3390/insects12030220

Reiff JM, Sudarsan K, Hoffmann C, Entling MH (2023) Arthropods on grapes benefit more from fungicide reduction than from organic farming. Pest Manag Sci. https://doi.org/10.1002/ps.7505

Schirmel J, Petschner S, Rösch V, Entling MH (2022) Positive effects of organic viticulture on carabid beetles depend on landscape and local habitat conditions. Ann Appl Biol 181(2):192–200. https://doi.org/10.1111/aab.12771

Schlumprecht H (2003) Heuschrecken in Bayern. Eugen Ulmer, Stuttgart. (Hohenheim)

Schmidt MH, Roschewitz I, Thies C, Tscharntke T (2005) Differential effects of landscape and management on diversity and density of ground-dwelling farmland spiders. J Appl Ecol 42:281–287. https://doi.org/10.1111/j.1365-2664.2005.01014.x

Seibold S, Gossner MM, Simons NK, Blüthgen N, Müller J, Ambarlı D, Ammer C, Bauhus J, Fischer M, Habel JC, Linsenmair KE, Nauss T, Penone C, Prati D, Schall P, Schulze E-D, Vogt J, Wöllauer S, Weisser WW (2019) Arthropod decline in grasslands and forests is associated with landscape-level drivers. Nature 574:671–674. https://doi.org/10.1038/s41586-019-1684-3

Statistisches Bundesamt (Destatis) (2023) Land- und Forstwirtschaft, Fischerei: Landwirtschaftliche Bodennutzung: Rebflächen. Fachserie 3, Reihe 3.1.5. Statistisches Bundesamt, Wiesbaden

Tacoli F, Cargnus E, Zandigiacomo P, Pavan F (2020) Side effects of sulfur dust on the european grapevine moth lobesia botrana and the predatory mite kampimodromus aberrans in Vineyards. https://doi.org/10.3390/insects11110825. Insects 11

Töpfer R, Hausmann L, Harst M, Maul E, Zyprian E, Eibach R (2011) New horizons for grapevine breeding

Töpfer R, Trapp O (2022) A cool climate perspective on grapevine breeding: climate change and sustainability are driving forces for changing varieties in a traditional market. Theor Appl Genet 135:3947–3960. https://doi.org/10.1007/s00122-022-04077-0

Tuck SL, Winqvist C, Mota F, Ahnström J, Turnbull LA, Bengtsson J (2014) Land-use intensity and the effects of organic farming on biodiversity: a hierarchical meta-analysis. J Appl Ecol 51:746–755. https://doi.org/10.1111/1365-2664.12219

Vogelweith F, Thiéry D (2018) An assessment of the non-target effects of copper on the leaf arthropod community in a vineyard. Biol Control 127:94–100. https://doi.org/10.1016/j.biocontrol.2018.08.011

Wagner DL (2020) Insect declines in the anthropocene. Annu Rev Entomol 65:457–480. https://doi.org/10.1146/annurev-ento-011019-025151

Wersebeckmann V, Biegerl C, Leyer I, Mody K (2023) Orthopteran diversity in steep slope vineyards: the role of vineyard type and vegetation management. Insects 14:83. https://doi.org/10.3390/insects14010083

Wickham H (2016) ggplot2: elegant graphics for data analysis, 2nd edn. Use R! Springer International Publishing, Cham

Winter S, Bauer T, Strauss P, Kratschmer S, Paredes D, Popescu D, Landa B, Guzmán G, Gómez JA, Guernion M, Zaller JG, Batáry P (2018) Effects of vegetation management intensity on biodiversity and ecosystem services in vineyards: a meta-analysis. J Appl Ecol 55:2848–2495. https://doi.org/10.1111/1365-2664.13124

Zuna-Kratky T, Buzzetti FM, Braud Y, Cálix M, García Criado M, Nieto A, Hochkirch A, Tumbrinck J, Stalling T, Savitsky V, Puskás G, Olmo-Vidal JM, Morin D, López H, Liana A, Korsunovskaya O, Kočárek P, Karjalainen S, Illich I, Holuša J, Gutiérrez-Rodríguez J, Gomboc S, Fartmann T, Defaut B, Cordero Tapia PJ, Barros F, Barat Domenech J, Vedenina V, Tzirkalli E, Szövényi G, Skejo J, Şirin D, Rutschmann F, Roesti C, Pushkar T, Prunier F, Papapavlou KP, Monnerat C, Massa B, Lemos P, Lemonnier-Darcemont M, Krištín A, Kleukers R, Kati V, Ivković S, Iorgu I, Heller K-G, García MD, Fontana P, Ferreira S, Dusoulier F, Correas JR, Clemente ME, Bushell M, Barranco Vega P, Willemse L, Presa Asensio JJ, Odé B, Chobanov D (2016) European red list of grasshoppers, crickets and bush-crickets. Publications Office, Luxembourg