

Agroecological transition increases arthropod diversity and decreases herbivore abundance on field margins

La transición agroecológica aumenta la diversidad de artrópodos y disminuye la abundancia de herbívoros en bordes de cultivo

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Abstract

1. In peri-urban areas, many farmers are transitioning from conventional agriculture to agroecological practices to reduce pesticide input and preserving ecosystem services such as natural pest control. Field margins represent a stable habitat for arthropods, but community structure depends on many factors, including management type and vegetation features.
2. We studied the effects of agroecological transitions and vegetation features on arthropods of horticultural field margins, focusing on three feeding guilds (herbivores, predators and parasitoids). We sampled arthropods using the beat-sheet method in five conventional fields and five under agroecological transition. We also measured vegetation height, richness, flower abundance and plant cover.
3. Our results showed that arthropod diversity was higher in agroecological fields whereas herbivore abundance was lower, with a consistent pattern across most taxonomic orders. Vegetation features displayed multiple effects among functional and taxonomic groups. Herbivores did not respond to most vegetation variables whereas predators correlated with several, with similar trends among orders.
4. We conclude that agroecological transitions and field margins with high vegetation richness and floral resources influence arthropod communities with potential benefits regarding pest regulation. These practices might be more effective if considered alongside other methods that enhance biodiversity and if they are consistent at a landscape scale.

Abstracta

1. En áreas periurbanas, muchos productores están pasando de un manejo agrícola convencional a prácticas agroecológicas para reducir el input de pesticidas a la vez de preservar servicios ecosistémicos tales como el control natural de plagas. Los márgenes de cultivo representan un hábitat estable para los artrópodos, pero la estructura de la comunidad depende de muchos factores, incluyendo el tipo de manejo y las características de la vegetación.
2. Estudiamos los efectos de la transición agroecológica y las características de la vegetación en artrópodos de márgenes de cultivo de campos hortícolas, concentrándonos en tres gremios tróficos (fitófagos, predadores y parasitoides).

- Colectamos muestras utilizando la técnica del paño vertical en cinco huertas convencionales y cinco en transición agroecológica. También medimos la altura de la vegetación, riqueza de especies, abundancia de flores y cobertura vegetal del suelo.
- Los resultados muestran un aumento de la diversidad de artrópodos en campos agroecológicos, acompañado de una disminución de la abundancia de fitófagos, la cual se mantuvo en la mayoría de los órdenes taxonómicos. Las características de la vegetación mostraron múltiples efectos entre grupos taxonómicos y funcionales. Los fitófagos no respondieron significativamente a la mayoría de las variables de vegetación, mientras que los predadores se correlacionaron con varias de ellas, con tendencias similares entre los distintos órdenes.
 - Concluimos que la transición agroecológica y los bordes de cultivo con mayor riqueza vegetal y abundancia de recursos florales influyen sobre las comunidades de artrópodos con beneficios potenciales en relación a la regulación de plagas. Estas prácticas podrían ser más efectivas si se consideran junto con otros métodos que favorezcan la biodiversidad y sean aplicados a escala de paisaje.

KEYWORDS

agroecology, conventional agriculture, herbivores, insects, management practices, natural enemies, spontaneous vegetation

INTRODUCTION

Conventional agriculture comprises a set of industrial tools and practices initially targeted towards increasing food production in response to the rising global demand, with synthetic fertilizers and pesticides playing a major role (Gliessman, 2014; Nicholls & Altieri, 1997). This model has shown profound flaws in terms of sustainability, as insecticide and herbicide use has driven a substantial increase in pests' resistance and is among the main causes of global insect declines (Benbrook, 2016; Sánchez-Bayo & Wyckhuys, 2019). The impact has been even more critical in horticultural green belts surrounding urban areas (i.e., peri-urban areas), where most fresh-food production is carried out, as wind, rain and irrigation drive a significant part of the applied chemicals towards surrounding landscapes, watercourses and households, threatening the health of nearby populations (Bonansea et al., 2018; García-Santos et al., 2016; Mac Loughlin et al., 2017; Shelton et al., 2014).

In this context, ecological intensification emerges as a set of agricultural paradigms that differ in methods and design but share their main principles, tackling food production through context-specific and ecosystem-based approaches (Tittonell, 2014). One of these models, known as agroecological farming or agroecology, combines traditional farming and family agriculture practices with scientific knowledge, leading towards restoring and maintaining ecosystem services whereas aiming to reduce or eliminate external inputs (Garibaldi et al., 2017; Tschardtke et al., 2012). It provides a common ground for farmers to transition away from conventional agriculture whereas seeking to ensure the stabilization of agroecosystems with a special focus on functional diversity (Altieri, 2018; Corrado et al., 2019).

There is strong evidence that increased arthropod diversity is associated with a lower incidence of pests in agroecosystems (Crowder & Jabbour, 2014; Dainese et al., 2019; Lundgren & Fausti, 2015). In this sense, both richness and abundance of natural enemies contribute to pest biological control; the first by allowing coverage of a higher number of prey/host species, and the second by increasing control strength (Snyder, 2019). In contrast, pesticide applications eliminate pest species but also natural enemies and their potential alternative prey/hosts, precluding natural enemies' re-colonization (Theiling & Croft, 1988). The 'pesticide treadmill' states that the populations of some herbivore species can eventually grow back as there is no top-down control, and due to both high growth rates and short generation times, reach even more abundant populations (Gliessman, 2014; Nicholls & Altieri, 1997; van den Bosch, 1978). This has also been supported by studies linking pest outbreaks and pesticide hormesis, even at an epigenetic level (Brevik et al., 2018; Guedes et al., 2022; Guedes & Cutler, 2014). Furthermore, pesticide applications are a major driver of biodiversity loss in conventional agroecosystems (Krauss et al., 2011; Kremen & Miles, 2012; Sánchez-Bayo & Wyckhuys, 2019), which is one of the many reasons farmers are transitioning away and adopting agroecological practices. A growing number of studies have shown that agroecological fields hold a higher overall arthropod abundance and diversity whereas also maintaining a lower incidence of herbivore species and a higher abundance of natural enemies (Birkhofer et al., 2016; Krauss et al., 2011; Padmavathy & Poyyamoli, 2011).

Arthropod diversity in horticultural fields is closely related to field margin vegetation, as crops only stay in the ecosystem for a short time span. Periodic disturbances related to intensive management and

habitat disruption have negative consequences on arthropod survival, and therefore these agroecosystems are subject to regular recolonization from surrounding crops and non-crop habitats (González et al., 2016; Thorbek & Bilde, 2004; Wissinger, 1997). In particular, the diversity and efficiency of natural enemies depend to a great extent on the availability of habitats that offer alternative prey/hosts, flower resources (nectar and pollen), shelter and nesting/overwintering sites (Altieri & Letourneau, 1982; Gallé et al., 2018; Morandin et al., 2014). It has been reported that mobility between crop and non-crop vegetation is higher for natural enemies than for herbivores, whereas crop phenology is a stronger determinant of pests' population dynamics (González et al., 2016; Macfadyen et al., 2015). Moreover, margins work as biological corridors and buffer zones between fields, contributing to the maintenance of biodiversity in highly simplified landscapes (Gill et al., 2014; Holzschuh et al., 2008; Nicholls et al., 2001). In addition, margin vegetation serves as a physical barrier against spray drift from nearby fields, whereas still being able to hold a variable amount of arthropod diversity (Otto et al., 2009). Therefore, assessing whether agroecological practices enhance arthropod diversity in margin vegetation, in contrast to those in fields where pesticides are periodically applied, could contribute to understanding the effectiveness of these transitions.

Beyond the role of margin vegetation as a nexus between field management and arthropods, field margin vegetation has its own set of variable attributes that can influence its ability to support arthropods and their associated ecosystem services. Increased flower resource availability can favour pollinator, parasitoid, predator and occasionally herbivore populations whose adults feed on nectar and pollen, enhancing their longevity and fecundity (M. Russell, 2015; Wäckers et al., 2007; Wäckers & van Rijn, 2012). Also, the abundance and diversity of flower resources in natural or semi-natural habitats favour early-season colonization by natural enemies such as syrphids, which might enhance preventive control (González et al., 2022). Floral resources might also enhance control and subsequently reduce crop damage when they represent an alternative food source for natural enemies and herbivores whereas outcompeting crops in terms of pests' preference (Balzan et al., 2014; van Rijn et al., 2002; Wäckers et al., 2007). These results have been observed for specific sown wildflowers but also for spontaneously growing vegetation as long as these communities are rich in entomophilous species (Balzan et al., 2014; Pollier et al., 2018), improving when combined with complementary natural enemy conservation strategies that do not represent potential intra-guild predation risk (Snyder, 2019). Likewise, an increment in plant cover and structure can benefit natural enemies by supplying habitat and shelter (Ebeling et al., 2018; Moreira et al., 2016; Snyder, 2019), along with promoting pollinator abundance and enhanced pollination service (Hass et al., 2018; Martin et al., 2019). Therefore, these features can determine the potential of field margin vegetation to serve as stable reservoirs and sources of beneficial arthropods, leading to better pest suppression and lower crop damage (Balzan & Moonen, 2014; Bianchi et al., 2006). Nonetheless, consistent patterns of vegetation effects on arthropod communities are elusive to find and often depend on given environmental

conditions and vegetation features, so context-dependent and site-specific assessments are necessary (Hatt et al., 2017; Norris & Kogan, 2005; Tschumi et al., 2018).

The sustainability of peri-urban areas in Argentina is particularly relevant for ensuring food production for cities and their surroundings (Hammelman et al., 2021). Despite their importance, they have been undergoing an accelerated loss of productive area due to urban expansion and industrial agriculture aimed at commodity export, which puts high pressure on the remaining horticultural fields (Baldini et al., 2021; Mari et al., 2019; Tiftonell & Giobellina, 2018). On the other hand, a growing number of horticultural farmers are transitioning away from conventional agriculture towards agroecology because of the increasing costs, current legislation on chemical use around urban areas, environmental protection and their own health (Propersi, 2008; Sarandon & Marasas, 2017). However, assessments of the effects of agroecological transitions on arthropod taxonomic and functional composition are only recently being performed in peri-urban areas (Baldini et al., 2021; Mari et al., 2019). Regarding the functionality of margin vegetation as a tool for pest management, the existing evidence in this region corresponds/belongs mainly to conventional soybean crops (De La Fuente et al., 2010; González et al., 2017). Therefore, it is of utmost value to assess the effect of agroecological transition strategies on arthropod diversity, pests and natural enemies. This work aimed to evaluate variations in arthropod communities associated with agroecological transitions and field margin vegetation in peri-urban horticultural farms. Specifically, we evaluated (1) whether arthropod abundance and diversity in field margins are enhanced by agroecological practices when compared with conventional management, (2) how vegetation features influence these arthropod communities and (3) whether these effects vary among feeding guilds, focusing on herbivore and natural enemies and among taxonomic groups/orders within these guilds.

MATERIALS AND METHODS

Study area

The study was conducted in peri-urban horticultural farms near Córdoba city (31.30–31.50°S and 64–64.20°W), in central Argentina (Figure 1). The area is located in the eastern sub-humid plain area within the Chaco Serrano phytogeographical district (Cabrera, 1976). The climate in this region is warm temperate with dry winters, an average temperature of 17°C, 750 mm annual rainfall, occurring mainly during the summer and very fertile loess soils (Kottek et al., 2006; Mari et al., 2019). The native vegetation consists mainly of low forests dominated by *Prosopis alba* and *P. nigra*, with a herbaceous stratum highly dominated by Asteraceae and Poaceae species (Cabido et al., 2018). However, most of the original ecosystems have been transformed into croplands, leaving only small forest remnants and peri-urban areas surrounded by both vegetable fields and monocultures (Agost et al., 2022; Cabido et al., 2018; González et al., 2017).

Ten fields of 3–5 ha cultivated with seasonal horticultural crops were selected for this study (Figure 1). As in most horticultural fields

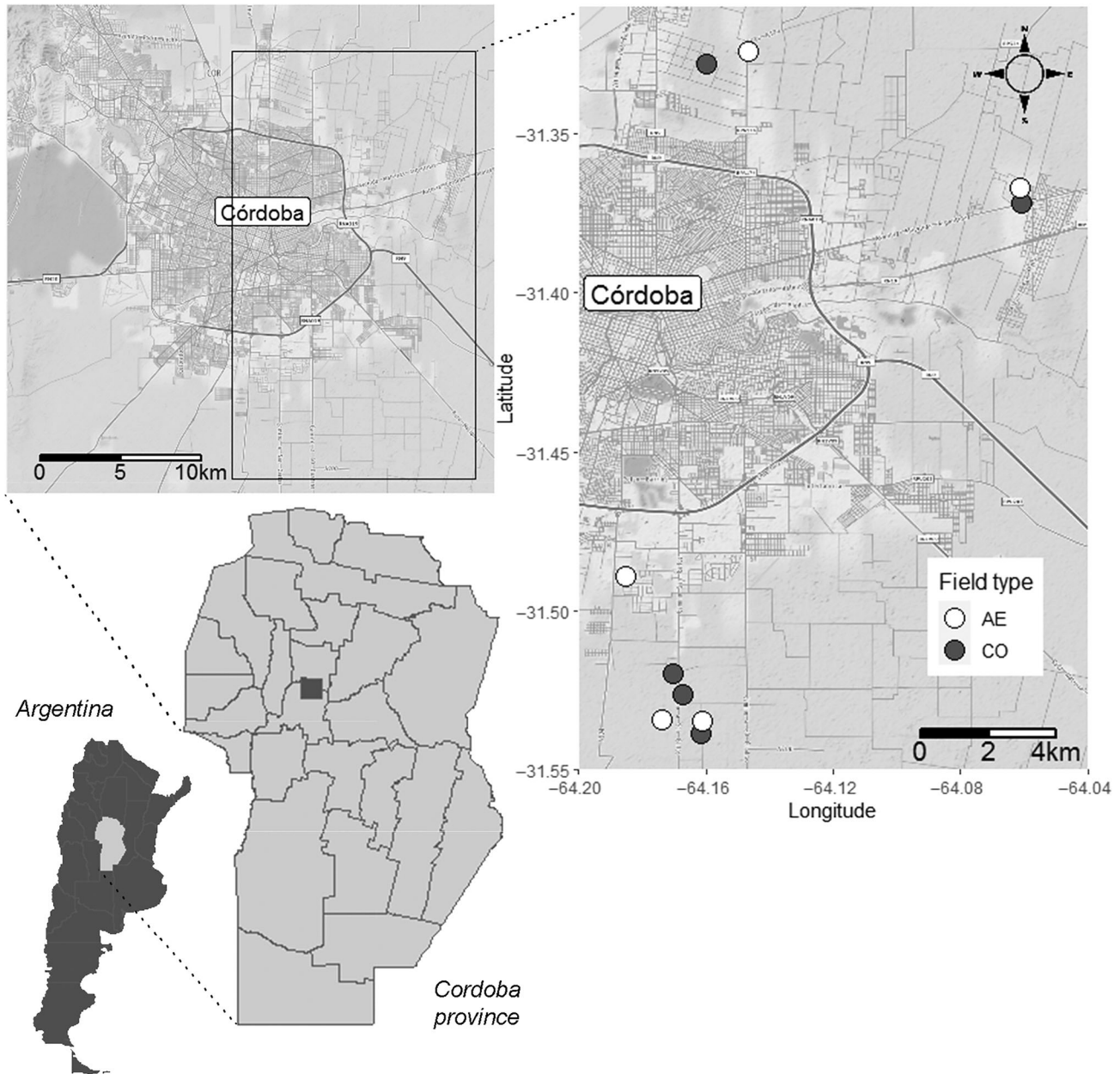


FIGURE 1 Location of the study sites. Agroecological fields (AE) and conventional fields (CO) are indicated with white and dark grey dots, respectively.

in this area, vegetable production is carried out year-round, alternating lines with different crop varieties and in different stages (Butinof et al., 2014). Half of them were cultivated under conventional practices, with a periodic input of synthetic pesticides, applied mainly with the use of hand-held knapsacks (Butinof et al., 2014). The other fields have had a history of conventional management but have been transitioning towards agroecological practices for the last 7–14 years. This shift mainly involved the replacement of synthetic pesticides and fertilizers with botanical repellents or insecticides (e.g., garlic extract, mixed chilli and pepper extract) only applied to infested crops (no preventive applications) and organic manures, respectively (Cabanillas et al., 2015). Conventional fields were selected based on

their proximity to each agroecological field so that there were five locations with both types of fields. All fields were embedded in similar landscapes, which consisted of other horticultural fields, urbanized areas and large monoculture crops, with low amounts of semi-natural habitats in their surroundings.

Data collection

Arthropods were sampled twice at the end of the summer (beginning of March and mid-April), which is a period of high arthropod activity and herbaceous density due to the mid-warm temperature and

accumulated rainfall. Field margin was considered as the non-crop area adjacent to the vegetable crops, with at least some presence of herbaceous vegetation, varying plant cover and height and a width of approximately 1 m. Random samples were collected on each of the four sides of the field. At each side, arthropods were sampled using a 1 m long vertical beat sheet (Drees & Rice, 1985). Each sample consisted of two adjacent sub-samples that were obtained by beating the vegetation against the sheet a fixed number of times (3) and then collected from its base with a modified hand vacuum. Afterwards, samples were taken to the laboratory and preserved in 70% ethanol for further processing.

Collected arthropods were classified into different orders and families using dichotomous keys. Specimens were identified at the family level and assigned to feeding guilds according to the dominant family habits, and families with multiple feeding habits were identified at the subfamily level (Triplehorn et al., 2005). All hemipterans found were considered herbivores except for families Anthocoridae (predators) and Miridae (omnivores) (Dempster, 1964; Lattin, 1999). Coleopterans were assigned to guilds representing the feeding habits of each family both in larval and adult stages; for example, Chrysomelidae, Cerambycidae and Curculionidae are widely known plant-feeding families, whereas Coccinellidae and Carabidae are predators (Triplehorn et al., 2005)—other ambiguous families were considered omnivorous. Adult dipterans were classified according to their most relevant life-stage regarding agricultural importance (Kitching et al., 2005). Ants were all considered omnivores for the scope of this work as per their wide variety and flexibility of feeding habits (Way & Khoo, 1992); the rest of the Hymenoptera were all parasitoids except for Vespidae (predators). All specimens of Lepidoptera and Neuroptera were juveniles and therefore considered herbivores and predators, respectively. Thrips were all considered herbivores because of their broad role as agricultural pests (Carmona et al., 2003). All spiders were considered predators, and mites were only accounted for in total arthropod abundance but not considered during feeding guild assignment nor species richness and diversity. On this basis, herbivores, and natural enemies (predators and parasitoids) were considered for further analysis whereas detritivores, omnivores and fungivores were only accounted for in total community analyses. Adults from each sample were classified into morphospecies (further referred to simply as 'species') (Obrist & Duelli, 2010) and considered for richness and diversity (Shannon-Wiener) analyses. Immature insects and arachnids were considered only in terms of their abundance.

To assess the effect of field margin vegetation on arthropod communities, five 1 × 1 m quadrats were placed along each field margin with a minimum distance of 20 m. Within each quadrat, maximum vegetation height (VH) was measured and vertical photographs were taken and later processed in the software ImageJ (Abramoff et al., 2004) to determine plant cover percentage (PC). Alongside the quadrats, 6 × 1 m transects were placed and used to determine floral resource abundance (FA). All plant species present in both squares and transects was accounted for to determine total vegetation species richness (VR) via in-field determination in the case of widely known and common species. Species that required further examination were

taken to the lab and identified by using dichotomous keys (Parodi & Dimitri, 1978; Sersic et al., 2006). Due to logistic and climatic restrictions, these measurements were done once, between arthropod sampling dates, and in 7 out of the 10 fields. However, note that given that arthropod samplings were only separated by a few weeks, field margin vegetation is expected to be relatively stable, with slight changes in flower abundance.

Statistical analysis

The effects of both field type and field margin vegetation features on arthropod communities were analysed using generalized linear mixed models (GLMMs) using the *glmmTMB* package (Brooks et al., 2017; Magnusson et al., 2017). As arthropod samples and vegetation samples data were not balanced, two sets of analyses were performed; one that included all arthropod samples, to assess field type effect and one that included only the arthropod samples matching vegetation sites. In both analyses, arthropod abundance was modelled using a negative binomial distribution, and for species richness and biodiversity, Poisson and Gaussian distributions were used, respectively.

In the first analysis, field type (agroecological = AE; conventional = CO) was introduced as the fixed factor. Sampling dates nested in location sites were considered as discrete random factors to model the dependence between margins of the same field and between sampling dates. To account for spatial autocorrelation, the geographic coordinates of the fields were also incorporated as random factors (Kristensen & McGillicuddy, 2019). Likelihood ratio tests were performed to assess the significance of fixed effects.

For the second analysis, model averaging was performed by building a global model with all variables (VH, PC, FA and VR), scaled and centred to enable their effect sizes estimates comparison, as each variable had a different measurement scale (i.e., proportion, count, centimetres). Then we constructed a set of models (Table S1) that included all the possible combinations between variables and ranked them based on their AICc using the *MuMIn* package (Barton & Barton, 2015). The best models were selected based on their Akaike weights for small sample sizes ($\Delta AICc < 2$), and averaged to obtain estimates coefficients, confidence intervals (CI) and relative variable importance (RVI) (following Grueber et al., 2011). Fixed variables were deemed important when RVI > 0.6 and the CI did not include zero (Table S2) and trends were also displayed using dotted lines (RVI > 0.5, CI includes zero). All model diagnostics and autocorrelation tests were performed using the *DHARMA* package (Hartig & Hartig, 2017). Statistical analyses were performed in R Studio, version 4.0.2 (R Core Team, 2020).

RESULTS

A total of 14,226 arthropods were collected, belonging to 77 families within 17 taxonomic orders. Thysanoptera showed the highest abundance per sample (111 ± 26.7 , mean \pm SE), followed by Hemiptera

TABLE 1 Effects of agroecological management on the abundance, richness and diversity of total, herbivore, predator and parasitoid arthropods fitted by generalized linear mixed models (GLMMs)

	Abundance			Richness			Diversity		
	Estimate	SE	p-value	Estimate	SE	p-value	Estimate	SE	p-value
Total	-0.239	0.227	0.293	-0.030	0.074	0.685	0.136	0.052	0.009
Herbivore	-0.626	0.236	0.008	-0.092	0.077	0.232	-0.048	0.093	0.605
Predator	-0.143	0.165	0.386	-0.015	0.107	0.886	0.013	0.013	0.332
Parasitoid	-0.570	0.303	0.060	-0.267	0.263	0.310	-0.049	0.042	0.251

Note: For each group, estimates, standard errors (SE) and p-values are shown. Significant ($p < 0.05$) effects are highlighted in bold.

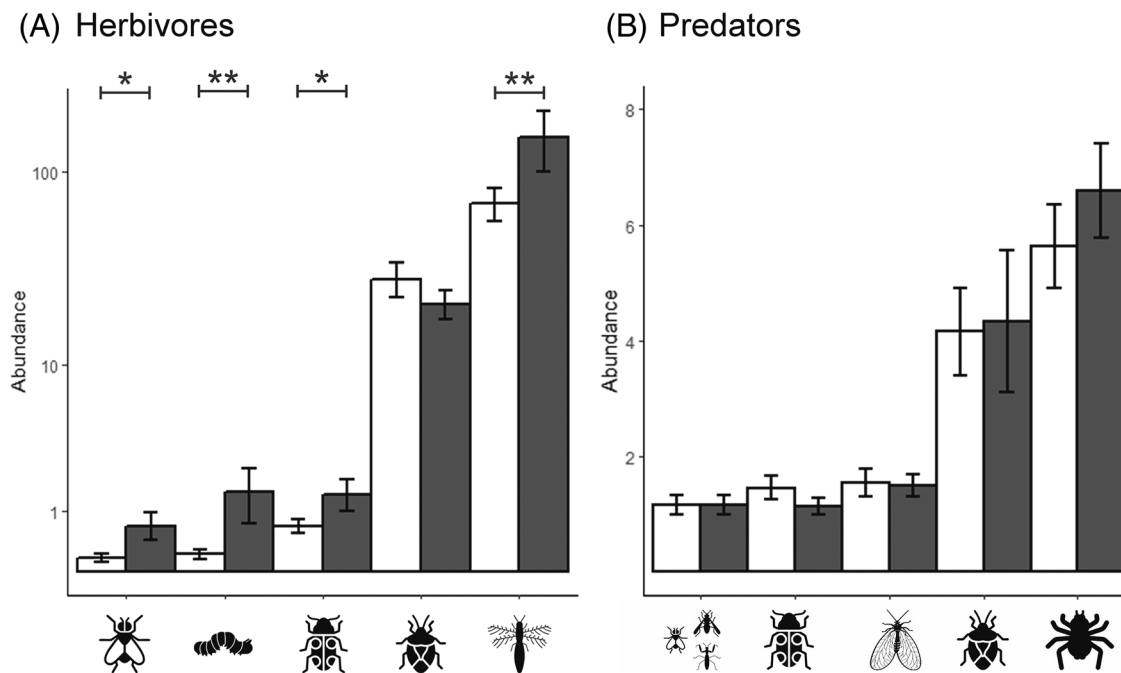


FIGURE 2 Abundance of herbivore (a) and predator (b) arthropods captured in agroecological (white) versus conventional (dark grey) fields. Columns represent the mean number of specimens of each order per sample (\pm SE). Double and single asterisks (**, *) represent p-values <0.01 and <0.05 , respectively. Taxonomic orders from left to right, A: Coleoptera; Diptera; Lepidoptera (larvae); Hemiptera and Thysanoptera; B: Others; Coleoptera; Neuroptera; Hemiptera and Araneae

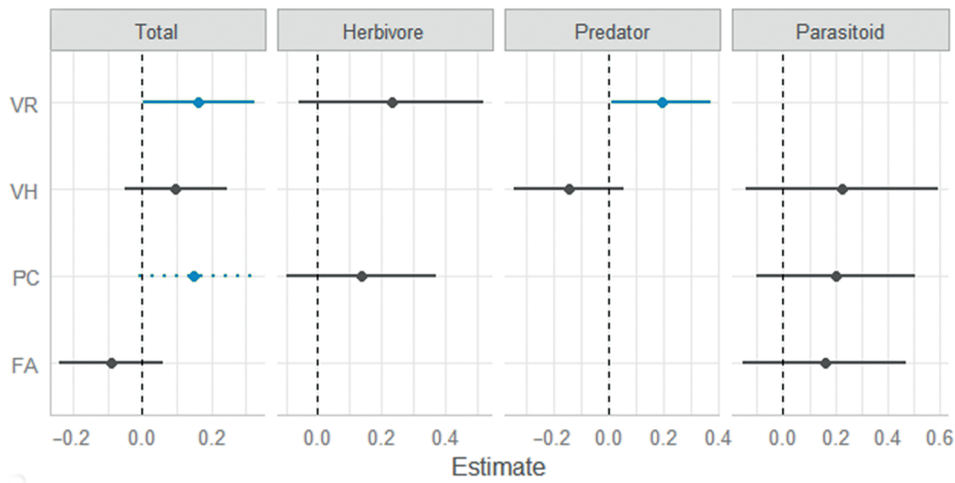
(30.9 ± 3.74 ; Figure S1a). Hemiptera also showed the highest richness (5.0 ± 0.2) followed by Hymenoptera (4.1 ± 0.4) (Figure S1b). The herbivore guild represented 77.7% of the total abundance and 45.5% of the collected species. In turn, predators and parasitoids reached 5.0% and 11.5% and 1.8% and 12.2%, of total abundance and richness, respectively (Figure S1c, d). The remaining 15.5% of the individuals included detritivorous, omnivorous, fungivorous and unidentified species ('Others').

Overall arthropod diversity showed a significant increase in agroecological (0.46 ± 0.04) versus conventional fields (0.33 ± 0.03), whereas a significant decrease in herbivore abundance was observed (100 ± 15 versus 176 ± 51 , Table 1). No significant differences were found in predator nor parasitoid abundance, richness or diversity between field management types. Among herbivore arthropods, Lepidoptera and Diptera abundance showed the strongest decrease in agroecological fields ($z = 1.77$; $p < 0.01$ and $z = 1.39$; $p < 0.05$,

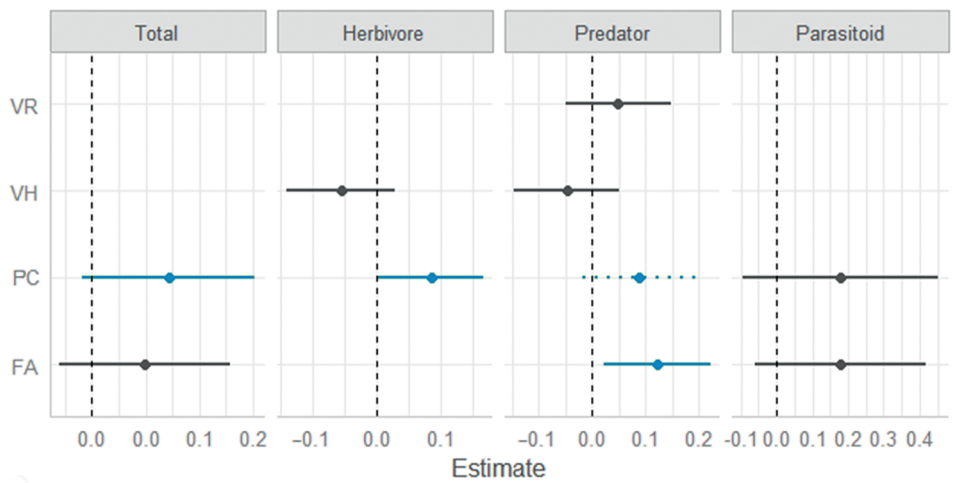
respectively; Figure 2), followed by Thysanoptera and Coleoptera ($z = 0.645$; $p < 0.05$ and $z = 0.641$; $p < 0.01$, respectively), whereas no significant differences were observed on herbivore Hemiptera abundance nor among any taxonomic order of natural enemies (Figure 2).

Total arthropod and predator abundance increased in field margins with higher vegetation richness ($z = 0.16$; RVI = 0.78 and $z = 0.19$; RVI = 0.83, Figure 3a). Although field margin vegetation variables tended to have a positive effect on herbivores and parasitoids they were not deemed significant by the model. Furthermore, no significant effects of maximum vegetation height, plant cover or flower abundance were found on the abundance of any arthropod guild. Herbivore species richness showed a significant increase when plant cover augmented ($z = 0.09$; RVI = 0.79, Figure 3b), whereas total arthropod richness showed a similar trend ($z = 0.07$; RVI = 0.59). Model averaging also showed a clear positive relationship between

(A) Abundance



(B) Species richness



(C) Diversity (Shannon-Wiener)

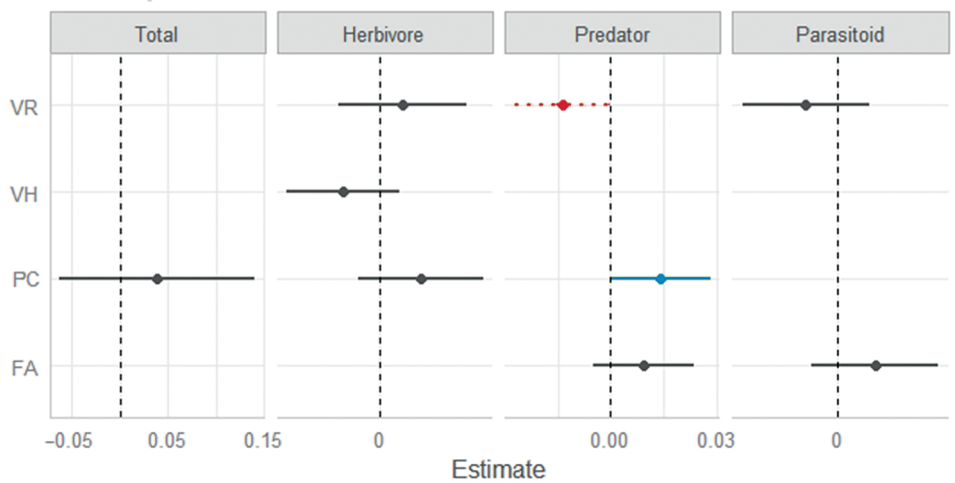


FIGURE 3 Effects of field margin vegetation features on total and by-guild arthropod abundance (a), species richness (b) and diversity (Shannon-Wiener index) (c). Only variables present in models where delta AIC < 2 are plotted. Dots represent estimated coefficients and lines represent confidence intervals. The vertical dash-line indicates no effect. Important effects (RVI > 0.6) are highlighted in blue (positive) and red (negative), whereas trends (RVI > 0.5, CI includes zero) are also highlighted and displayed with a dotted line. FA, flower abundance; PC, plant cover; VH, maximum vegetation height; VR, vegetation species richness

predator richness and the availability of floral resources ($z = 0.12$; $RVI = 1.0$, Figure 3b). Finally, predator diversity showed a significant increase with plant cover ($z = 0.14$; $RVI = 0.69$, Figure 3c). None of the FMV variables had an important effect on parasitoids (Table S2). Separate analyses on taxonomic orders within each guild displayed multiple responses to vegetation features, without showing any consistent patterns (Figure S2).

DISCUSSION

Field management practices and field margin vegetation features are expected to affect arthropod communities and the ecosystem services they provide. Conventional pesticide applications are effective in reducing crop pests in the short term, but they have long-term negative effects on natural enemies (Brevik et al., 2018; Guedes et al., 2022; Nicholls & Altieri, 1997; van den Bosch, 1978). Agroecological practices, on the contrary, rely on arthropod diversity to ensure ecosystem stability and functionality (Corrado et al., 2019; Garibaldi et al., 2017; Tittonell, 2014). Here, we assessed arthropod communities in the spontaneous margin vegetation of horticultural fields with contrasting management types and found that overall arthropod diversity was higher in agroecological fields, where synthetic pesticide application has been replaced by botanical insecticides for several years. Moreover, we found that herbivore abundance was significantly higher in conventional fields, suggesting that agroecological transitions could have desirable effects on pests.

Changes in agroecosystem management practices do not always show immediate effects on biodiversity, depending on the socioecological context, the strategies applied and the organisms involved (Duru et al., 2015; Jonason et al., 2011; Petit et al., 2020). In this study, the increase in total diversity in field margins could be an indicator that agroecological transitions are recovering the functionality of edges as a stable habitat for arthropods (Altieri & Letourneau, 1982; Holzschuh et al., 2008; Morandin et al., 2014; Toivonen et al., 2018). This is consistent with the decrease in herbivore abundance found in agroecological fields in our study, supporting the idea that interrupting pesticide applications might eventually enhance pest control (Balzan & Moonen, 2014; Pollier et al., 2018).

Among herbivore groups, we found that the decrease was consistent across all the most abundant orders (Lepidoptera, Diptera, Thysanoptera and Coleoptera), except for Hemiptera. This has important implications because each of these groups includes species that are considered pests and a threat to food production in this region and worldwide (Álvarez et al., 2021; Espinoza-Gavilanez & Grilli, 2019; Fenoglio et al., 2019; He et al., 2020). Hemiptera also includes the most widely spread pest species, so efforts should be oriented towards a clearer understanding of how agroecological transitions might help decrease their populations in the absence of synthetic inputs. However, overall increases in arthropod diversity could result in lower levels of damage, even when herbivore abundances are similar (Letourneau & Goldstein, 2001).

Neither predators nor parasitoids showed responses to management type. Many natural enemies tend to move actively as they need to forage around looking for their prey, whereas herbivore species tend to concentrate on food resources. Thus, the effect of pesticide suppression at the field scale might be more evident in pests rather than in natural enemies (Evans et al., 2015; Nicholls et al., 2001; Tscharntke et al., 2007). Studies that compare landscape composition with farming practices show that landscape variables tend to override local effects (Chaplin-Kramer et al., 2011; Martin et al., 2019), supporting the idea that biological control needs larger-scale management strategies, rather than field scale decisions. In our study, both types of horticultural fields are part of the same landscape along with non-crop areas and monocultures. Thus, agroecological transitions adopting limited management strategies (pesticide use) at a local level may not be sufficient to contribute to the increase in the abundance and diversity of natural enemy populations. Additional measures like planting flower strips could benefit natural enemy communities (Balzan et al., 2014; Hatt et al., 2017).

Beyond pesticide-related direct mortality, non-lethal pesticide doses have also been linked with decreasing numbers of beneficial and non-target arthropods due to detrimental effects of behavioural and physiological traits such as fertility, mobility or feeding rates (Desneux et al., 2007). Furthermore, growing evidence suggests that a certain range of non-lethal concentrations might actually boost herbivore populations (Guedes & Cutler, 2014). Therefore, the higher herbivore abundance found in conventional fields may also be explained by herbivore enhancement via resistance (Cutler & Guedes, 2017) and lower parasitism and predatory activity due to the non-lethal effects of pesticides. Lastly, the higher arthropod diversity found in agroecological fields could be related to small non-lethal pesticide effects at the species-level inducing cascading effects in the whole community (e.g., shifts in dominance, interspecific competition, plant-stress signalling), leading to higher arthropod diversity in an intermediate-disturbance manner (Guedes et al., 2022). Further studies will be needed to confirm these potential effects.

Field margin vegetation functions as a stable source of food and shelter, but the availability of resources and microhabitats can change substantially based on vegetation structure (Balzan & Moonen, 2014; Pollier et al., 2018). Here we identified several important effects of field margin vegetation features on arthropod guilds, regardless of management type. Vegetation richness (VR) sustained a greater abundance of arthropods in general and predators in particular, which suggests that a higher number of plant species provide a variety of feeding niches, habitats and refuge, sustaining a higher abundance of beneficial arthropods. Similar results supporting this mechanism were also obtained in experimental conditions (Ebeling et al., 2018). This trend was not reflected in herbivore abundance, which suggests that field margin vegetation richness could benefit biological control as proposed by the 'enemies' hypothesis' (Moreira et al., 2016; E. P. Russell, 1989). Moreover, vegetation communities with higher species richness imply the existence of different survival strategies during annual climatic variations, which ensures the availability of prey throughout the year and contributes to the stabilization of a greater

variety of predator populations over time (Moir et al., 2011; Snyder, 2019). On the other hand, plant cover (PC) was associated with a higher richness of herbivore species, which may be related to a decrease in interspecific competition due to a greater abundance of resources ('resource specialization hypothesis') (Moreira et al., 2016). However, this did not result in higher herbivore abundance, which is a determining factor in pest damage in crops. Additionally, plant cover was also positively linked to predator diversity, which reinforces the results mentioned above and the importance of plant communities for this guild.

Finally, predator richness was enhanced by flower abundance (FA). Predators such as syrphids and lacewings consume flower resources (nectar and pollen) as adults, whereas many other species display facultative consumption of these resources, relying on these as alternative food sources (Lundgren, 2009). Therefore, many studies reported that increasing flowering plants resulted in lower crop damage levels by herbivore arthropods via predator enhancement (Bischoff et al., 2016; Pollier et al., 2018; Török et al., 2021; Zytynska et al., 2021). Many parasitoids also feed on flowers as adults, and although our analysis did not show a significant link between this guild and any vegetation trait, all variables showed a positive trend. Specific floral traits, such as nectar availability and attractiveness, may be more relevant for this group (Bianchi & Wäckers, 2008) and explain their lack of responses.

Maximum vegetation height (VH) did not show any effect on any of these groups. This is not consistent with other studies where this structural feature was relevant for herbivores (Rossetti et al., 2019). In our system, this might be explained by the dominance of a tall grass invasive species (*Sorghum halepense*) on some edges. This species grows higher than most herbaceous plants and dominates the edges where it is present, but offers few resources for arthropods and could confound the effect of plant height.

Arthropods in horticultural fields are subject to regular perturbations and habitat disruption related to intensive management so these agroecosystems are re-colonized from surrounding crops and non-crop habitats, especially by natural enemies (González et al., 2016; Thorbek & Bilde, 2004; Wissinger, 1997). Therefore, horticultural fields surrounded by diverse vegetation margins, which offer more varied rewards, will presumably be benefitted from an increased spillover of natural enemies, ultimately leading to herbivore suppression (Rand et al., 2006; Skirvin et al., 2011; Tschamtker et al., 2012). This hypothesis is supported by our findings, as margins with higher vegetation richness displayed a higher number of predators, and those with higher availability of floral resources hold more predator species without enhancing herbivore populations, so predator species in these margins are likely to also spill over into crops providing in-field pest suppression. Nevertheless, future studies looking into the directional movement of insects into the crops will confirm if horticultural fields are receiving ecosystem service providers.

In conclusion, our study shows that agroecological practices influence arthropod communities inhabiting field margin vegetation in the peri-urban green belt of Córdoba. Stronger effects might appear with time as these fields are still transitioning. Agroecological management

might be more effective if input substitution is accompanied by other methods to enhance the benefits of pesticide interruption, such as flower strips and landscape design. Further on, field margin vegetation features, plant richness and flower availability in particular, need to be considered to ensure the ecosystem services required to prevent and control pest outbreaks.

AUTHOR CONTRIBUTIONS

Camila Pérez Roig, Ezequiel González and Martin Videla conceived the research and conducted fieldwork. Martin Videla secured funding. Camila Pérez Roig analysed arthropod samples. Camila Pérez Roig and Ezequiel González conducted the statistical analysis. All authors contributed to writing and reviewing the paper. All authors have read and agreed to the published version of the manuscript.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in Mendeley Data at <http://doi.org/10.17632/k6sdfh3hbp.2>

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Data S1. Supporting Information.

Data S2. Supporting Information.

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