Bulletin of Entomological Research

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Research Paper

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Cite this article: Hamza A, Farooq MO, Razaq M, Shah FM (2023). Organic farming of maize crop enhances species evenness and diversity of hexapod predators. *Bulletin of Entomological Research* **113**, 565–573. https://doi.org/10.1017/S000748532300024X

Received: 27 January 2023
Revised: 1 June 2023
Accepted: 5 June 2023
First published online: 12 July 2023

Keywords:
Biological control; ecosystem services; herbivores; predators; species evenness; sustainability

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Organic farming of maize crop enhances species evenness and diversity of hexapod predators

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Abstract

Arthropod species diversity enhances ecosystem productivity and sustainability by increasing pollination and biological control services. Although, it is declining rapidly due to conventional agricultural intensification, organic agriculture with reduced reliance on agronomic inputs can regenerate ecosystems' resilience and restore them. Here, we report whether hexapod communities differ on both types of farming systems in small-scale field plot experiments, wherein Maize variety AG-589 was grown organically and conventionally in the 2020 and 2021 seasons. Livestock manure was applied in organic fields, whereas nitrogen and phosphorous were used as synthetic fertilizers in conventional fields. Hexapods were sampled three weeks after sowing once a week from the middle rows of subplots from both organically and conventionally grown maize. Twelve species of herbivores and four species of predators were recorded. Hexapod abundance overall and that of herbivores only was higher in conventionally cultivated maize, while predator abundance was higher in organic maize. Herbivores species diversity and evenness were significantly higher in conventional maize. Predator species diversity and evenness were significantly higher in organic maize fields. We noted predator abundance, diversity, and evenness as strong predictors to lower herbivore populations. These findings suggest that organic farming conserves natural enemies' biodiversity and regulates herbivores with increased provision of suitable habitats and prey resources for natural enemies, leading to enhanced relative abundance in their specialized niches. Thus, organic agriculture can potentially mediate better ecosystem services.

Introduction

Global agriculture is now facing the unprecedented challenges of providing food, feed, and fiber for a rapidly growing population. Achieving these goals while maintaining ecosystem resilience, conserving biodiversity, and socio-economic balance of farmers represents a formidable challenge (Cooper & Dobson, 2007). Pesticides are often used to enhance agriculture production by suppressing agricultural pests, but the efficacy of pesticides is saturated over time (Lechenet *et al*., 2014; Gaba *et al*., 2016). Their repeated, long-term indiscriminate use can also degrade agricultural soils (Shahid *et al*., 2016) by affecting the physicochemical properties (AL-Ahmadi, 2019) as well as harming microbial communities and disturbing their beneficial activities (Arora *et al*., 2019). Biodiversity loss is another big challenge resulting from pesticide overuse (Maxwell *et al*., 2016). Biodiversity losses in terrestrial ecosystems also decrease provision of ecosystem services, like pollination and biomass production that provide vital benefits to humans and are important for ecosystem resilience (Tilman *et al*., 2002; Chaplin-Kramer *et al*., 2015). Yields of many crops are no longer increased in intensified farming (Ray *et al*., 2012), compromising the economic and environmental viability of this strategy (Tittonell, 2014).

Sustainable development aims at improving conservation, protection, restoration, and sustainability of the terrestrial ecosystems for the long-term benefits to mankind (Newbold *et al*., 2016). In order to maintain the balance between food security and conserving biodiversity, sustainable production practices like organic farming can lower ecological footprints without sacrificing the economic benefits and food security (Foley *et al*., 2011). Organic farming systems increase arthropod diversity and enhance ecosystem services, like predation and parasitism, ultimately reducing insecticide use by up to 97% (Mäder *et al*., 2002). Organic production maximizes the use of local resources to enhance soil fertility (Gomiero *et al*., 2011; Leifeld, 2012), but also has some socio-economic pros and cons for small holder farmers and developing countries. Since synthetic chemicals are prohibited in certified organic production systems, organic crops contain lower levels of insecticide and heavy metal residues compared to conventionally grown ones (Baker *et al*., 2002).

Herbivore densities in organic farms are generally regulated vertically and horizontally (fig. 1) i.e. mediated through bottom-up forces by soil or plant quality (Scherber *et al.*, 2010; Letourneau *et al.*, 2011), and top-down forces, those governed by the natural enemies (Cardinale *et al.*, 2003; Finke & Denno, 2004) while horizontal herbivore regulation is through competition among members of same trophic levels. Organic farming may enhance below and above ground biodiversity and boost up plant resistance to herbivores, facilitating the bottom-up forces on the herbivores and possibly help to reduce insecticide loads and concerns in agriculture sector (Birkhofer *et al.*, 2008; Krey *et al.*, 2020; Gu *et al.*, 2022). For instance, lower populations of leafhoppers, *Circulifer tenellus* (Baker) was noted in organic production systems of tomatoes due to higher accumulation of salicylic acid produced by well-established rhizosphere microbial communities (Blundell *et al.*, 2020). So, organic farming can increase plant resistance and decrease plant attractiveness toward herbivores. Meanwhile, manure amended soil provides brown food web species to the generalist predators as alternate resources and directly support the top down effects in the organic farming (Brown and Tworkoski, 2004; Muñoz-Cárdenas *et al.*, 2017). Organic farming enhances the abundance of arthropods (Tuck *et al.*, 2014; Van Bruggen & Finckh, 2016), which, in turn, results in the higher resource competition among the members of same trophic levels (Kaplan & Denno, 2007). Altogether, organic farming is a system of sustainable production of crops that have the potential to regulate herbivore communities by supporting bottom up and top-down forces.

Greater abundance and diversity (Gurr *et al.*, 2003; Simon *et al.*, 2011; Lichtenberg *et al.*, 2017; Mabin *et al.*, 2020) of arthropod predators translates to higher likelihood of biological control of herbivore on organic farms (Farooq *et al.*, 2022). For example, increased predator diversity was observed to suppress cabbage aphid, *Brevicoryne brassicae* L. and green peach aphid *Myzus persicae* Sulzer (Hemiptera: Aphididae) populations in collards (Snyder *et al.*, 2006). Herbivore suppression due to diverse predator communities might be linked with complementary use of shared prey resources (Niche complementarity hypothesis) (Straub & Snyder, 2006; Lynch *et al.*, 2022). Moreover, soil organic matter improves soil microclimate in organic mix vegetables farms and is responsible for even distribution of coleopteran carabid predators (Aldebron *et al.*, 2020). Crowder *et al.* (2010) also reported that more evenly structured and abundant predator communities can strongly suppress herbivore communities and increase plant growth in organic farms.

Although, a number of past studies have illustrated the role of organic farming in top-down regulation of herbivores by attracting insectivorous birds (Tremblay *et al.*, 2001; Otieno *et al.*, 2019*a*, 2019*b*), little has been reported on the community structure of hexapods, i.e., abundance, species evenness and diversity, in organic maize crops compared to conventional ones at field scales. Here, we aim to (1) assess the role of predator's abundance, diversity, and evenness in lowering the herbivore populations, and hypothesized that maize production systems (organic and conventional) affect (2) hexapod community structures and (3) their diversity.

Materials and methods

Field site description

We conducted experiments in the research area of Department of Entomology, Bahauddin Zakariya University (BZU), Multan, Pakistan, at an elevation of about 123 m above the sea level. The climatic conditions of the region is semi-arid with very hot summers (highest temperature 50°C) and cold winters (lowest temperature 4.5°C) with an average annual rainfall of 190 mm (Amer *et al.*, 2009; Hussain *et al.*, 2020). The Multan region produces major share of the country's staple food and fiber crops, such as wheat, maize, rice, and cotton. In the BZU, organic land has been maintained since 2003 for research purposes and livestock manure applied regularly to maintain soil fertility, whereas synthetic fertilizers have been used only in the conventional fields.

Experimental design

The seeds of maize variety AG-589 were cultivated on 10 August 2020, and 12 February 2021, in two separate maize experimental fields (organic and conventional). The organic and conventional fields were approximately1 km apart from each other. Each field comprised of three subplots, each measuring 20×6 m and separated from the nearby plot with one meter buffer zone which was a walking pathway without any vegetation. Although, individual subplots in either organic or conventional systems were very close to each other and were unlikely to be independent due to arthropod dispersal ability. Still, such dispersal was possible within the system but not between the systems (from organic to conventional fields) due to large separating difference between both systems. Additionally, to ensure effective sampling and to avoid edge effects, we counted hexapods from middle rows of individual subplots. We planted the seeds on the ridges (0.75 m apart) with the dibbling method at a plant spacing of 45 cm. One month prior to sowing, livestock manure (9.25 t ha^{-1}) with 0.46% Nitrogen (N), 0.46 mgg^{-1} phosphorus (P) and 0.89 mgg^{-1} potassium (Aziz *et al.*, 2010) was applied into the organic field. We applied 227.24 kg ha^{-1} and 143.26 kg ha^{-1} N and P, respectively, as diammonium phosphate (18% N and 46% P) and urea (46% N), as per the local recommendation of the region after sowing of maize in the conventional field using the broadcast method. No pesticides were applied to either fields to suppress insect herbivores or weeds. Weeds were removed manually using hand.

Hexapod sampling

Hexapod populations were recorded from two consecutive years at weekly intervals. Sampling began three weeks after sowing, as negligible hexapods were present in the first two weeks, and remained continued once a week until crops were matured. Sampling was started from 2nd week of September in 2020 and 2nd week of March in 2021 that continued through 1st week of October in 2020 and 1st week of May in 2021. From each subplot of both field types (i.e., conventional and organic), we selected 16 plants at random from the middle two rows to avoid aggregation and edge effects and observed the whole plant to assess hexapod communities being present on selected plants. All hexapods were brought back to the laboratory and identified using morphological keys (Edde, 2021). The collected voucher specimens were stored as wet collection as well as dry collections in the IPM laboratory at Department of Entomology, Faculty of Agricultural Sciences and Technology, BZU, Multan, Pakistan. Hexapods were categorized as herbivores and predators based on their ecological role, feeding behavior, and trophic position. The phytophagous hexapods that feed on green plants and carnivore hexapods that feed upon

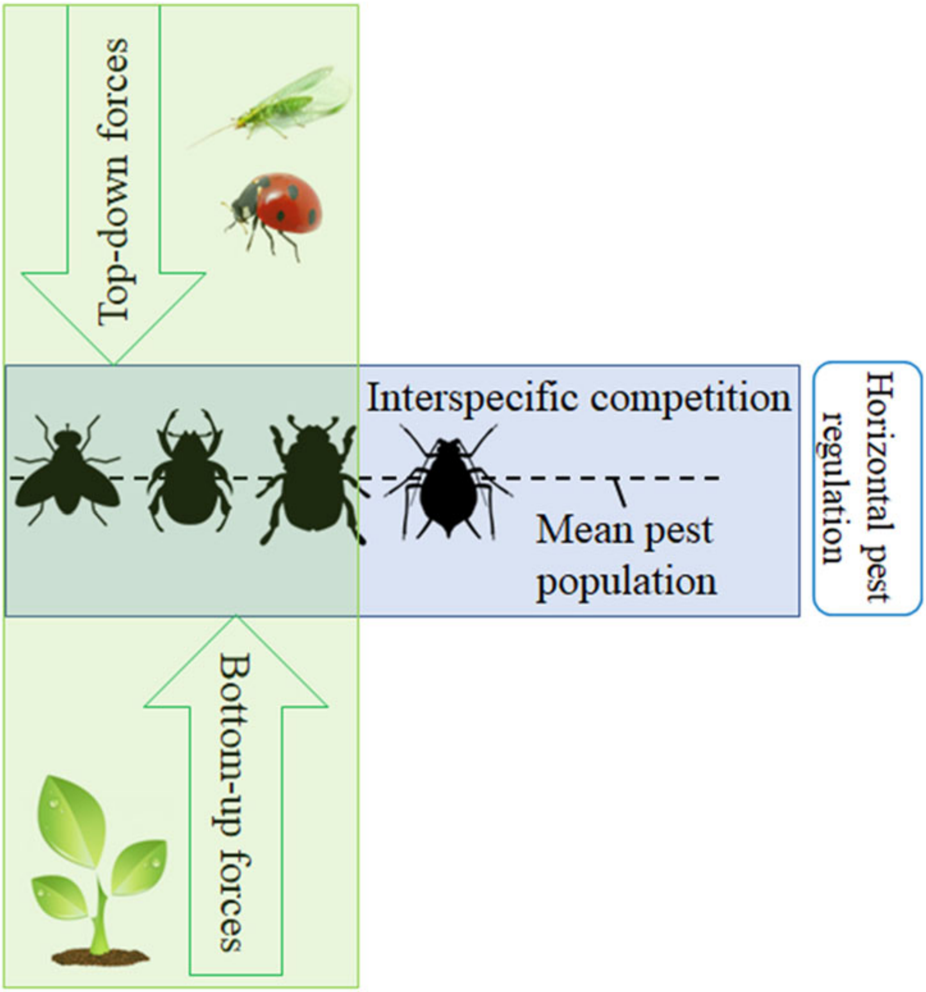

Figure 1. Horizontal and vertical modes of herbivorous pest regulation in organic farming.

phytophagous insects were classified as herbivores and predators, respectively. Hexapods were visually observed from the selected plants and the numbers of the larvae of Lepidoptera and Diptera, whereas adults and nymphs (for Hemiptera only) or larvae of Coleoptera, Thysanoptera, and Neuroptera (see Tables for species names) were counted and recorded.

Statistical analysis

We pooled the number of individuals for each insect species present in the organic and conventional maize fields across all sampling dates in each year. Principal component analysis (PCA) was used to measure various patterns of variations among the herbivore and natural enemy communities in organic and conventional maize production. For this purpose, two primary components were selected based on the eigenvalues as suggested by Kaiser (1974), who suggested that only those components will be selected that have eigenvalues greater than 1. Moreover, the first two components comprise the 90.99% proportion of variance. PCA analysis was performed using GraphPad Prism Version 9.0 (GraphPad Inc., San Diego, California, USA).

Diversity index of hexapods in organic and conventional fields was calculated by using the Shannon–Weaver diversity index formula (Shannon, 1948),

$$D = -\Sigma P_i ln P_i$$

where P_i represents the proportion of single species in the total abundance of a given sampling unit.

Dominance or evenness index of hexapods in organic and conventional fields was calculated by using the Simpson dominance index formula (Simpson, 1949),

$$C = \Sigma(P_i)^2$$

where C is the Simpson dominance or evenness, P_i represents the proportion of single species in the total abundance of a given sampling unit.

The effect of farming systems on the overall abundance of hexapods and each functional group i.e., herbivores and predators, was assessed by using multivariate Analysis of Variance (MANOVA). The effect of farming system on individual species, diversity, and dominance were assessed by using non parametric generalized linear mixed model (GLMM). Year was fitted as the random effect in the models and the farming systems treated as the fixed effect. The relationship between herbivore density and four predictors i.e., predator density, predator diversity, and predator evenness was determined by using simple linear regression. The means of herbivore densities were tested for homogeneity of variance using a Shapiro–Wilk test and found to be typically non-normal. Therefore, these means were log (x + 1) transformed to satisfy conditions of normality and then subjected to analysis. All the data were analyzed by using Statistix 8.1 and graphs were plotted using Origin Pro 2022.

Results

Hexapod communities

A total of 16 hexapod species (12 herbivorous pest and 4 natural enemies) were recorded in this study from organic and conventional maize fields during 2020 and 2021 (Table 1). Figures 2 and 3 present hexapod abundance overall and that of herbivores and predators between conventional and organic maize. We found that overall hexapod abundance was higher in conventional fields (MANOVA: Wilks lambda = 0.327, $F_{17, 174} = 21.1$, $P < 0.001$); whereas herbivore density (MANOVA: Wilks lambda = 0.410, $F_{13, 178} = 19.73$, $P < 0.001$) was significantly lower in organic plots as compared to conventional maize plots. Conversely, predator density (MANOVA: Wilks lambda = 0.854, $F_{4, 187} = 7.99$, $P < 0.001$) was higher in organic vs conventional maize plots. Of all the hexapods observed, only populations of *Rhopalosiphum maidis* and *Bemisia tabaci* differed not significantly between organic and conventional maize plots (Table 2).

Farming systems and diversity indices

The Shannon–Weaver diversity index of overall hexapods were similar in both types of farming systems ($F_{1, 4} = 3.44$, $P = 0.137$, fig. 4a). Herbivores diversity was significantly lower in organic fields ($F_{1, 4} = 262.81$, $P < 0.001$, fig. 4b), while predator diversity was significantly higher in organic fields ($F_{1, 4} = 256.82$, $P = 0.001$, fig. 4c). Simpson dominance index of hexapods was significantly lower in organic maize when compared to conventional maize ($F_{1, 4} = 158.01$, $P < 0.001$, fig. 5a). Herbivore dominance was significantly lower in organic fields ($F_{1, 4} = 78.61$, $P = 0.001$, fig. 5b), while predator dominance was significantly higher in organic fields ($F_{1, 4} = 335.7$, $P < 0.001$, fig. 5c).

There was a significant, but negative relationship, between mean predator abundance and mean herbivore abundance ($F_{1, 94} = 32.78$, $P < 0.001$, fig. 6a). Predator diversity ($F_{1, 4} = 101.29$, $P < 0.001$, fig. 6b) and evenness ($F_{1, 4} = 101.29$, $P < 0.001$, fig. 6c) were significantly and negatively associated with herbivore abundance.

Discussion

We observed a higher abundance of herbivores in conventional maize plots, while predator abundance was greater in organic maize plots. In prior studies, hexapod herbivores of maize, including *Ostrinia nubilalis* Hubner (Phelan *et al.*, 1995), often have ovipositional preference for conventionally grown maize compared to organic. Similarly, *Aphis gossypii* Glover was more abundant in conventional cotton fields, while its predators *Coccinella septempunctata* L. (Coleoptera: Coccinellidae), *Chrysoperla carnea* Stephens (Neuroptera: Chrysopidae) and *Allograpta exotica* (Widemann) (Syrphidae: Diptera) were in greater densities on organic cotton plants (Lu *et al.*, 2015). Higher densities of cereal leaf beetles, *Oulema* spp. (Coleoptera, Chrysomelidae) and aphids were found in conventional wheat fields as compared to organic ones, whereas organic farming supported greater abundance of predators and parasitoids (Török *et al.*, 2021). Another study

Table 1. Total numbers of hexapod species observed in organic and conventional maize fields

Species	2020 Organic	2020 Conventional	2021 Organic	2021 Conventional
Herbivores				
Atherigona soccata Rodani	230	366		
Chilo partellus Swinhoe	74	169	148	238
Spodoptera litura Fabricius	132	254	294	420
Spodoptera frugiperda Smith	72	161		
Helicoverpa armigera (Hübner)	64	99		
Cicadulina mbila Naude	175	213	202	272
Rhopalosiphum maidis Fitch	476	495		
Bemisia tabaci Gennadius	364	427		
Frankliniella occidentalis Pergande	109	290		
Oxycarenus hyalinipennis Costa	97	290		
Dalbulus maidis DeLong & Wolcott			373	810
Chaetocnema pulicaria Melsheimer			198	444
Predators				
Chrysoperla carnea Stephens[a]	96	27	265	155
Coccinella septempunctata Linnaeus			251	135
Cheilomenes sexmaculata Fabricius			298	151
Brumoides suturalis Fabricius			348	117

[a]Only predacious phase (larvae) was observed.

https://doi.org/10.1017/S000748532300024X Published online by Cambridge University Press

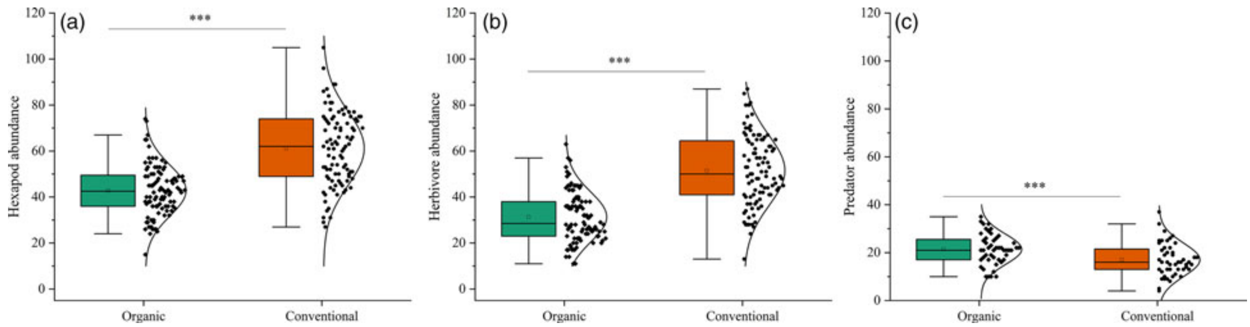

Figure 2. Effect of organic and conventional farming of maize on hexapod abundance (a), herbivores abundance (b) and predator abundance (c) in 2020 and 2021 pooled data. Bars and boxes topped with line having *, ** and *** show significant differences between groups at $P < 0.05$, 0.01, and 0.001, respectively.

demonstrated that phytophagous mites were significantly higher in conventional strawberry systems as compared to organic fields, whereas reverse situation was observed for hexapod natural enemies (Jacobsen *et al*., 2019). Conventional agricultural practices accompanied by the use of synthetic fertilizers enhance herbivore abundance (Yardım and Edwards, 2003). The manure application could reduce herbivore populations (Chau and Heong, 2005) by increasing predator densities in manure-treated areas (Brown and Tworkoski, 2004).

Our results show that organic maize supports a higher abundance of predators as compared to conventional maize. This direct positive impact of organic farming on predator abundance was consistent with previous studies, those demonstrating enhanced abundance of predator functional groups on organic fields (Bengtsson *et al*., 2005; Tuck *et al*., 2014). On organic farms, synthetic pesticides are rarely used to manage insect herbivores and farmland weeds (Muneret *et al*., 2019), which results in (1) increased availability of prey resources for predators and (2) increased local heterogeneity due to the production of natural vegetation in and around the field. Enhanced plant heterogeneity due to the production of natural vegetation in the form of farmland weeds is crucial for driving biological control on organic farms because they provide diverse floral resources and more hunting and hiding sites for predators (Galloway *et al*., 2021). Moreover, organic agriculture provides favorable microclimates responsible for enhanced plant resistance against herbivory supporting bottom up control of herbivores (Blundell *et al*., 2020) and also provide the brown food web species as an alternate host to the predators that directly triggers the top down control of herbivores (Muñoz-Cárdenas *et al*., 2017). Altogether, higher predator abundance can be attributed to favorable environments generated by organic managements like, lower pesticides exposure and supplement fields with offsite fertilizer like manure.

It has long been debated that increased predator biodiversity enhances biocontrol services in ecosystems (Root, 1973; Cardinale *et al*., 2003, 2006; Snyder *et al*., 2006; Farooq *et al*., 2022). Increasing the species evenness or enhancing the relative abundance of predators have the potential to improve biocontrol services (Crowder *et al*., 2010). The reason might be that relatively more even predator communities can occupy various complementary feeding niches. To sum up, more evenly distributed predator communities are potentially more important for providing biocontrol services on organic fields.

We noted predator abundance, diversity, and evenness as strong predictors of herbivore suppression because organic maize supports higher abundance of predators and there was a

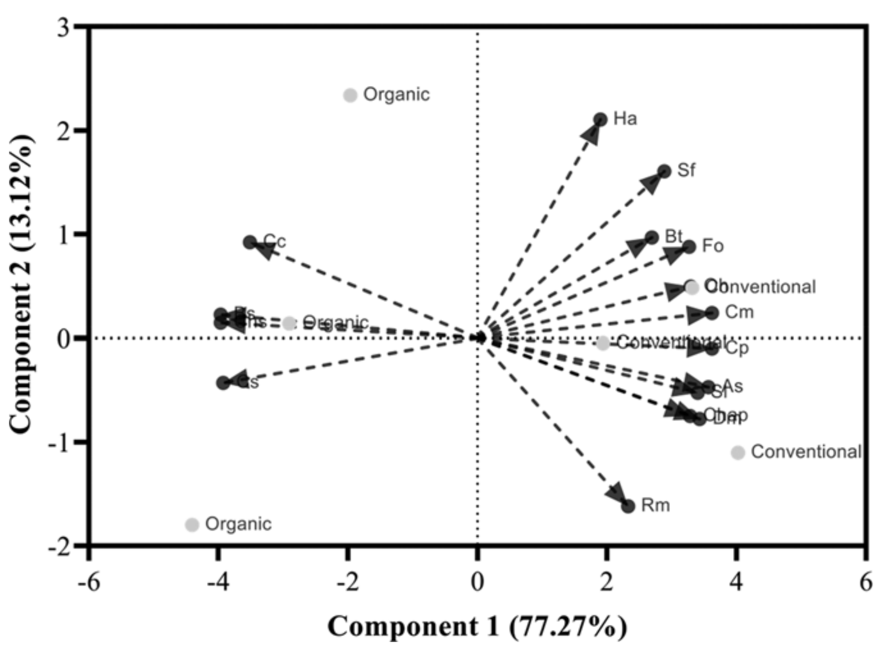

Figure 3. Biplot of herbivores *Atherigona soccata* (As), *Chilo partellus* (Cp), *Spodoptera litura* (Sl), *Spodoptera frugiperda* (Sf), *Helicoverpa armigera* (Ha), *Cicadulina mbila* (Cm), *Rhopalosiphum maidis* (Rm), *Bemisia tabaci* (Bt), *Frankliniella occidentalis* (Fo), *Oxycarenus hyalinipennis* (Oh), *Dalbulus maidis* (Dm) and *Chaetocnema pulicaria* (Chap) and predators *Chrysoperla carnea* (Cc), *Coccinella septempunctata* (Cs), *Chilomenes sexmaculata* (Chs) and *Brumoides suturalis* (Bs). The light shaded spots represent the farming system i.e., organic and conventional, and arrows represent the vector of variables.

https://doi.org/10.1017/S000748532300024X Published online by Cambridge University Press

Table 2. Generalized linear mixed model effects of organic and conventional farming of maize on seasonal totals (per plant) of herbivores and predators in 2020 and 2021 (insect counts pooled across the years)

Species	*df*	*F*-value	*P*-value
Herbivores			
Atherigona soccata Rodani	1, 189	9.749	0.002
Chilo partellus Swinhoe	1, 189	103.47	<0.001
Spodoptera litura Fabricius	1, 189	26.35	<0.001
Spodoptera frugiperda Smith	1, 189	20.5	<0.001
Helicoverpa armigera Hubner	1, 189	5.07	0.025
Cicadulina mbila Naude	1, 189	8.8	0.003
Rhopalosiphum maidis Fitch	1, 189	0.119	0.73
Bemisia tabaci Gennadius	1, 189	1.098	0.296
Frankliniella occidentalis Pergande	1, 189	18.24	<0.001
Oxycarenus hyalinipennis Costa	1, 189	23.95	<0.001
Dalbulus maidis DeLong & Wolcott	1, 189	47.49	<0.001
Chaetocnema pulicaria Melsheimer	1, 189	46.12	<0.001
Predators			
Chrysoperla carnea Stephens[a]	1, 189	42.67	<0.001
Coccinella septempunctata Linnaeus	1, 189	27.15	<0.001
Cheilomenes sexmaculata Fabricius	1, 189	33.74	<0.001
Brumoides suturalis Fabricius	1, 189	45.56	<0.001

[a]Only predacious phase (larvae) was observed.

negative relationship between herbivore densities and predator abundance. This conclusion supports the natural enemy hypothesis that confers the herbivore suppression through enhanced abundance of natural enemies (Root, 1973; Cook-Patton *et al.*, 2011). It is well documented that organic farming supports higher densities and diversity of predators (Muneret *et al.*, 2019; Galloway *et al.*, 2021). Increased abundance and evenness of predator species can improve or weaken the biological control (Hooper *et al.*, 2005; Cardinale *et al.*, 2006; Hillebrand *et al.*, 2008; Crowder *et al.*, 2010). The key factor determining the effect of predator evenness on herbivore suppression is the overlapped foraging areas of predator communities. If predator communities share common food niches and foraged in the overlapped areas of each other, they often encounter each other while searching and hunting for the same prey (Laubmeier *et al.*, 2020). This phenomenon more likely results in negative interactions like interference and intraguild predation that ultimately reduce herbivore suppression.

Organic farming has socio-economics pros and cons for small land holders. The major concerns related to this production system in developing countries includes market barriers and certification (Gómez *et al.*, 2011) of organic product, lower productivity (Connor, 2013; Ponisio *et al.*, 2015) and lack of research and education for small scale farmers (Kleemann, 2011). Meanwhile, organic farming systems provide several benefits to small land holders. In spite of lower productivity of organic farms, the economic profitability of this system is still maximum as compared to others (Ramesh *et al.*, 2010; Reganold and Wachter, 2016), because organic products are demanded globally and sold at a premium price as compared to conventional products (Aryal *et al.*, 2009). In organic farming systems, substitutions of synthetic chemicals with low-energy and locally available farm inputs reduces the production cost of the farmer (Setboonsarng, 2006). However, this production system is labor intensive, but, the working of kith and kins on subsistence farms also reduces the external production costs of farmers (Kleemann, 2011). Organic farming has high environmental resilience to climatic shifts (Gattinger *et al.*, 2012; Skinner *et al.*, 2014), and together with the diversified ecosystem techniques (intercropping, crop rotation), it can potentially lower the risk of crop failure. Cost–benefit analysis of organic production systems proved reasonable benefits for resource-poor farmers due to the reduction of production costs in developing countries (Amoabeng *et al.*, 2014). Nevertheless, organic farming is a favorable system for the subsistence growers as they do not need to buy synthetic chemicals like fertilizers and pesticides, rather they apply farmyard manure and extracts of plants or their parts as fertilizers and pesticides, respectively (Carvalho, 2017). Mostly, these inputs are easily and freely available in developing countries, for instance, manure of cattle raised for household needs can be used as organic fertilizers.

In conclusion, conventional maize supported a higher herbivore population, while organic maize supported a higher predator population. The predator diversity and evenness increased more in organic fields. We conclude that enhancing the relative abundance of predators has the potential to suppress herbivores on organic farms. Moreover, predator abundance, diversity, and evenness were shown to be strong predictors of herbivore suppression. To sum up, organic farming may not only be able to restore degraded ecological services but can also help subsistence farmers by lowering input costs for crop production. However, this is

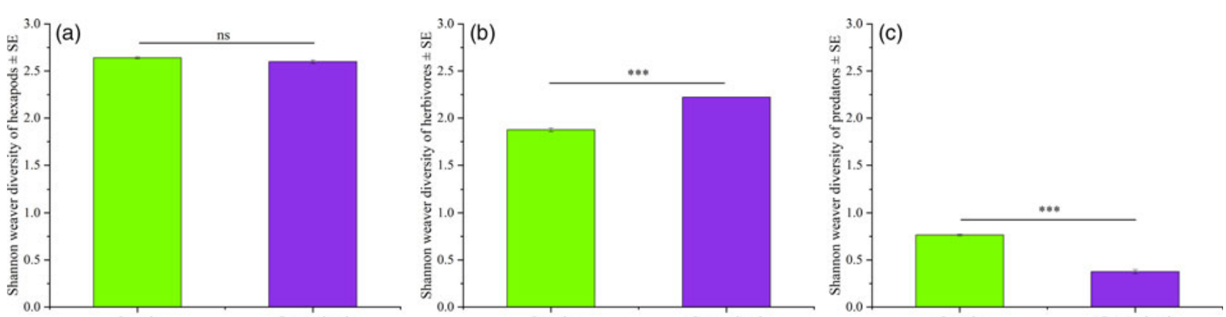

Figure 4. Shannon–Weaver diversity index for hexapods (a), herbivores (b), and predator (c) communities in organic and conventional maize in 2020 and 2021 (pooled data). Bars and boxes topped with line having ns show no significance and *** show significant differences between groups at $P < 0.001$.

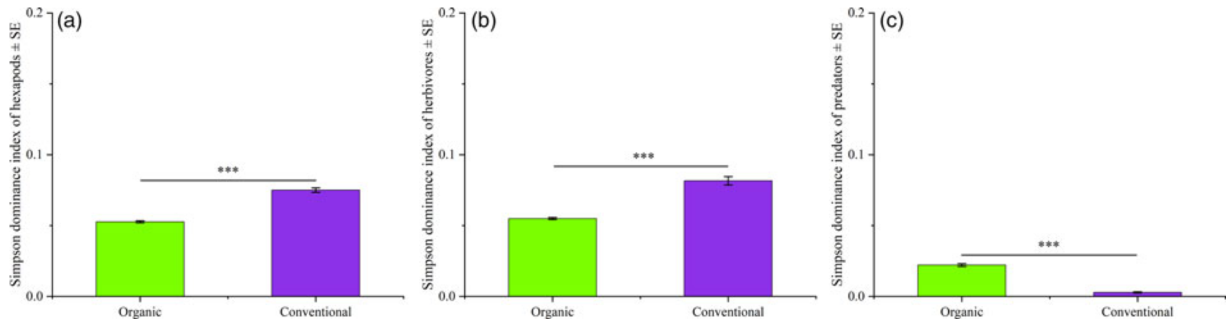

Figure 5. Simpson dominance index for hexapods(a), herbivores (b), and predator (c) communities in organic and conventional maize in 2020 and 2021 (pooled data). Bars and boxes topped with line having *** show significant differences between groups at $P < 0.001$.

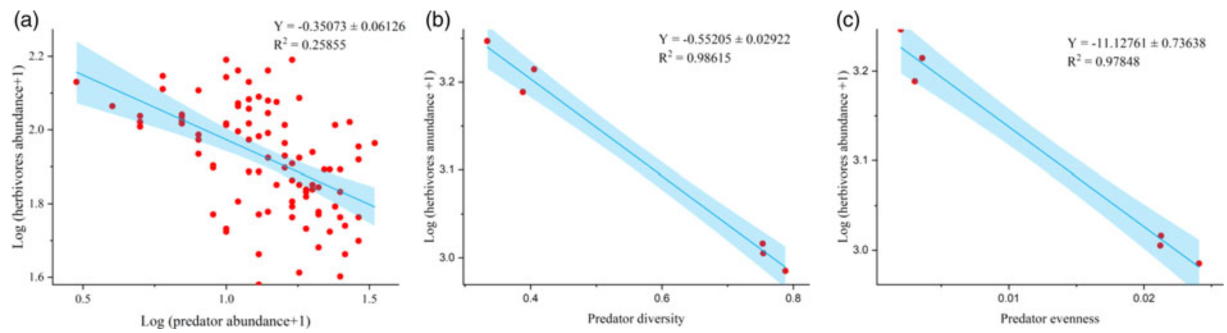

Figure 6. Relationships between the herbivore densities and (a) predator densities (b) predator diversity, and (c) predator evenness in maize fields. Note that population data for herbivore and predators are log (x + 1) transformed and pooled for both the years.

preliminary research and further research will be directed toward the determination of losses due to insect herbivores for cost–benefit analysis of both types of crops and evaluation of indigenous plant extracts for managing insect pests.

Data. The datasets generated and/or analyzed during current study are available from the corresponding author on reasonable request

Acknowledgements. We thank Dr Jessica Pruett (Thad Cochran Research Center, The University of Mississippi, Oxford, MS, USA) and Miss Faiza Hafeez (School of Biological Sciences; University of Nebraska—Lincoln, Lincoln, United States) for reading the manuscript, edits, and comments, and to Shahbaz Asghar, Haider Ali, and Hafiz Muhammad Usman (MSc scholars at Department of Entomology, Bahauddin Zakariya University) for help with data collection and species identification.

Author contributions. This research is the part of MS thesis of A. H. M. R. conceived, designed the experiment, and supervised all the research. A. H. conducted field experiment and collected data. F. M. S. and M. O. F. analyzed the data. M. O. F. and A. H. wrote the initial draft and F. M. S. reviewed, edited, and wrote the final draft. All authors improved and upgraded the manuscript.

Financial support. The authors did not receive specific support from any organization for the submitted work.

Competing interest. The authors have no conflict of interest.

Ethical standards. This article does not contain any studies with human or other animal subjects.

Declaration. This study was approved by the Advance Studies and Research Board of the Bahauddin Zakariya University.

Consent to participate. All the authors agree to participate.

Consent to publication. All authors agree to publish.

References

AL-Ahmadi MS (2019) Pesticides, anthropogenic activities, and the health of our environment safety M. Larramendy, S. Soloneski (Eds.), In *Pesticides-use and misuse and their impact in the environment* London, UK: IntechOpen, pp. 1–23.

Aldebron C, Jones MS, Snyder WE and Blubaugh CK (2020) Soil organic matter links organic farming to enhanced predator evenness. *Biological Control* **146**, 104278.

Amer M, Aslam M, Razaq M and Afzal M (2009) Lack of plant resistance against aphids, as indicated by their seasonal abundance in Canola, *Brassica napus* (L.) in Southern Punjab, Pakistan. *Pakistan Journal of Botany* **41**, 1043–1051.

Amoabeng BW, Gurr GM, Gitau CW and Stevenson PC (2014) Cost: benefit analysis of botanical insecticide use in cabbage: implications for smallholder farmers in developing countries. *Crop Protection* **57**, 71–76.

Arora S, Arora S, Sahni D, Sehgal M, Srivastava D and Singh A (2019) Pesticides use and its effect on soil bacteria and fungal populations, microbial biomass carbon and enzymatic activity. *Current Science* **116**, 643–649.

Aryal KP, Chaudhary P, Pandit S and Sharma G (2009) Consumers' willingness to pay for organic products: a case from Kathmandu valley. *Journal of Agriculture and Environment* **10**, 15–26.

Aziz T, Ullah S, Sattar A, Nasim M, Farooq M and Khan MM (2010) Nutrient availability and maize (*Zea mays*) growth in soil amended with organic manures. *International Journal of Agriculture and Biology* **12**, 621–624.

Baker BP, Benbrook CM, Iii EG and Benbrook KL (2002) Pesticide residues in conventional, integrated pest management (IPM)-grown and organic

https://doi.org/10.1017/S000748532300024X Published online by Cambridge University Press

foods: insights from three US data sets. *Food Additives & Contaminants* **19**, 427–446.
Bengtsson J, Ahnström J and Weibull AC (2005) The effects of organic agriculture on biodiversity and abundance: a meta-analysis. *Journal of Applied Ecology* **42**, 261–269.
Birkhofer K, Bezemer TM, Bloem J, Bonkowski M, Christensen S, Dubois D, Ekelund F, Fließbach A, Gunst L and Hedlund K (2008) Long-term organic farming fosters below and aboveground biota: implications for soil quality, biological control and productivity. *Soil Biology and Biochemistry* **40**, 2297–2308.
Blundell R, Schmidt JE, Igwe A, Cheung AL, Vannette RL, Gaudin A and Casteel CL (2020) Organic management promotes natural pest control through altered plant resistance to insects. *Nature Plants* **6**, 483–491.
Brown M and Tworkoski T (2004) Pest management benefits of compost mulch in apple orchards. *Agriculture, Ecosystems & Environment* **103**, 465–472.
Cardinale BJ, Harvey CT, Gross K and Ives AR (2003) Biodiversity and biocontrol: emergent impacts of a multi-enemy assemblage on pest suppression and crop yield in an agroecosystem. *Ecology Letters* **6**, 857–865.
Cardinale BJ, Srivastava DS, Emmett Duffy J, Wright JP, Downing AL, Sankaran M and Jouseau C (2006) Effects of biodiversity on the functioning of trophic groups and ecosystems. *Nature* **443**, 989–992.
Carvalho FP (2017) Pesticides, environment, and food safety. *Food and Energy Security* **6**, 48–60.
Chaplin-Kramer R, Sharp RP, Mandle L, Sim S, Johnson J, Butnar I, Milà i Canals L, Eichelberger BA, Ramler I and Mueller C (2015) Spatial patterns of agricultural expansion determine impacts on biodiversity and carbon storage. *Proceedings of the National Academy of Sciences* **112**, 7402–7407.
Chau LM and Heong K (2005) Effects of organic fertilizers on insect pest and diseases of rice. *Omonrice* **13**, 26–33.
Connor DJ (2013) Organically grown crops do not a cropping system make and nor can organic agriculture nearly feed the world. *Field Crops Research* **144**, 145–147.
Cook-Patton SC, McArt SH, Parachnowitsch AL, Thaler JS and Agrawal AA (2011) A direct comparison of the consequences of plant genotypic and species diversity on communities and ecosystem function. *Ecology* **92**, 915–923.
Cooper J and Dobson H (2007) The benefits of pesticides to mankind and the environment. *Crop Protection* **26**, 1337–1348.
Crowder DW, Northfield TD, Strand MR and Snyder WE (2010) Organic agriculture promotes evenness and natural pest control. *Nature* **466**, 109–112.
Edde PA (2021) *Field Crop Arthropod Pests of Economic Importance*. San Diego, CA: Academic Press.
Farooq MO, Razaq M and Shah FM (2022) Plant diversity promotes species richness and community stability of arthropods in organic farming. *Arthropod-Plant Interactions* **16**, , 1–14.
Finke DL and Denno RF (2004) Predator diversity dampens trophic cascades. *Nature* **429**, 407–410.
Foley JA, Ramankutty N, Brauman KA, Cassidy ES, Gerber JS, Johnston M, Mueller ND, O'Connell C, Ray DK and West PC (2011) Solutions for a cultivated planet. *Nature* **478**, 337–342.
Gaba S, Gabriel E, Chadœuf J, Bonneu F and Bretagnolle V (2016) Herbicides do not ensure for higher wheat yield, but eliminate rare plant species. *Scientific Reports* **6**, 1–10.
Galloway AD, Seymour CL, Gaigher R and Pryke JS (2021) Organic farming promotes arthropod predators, but this depends on neighbouring patches of natural vegetation. *Agriculture, Ecosystems & Environment* **310**, 107295.
Gattinger A, Muller A, Haeni M, Skinner C, Fliessbach A, Buchmann N, Mäder P, Stolze M, Smith P and Scialabba NE-H (2012) Enhanced top soil carbon stocks under organic farming. *Proceedings of the National Academy of Sciences* **109**, 18226–18231.
Gómez MI, Barrett C, Buck L, De Groote H, Ferris S, Gao H, McCullough E, Miller D, Outhred H and Pell A (2011) Research principles for developing country food value chains. *Science (New York, N.Y.)* **332**, 1154–1155.
Gomiero T, Pimentel D and Paoletti MG (2011) Environmental impact of different agricultural management practices: conventional vs. organic agriculture. *Critical Reviews in Plant Sciences* **30**, 95–124.
Gu S, Zalucki MP, Men X, Li J, Hou R, Zhang Q, Ge F and Ouyang F (2022) Organic fertilizer amendment promotes wheat resistance to herbivory and biocontrol services via bottom-up effects in agroecosystems. *Journal of Pest Science* **95**, 339–350.
Gurr GM, Wratten SD and Luna JM (2003) Multi-function agricultural biodiversity: pest management and other benefits. *Basic and Applied Ecology* **4**, 107–116.
Hillebrand H, Bennett DM and Cadotte MW (2008) Consequences of dominance: a review of evenness effects on local and regional ecosystem processes. *Ecology* **89**, 1510–1520.
Hooper DU, Chapin FS III, Ewel JJ, Hector A, Inchausti P, Lavorel S, Lawton JH, Lodge D, Loreau M and Naeem S (2005) Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. *Ecological Monographs* **75**, 3–35.
Hussain S, Mubeen M, Akram W, Ahmad A, Habib-ur-Rahman M, Ghaffar A, Amin A, Awais M, Farid HU and Farooq A (2020) Study of land cover/land use changes using RS and GIS: a case study of Multan district, Pakistan. *Environmental Monitoring and Assessment* **192**, 1–15.
Jacobsen SK, Moraes GJ, Sørensen H and Sigsgaard L (2019) Organic cropping practice decreases pest abundance and positively influences predator-prey interactions. *Agriculture, Ecosystems & Environment* **272**, 1–9.
Kaiser HF (1974) An index of factorial simplicity. *Psychometrika* **39**, 31–36.
Kaplan I and Denno RF (2007) Interspecific interactions in phytophagous insects revisited: a quantitative assessment of competition theory. *Ecology Letters* **10**, 977–994.
Kleemann L (2011) *Organic farming in Ghana-A good choice for smallholders? Organic Certification, Sustainable Farming and Return on Investment: Empirical Evidence from Ghana.*
Krey KL, Nabity PD, Blubaugh CK, Fu Z, Van Leuven JT, Reganold JP, Berim A, Gang DR, Jensen AS and Snyder WE (2020) Organic farming sharpens plant defenses in the field. *Frontiers in Sustainable Food Systems* **4**, 97.
Laubmeier AN, Rebarber R and Tenhumberg B (2020) Towards understanding factors influencing the benefit of diversity in predator communities for prey suppression. *Ecosphere (Washington, D.C)* **11**, e03271.
Lechenet M, Bretagnolle V, Bockstaller C, Boissinot F, Petit M-S, Petit S and Munier-Jolain NM (2014) Reconciling pesticide reduction with economic and environmental sustainability in arable farming. *PLoS One* **9**, e97922.
Leifeld J (2012) How sustainable is organic farming? *Agriculture, Ecosystems & Environment* **150**, 121–122.
Letourneau DK, Armbrecht I, Rivera BS, Lerma JM, Carmona EJ, Daza MC, Escobar S, Galindo V, Gutiérrez C and López SD (2011) Does plant diversity benefit agroecosystems? A synthetic review. *Ecological Applications* **21**, 9–21.
Lichtenberg EM, Kennedy CM, Kremen C, Batary P, Berendse F, Bommarco R, Bosque-Pérez NA, Carvalheiro LG, Snyder WE and Williams NM (2017) A global synthesis of the effects of diversified farming systems on arthropod diversity within fields and across agricultural landscapes. *Global Change Biology* **23**, 4946–4957.
Lu ZZ, Perkins L, Li JB, Wu WY, Zalucki M, Gao GZ and Furlong M (2015) Abundance of *Aphis gossypii* (Homoptera; Aphididae) and its main predators in organic and conventional cotton fields in north-west China. *Annals of Applied Biology* **166**, 249–256.
Lynch CA, Smith OM, Chapman EG, Crossley MS, Crowder DW, Fu Z, Harwood JD, Jensen AS, Krey KL and Snyder GB (2022) Alternative prey and farming system mediate predation of C olorado potato beetles by generalists. *Pest Management Science* **78**, 3769–3777.
Mabin MD, Welty C and Gardiner MM (2020) Predator richness predicts pest suppression within organic and conventional summer squash (Cucurbita pepo L. Cucurbitales: Cucurbitaceae). *Agriculture, Ecosystems & Environment* **287**, 106689.
Mäder P, Fliessbach A, Dubois D, Gunst L, Fried P and Niggli U (2002) Soil fertility and biodiversity in organic farming. *Science (New York, N.Y.)* **296**, 1694–1697.

Maxwell SL, Fuller RA, Brooks TM and Watson JE (2016) Biodiversity: the ravages of guns, nets and bulldozers. *Nature* **536**, 143–145.

Muneret L, Auriol A, Bonnard O, Richart-Cervera S, Thiéry D and Rusch A (2019) Organic farming expansion drives natural enemy abundance but not diversity in vineyard-dominated landscapes. *Ecology and Evolution* **9**, 13532–13542.

Muñoz-Cárdenas K, Ersin F, Pijnakker J, van Houten Y, Hoogerbrugge H, Leman A, Pappas ML, Duarte MV, Messelink GJ and Sabelis MW (2017) Supplying high-quality alternative prey in the litter increases control of an above-ground plant pest by a generalist predator. *Biological Control* **105**, 19–26.

Newbold T, Hudson LN, Arnell AP, Contu S, De Palma A, Ferrier S, Hill SL, Hoskins AJ, Lysenko I and Phillips HR (2016) Has land use pushed terrestrial biodiversity beyond the planetary boundary? A global assessment. *Science (New York, N.Y.)* **353**, 288–291.

Otieno NE, Jacobs SM and Pryke JS (2019*a*) Maize-field complexity and farming system influence insectivorous birds' contribution to arthropod herbivore regulation. *Biotropica* **51**, 851–861.

Otieno NE, Pryke JS, Butler M and Jacobs SM (2019*b*) Top-down suppression of arthropod herbivory in intercropped maize and organic farms evidenced from δ13C and δ15N stable isotope analyses. *Agronomy for Sustainable Development* **39**, 1–10.

Phelan P, Mason J and Stinner B (1995) Soil-fertility management and host preference by European corn borer, *Ostrinia nubilalis* (Hübner), on *Zea mays* L.: a comparison of organic and conventional chemical farming. *Agriculture, Ecosystems & Environment* **56**, 1–8.

Ponisio LC, M'Gonigle LK, Mace KC, Palomino J, De Valpine P and Kremen C (2015) Diversification practices reduce organic to conventional yield gap. *Proceedings of the Royal Society B: Biological Sciences* **282**, 20141396.

Ramesh P, Panwar N, Singh A, Ramana S, Yadav SK, Shrivastava R and Rao AS (2010) Status of organic farming in India. *Current Science* **98**, 1190–1194.

Ray DK, Ramankutty N, Mueller ND, West PC and Foley JA (2012) Recent patterns of crop yield growth and stagnation. *Nature Communications* **3**, 1–7.

Reganold JP and Wachter JM (2016) Organic agriculture in the twenty-first century. *Nature Plants* **2**, 1–8.

Root RB (1973) Organization of a plant-arthropod association in simple and diverse habitats: the fauna of collards (*Brassica oleracea*). *Ecological Monographs* **43**, 95–124.

Scherber C, Eisenhauer N, Weisser WW, Schmid B, Voigt W, Fischer M, Schulze E-D, Roscher C, Weigelt A and Allan E (2010) Bottom-up effects of plant diversity on multitrophic interactions in a biodiversity experiment. *Nature* **468**, 553–556.

Setboonsarng S (2006) Organic Agriculture, Poverty Reduction, and the Millennium Development Goals: Discussion Paper No. 54. Tokyo: Asian Development Bank.

Shahid M, Ahmad A, Khalid S, Siddique HF, Saeed MF, Ashraf MR, Sabir M, Niazi NK, Bilal M and Naqvi STA (2016) Pesticides pollution in agricultural soils of Pakistan. In Hakeem KR, Akhtar J and Sabir M (eds), *Soil Science: Agricultural and Environmental Prospectives*. Springer, pp. 199–229.

Shannon CE (1948) A mathematical theory of communication. *The Bell System Technical Journal* **27**, 379–423.

Simon S, Bouvier J-C, Debras J-F and Sauphanor B (2011) Biodiversity and pest management in orchard systems. In Lichtfouse E, Hamelin M, Navarrete M and Debaeke P (eds). *Sustainable Agriculture*, Vol. 2. Dordrecht: Springer, pp. 693–709.

Simpson E.H. (1949) Measurement of diversity. *Nature* **163**, 688–688.

Skinner C, Gattinger A, Muller A, Mäder P, Flieβbach A, Stolze M, Ruser R and Niggli U (2014) Greenhouse gas fluxes from agricultural soils under organic and non-organic management—a global meta-analysis. *Science of the Total Environment* **468**, 553–563.

Snyder WE, Snyder GB, Finke DL and Straub CS (2006) Predator biodiversity strengthens herbivore suppression. *Ecology Letters* **9**, 789–796.

Straub CS and Snyder WE (2006) Species identity dominates the relationship between predator biodiversity and herbivore suppression. *Ecology* **87**, 277–282.

Tilman D, Cassman KG, Matson PA, Naylor R and Polasky S (2002) Agricultural sustainability and intensive production practices. *Nature* **418**, 671–677.

Tittonell P (2014) Ecological intensification of agriculture—sustainable by nature. *Current Opinion in Environmental Sustainability* **8**, 53–61.

Török E, Zieger S, Rosenthal J, Földesi R, Gallé R, Tscharntke T and Batáry P (2021) Organic farming supports lower pest infestation, but fewer natural enemies than flower strips. *Journal of Applied Ecology* **58**, 2277–2286.

Tremblay A, Mineau P and Stewart R (2001) Effects of bird predation on some pest insect populations in corn. *Agriculture, Ecosystems & Environment* **83**, 143–152.

Tuck SL, Winqvist C, Mota F, Ahnström J, Turnbull LA and Bengtsson J (2014) Land-use intensity and the effects of organic farming on biodiversity: a hierarchical meta-analysis. *Journal of Applied Ecology* **51**, 746–755.

Van Bruggen A and Finckh M (2016) Plant diseases and management approaches in organic farming systems. *Annual Review of Phytopathology* **54**, 25–54.

Yardım EN and Edwards CA (2003) Effects of organic and synthetic fertilizer sources on pest and predatory insects associated with tomatoes. *Phytoparasitica* **31**, 324–329.

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