

# Organic farming supports lower pest infestation, but less natural enemies than flower strips

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## Abstract

1. Agricultural intensification has led to dramatic losses of species and associated ecosystem services. In the European Union, agri-environment schemes (AESs) have been developed to mitigate these challenges. There are two opposing AES strategies, targeting either production or non-production areas. Organic farming focuses on production and conservation on the same land-use area, whereas flower strips adjacent to crop fields are in favour of intensified conventional production combined with conservation strips outside the cultivated area.
2. We investigated pest and natural enemy abundances of organic farming versus establishing flower strip in 10 agricultural landscapes in Central Germany along a gradient of mean field size (1.24–6.78 ha). We focused on three winter wheat fields per landscape: conventional field (control), conventional field with adjacent flower strip and organic field. We sampled crop pests such as cereal leaf beetles (CLBs) and cereal aphids as well as their natural enemies.
3. Our results indicated that the abundance of CLB larvae was more than two times higher in conventional farming with and without flower strip than that in the organic farming. The abundance of natural enemies was supported by landscapes with small mean field size, that is their numbers increased c. threefold when field size decreased from 7 to 2 ha.
4. Aphid abundance was lower in organic fields and conventional control fields than in conventional fields with flower strips suggesting a potential disservice of flower strips. Parasitoids and natural enemies benefited from flower strips, but they were obviously not able to control the aphids.
5. *Synthesis and applications.* The major pests in cereals, aphids and CLBs infested organic farming less than flower strips along conventional fields. However, the abundance of natural enemies of pests benefited from flower strips and, in addition, from decreasing field size in agricultural landscapes. Hence, enhancing predator populations for more effective biological pest control may be best with decreasing field sizes combined with organic farming and flower strips. Altogether,

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organic farming might contribute much more to low pest damage than a conventional farming strategy with flower strips.

#### KEYWORDS

agri-environment schemes, aphid predation, biological control, cereal leaf beetle, conventional field, edge effect, field size, landscape heterogeneity

## 1 | INTRODUCTION

Agricultural intensification has led to a dramatic species loss during the past hundred years (Hallmann et al., 2017). Transformations of extensive grasslands to arable fields and destructions of field boundaries and hedges resulted in a loss of semi-natural habitats and homogenization at landscape scales in Europe (Tschardt et al., 2005). These are expected to jeopardize ecosystem services such as natural biocontrol and pollination (Zhao et al., 2015).

Agri-environment schemes (AESs) have been developed to react to the challenges of increased agricultural intensification. In the European Union, AESs were initially designed to protect environmentally sensitive areas by compensating farmers for income losses associated with less intensive management (Batáry et al., 2015). However, recently also the improvement and conservation of ecosystem services are in the focus of AESs (Ekroos et al., 2014). Two of the most popular AESs are organic farming and flower strips. Organic farming is considered as an environmentally friendly agricultural strategy, excluding the use of synthetic pesticides and mineral fertilizers. In contrast, conventional agriculture with the partial transformation of fields to flower strips can be viewed as a conservation strategy at a small local scale. These contrasting strategies raise the question which of them is better in terms of promoting biodiversity and ecosystem services.

In this study, we compare and evaluate the two strategies. Organic farming is a management type that is financially supported by AESs in the EU and may encourage higher biological pest control than conventional farming (Puech et al., 2014). The prohibited use of synthetic pesticides and mineral fertilizers generally allows a high abundance and species richness of arable weeds and insects depending on them (Gabriel & Tschardt, 2007). Moreover, the higher abundance and diversity of non-crop plants results in higher micro-climatic heterogeneity within organic fields (Kromp, 1989). Riggi and Bommarco (2019) reported that organic fertilizers supported soil fauna and increased coleopteran abundances. Thus, enhancing the soil mesofauna through providing refuge and/or a beneficial microclimate by adding organic matter has been shown to benefit generalist arthropod predators. Further, organic farming provides habitat and flower resources to insect predator and parasitoid species with different ecological traits, thereby increasing higher functional diversity and a higher potential for biological pest control (Kleijn et al., 2011).

In contrast, flower strips are typically implemented by sowing along the edge of conventional crop fields. They are implemented most often as part of AESs or sometimes as a private initiative. They

show a great heterogeneity based on regulations concerning design of and compensation. For example, they can be established as annual or perennial flower strips or even as whole fields (Gayer et al., 2021). Flower strip management can vary following sowing time, harvest time and seed mixture, partly depending on the objective, for example whether pollinators or natural enemies or biodiversity in general should be supported (Albrecht et al., 2020). Flower strips provide complementary food resources and shelter to natural enemies of crop pests (Ekroos et al., 2014). Nectar and pollen are attractive also for adult hoverflies, and lacewings, many of which are known as pest predators. For instance, the positive effect of sown flower strips on parasitoid communities has been shown by several studies (Haaland et al., 2011). A possible reason is that parasitoid adults require nectar or other sugar sources to cover their energetic needs and to extend their lifetime (Wäckers & Van Rijn, 2012), whereas larvae of many parasitic wasps and flies attack pest insects such as pest aphids (Bianchi & Wäckers, 2008). Furthermore, flower strips can provide shelter from pesticides and offer potential overwintering sites (Landis et al., 2000). On the one hand, flower strips provide heterogeneous habitat, also after the harvest of crop plants, and may therefore be important to sustain populations of natural enemies (Tschumi et al., 2016). On the other hand, this might also benefit the pest populations. As pests can use flower strips as a shelter habitat from disturbances such as environmental extremes or pesticides.

Beyond the focal field, landscape-scale crop heterogeneity can determine ecosystem services (Martin et al., 2019), because small field sizes in a landscape create high landscape heterogeneity, which supports different food resources and habitat conditions for a higher biodiversity (Gallé et al., 2018). Recent research has shown that high landscape configurational heterogeneity, which can be obtained by reducing field sizes, supports much higher functional diversity of predatory arthropods of agroecosystems (Gallé et al., 2019; Martin et al., 2019).

Due to their importance as pests in cereals, the organisms used in our study were cereal leaf beetles (CLBs) and cereal aphids, which are well-known pests and cause economically important crop damage in Europe (Dedryver et al., 2010). In addition to the direct damage by herbivory, aphids may transmit virus infections such as the barley yellow dwarf virus, when damaging plant cells with their stylet. Further, the excretion of aphid honeydew facilitates the colonization of fungi on the leaf surface, which also harms the plants. All three factors may result in considerable losses of grain, both in quantity and quality (Dedryver et al., 2010). Cereal leaf beetle larvae damage their host plants by removing long strips of tissue from the upper leaf surface, while leaving the translucent cuticle of the lower

surface intact. Tips of damaged leaves frequently turn white, giving heavily infested fields a frost-damage appearance. Adults chew completely through the leaf, which results in narrow slits, although the damage they cause is usually insignificant. Yield loss is influenced by crop vigour and the timing and duration of the CLB infestation. Stressed growing conditions or poorly developed plants may increase potential damage (Philips et al., 2011).

As little is known about the relative effectiveness of biological pest control of flower strips compared to organic management. Therefore, the aim of the present study was to compare their effectiveness in terms of potential biological pest control. For this reason, we addressed two opposing hypotheses: flower strips probably offer more additional habitat and shelter to natural enemies than organic fields, thus crop fields adjoined to flower strips are more effective in enhancing natural pest control than organic fields. Alternatively, organic fields support higher natural pest control than flower strips, as the area that is managed biodiversity friendly covered is larger, whereas the positive effect of the narrow flower strips may decay rapidly with distance into the field. Finally, we tested an additional hypothesis: landscapes with smaller field sizes support higher abundances of natural enemies than landscapes with large fields. Smaller fields have a higher proportion of field margins, which provide more habitat and food resources, and allow higher connectivity across the landscape, thereby reducing extinction probability (Grass et al., 2021).

## 2 | MATERIALS AND METHODS

### 2.1 | Study area and design

The study sites were located in central Germany (Southern Lower Saxony), a typical example of an intensive agricultural region in Western Europe (Figure S1). We studied 10 landscapes and selected three winter wheat fields in each of them: (a) one organic field of an organic farmer (Org), (b) one conventional with a field adjacent to flower strip (CFS; mean  $\pm$  SEM size of flower strip:  $0.47 \pm 0.06$  ha) and (c) one control conventional field (Con) without flower strip (Figure S3a). Conventional farms used common wheat (*Triticum aestivum*), whereas organic farms used spelt wheat (*Triticum aestivum spelta*), belonging to a total of 20 farmers. We obtained 30 study fields with a mean size of  $5.83 \pm 0.79$  ha (mean  $\pm$  SEM CFS:  $3.43 \pm 0.44$  ha, Org:  $3.45 \pm 0.40$  ha, Con:  $3.35 \pm 0.49$  ha). In each landscape, the selected fields were situated within the area of one village close to each other with maximum distance of 3.4 km (mean  $\pm$  SEM:  $1,636 \pm 176$  m), in order to minimize edaphic and climatic differences among them, but also having a minimum distance of 0.2 km among them for reducing spillover between the treatments and ensuring independence. The landscapes around the fields represented a gradient of configurational heterogeneity. Mean arable field size within a 1,000-m radius around each study field was 3.41 ha (SEM = 0.25 ha) and range was 1.24–6.78 ha. This radius is considered adequate to study the responses of specialist pests and natural enemies to the landscape context (Chaplin-Kramer et al., 2011).

Studied edges of organic and conventional fields without flower strips were bordered by grassy field margins (1–2 m) and a dirt road adjacent to it. In each field, we established two transects, each 50 m long. The first transect was located at the edge (hereafter edge transect) and another transect parallel to it, 10 m inside the field (hereafter interior transect). This way we had 3 fields  $\times$  2 transects per landscape (Figure S2).

### 2.2 | Cereal leaf beetle larvae

We quantified the infestation of wheat by *Oulema* spp., CLBs (Figure S3b). We used the transect walk method, searched for CLB larvae at each transect for 10 min and recorded the number of CLB larvae spotted within 1 m to either side (Evans, 2018). The counting of CLB larvae was performed between 6 and 9 June 2016, during the peak of larval infestation (Ihrig et al., 2001).

### 2.3 | Natural enemy abundance

We carried out sweep net sampling to collect all natural enemies along the transects. We collected adult and immature stages of natural enemies, and classified them into following groups: spiders, lacewings, hoverflies, ladybirds and predatory bugs, many of which can predate both CLB larvae and aphids. Sweep netting was standardized with 60 sweeps per transect (one sweep per footstep). We used a heavy duty sweep net with 38 cm in diameter. The sampling was carried out in the beginning of July 2016.

### 2.4 | Aphids and natural enemies on wheat tillers

We randomly selected 10 tillers at five spots per transect (10 tillers  $\times$  5 spots = 50 tillers per transect). We screened the tillers from base to spike and counted the number of aphid and their natural enemy individuals present. We recorded ladybirds (adults and larvae), hoverflies (pupae and larvae), lacewing larvae and spiders. We determined the ratio of aphid natural enemies to total number of aphids. Furthermore, we registered whether aphids were parasitized by Hymenopteran wasps to determine parasitism rate [ratio of mummies (mummified aphids) to total number of aphids (including mummies; Figure S3b)]. The survey was carried out two times, that is during wheat flowering (mid of June) and milk ripening stage (beginning of July). We pooled the data from the two rounds; data are given as the sum of aphids and natural enemies on 100 tillers per transect and aphid parasitism rate as an average of the two rounds.

### 2.5 | Data analysis

To test whether arable field size, management type, transect position and their second-order interactions had a significant effect

on the pests and the natural enemies, we used five generalized linear mixed-effects models with binomial distribution (ratio of parasitized/survived aphids, ratio of enemies/aphids) or negative binomial distribution (abundance of CLB larvae, abundance of all natural enemies and abundance of aphids) error distribution in R package `LME4` (Bates et al., 2015). In the case of aphid parasitism, we fitted a binomial error distribution model with parasitized aphids as numerator and non-parasitized aphids in the denominator. The number of observations was 60 (10 landscapes  $\times$  3 management types  $\times$  2 transects). We used management (factor with three levels: conventional, conventional flower strip and organic), transect position (factor with two levels: edge and interior), mean arable field size within 1,000-m radius around the focal field (continuous explanatory variable) and their two-way interaction terms as fixed effects. The hierarchical random effects were 'field' nested in 'farmer' and 'farmer' nested in 'landscape'. Full model in R syntax:

```
'glmer(y ~ (Field size + Management + Field position)^2 + (1|Landscape/Farmer/Field))'
```

The model for each response variable was simplified using the `drop1` function to eliminate non-significant variables until a final model was found. Plots were created using the R package `GGPLOT2` (Wickham, 2016). We also tested the quadratic effects of field size, but it had no influence on our results (data not shown).

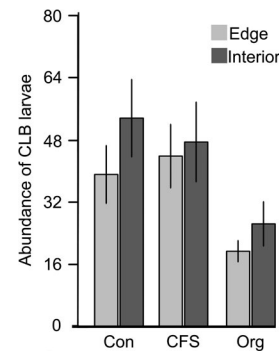
### 3 | RESULTS

#### 3.1 | Cereal leaf beetle larvae

We counted 2,286 individuals of CLB larvae, ranging from 3 to 134 larvae per transect. Abundances differed significantly between management types. The number of observed CLB larvae in CFS and Con fields was significantly higher than that in Org fields. We observed the highest CLB larvae abundances in the interior transects of Con fields, whereas the lowest abundances were found in the edge transects of Org fields (Figure 1; Table 1). In general, however, interior transects hosted more CLB larvae than edge transects with less expressed edge effect in the case of CFS (Figure 1; Table 1).

#### 3.2 | Natural enemy abundance

We counted 521 individuals of natural enemies. The total abundance of all natural enemies was influenced by management type and mean field size (Table 1). In CFS fields, the abundances of all natural enemies were significantly higher than in the other treatments (Figure 2a). Furthermore, the abundance of all natural enemies decreased with increasing mean field size (abundance of natural enemies increased threefold when decreasing field size from 6.8 ha to 2.0 ha), independent of management type or transect position (Figure 2b).



**FIGURE 1** Mean abundance of cereal leaf beetle larvae (CLB;  $N = 2,286$ ) in relation to transect position (edge vs. interior) and management type (conventional = Con, conventional + flower strip = CFS, organic = Org). Error bars represent standard error of mean (SEM). Management effects were significant ( $p < 0.01$ )

#### 3.3 | Aphids and natural enemies on wheat tillers

We counted 2,457 aphids on 6,000 tillers during the two survey rounds, 0.4 aphids per tiller on average. In addition, we counted 181 individuals of natural enemies and 435 mummified aphids. Numbers of aphids were significantly different between management types. CFS had far the highest aphid abundances (Figure 3a; Table 1). Similarly, aphid parasitism rates were highest in CFS management, whereas Con control and Org management showed lower parasitism especially in edge transects (Figure 3b; Table 1). The ratio of aphid natural enemies to aphids per tiller was not affected significantly by management types, transect position or field size (Table 1). Field size and transect position did not affect the abundance of aphids and natural enemies either on wheat tillers.

### 4 | DISCUSSION

Our first hypothesis that flower strips perform better than organic farming regarding reduced pest loads and more effective natural enemies was not supported by the results. Yet, according to our opposing hypothesis, organic farming may support better biocontrol as indicated by the lower amount of pests than in fields next to flower strips. Finally, landscapes with smaller fields supported a higher abundance of natural enemies than landscapes with larger fields, confirming our third hypothesis.

#### 4.1 | Cereal leaf beetle larvae

Unexpectedly, we found a high abundance of CLB in conventional farming. Conventional farming uses generally agrochemicals (insecticides) to control CLB population. Our results suggest that chemical control in conventional farms was not enough to control the abundance of CLB larvae. Insecticide treatments usually have

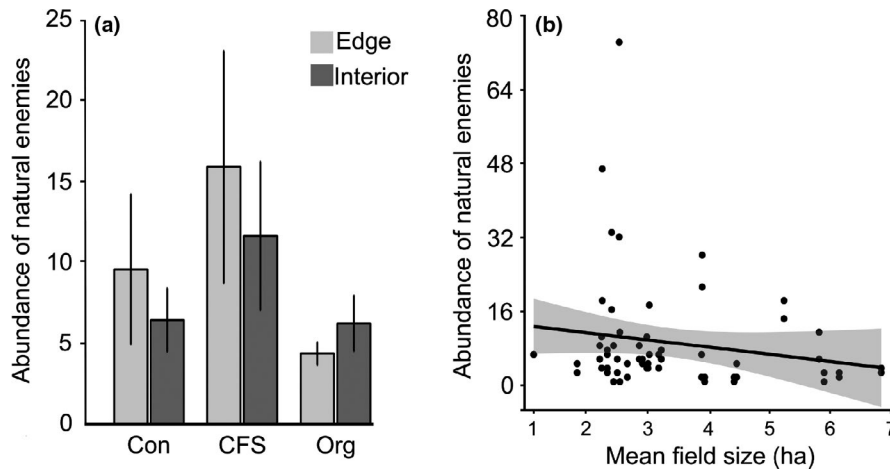
**TABLE 1** Summary table for GLMM results after full model simplification of survey of cereal leaf beetles (CLBs) larvae, aphids and their natural enemies, showing relative importance of each explanatory variable [Field size (F); Management type (conventional = Con, conventional + flower strip = CFS, organic = Org); and Transect position (T: edge (E) vs. interior (I))], its estimated effect on the response  $\pm$ SE and 95% CI, significance levels: \* $<0.05$ , \*\* $<0.01$ , \*\*\* $<0.001$

Model	Variable	ES $\pm$ 95% CI	p value
Abundance of CLB larvae	F	-0.12 $\pm$ 0.15	0.12
	F $\times$ T (E – I)	0.11 $\pm$ 0.13	0.078
	Con – CFS	-0.04 $\pm$ 0.19	0.686
	Con – Org	-0.7 $\pm$ 0.43	0.001**
	CFS – Org	-0.65 $\pm$ 0.43	0.002**
	T (E – I)	-0.19 $\pm$ 0.49	0.428
Abundance of all natural enemies	F	-0.38 $\pm$ 0.29	0.012*
	Con – Org	-0.14 $\pm$ 0.41	0.49
	CFS – Org	-0.57 $\pm$ 0.41	0.006**
	CFS – Con	-0.42 $\pm$ 0.37	0.031*
	T (E – I)	-0.16 $\pm$ 0.31	0.325
Abundance of aphids	F	-0.04 $\pm$ 0.17	0.632
	Con – CFS	0.63 $\pm$ 0.41	0.002**
	Con – Org	-0.08 $\pm$ 0.5	0.610
	CFS – Org	-0.71 $\pm$ 0.5	0.008**
	T (E – I)	-0.08 $\pm$ 0.33	0.631
Ratio of parasited/survived aphids	F	-0.03 $\pm$ 0.17	0.717
	Con – CFS	1.22 $\pm$ 0.43	<0.001***
	Con – Org	-0.32 $\pm$ 0.62	0.344
	CFS – Org	-1.54 $\pm$ 0.52	<0.001***
	T (E – I)	-0.35 $\pm$ 0.27	0.015*
	T (E – I) $\times$ (Con – CFS)	-0.88 $\pm$ 0.56	0.003**
	T (E – I) $\times$ (Con – Org)	0.66 $\pm$ 0.72	0.075
	T (E – I) $\times$ (CFS – Org)	1.51 $\pm$ 0.58	<0.001***
Ratio of enemies/aphids	F	-0.22 $\pm$ 0.39	0.369
	Con – CFS	0.94 $\pm$ 1.09	0.395
	Con – Org	0.45 $\pm$ 1.90	0.668
	CFS – Org	-0.48 $\pm$ 1.78	0.628
	T (E – I)	0.32 $\pm$ 0.82	0.444
	F $\times$ (CFS – Con)	-0.16 $\pm$ 0.29	0.185
	F $\times$ (CFS – Org)	0.40 $\pm$ 0.52	0.143
	F $\times$ (Con – Org)	0.02 $\pm$ 0.56	0.922
	F $\times$ T (E – I)	-0.18 $\pm$ 0.23	0.147

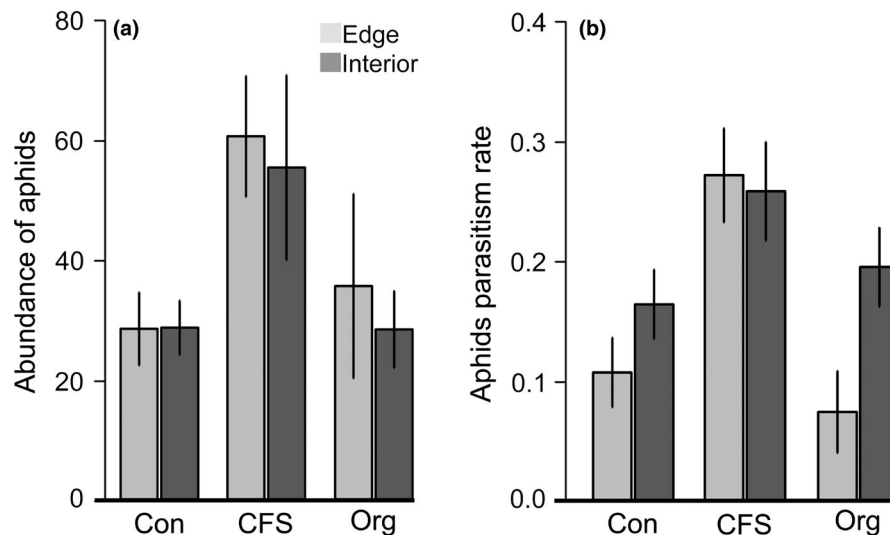
only a short-term effect on pest densities (Krauss et al., 2011). The case study of Wenda-Piesik et al. (2018) indicated that only one CLB insecticide treatment cannot control CLB population. The authors found that several insecticides together can generate a synergistic effect in terms of reducing CLB population, but this can be highly expensive.

We found a lower abundance of CLB larvae in organic fields than in conventional fields with and without flower strip. This can be related to the different agricultural practices, in particular the fertilization regime and the different densities of the crop plants. Synthetic fertilizers are not allowed in organic farming and also nitrogen inputs are typically lower in organic than in conventional farming (Schneider et al., 2015). Conventional farming uses large amounts of synthetic fertilizers to grow crops. Improved nitrogen nutrition enhances

herbivore density, as herbivores are in need of sufficient nitrogen supply, also showing that the reliance on biocontrol is less necessary in organic than in conventional farming (Duffield et al., 1997). Plants supplied with high nitrogen levels retain photosynthetically active leaves for longer due to delayed senescence (Gash, 2012). Hence, according to the vigour hypothesis, herbivores feed preferentially on vigorous, that is, large and/or fast-growing plants or plant parts (Price, 1991). Since trophic levels are often limited by the quantity and quality of food resources, changes at the bottom of the food web can affect the entire food web, including bottom-up effects of the vegetation on herbivore populations (Hunter & Price, 1992; Gandiwa, 2013). According to Riggi and Bommarco (2019), synthetic fertilizers can disrupt top-down control of herbivores due to reduced predator abundance and fitness, which is presumably caused by changes in soil



**FIGURE 2** Mean abundance of natural enemies ( $N = 521$ ) per transect (a) in relation to management type (conventional = Con, conventional + flower strip = CFS, organic = Org;  $p < 0.05$ ). Error bars represent standard error of mean (SEM). Abundance of natural enemies (b) in relation to mean field size ( $p < 0.05$ ) and 95% confidence interval



**FIGURE 3** Mean abundance of aphids ( $N = 2,457$ ) (a) per transect (data pooled from both rounds) in relation to transect position (edge vs. interior) and management type (Con = conventional, CFS = conventional + flower strip, Org = organic;  $p < 0.05$ ). Proportion of parasitized aphids (b) on the total number of aphids per transect (data pooled from both rounds) in relation to transect position (edge vs. interior) and management type (Con = conventional, CFS = conventional + flower strip, Org = organic). Management effect ( $p < 0.001$ ) and transect position ( $p < 0.001$ ) were significant. Error bars represent standard error of mean (SEM)

mesofauna. Further, high density of wheat may indirectly influence pest abundance. Conventional fields are characterized by a homogeneous vegetation structure with largely missing weed communities (Hyvönen et al., 2003). This dense hostplant vegetation consisting of nearly pure wheat creates a favourable structure for pests, as they move easily in dense vegetation. Organic fields were characterized by a more diverse plant community, as spelt wheat density is lower than that of common wheat, which increases their within-field heterogeneity and allows more non-crop plant establishment (Bavec & Bavec, 2015). The lower wheat density makes it more time-consuming for pests to move or to find their host plants (Hannunen, 2005). Finally, CLB adults need to feed on grass after emerging from wintering sites, before moving into crops for egg laying. Field margins and flower strips might offer wild grasses for the CLB adults, which support spillover into conventional fields with and without flower strips.

The density of wheat tillers is lower and leaves are drier at the field edges than in field interiors (based on field observations). This can be related to our results that both organic and conventional farming with and without flower strips hosted more CLB larvae in interior than in edge transect positions. Lower CLB larvae densities in the edge transect can be related to a higher impact of natural enemies, as natural enemies spillover from the semi-natural field margin to field edge (Haenke et al., 2009). The most common predators of CLB are lady beetles, *Nabis* bugs and wolf spiders (Kheirodin et al., 2019). One explanation is that the higher predation rates reduce the number of CLB larvae. Alternatively, CLB larvae might recognize edge habitat as landscape of fear causing an escape of pests from the edge to the interior. Thus, the field interior probably provides more enemy free space, but possibly also higher quality food (Rand et al., 2006).



## 4.2 | Natural enemy abundance

We detected a positive effect of flower strips on all natural enemies compared to organic and conventional farming. Flower strips offer higher diversity of microhabitats and additional resources for natural enemies (Hatt et al., 2017). Flower strips function like semi-natural habitats, as they provide shelter for natural enemies from factors such as environmental extremes or pesticides (Landis et al., 2000). Furthermore, flower strips provide resources and habitat for natural enemies when the crop plants are harvested, and may therefore be important to stabilize the populations (Haaland et al., 2011). Larvae of parasitic wasps, hoverflies or lacewings are predators of many pest insects, whereas their adult stages are flower visitors and feed on floral nectar and pollen (Bianchi & Wäckers, 2008), and they may lay eggs on adjacent fields infested by aphids (Ramsden et al., 2017).

We found clear effects of landscape configurational heterogeneity, with small field size having a positive effect on natural enemy abundances. Landscapes with high configurational heterogeneity (i.e. small fields and long edges) are generally associated with increased diversity and abundance of predatory arthropods (Dominik et al., 2018; Gallé et al., 2019). Decreasing field sizes increases the length of field margins, so both pests and natural enemies benefit from the higher amount of habitat. This is because field margin strips have the capacity to provide milder temperature conditions and a higher soil water content, which does not only support plants but also arthropods (Gardiner & Dover, 2008; Hathaway-Jenkins et al., 2011).

## 4.3 | Aphids and natural enemies on wheat tillers

The abundance of aphids was higher on conventional fields with flower strips than in organic fields and conventional fields without flower strips. Flower strips might support colonization of fields leading to higher aphid populations in their vicinity (Pascual-Villalobos et al., 2006). Furthermore, flower strips may provide long-term habitat structures, but aphids spillover into the field because of the higher in-field food resources (Blitzer et al., 2012). Some of the herbivores gain fitness benefits when provided with floral resources. According to Balzan et al. (2016), increased availability and diversity of flowering resources can lead to increased pest infestation. Additionally, flower strips might include wild grass species, which can be also attractive for the pests, such as for CLB adults. These studies show the opposite effect of flower strips, which might also provide ecosystem disservice through increased pest-induced crop damage (Tschumi et al., 2015). The increased abundance of aphids next to flower strips might be related mainly to alate aphids that tend to move mainly short distances over their lifetime, of the order of 20 m in favourable habitat and 100 m in poor habitat (Parry, 2013). If an aphid encounters an unsuitable host plant, it will move on, until it finds a suitable host in the shortest possible time (Loxdale et al., 1993). Aphid dispersal is related to the aphid host-alternating life cycle. In winter, cereal aphids live on their primary host plant, and winged females migrate to the cereals as a second host in summer (Hardie, 2017). During the wheat flowering

stage, invasion of winged aphids is typical, while during the milk ripening stage, aphid populations build up rapidly by vivipary. Flower strips could have a significantly high abundance of aphid, which probably negatively affected crop infestation and yield in the adjacent conventional field (Thies et al., 2005). The lower abundance of aphids in organic farming is probably related to the higher plant diversity and lower crop density, which may impede pest aphids searching for their host plants (Hatt et al., 2017).

Although total numbers of aphids were highest in fields with flower strips, these aphids also exhibited highest rates of parasitism. Results are in favour of the 'exporter' hypothesis, which predicts enhanced delivery of ecosystem services through functional spillover from floral plantings (Kremen et al., 2019). In our case, this was not supported by an effective biological pest control in flower strip fields. Parasitic wasps were probably attracted to the fields, where aphid densities were highest. In line with our results, Ramsden et al. (2015) also observed higher rates of mummified aphids adjacent to floral resources. Floral resources and their spatial distribution in and around crop fields influence cereal aphid parasitoid survival and population dynamics (Vollhardt et al., 2010). As adult wasps feed on floral nectar, flower strips may attract parasitoids from the surrounding landscape (Bianchi et al., 2008).

## 4.4 | Potential costs and benefits of organic farming versus flower strips

Conventional farming benefits the farmers economically due to the higher yield, but causes costs that are often not considered. Biological control can reduce the need for pesticide application, and thus saves money for the farmers, and in addition, contributes to biodiversity conservation in agricultural landscapes (Bianchi et al., 2006; Ekroos et al., 2014). Meta-analyses across different crops show mean yield gaps between organic and conventional farming ranging from 10% to 34% (e.g. Crowder & Reganold, 2015), with an average around 19% (Poniso et al., 2015). In Germany, organic farming led to an even halving of wheat yield (Batáry et al., 2017). However, the profit was two times as high, because of organic marketing and high consumer demand. Overall our study demonstrates that the two currently most popular AES strategies, organic farming and implementation of flower strips, are both not optimal regarding natural pest control. Whether they provided services or disservices to farmers depended on the type of crop pest. Regarding control of CLB larvae, organic farming seemed most effective, whereas flower strips increased parasitism of aphids best. Our results did not support a general conclusion on whether the implementation of flower strips in the current form or organic farming is a better strategy for enhancing biocontrol, but show that both measures have merit and may be combined, which is so far rarely the case. The performance of flower strips may be improved, but more studies on flower strip design and the best location of their implementation are needed (Albrecht et al., 2020). For example, flower strips could be created in the middle of large fields, in order to increase the proportion of field edges within fields (Blaauw & Isaacs, 2014). Furthermore,

selection of a flower composition could be more tailored for predators and parasitoids (Tschumi et al., 2015, 2016). We recommend that farmers should be allowed to apply schemes more flexible in order to adapt to local features such as high pest pressures. For the effective biological pest control, we recommend decreasing field size and combination of organic farming with flower strip. More research is needed in order to design the combination of organic farming with flower strip schemes so they meet the objectives that they are targeted for effective biological pest control. Therefore, regular monitoring and evaluation of the success of AESs is crucial.

## 5 | CONCLUSIONS

In this study, we demonstrated that organic farming had less pests than conventional farming with flower strips. Our results indicated that low management intensity by organic farming (and thereby, probably the high plant diversity) is promising tool for controlling crop pests via natural enemies. However, flower strips provide complementary food resources and shelter not only for natural enemies and parasitic wasps, but also for pests. Thus, the relatively high abundance of natural enemies and parasitoids could not control higher abundance of CLBs and cereal aphids. In addition, decreasing field size in agricultural landscapes turned out to be a measure to enhance the natural enemies of both CLBs and cereal aphids. Organic farming, flower strip and small field sizes are all promising measures to reduce crop pests. In the future, these three measures may be not implemented separately, but combined to enhance natural enemy populations and facilitate biological control of the main crop pests.

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## AUTHORS' CONTRIBUTIONS

P.B. and T.T. conceived the study; P.B., S.Z., J.R., R.F., R.G., T.T. and E.T. developed the study; S.Z. and J.R. collected the data; R.G. analysed the data with substantial input from S.Z., J.R. and P.B.; E.T. wrote the paper with substantial input from all the authors.

## DATA AVAILABILITY STATEMENT

Data available via Zenodo <https://doi.org/10.5281/zenodo.4757528> (Török et al., 2021).

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## SUPPORTING INFORMATION

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