RESEARCH ARTICLE

GCB-BIOENERGY
BIOPRODUCTS FOR A SUSTAINABLE BIOECONOMY   Open Access

WILEY

The perennial biogas crops cup plant (*Silphium perfoliatum* L.) and field grass pose better autumn and overwintering habitats for arthropods than silage maize (*Zea mays* L.)

Bastian Häfner[1,2] | **Jens Dauber**[1,2] | **Siegfried Schittenhelm**[3] | **Luisa Maria Böning**[2] | **Maren Darnauer**[2] | **Lena Luise Wenkebach**[2] | **Fabian Nürnberger**[1]

[1]Thünen Institute of Biodiversity, Braunschweig, Germany

[2]Biodiversity of Agricultural Landscapes, Institute of Geoecology, Technische Universität Braunschweig, Braunschweig, Germany

[3]Institute for Crop and Soil Science, Julius Kühn-Institut (JKI), Federal Research Centre for Cultivated Plants, Braunschweig, Germany

Correspondence
Bastian Häfner, Thünen-Institut für Biodiversität, Bundesallee 65, 38116 Braunschweig, Germany.
Email: bastian.haefner@thuenen.de

Abstract

Perennial energy crops (PECs) can reduce the negative impacts of intensive silage maize cultivation on agroecosystems in Central Europe. Furthermore, the remaining vegetation of PECs after harvest may provide suitable habitat and more beneficial overwintering conditions for arthropods than maize. It was hypothesized that after harvest and in winter, arthropod abundance and biomass are higher in PECs than in silage maize. In a field experiment arranged in a factorial split-plot design of eight main plots (plot size: 240 m^2), the two PECs cup plant (*Silphium perfoliatum* L.) and field grass were compared with silage maize (*Zea mays* L.) regarding their suitability as autumn (post-harvest) and overwintering habitats for arthropods. Soil temperature, moisture as well as biomass and abundance of autumn-active and overwintering arthropods were analyzed for these three crops. Suction sampling was used during autumn and emerging arthropods were sampled with emergence trap sets in spring. In PEC plots, soils were moister and less exposed to cold temperatures than in silage maize. Compared with silage maize, total arthropod abundance and biomass were higher in PEC plots for both sampling periods. Results were similar for most examined arthropod taxa. The results of this study demonstrate that, compared with silage maize, PECs provide suitable post-harvest habitats and constitute more suitable overwintering habitats for arthropods. Differences are likely to be based on lack of disturbance and the provision of vegetation structures after harvest that function as overwintering habitats for arthropods. It can be concluded that the positive effects of PECs on ground arthropods are not limited to their growing time but continue to a certain extend after harvest and during winter.

KEYWORDS

bioenergy, ground photo-eclector, insect, *Silphium perfoliatum*, spider, *Zea mays*

1 | INTRODUCTION

Biomass as feedstock for energy is strongly debated from the aspect of biodiversity conservation on farmland (Immerzeel et al., 2014; Tudge et al., 2021). First-generation energy crops such as maize (*Zea mays* L.) are considered more harmful for farmland biodiversity compared with second generation or dedicated energy crops (Dotzauer et al., 2019; Haughton et al., 2016). Silage maize has been the dominating biogas substrate in Germany for more than 10 years (FNR & BMEL, 2022a, 2022b). Maize has a high water-use efficiency, is relatively easy to cultivate and provides high biogas yields (Schoo, Wittich, et al., 2017). However, if best management practices are not met, nutrient losses and a reduction in soil organic matter can appear (Möller et al., 2011). Additionally, maize cultivation is associated with an increased risk of erosion, especially when cultivated on sloped land (Vogel et al., 2016), which can lead to eutrophication of waterways and flooding. The dominance of maize as an energy crop in a landscape also raises concern about environmental sustainability and conservation of biodiversity (Bennett et al., 2014; Gevers et al., 2011; Sauerbrei et al., 2014) as well as the aesthetic value of the landscape (Huth et al., 2019). Considering these adverse effects, alternative crops, in particular perennial energy crops (PECs), are increasingly investigated for their bioenergy–environment–biodiversity trade-offs (Carlsson et al., 2017; Englund et al., 2020; Haughton et al., 2016). Compared with annual crops such as maize, perennials often offer more diverse microhabitats for small animals (Bourke et al., 2014) and provide greater habitat stability, which generally supports the diversity of insects (Gardiner et al., 2010), arachnids (Platen et al., 2017), earthworms (Emmerling, 2014) and birds (Werling et al., 2014).

The second most important biogas substrate in Germany, with a share of 10%, is grass (FNR & BMEL, 2022a), which comes as field grass from arable land, from permanent grassland or areas in landscape conservation programs. Mixtures of perennial grasses can be cut several times a year but provide a continuous ground coverage. After harvest, the remaining vegetation covers the soil and provides habitats and nutrient resources for soil flora and fauna (Ruf & Emmerling, 2017). The absence of tillage measures results in reduced soil disturbance and an enhanced root biomass production (Glover et al., 2010). As perennial grasses comprise several species, which can differ in yield (Nazli et al., 2020), it is difficult to make general statements about their usefulness for biomass production. However, generally higher ecosystem service provisioning and greater species richness for plants, arthropods and birds were recorded in perennial grasslands compared with maize (Blank et al., 2014; Werling et al., 2014).

Additionally, predatory arthropod diversity was reported to be higher in perennial grassland fields than in maize, and the biocontrol service provided increases with an increasing amount of perennial grassland in the landscape (Werling et al., 2014).

The novel PEC cup plant (*Silphium perfoliatum* L.) is another promising candidate for diversifying bioenergy cropping and is gaining increasing attention as an alternative to silage maize. The area cultivated with cup plants in Germany has steadily increased from about 400 ha in 2015 to around 6000 ha in 2020 (Schittenhelm et al., 2021). This development was supported by (i) the significant reduction of costs for establishing cup plant stands through sowing instead of planting (Frölich et al., 2016), (ii) gradually capping of maize inputs to biogas plants to a maximum mass-based share of 44% from 2021 onwards (EEG, 2017) and (iii) the introduction of cup plant as a new type of ecological focus area under the EU Greening Programme (European Commission, 2018). Cup plant is a perennial C3 crop indigenous to the temperate zones of North America and can be grown successfully under similar conditions in Europe (Gansberger et al., 2015). It was reported to have a dry matter yield per hectare that is about 20% lower, and a methane yield that is about 35% lower than that of silage maize (Gansberger et al., 2015). On soils with a high water supply, the cup plant has the potential to achieve higher biomass yields than usual (Ende et al., 2021; Schoo, Schroetter, et al., 2017), but methane yields are still generally lower than in silage maize (Ruf & Emmerling, 2022). Cup plant was found to improve the soil fertility and its greenhouse gas balance due to carbon sequestration and enhanced soil formation (Feldwisch, 2011; Franzaring et al., 2015). Although it strongly depends on management and management history, cup plant could thereby mitigate greenhouse gas emissions (Kemmann et al., 2021). During the first vegetation period, cup plants merely form leaf rosettes close to the ground, which makes weed control necessary (Gansberger et al., 2015). Thereafter, the crop can be harvested for at least 10 years with low pesticide application (Gansberger et al., 2015). Cup plant is harvested using a forage harvester, leaving 10 to 20 cm of stubble on the ground (Cumplido-Marin et al., 2020; Von Cossel et al., 2019). It is typically harvested once a year between late August and early September, which is at the end of flowering or the start of seed maturation. Several weeks after harvesting, cup plants usually sprout again from rootstock buds, partly covering the ground before temperatures drop. In spring of the following year, the growing process starts at temperatures of about 5°C and the optimal growing temperature is about 20°C (Gansberger et al., 2015). During the entire growing season, the soil remains undisturbed, which was shown to positively affect soil fauna (Burmeister & Walter, 2016; Emmerling, 2014;

Schorpp et al., 2021). Furthermore, cup plant has several other characteristics beneficial for biodiversity. In the northern hemisphere, it reaches a complete ground coverage at the end of May and develops flowers from the start of July to the end of September (Gansberger et al., 2015), which are used as food resources by honey bees, wild bees and syrphid flies (Mueller et al., 2020). The full life cycle and other botanical characteristics are described by Gansberger et al. (2015). Compared with maize, these features result in higher abundances and species richness of pollinators and natural enemies in cup plant during the growing season (Chmelíková & Wolfrum, 2019). Despite its benefits, cup plant is a neophyte with some invasive potential (Ende et al., 2021; Ende & Lauerer, 2020) that should be regarded with caution.

While previous studies focused on the value of biomass crops for arthropods during the growing season, little is known about the quality of alternative bioenergy crops as post-harvest and overwintering habitats for these animals (e.g. Burmeister, 2021). Throughout the cold seasons, the majority of arthropods remain inactive in the form of cold-resistant eggs, or as larvae or adults within winter refuges (Leather et al., 1995). The selection of overwintering sites can be influenced by soil temperature or moisture, food availability, presence and distribution of competitors and life-history traits (Leather et al., 1995; Lovei & Sunderland, 1996). Most carabids, for example, favor stable and warm parts of the soil (Leather et al., 1995). Their preference for moisture can vary, depending on the time of oviposition and species identity (Holland et al., 2007; Huk & Kühne, 1999; Maudsley et al., 2002). Arthropods can overwinter in a variety of habitats including non-crop and crop systems (Geiger et al., 2009; Pywell et al., 2005). Within agricultural fields, remaining vegetation and crop residues after harvesting determine the overwintering habitat quality (Frank & Reichhart, 2004; Labruyere et al., 2016). Some taxa of natural enemies can overwinter even in fields with low temporal continuity and recent soil disturbance, while other taxa require habitats of higher temporal continuity for overwintering (Boetzl et al., 2022). However, because crops differ in ground coverage and consequently in temperature and moisture at the ground level, especially after harvest, the type of the crop affects the overwintering potential for carabids and possibly other arthropods (Holland & Luff, 2000; Honěk & Jarošík, 2000). A lack of vegetation or crop residue after harvest is found in many annual silage crops and could be one reason why many arthropods preferably overwinter in field margins and other semi-natural habitats (Andersen, 1997; Sotherton, 1984).

The amount of vegetation residues for overwintering in silage maize fields depends on the agricultural practice. The use of catch crops and the timing of plowing the stubbles from harvest determine the amount of structures arthropods can use for overwintering. Little remaining vegetation increases the possibility of the soil being exposed to lower temperatures in comparison with fields with remaining vegetation. Because perennial crops, on the other hand, are not entirely removed at harvest, arthropods might benefit from using the remaining vegetation structures and the associated more favorable microclimatic conditions for overwintering.

This study aims to broaden the knowledge about the value of alternative PECs as post-harvest and overwintering habitat for arthropods. It was hypothesized that (1) winter soils in PECs are exposed to less cold temperatures than in silage maize and that (2) abundance and (3) biomass of arthropods are higher in the PECs, compared with maize plots in autumn and spring.

2 | MATERIALS AND METHODS

2.1 | Experimental site and crop management

The present study is based on a field experiment that was established at the JKI Institute for Crop and Soil Science in Braunschweig (52,296 °N: 10,438 °E) in the spring of 2012 (Schittenhelm et al., 2021). The site is elevated 76 m above sea level with a mean long-term (1962–2006) annual air temperature and precipitation of 9.1°C and 616 mm, respectively. Monthly mean temperature and precipitation (Data S1, Figure A1) as well as annual means for individual growing seasons during the experiment (Data S1, Table A.1) are shown in the supplements. The soil at the site is a loamy sand with locally compacted clay-rich bands in the 60–90 cm soil layer, typical for a Lamellic Luvisol (FAO, 2015). The plant-available water content at field capacity amounts to 185 mm in the upper 150 cm of the soil. The experiment was arranged in a factorial split-plot design with four replications (blocks) with two water regimes (with and without artificial irrigation) as main plots and three bioenergy crops (permanent cup plant, perennial lucerne-grass and continuous silage maize) as randomized sub-plots. Each of the 24 sub-plots had a size of 240 m². The main focus in the first phase of the experiment (2012–2014) was on root traits, water-use efficiency and methane yield as well as on nectar sugar production and insect visitation of the cup plant. The primary emphasis in the second experimental phase was on water infiltration, nitrate leaching and soil erosion as well as on soil aggregation and aggregate associated soil organic carbon. During this phase, heavy rain simulation was practiced on the formerly irrigated main plots aiming to provoke seepage and surface runoff. In 2015, before the beginning of the

second phase of the experiment (2016–2019), the lucerne-grass was replaced by field grass (hereafter referred to as grass for brevity) consisting of a mixture of 20% *Dactylis glomerata* L., *Festulolium* sp., *Lolium perenne* L., *Festuca pratensis* Huds. and *Festuca arundinacea* Schreb., respectively, and was cut four to six times per year. To establish the field grass, the soil was tilled for seedbed preparation.

In the present study, the maize monoculture was chosen intentionally. On biogas farms in Germany, silage maize is by far the most important feedstock (FNR & BMEL, 2022b). Crop rotations can have a high share of silage maize, but continuous maize monocultures do not represent the actual agricultural practice in all of Germany (Blickensdörfer et al., 2022). In the experiment, the stubbles were crushed with a flail mower after the maize harvest and maize stubbles were left on the field over winter. The maize plots were always plowed in spring just before sowing and the seedbed was prepared with a rotary harrow. Each year, maize was sown in the first week of May and herbicides were used for weed control only in maize. In 2019, maize was plowed on 25 April and sown on 30 April. Herbicide applications took place on 04 April 2019 and 17 April 2019. Annually, maize received 180 kg N/ha calcium ammonium nitrate fertilizer each year in mid-May, while cup plant received 170 kg N/ha in mid-March. The N fertilization of grass was carried out by split application at the beginning of the growing season and after each of the first four harvests with a total of 280 kg N/ha in 2016 and 310 kg N/ha in each of 2017 and 2018.

Autumn and spring sampling of arthropods were conducted during the second experimental phase (2016–2019). As sub-plots or parcels with different crops are the experimental units in this study, they are referred to as plots from now on.

2.2 | Microclimate

In six out of eight plots of each crop, soil temperature and moisture were assessed during each of the 4 weeks of emergence sampling that took place between 19 March and 10 May 2019 (spring). The six plots were evenly distributed over formerly irrigated and non-irrigated plots. In every sampling week, temperature was measured every 15 min with data loggers 'Tinytag Plus 2-TGP-4500' (Gemini Data Loggers) that have a range of −25°C to +85°C and an accuracy of 0.01°C. They were placed in waterproof plastic boxes for protection, positioned 15 cm below soil level and covered with soil. With the device 'HD2' and the probe 'TRIME-PICO 64' (IM-KO Micromodultechnik GmbH) relative soil moisture was measured at three points around the emergence trap set of each plot on every first and last day of emergence sampling in 2019. The device measures

volumetric water content of soils based on conductivity. It is suited for different types of soil and works efficiently at a temperature range from −15°C to +70°C. Mean values for temperature and moisture were calculated for each plot and week for statistical analysis.

Soil temperature and moisture were measured in the winter of 2016/2017 with the same devices in six plots of each crop. Soil temperature was recorded in hourly intervals with two data loggers per plot from 16 December 2016 to 08 March 2017. Minimum values per plot, crop and day were calculated and averaged per crop and day. Moisture was measured at two points per plot on 20 December 2016 and 07 March 2017, and mean values were calculated.

2.3 | Suction sampling

Suction samples were taken on 26 September 2016 in all 24 plots (eight replicates per crop) in the time between 10:30 and 16:30 using an insect suction sampler ('eco-Vac', ecoTech GmbH). The suction hose had an aperture of 14 cm in diameter. In eight plots per crop, sampling was conducted at 18 consecutive sampling points with a distance of 2 m along a central line, starting 2 m in from the edges of the plots. This resulted in a sampled area of $0.28\,m^2$ for each plot and $2.24\,m^2$ for each crop. Suction strength was $14\,m\,s^{-1}$. For 20 s, arthropods and loose soil material were sucked in and collected in a mesh bag. Afterwards, samples were stored in freezing bags at −18°C until further analysis. All suction samples of respective plots were examined for arthropods and sorted into coarse taxonomic groups (Araneae, Opiliones, Isopoda, Chilopoda, Diplopoda, Diptera, Hymenoptera, Carabidae, Staphylinidae, other Coleoptera, Hemiptera, Dermaptera and 'others'). After sorting, arthropods of each plot were poured onto a sieve of 0.5 mm mesh width and rinsed with tap water. The sieve was placed over a vessel until the time between two drops reached more than 20 s after which the sample was weighted ('Sartorius handy h51' by Sartorius AG).

2.4 | Emergence sampling

In the spring of 2019, arthropods emerging from the soil were sampled in 18 plots (six replicates per crop; three formerly irrigated and three formerly non-irrigated). Sampling was conducted four times for 1 week each (19 March 2019 to 26 March 2019; 26 March 2019 to 02 April 2019; 09 April 2019 to 16 April 2019 and 03 May 2019 to 10 May 2019). Trapping was not always conducted consecutively because the traps had to be taken from the plots during crop management. However, the traps were always

placed at the same location within a plot. For trapping of arthropods, emergence trap sets (ground photo-eclector 'Modell 250' by ecoTech GmbH) were used. Emergence trap sets were 95 cm high and consisted of a plastic cylinder and a cone-shaped tent-structure on top of it. The cylinder was dug partly into the ground, encircling an area of 0.25 m^2. One pitfall trap (plastic cups with a volume of 0.5 L and a diameter of 9.5 cm) was dug into the ground near the inner wall of the cylinder. Pitfall traps were partly filled with monoethylene glycol (MEG). Transparent eclector head boxes attached to the top of the tents were also filled with MEG and conserved arthropods that had moved toward the light at the top of the tent. One emergence trap set was placed on the longitudinal side of each plot, 1 m from the edge. In plots with maize or cup plant, emergence trap sets were placed on the rows of plants or respective stubbles. To obtain biomass per sample, arthropods from pitfall traps and eclector head boxes of each emergence trap set were pooled and, prior to sorting, weighted as described above ('Sartorius handy h51' by Sartorius AG). Afterwards, emergence trap samples were sorted into coarse taxonomic groups (Araneae, Opiliones, Isopoda, Chilopoda, Diplopoda, Diptera, Hymenoptera, Carabidae, Staphylinidae, other Coleoptera, Hemiptera, Dermaptera and 'others').

2.5 | Statistical analysis

All statistical analyses were performed with R (version 4.1.1; R Core Team, 2021). For comparison of the different bioenergy crops, (generalized) linear mixed models were fitted with the function *glmmTMB* from the 'glmmTMB' package (Magnusson et al., 2019) with respective error distributions and their canonical link functions. In the original study design main plots consisted of three sub-plots with different crops. Main plots were either irrigated or non-irrigated and were replicated four times. Because the analyses were conducted during autumn and winter when no irrigation occurred, irrigation was not expected to affect the response variables. Although the effect of irrigation was not significant in any model for the different response variables (Data S1, Table A2), previous irrigation was nonetheless accounted for by including the term 'main plot' (PLOT) as a random intercept in all of the models. This term was primarily added to include the effects of spatial variation between main plots on the field.

To test the hypotheses that the different crops affect soil temperature, soil moisture, arthropod abundance and biomass, the term CROP (cup plant, grass and maize) was used as an explanatory variable in all models: Y ~ CROP, with Y being the response variable. Soil moisture from measurements in winter and arthropod biomass from suction samples after harvest were used as response variable in models with a Gaussian error distribution. Biomass was box-cox transformed to achieve normality and to account for heteroscedasticity. Winter temperatures were only examined via descriptive comparison of minimum values per date and crop. Total abundance of arthropods and abundances of respective taxa (Araneae, Carabidae, Diptera, Staphylinidae, other Coleoptera, Hemiptera and Hymenoptera) were used as response variables in models for the analysis of data from suction samples using a negative binomial error distribution.

To test for temporal effects of sampling week (WEEK) and their interactions with CROP during emergence sampling, the models were extended as follows: Y ~ CROP * WEEK. In the analysis of data from emergence sampling in spring, soil temperature, moisture and log-transformed arthropod biomass were used as response variables in models with a Gaussian error distribution. Total arthropod abundance and abundances of respective taxa (Araneae, Carabidae, Diptera, Staphylinidae, other Coleoptera, Hemiptera and Hymenoptera) were used as response variables in models with a negative binomial error distribution. By conducting Durbin-Watson-tests two instances of temporal autocorrelation in emergence data ('other Coleoptera' and biomass) were found. In these cases, a crossed random intercept for each trap (TRAP) was added to the respective models. Non-significant interactions were removed from the model. Full models are listed in the supplements (Data S1, Table A3).

Model assumptions were confirmed visually. The statistical significance of fixed effects was determined by Wald's chi-square tests on each model (*Anova* function, 'car' package). A significance level of 0.05 was considered. The *emmeans* function from the 'emmeans' package (Lenth et al., 2018) was used to disentangle how crops differed from each other. Here, a confidence level of 0.95 and a significance level of 0.05 were used. Intervals were back transformed if applicable and the Tukey method was used for adjusting *p*-values for multiple comparisons.

All plots were created with the 'ggplot2' package (Wickham et al., 2016). Boxes of boxplots show first and third quartiles and median, whiskers extend to the highest and lowest value, respectively, but are limited to 1.5 times inter-quartile range.

3 | RESULTS

3.1 | Microclimate

From mid-December 2016 to mid-March 2017 soil temperatures ranged from −2.13 to 22.87°C (mean ± SE: 2.88 ± 0.03°C; Figure 1a). Mean winter temperatures in
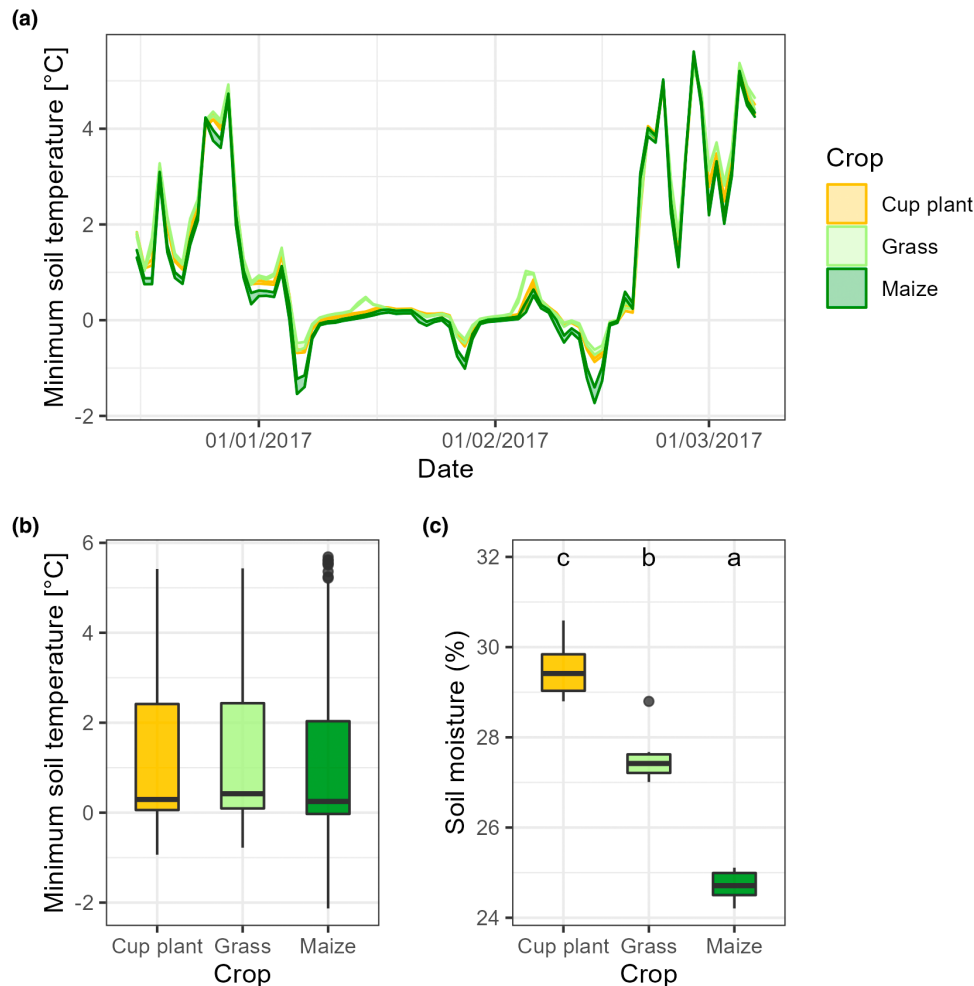
FIGURE 1 Results of microclimate measurements from 16/12/2016 to 08/03/2017 (winter). (a) Average minimum temperature and standard error (ribbons) per day and crop for cup plant, grass, and maize ($N = 6$). (b) Minimum soil temperature in cup plant, grass and maize per day. (c) Soil moisture for the crops cup plant, grass and maize ($N = 6$). Letters indicate statistical groups determined via post hoc analysis with emmeans at a significance level of 0.05.

TABLE 1 Effects of crop, sampling week and their interactions on mean soil temperature and mean soil moisture from mid-March to mid-May 2019 (spring, $N = 72$). Significance values were obtained using Wald's chi-square tests of the final model. p-Values below 0.05 were considered significant

	Soil temperature			Soil moisture		
Explanatory variable	**df**	X^2	p-**Value**	**df**	X^2	p-**Value**
Crop	2	218.45	<0.001	2	126.32	<0.001
Sampling week	3	10537.08	<0.001	3	921.63	<0.001
Crop: sampling week	6	700.33	<0.001	6	141.24	<0.001

soils of grass plots (2.94 ± 0.04°C) were similar to cup plant (2.86 ± 0.04°C) and maize plots (2.82 ± 0.04°C). Lowest daily temperatures were repeatedly measured in harvested maize plots (minimum: -2.13°C), followed by cup plant (-0.94°C) and grass plots (-0.78°C; Figure 1b). Crop affected winter soil moisture ($X^2 (2, N = 36) = 269.21$, $p < 0.001$) with cup plant plots ($29.5 \pm 0.27\%$) being more humid than grass ($27.6\% \pm 0.26\%$) and maize plots ($24.7\% \pm 0.15\%$), the latter being the driest (Figure 1c).

Soil temperatures between mid-March and mid-May 2019 ranged from 1.9°C to 17.4°C with a mean of 7.7 ± 0.01°C. Continuous temperature measurements with data loggers are shown in the supplements (Data S1, Figure A2). Relative soil moisture ranged from 11.63% to 29.48% and average soil moisture was $20.88\% \pm 0.47\%$. Soil temperature and soil moisture were affected by crop, depending on sampling week (Table 1). Other than in the first two sampling weeks, soil temperatures differed between crops

in the last two sampling weeks in mid-April and mid-May. While in mid-April, soil temperatures in grass were higher than in maize and cup plant plots in mid-May, soil temperatures in maize were higher than in grass and cup plant by one and 2°C, respectively (Figure 2a). Apart from the last sampling week, mean moisture in spring was lower in maize than in the PEC plots by at least 2.5 percent points. In comparison, moisture of grass and cup plant plots was more similar throughout the measurements (Figure 2b).

3.2 | Suction samples

In total, 3748 arthropods were collected by suction sampling after harvest. Arthropod abundance was highest in harvested plots with grass (sum: 2697), followed by cup plant (944) and maize plots (107; X^2 (2, $N = 24$) = 259.55, $p < 0.001$). Extrapolated to one square meter and averaged for each crop 422 arthropods of examined groups were found in cup plant, 1204 in grass and 48 in maize. Compared with the PECs, maize plots showed little variation in arthropod abundance (Figure 3a).

Abundances of Araneae, Diptera and Hemiptera were highest in grass plots, followed by abundance in cup plant and maize (Table 2, Figure 4a–c). In grass, mean abundances of Araneae and Diptera were about 20 times higher than in maize and 80 times higher for Hemiptera. The average abundance of Araneae in cup plant was seven times, and Diptera and Hemiptera abundance was three times higher compared with maize. Grass harbored a higher abundance of Hymenoptera (16.80 ± 2.43) than plots of the other crops (cup plant: 2.12 ± 0.64; maize: 1.00 ± 0.42; Figure 4d). The abundance of Carabids was slightly higher in cup plant than in maize and grass plots, but the effect of crop was not significant (Table 2, Figure 4e). While Staphylinidae abundances in grass (8.38 ± 1.39) and cup plant (4.88 ± 1.72) were higher than in maize (0.25 ± 0.16), 'other Coleoptera' were more abundant in cup plant (62.8 ± 13.6) than in grass (2.38 ± 0.625) and maize (1.50 ± 0.378; Figure 4f,g). This difference was not caused by a single family or species of Coleoptera. Abundances of Chilopoda, Dermaptera, Opiliones, Isopoda, and 'others' were very low and were, therefore, not analyzed. Diplopoda were not found at all.

Crop had a significant effect on total biomass (X^2 (2, $N = 24$) = 115.40, $p < 0.001$), which was on average 14 times higher in cup plant (0.14 ± 0.03 g) and grass (0.14 ± 0.01 g), than in maize (0.01 ± 0.01 g; Figure 3b).
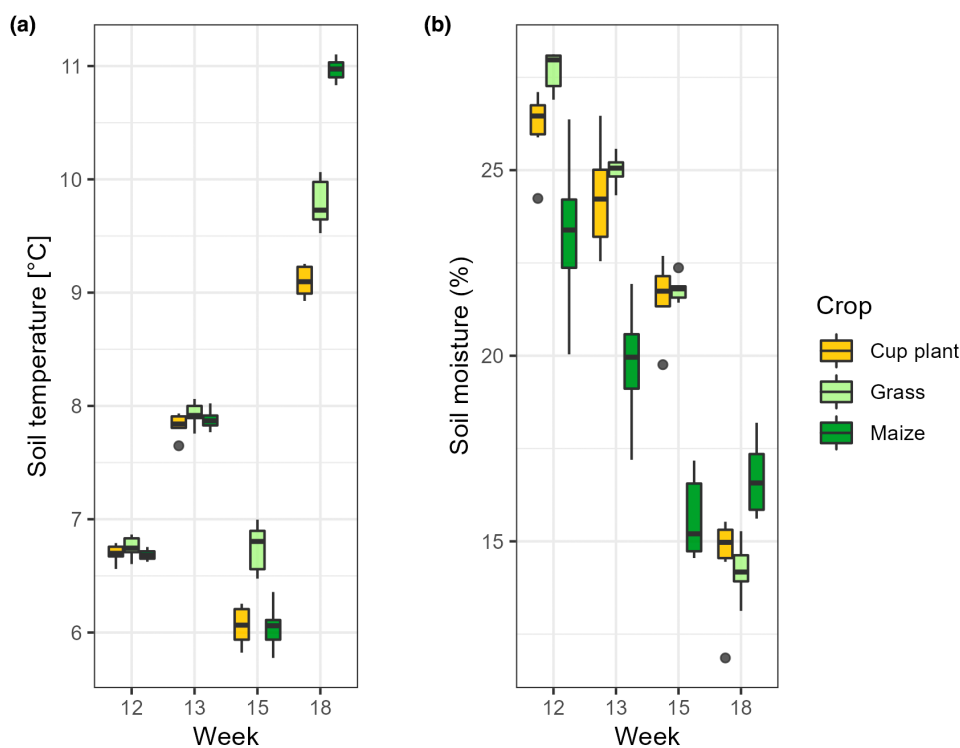

FIGURE 2 Results of microclimate measurements in sampling weeks from 26/03/2019 to 10/05/2019 (calendar week 12 to 18; spring). (a) Mean soil temperature and (b) mean soil moisture per sampling week and crop (cup plant, grass and maize), during emergence sampling in spring 2019 ($N = 6$).
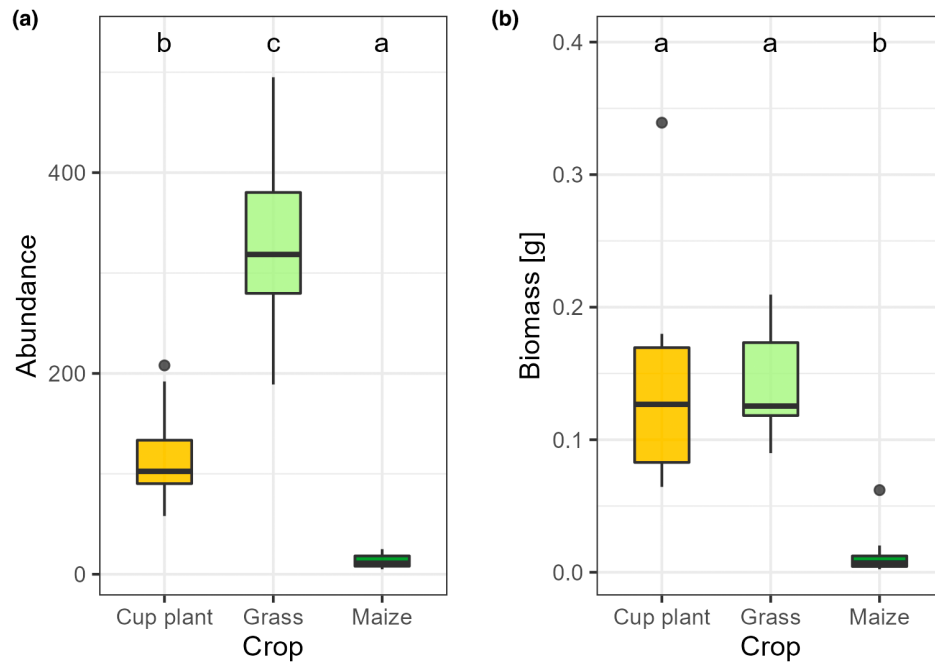
FIGURE 3 (a) Arthropod abundance per $0.28\,m^2$ and (b) arthropod biomass per $0.28\,m^2$ for the crops cup plant, grass and maize from post-harvest suction sampling on the experimental field on 26/09/2016 ($N = 8$). Letters indicate statistical groups determined via post hoc analysis with emmeans at a significance level of 0.05.

TABLE 2 Abundances for examined taxonomic arthropod groups from suction sampling for the crops cup plant, grass, and maize (sum, $N = 24$) and the effect of crop on abundances of these groups. Significance values were obtained using Wald's chi-square tests of the final model. p-Values below 0.05 were considered significant

	Abundance			Crop		
Taxon	**Cup plant**	**Grass**	**Maize**	**df**	**X^2**	**p-Value**
Araneae	210	543	27	2	110.32	<0.001
Diptera	57	460	17	2	139.63	<0.001
Hemiptera	52	1416	16	2	247.32	<0.001
Hymenoptera	17	134	8	2	61.76	<0.001
Carabidae	27	10	13	2	5.07	0.079
Staphylinidae	39	67	2	2	18.27	<0.001
other Coleoptera	502	19	12	2	136.47	<0.001

3.3 | Emergence sampling

Altogether, 2477 arthropods were caught in emergence trap sets during spring. Crop had a significant effect on arthropod abundance depending on the sampling week (crop: X^2 (2, $N = 72$) = 104.97, $p < 0.001$; sampling week: X^2 (3, $N = 72$) = 22.61, $p < 0.001$; crop: sampling week: (X^2 (6, $N = 72$) = 14.12, $p = 0.028$)). In sum and on average for each sampling week, the highest emergence of arthropods was found in grass (sum: 1272), followed by cup plant (916) and maize (289). In the last two sampling weeks, differences between crops were highest. In the last sampling week, average arthropod abundance in grass was 1.25 times higher than in cup plant and almost four times higher than in maize (Figure 5a). Summed over sampling weeks and extrapolated, a mean of 153 arthropods per m^2

emerged in cup plant, 212 arthropods per m^2 in grass and 49 arthropods per m^2 in maize.

Abundances of Araneae and Coleoptera (excluding Carabidae and Staphylinidae) were higher in plots with grass and cup plant, compared with maize (Table 3). While the mean abundance of Araneae in maize was below one (0.67 ± 0.2), it was about 10 times higher in cup plant (7.96 ± 2.99) and grass (6.58 ± 1.04; Figure 6a). Grass hosted the highest Diptera abundance (18.2 ± 3.38), which was on average about 10 times higher compared with maize (1.79 ± 0.37) and twice as high as in cup plant (9.75 ± 3.01). Effects of crop on the emergence of Diptera, Hemiptera, Hymenoptera and Staphylinidae depended on the sampling week (Table 3). Especially in the last sampling week, abundances for Diptera, Hemiptera and Hymenoptera differed strongly between the crops with
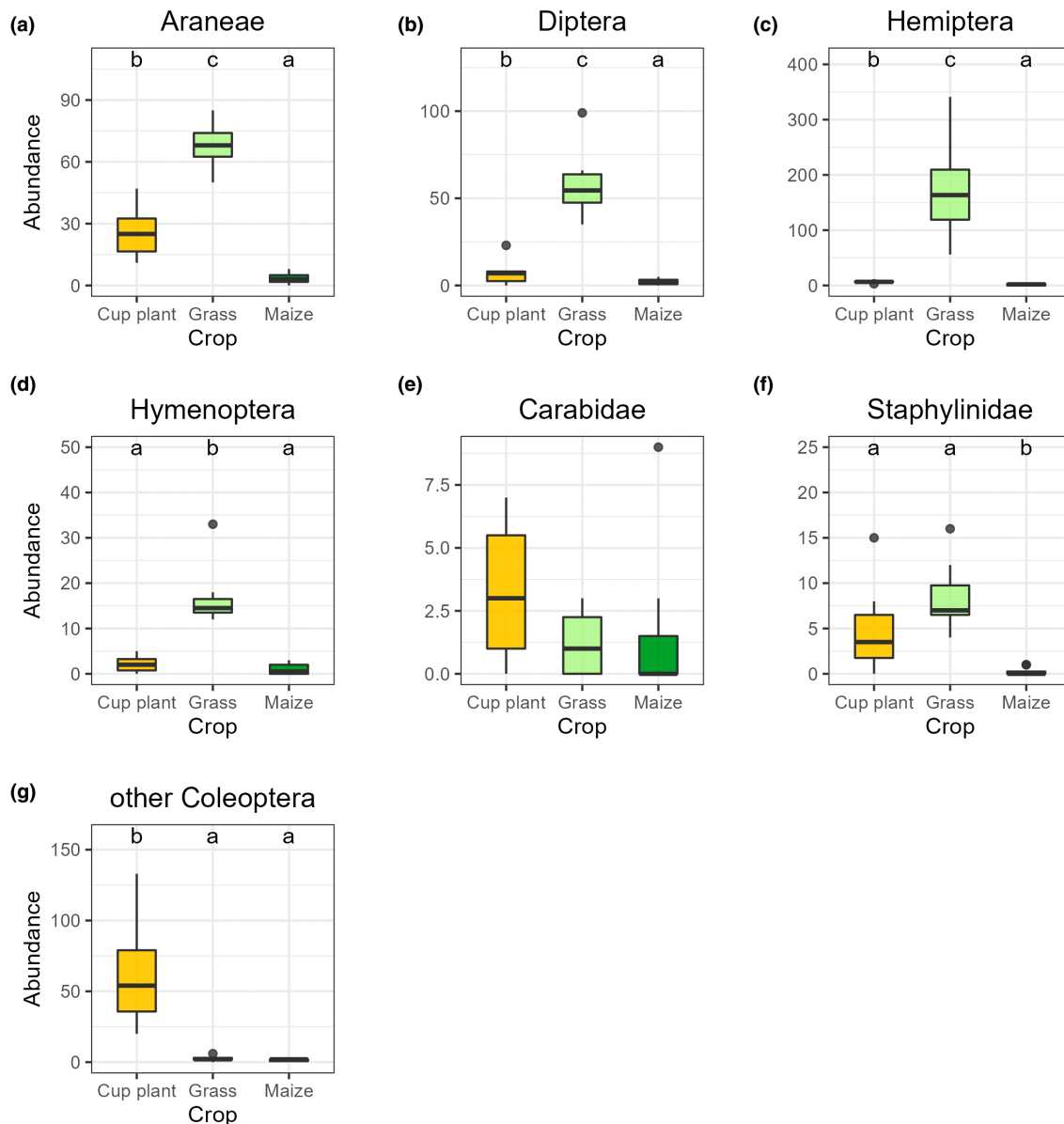
FIGURE 4 (a–g) Abundances of examined arthropod groups per 0.28 m² for the crops cup plant, grass and maize from post-harvest suction sampling of the field plots on 26/09/2016 (N = 8). Other groups were not analyzed due to low abundances. Letters indicate statistical groups determined via post hoc analysis with emmeans at a significance level of 0.05.

more individuals emerging in PEC plots than in maize (Figure 6d–f). Compared with maize, the abundance of Staphylinidae was higher in PEC in the first sampling week by a factor of nine and in the last sampling week it was on average about 2.5 times higher in grass and maize than in cup plant (Figure 6g). Of all examined taxa this was the only occurrence of higher abundances in maize than in the PECs. Mean Carabidae abundances in maize (0.88±0.26) were slightly lower than in grass (1.58±0.25) and cup plant (1.25±0.26) but the difference was not significant (Table 3). Opiliones, Isopoda, Chilopoda, Diplopoda and Dermaptera were not analyzed, due to low abundances.

Contrary to sampling week (X^2 (3, N = 72) = 3.39, p = 0.335), crop affected biomass of spring-emerging arthropods (X^2 (2, N = 72) = 17.78, p = 0.001). Arthropod biomass in grass (0.40±0.04 g) did not differ from that in cup plant (0.53±0.13 g), but the arthropod biomass in both PECs was on average about 2.5–3.5 times higher than in maize plots (0.15±0.01 g; Figure 5b).

4 | DISCUSSION

In this study, the aim was to compare the suitability of maize and two PECs, cup plant and field grass, as autumn
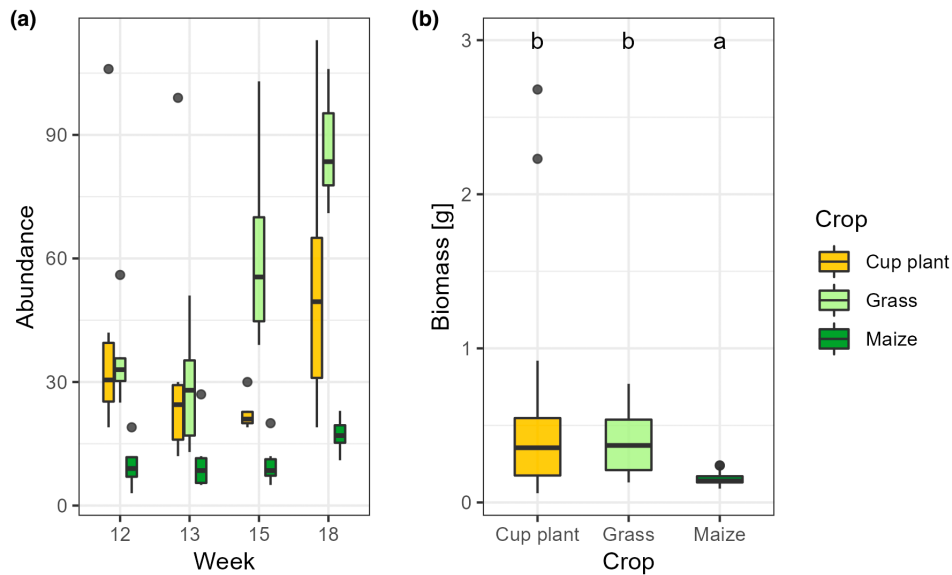
FIGURE 5 (a) Abundance of spring-emerging arthropods in cup plant, grass and maize for different sampling weeks from 26/03/2019 to 10/05/2019 (calendar week 12 to 18) and (b) biomass of spring-emerging arthropods in cup plant, grass and maize ($N = 6$). Letters indicate statistical groups determined via post hoc analysis with emmeans at a significance level of 0.05.

TABLE 3 Abundances for examined taxonomic arthropod groups from emergence trap sets for the crops cup plant, grass, and maize (sum, $N = 6$) and the effect of crop, sampling week and their interactions on respective abundances. Where there are no values for the interaction, the term was not significant and therefore removed from the model. Significance values were obtained using Wald's chi-square tests of the final model ($N = 72$). p-Values below 0.05 were considered significant

Taxon	Crop			Sampling week			Crop: sampling week		
	df	X^2	p-Value	df	X^2	p-Value	df	X^2	p-Value
Araneae	2	23.20	<0.001	3	5.53	0.137			
Diptera	2	71.01	<0.001	3	26.42	<0.001	6	18.51	0.005
Hemiptera	2	10.09	0.001	3	25.09	<0.001	6	18.10	0.006
Hymenoptera	2	58.02	<0.001	3	14.67	0.002	6	16.80	0.010
Carabidae	2	4.67	0.097	3	1.20	0.753			
Staphylinidae	2	2.24	0.33	3	32.79	<0.001	6	29.04	<0.001
other Coleoptera	2	20.65	<0.001	3	27.32	<0.001			

and overwintering habitat for arthropods. It was expected that PECs provide more habitat structure as well as a higher aboveground vegetation cover after harvest and over winter and hence hypothesized that during winter, soils under PECs are exposed to less cold temperatures than in maize. Therefore, due to other factors from remaining vegetation, that is, shelter and availability of alternative prey arthropod abundance and biomass in PECs were expected to be higher than in maize plots after harvest and in spring. As expected, lower minimum soil temperatures in maize were observed than in PECs during winter. Both, after harvest and in spring, arthropod biomass and abundance was higher in PECs than in maize, confirming the hypotheses. Although the effects of crop differed between arthropod groups, and for some taxa depended on sampling week, the overall pattern was mostly similar across taxa.

4.1 | Microclimate

Compared with PECs, maize plots were exposed to lower minimum soil temperatures in winter. Furthermore, soils under PECs were moister than under maize. Generally, microclimate is influenced by ground coverage and vegetation density (Song et al., 2013) as well as by soil management, such as plowing (Sharratt et al., 1998). In this experiment, it was observed that ground coverage during winter differed strongly between continuous silage maize on the one hand and perennial cup plant and grass on the other. While resprouting of cup plant after harvest leads to some ground cover in winter, grass that is merely cut before the winter, leaves no open soil at all. Ground coverage during winter from remaining vegetation in perennial crops can reduce temperature fluctuations (Ni
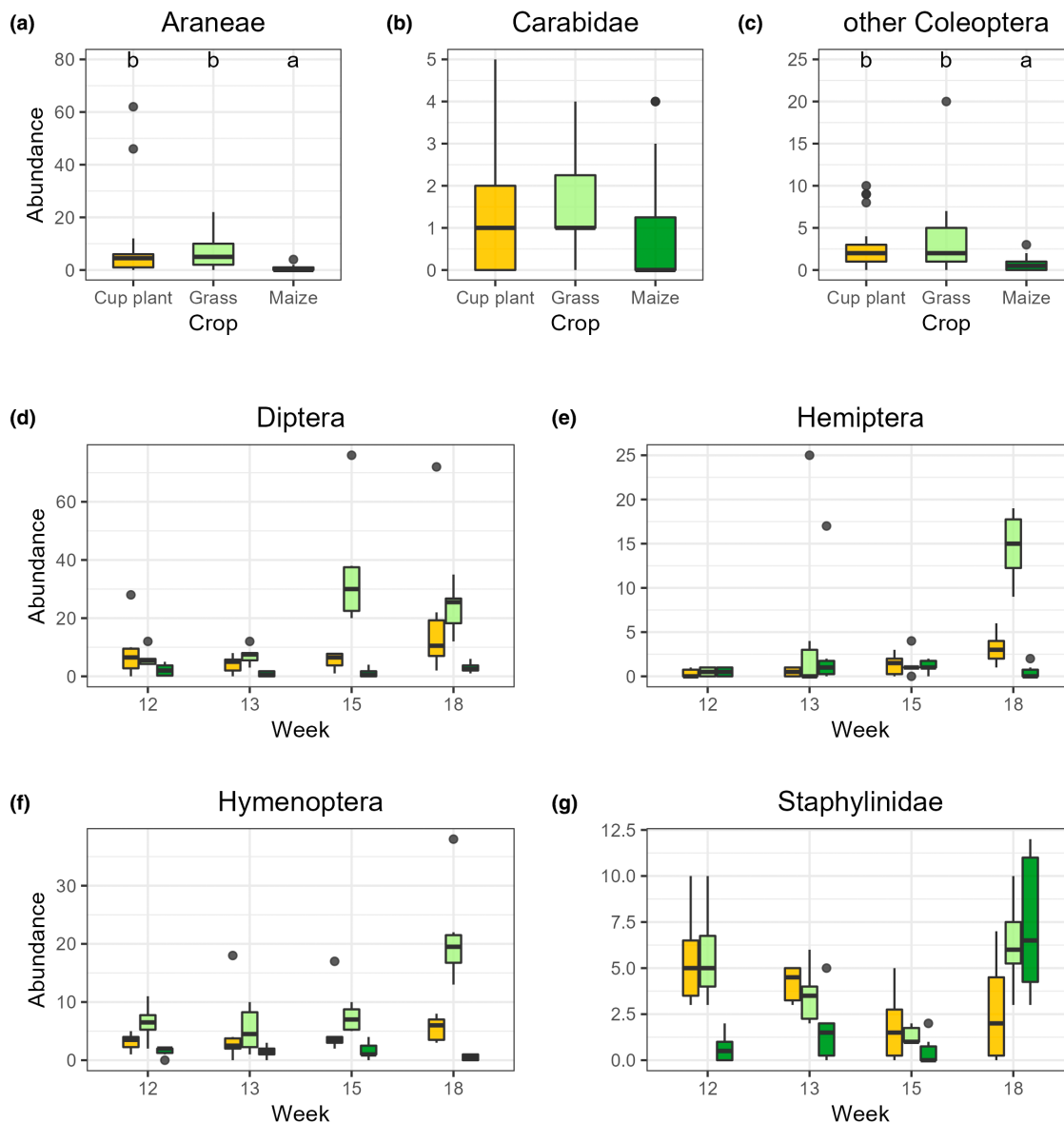
FIGURE 6 (a–c) Abundance of spring-emerging arthropod taxa in cup plant, grass and maize (*N* = 6). Letters indicate statistical groups determined via post hoc analysis with emmeans at a significance level of 0.05. (d–g) Abundance of arthropods emerging in spring for different taxa, crops (cup plant in yellow, grass in light green and maize in dark green) and sampling weeks from 26/03/2019 to 10/05/2019 (calendar week 12 to 18; *N* = 6).

et al., 2019; Thomas et al., 1991) as well as winter mortality rates of arthropods (Bürki & Hausammann, 1993; Luff, 1966). Recent studies suggest that large variability in winter temperature causes stress (Williams et al., 2015) and is therefore likely to contribute to winter mortality in arthropods. The temperature buffering capacity of grasses, for example, differs between grass species and growth-forms and is much higher in tussock-forming grasses than in, for example, mat-forming grass species (Bossenbroek et al., 1977; Luff, 1965; Thomas et al., 1991). Besides reducing temperature variability, an increase in temperature due to ground cover from PECs can also decrease winter mortality in arthropods. Kiritani (2006), for example, who reviewed the impacts of global warming on arthropods, found that winter mortality of adults of two Japanese hemipteran species is predicted to be reduced by 15% by each rise of 1°C.

In none of the plots, soil temperature fell below −2.3°C and differences between crops were small. However, on days with negative temperature extremes, average minimum temperatures between crops differed by almost 1°C. In more harsh winters, this difference might be more pronounced and, depending on taxon, might have an effect on hibernating arthropods. By contrast, many common carabid species are relatively tolerant against cold, due to their distribution across Scandinavia and eastern Europe

(reviewed by Kromp, 1999). Extreme positive temperatures during winter, on the other hand, were shown to decrease the survival of carabid larvae at temperatures above 10°C (Luff, 1994).

During emergence sampling in spring, differences in soil temperature and soil moisture between crops depended on the sampling week. Soil moisture generally decreased under all crops over time and soils under maize were dryer than under PECs, apart from the last sampling week. In addition, after overall soil temperatures increased considerably between the second last and last sampling week, temperatures in maize plots were consistently higher than those in PEC plots. Most likely, this was due to plowing of the maize plots between the last two experimental measurements. Tillage, such as plowing, can strongly affect soil microclimate due to its effects on bulk density and other soil properties (Badalíková, 2010; Sharratt et al., 1998). Tillage is also very likely to cause differences between microclimate of soils under maize and soils under PEC, which are not tilled. Additionally, at high temperatures in spring, soils of PECs might be less moist due to an increasing water demand of grass and cup plant as well as losses from plant surface, while maize plants are not fully developed yet.

Overall, differences in soil microclimate between vegetated habitats, like PECs, and agricultural fields with annual crops can be substantial, which can have implications for habitat choice and abundance of arthropods (Bürki, 1993). In this study, the aim was to examine the habitat suitability of energy crops for arthropods with suction samples post-harvest and as overwintering habitats by assessing overwintered arthropods with emergence trap sets in spring. It can be assumed that post-harvest and overwintering habitat suitability of arthropods was affected by the influence of crop on the microclimatic conditions of respective plots.

4.2 | Suction samples

Harvesting can force arthropods to emigrate out of the crop habitat into adjacent habitats either directly because of the disturbance or indirectly via declines in resource availability or in search for shelter (French et al., 2001; Rand et al., 2006; Thorbek & Bilde, 2004). At the time of sampling, either most individuals migrated to field boundaries and other neighbouring habitats or there were less arthropods in maize initially. In both cases, the results suggest that PECs constitute a better-suited post-harvest habitat than maize.

Bürki (1993) reported that suction sampling is more efficient for taxa living on vegetation, in contrast to those living closely to the soil surface. We, too, found high abundances of small-bodied arthropod taxa in PECs, for example, Hemiptera, which usually live on plants. As a consequence of higher prey densities, predatory arthropods should also find more food resources in vegetated PEC plots after harvest.

At some point in the year, low temperatures and a shorter photoperiod initiate overwintering for most arthropods (Leather et al., 1995). The majority of arthropods seek out warm and stable overwintering habitats (Leather et al., 1995). For carabids, for example, the selection of overwintering habitats is influenced by temperature and moisture extremes (Lövei & Sunderland, 1996). In the considered PECs, arthropods would not necessarily need to migrate to overwintering habitats, because, as it was shown, cup plant and grass already develop more suitable overwintering habitat conditions than maize. Arthropods from neighbouring habitats might even be attracted to PECs for overwintering. It can not be guaranteed, however, that arthropods captured by suction sampling in autumn would necessarily have overwintered in the plots where they were caught. Therefore, the study was complemented by emergence sampling in spring.

4.3 | Emergence sampling

With the help of emergence trap sets, emerging arthropods could be assessed that have successfully overwintered in the field plots. In sum, the total abundance and biomass of emerged arthropods were higher in the PECs than in maize. Most examined taxa showed similar results. Both are consistent with observations in autumn. This demonstrates that PECs are not only important post-harvest habitats but also provide better-suited overwintering habitats than maize. Emergence is generally affected by temporal, phenological patterns (Holland et al., 2009; Leingärtner et al., 2014). Total arthropod abundance and abundances of Diptera, Hemiptera, Hymenoptera and Staphylinidae differed between crops, depending on the sampling week. This means that the conditions created by the different crops have modulated the respective usual phenological patterns of these arthropods. For all these groups, except Staphylinidae, the difference between crops was largest in the last two sampling weeks. During this time abundances in PECs were higher than in maize and abundance of grass often exceeded those in cup plant. This temporal effect is similar to the observed shift in soil temperature between the last two sampling weeks, mid-April and May. However, while one may assume an increase of emergence with a rise in temperature, the plowing of maize between the last two sampling periods might have diminished the remainder of animals

still hibernating in the soil. Contrarily, the abundance of Staphylinidae in May (last sampling week) was highest and did not differ between maize and grass plots. If arguing that tillage can explain the interactions between crop and sampling week on emergence, it can be assumed that responses are taxon-specific. This is supported by Boetzl et al. (2022) who found that activity-density of Carabidae and Stapyhlinidae was higher in flowering fields with recent soil disturbance, compared with a less recent one, while this was not the case for other taxa, for example, Araneae and Hymenoptera.

Besides tillage, the different vegetation cover and, thus, microclimate of habitats will cause physiological development stages of respective arthropods to vary, affecting the timing of emergence (Leingärtner et al., 2014). While at one point microclimatic conditions can lead to accelerated development and earlier emergence in one habitat, arthropods might emerge later in others. Therefore, it was expected that temperatures and moisture can play a crucial role in post-harvest and overwintering habitat suitability, measured by abundance and biomass. Indeed, the interacting effect of crop and sampling week found for arthropod abundance in spring points in this direction. Yet, this study was not designed to consider physiological explanations for each examined taxon. Besides, apart from crop-specific microclimate, there are other factors, for example, migration and mortality, which were not assessed in this study, that influence the abundance of arthropods. Nevertheless, provisioning of suitable overwintering habitats in agricultural fields through PECs can have considerable effects on biodiversity and crop production, for example, via biocontrol.

Polyphagous predators, such as Araneae, Carabidae and Staphylinidae are key predators of many crop pests (Holland et al., 2008). Increased abundances likely lead to increased biological control of weeds (Gallandt et al., 2005; Westerman et al., 2005) and insect pests during the growing season (Michalko et al., 2019; Speight & Lawton, 1976). At that time, a highly structured and dense vegetation is one main driver for diverse and species-rich natural enemy communities. A field study in Germany (Platen et al., 2017) comparing carabid beetle and arachnid assemblages in cup plant, Szarvasi grass and wildflower mixtures to silage maize found that vegetation structure explained more than half of the variance in species diversity. In grass and wildflower mixtures, vegetation structure was more complex and biodiversity indices were mostly higher than in cup plant and maize. Similarly, higher vegetation cover positively influences assemblages of overwintering staphylinid and carabid beetles (Frank & Reichhart, 2004), and the number of emerging spiders is negatively affected by the percentage of bare soil (Ganser et al., 2019). In temperate agroecosystems, overwintering

habitat is likely to be a key limiting structural resource for natural enemies because highly intensified crop fields provide little suitable substrate outside of the growing season (Iuliano & Gratton, 2020). Because of its high temperature requirement, a significant vegetation cover in maize fields only exists from late June and lasts until the end of September to mid-October. In contrast to maize, PECs have a significantly longer growing period. In the case of grass, the field is covered with a more or less extended vegetation during the whole year. But cup plant covers the soil for about 3 months longer than maize. This is due to its very rapid early growth, which results in closed stands already by the end of April. After harvest in autumn, the cup plant resprouts from rootstock buds. This resprouting forms a living groundcover and, due to its death after the first heavier frost, a protective dead mulch on the soil surface.

Still, little is known about the suitability of PECs as overwintering habitats for arthropods and for generalist arthropod predators in particular. Burmeister (2021) observed a temporary peak of activity-density of ground beetles in cup plant fields in February and March, which suggests a higher emergence, compared with other examined crops. They concluded that ground beetle larvae seem to benefit from better hibernating conditions in cup plant fields, compared with winter wheat and tall wheatgrass. While in this study carabid abundances were not affected by the culture, abundances of spiders and staphylinid beetles were generally higher in PECs, compared with harvested maize plots during autumn and spring. In both sampling phases, spider abundances were about 10 times higher in PECs than in maize plots. The number of spiders found in emergence trap sets in PEC plots is comparable with that of annual winter wheat and oilseed rape fields, but can be about three times higher in semi-natural habitats (SNHs; Mestre et al., 2018).

As undisturbed, permanent vegetated habitats, SNHs provide important habitats for arthropods outside the growing season (Frank & Reichhart, 2004; Labruyere et al., 2016; Pfiffner & Luka, 2000). However, differences between SNHs and crops depend on the specific reference habitat and taxon. Compared with fields of winter oilseed rape, for example, Sutter et al. (2018) found fewer individuals of overwintering predatory ground beetles in flower strips, which can be regarded as a herbaceous SNH. Winter oilseed rape is sown relatively early and there is little soil management until the emergence of predatory ground beetles in the spring or early summer of the following year. They suggest that, due to this reduced disturbance on winter oilseed rape fields, compared with other annual crops, fewer beetles vacate to overwinter in neighbouring habitats. Therefore, the animals would not need to recolonize fields after overwintering. Since an early effective

colonization of crops by natural enemies may result in effective pest suppression, the capability of PECs to provide suitable overwintering habitats could promote biocontrol (Bianchi & Van Der Werf, 2003; Chiverton, 1986; Coombes & Southerton, 1986; Symondson et al., 2002). Although there were no differences between crops for Carabidae specifically, the same argument could be made for staphylinid beetles and spiders in PECs, as the crops experience as little or less disturbance than winter oilseed rape fields.

Yang et al. (2020) found that during winter, flower strips function as bridge habitats for natural enemies in wheat-maize rotations. However, like flower strips and other SNHs, PECs might not only provide bridge habitats for natural enemies but also for agricultural pests (Alford, 2003; Leather et al., 1995). Their success of overwintering often increases in mild winters (Leather et al., 1995). Therefore, it is likely that crop pests, like their antagonists, benefit from the temperature-buffering potential of vegetation in PECs. Addressing this concern for pest spillover is key to promoting the uptake and implementation of agri-environmental measures (Home et al., 2014). After harvest and/or in spring, abundances of Diptera and Hemiptera were higher in PECs than in maize. Both taxa include a high number of relevant pest species. However, in the present study, it was not possible to provide more detailed information on the occurrence of pest taxa. Further identification of captured arthropods could reveal if and which agronomically relevant pests use perennials as overwintering habitats. The authors support the conclusion drawn by Boetzl et al. (2022) that 'a better understanding of the overwintering ecology of different arthropod groups is required to counteract current biodiversity decline in agricultural landscapes'.

Depending on how dedicated (i.e. only usable as energy feedstock in ways that do not displace food production) energy crops such as PECs are integrated into food crop production, cultivation of energy crops can have varying outcomes for biodiversity (Dauber & Miyake, 2016). The results add to the growing evidence that biodiversity can be facilitated by substituting annual with perennial bioenergy crops. Several previous publications already showed that novel, dedicated energy crops offer benefits for biodiversity during the growing season. Cup plant can sustain more parasitoids (Chmelíková & Wolfrum, 2019) and pollinators (Mueller & Dauber, 2016), than maize. Platen et al. (2017) found that, compared with maize, species richness of natural enemies was higher in Szarvasi grass, wildflower mixtures and cup plant. Additionally, perennial grasses like switchgrass and prairie plantings harbor significantly greater plant, arthropod and bird diversity than maize, as well as having lower pest pressures (Werling et al., 2014). From a landscape perspective, planting PECs can increase landscape heterogeneity, and by increasing the number landscape elements, improve the overwintering conditions of natural enemies (Diekötter et al., 2010).

The authors are aware, however, that the findings of this one-year and one-location study cannot be generalized or uncritically transferred to other regions or to cropping systems with other energy crops. Furthermore, it is to be emphasized that substitution of maize with PECs can only mitigate some negative effects of bioenergy production. Compared with semi-natural habitats, PECs perform less advantageous, as, for example, switchgrass and miscanthus (*Miscanthus × giganteus*), only host up to half as many spider species as semi-natural grassland (Tymchuk et al., 2021).

5 | CONCLUSIONS

Ecological benefits from PECs that have been described in literature for the vegetation period also hold true for non-cultivating seasons. Cup plant and field grass provide a higher cover of vegetation and plant residues after harvest than silage maize and appear to provide more beneficial overwintering conditions for arthropods in terms of soil temperatures and soil moisture. So far, knowledge on the potential benefits of these PECs and PECs in general on arthropod overwintering was scarce. This field experiment showed that there are higher abundances of arthropods, including that of natural enemies, and higher arthropod biomass in cup plant and field grass than in silage maize. Hence, PECs may promote the temporal and spatial diversification of agricultural landscapes in regions dominated by silage maize production by enhancing the often limited amount of undisturbed soil in which arthropods can hibernate and recolonize the landscape in spring. Arthropods overwintering in PECs included both potential natural biocontrol agents and potential pest species. Furthermore, more in-depth studies on the species pool emerging from PECs in different agricultural landscapes and soils would be required to infer whether PECs would support ecosystem service providers such as generalist predatory arthropods more than disservices connected to pest species of crops.

Provided that the cup plants' potential invasiveness will be handled with caution, the cultivation cup plant and other PECs can promote landscape diversity and, thereby, not only facilitate arthropods, but farmland biodiversity as a whole. Together with their positive abiotic aspects, such as erosion mitigation, the use of PECs can contribute to more sustainable agriculture and bioenergy production.

AUTHOR CONTRIBUTIONS
Bastian Häfner: Formal analysis, Writing—Original draft, Visualization. Siegfried Schittenhelm: Design,

CONFLICT OF INTEREST
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY STATEMENT
The data that support the findings of this study are openly available in Dryad at https://doi.org/10.5061/dryad.31zcr jdq1.

ORCID
Bastian Häfner https://orcid.org/0000-0002-7214-0972
Jens Dauber https://orcid.org/0000-0002-3420-0380
Siegfried Schittenhelm https://orcid.org/0000-0002-2743-0989
Fabian Nürnberger https://orcid.org/0000-0002-7360-3617

REFERENCES
Alford, D. V. (2003). *Biocontrol of oilseed rape pests*. Blackwell Science Ltd. https://doi.org/10.1603/0022-0493-97.5.1772

Andersen, A. (1997). Densities of overwintering carabids and staphylinids (Col., Carabidae and Staphylinidae) in cereal and grass fields and their boundaries. *Journal of Applied Entomology*, *121*(1–5), 77–80. https://doi.org/10.1111/j.1439-0418.1997.tb01374.x

Badalíková, B. (2010). Influence of soil tillage on soil compaction. In A. P. Dedousis & T. Bartzanas (Eds.), *Soil engineering* (pp. 19–30). Springer. https://doi.org/10.1007/978-3-642-03681-1_2

Bennett, A. B., Meehan, T. D., Gratton, C., & Isaacs, R. (2014). Modeling pollinator community response to contrasting bioenergy scenarios. *PLoS One*, *9*(11), e110676. https://doi.org/10.1371/journal.pone.0110676

Bianchi, F. J. J. A., & Van Der Werf, W. (2003). The effect of the area and configuration of hibernation sites on the control of aphids by *Coccinella septempunctata* (Coleoptera: Coccinellidae) in agricultural landscapes: A simulation study. *Environmental Entomology*, *32*(6), 1290–1304. https://doi.org/10.1603/0046-225X-32.6.1290

Blank, P. J., Sample, D. W., Williams, C. L., & Turner, M. G. (2014). Bird communities and biomass yields in potential bioenergy grasslands. *PLoS One*, *9*(10), 1–10. https://doi.org/10.1371/journal.pone.0109989

Blickensdörfer, L., Schwieder, M., Pflugmacher, D., Nendel, C., Erasmi, S., & Hostert, P. (2022). Mapping of crop types and crop sequences with combined time series of Sentinel-1, Sentinel-2 and Landsat 8 data for Germany. *Remote Sensing of Environment*, *269*(January), 112831. https://doi.org/10.1016/j.rse.2021.112831

Boetzl, F. A., Krimmer, E., Holzschuh, A., Krauss, J., & Steffan-Dewenter, I. (2022). Arthropod overwintering in Agri-environmental scheme flowering fields differs among pollinators and natural enemies. *Agriculture, Ecosystems and Environment*, *330*(January), 107890. https://doi.org/10.1016/j.agee.2022.107890

Bossenbroek, P., Kessler, A., Liem, A. S. N., & Vlijm, L. (1977). The significance of plant growth-forms as "shelter" for terrestrial animals. *Journal of Zoology*, *182*(1), 1–6. https://doi.org/10.1111/j.1469-7998.1977.tb04135.x

Bourke, D., Stanley, D., O'Rourke, E., Thompson, R., Carnus, T., Dauber, J., Emmerson, M., Whelan, P., Hecq, F., Flynn, E., Dolan, L., & Stout, J. (2014). Response of farmland biodiversity to the introduction of bioenergy crops: Effects of local factors and surrounding landscape context. *GCB Bioenergy*, *6*(3), 275–289. https://doi.org/10.1111/gcbb.12089

Bürki, H. M. (1993). Überwinterung von Arthropoden im Boden und an Ackerkräutern künstlich angelegter Ackerkrautstreifen. *Verhandlungen der Gesellschaft fur Okologie*, *22*(1993), 35–38.

Bürki, H.-M., & Hausammann, A. (1993). *Überwinterung von Arthropoden im Boden und an Ackerkräutern künstlich angelegter Ackerkrautstreifen*. Haupt.

Burmeister, J. (2021). Promotion of ground beetles by integrating perennial energy crops into existing agricultural landscapes. *Biomass and Bioenergy*, *146*, 105973. https://doi.org/10.1016/j.biombioe.2021.105973

Burmeister, J., & Walter, R. (2016). Untersuchungen zur ökologischen Wirkung der Durchwachsenen Silphie aus Bayern. *Journal Fur Kulturpflanzen*, *68*(12), 407–411. https://doi.org/10.1399/JFK.2016.12.11

Carlsson, G., Mårtensson, L. M., Prade, T., Svensson, S. E., & Jensen, E. S. (2017). Perennial species mixtures for multifunctional production of biomass on marginal land. *GCB Bioenergy*, *9*(1), 191–201. https://doi.org/10.1111/gcbb.12373

Chiverton, P. A. (1986). Predator density manipulation and its effects on populations of Rhopalosiphumpadi (Horn: Aphididae) in spring barley. *Annals of Applied Biology*, *109*(1), 49–60. https://doi.org/10.1111/j.1744-7348.1986.tb03183.x

Chmelíková, L., & Wolfrum, S. (2019). Mitigating the biodiversity footprint of energy crops—A case study on arthropod diversity.

Biomass and Bioenergy, *125*(January), 180–187. https://doi.org/10.1016/j.biombioe.2019.04.023

Coombes, D. S., & Southerton, N. W. (1986). The dispersal and distribution of polyphagous predatory Coleoptera in cereals. *Annals of Applied Biology*, *108*(3), 461–474. https://doi.org/10.1111/j.1744-7348.1986.tb01985.x

Cumplido-Marin, L., Burgess, P. M., Morhart, C., Paris, P., Martens, R., & Nahm, M. (2020). Two novel energy crops: *Sida hermaphrodita* (L.) Rusby and *Silphium perfoliatum* (L.)—State of knowledge. *Agronomy*, *10*(7), 928. https://doi.org/10.3390/agronomy10070928

Dauber, J., & Miyake, S. (2016). To integrate or to segregate food crop and energy crop cultivation at the landscape scale? Perspectives on biodiversity conservation in agriculture in Europe. *Energy, Sustainability and Society*, *6*(1). https://doi.org/10.1186/s13705-016-0089-5

Diekötter, T., Wamser, S., Wolters, V., & Birkhofer, K. (2010). Landscape and management effects on structure and function of soil arthropod communities in winter wheat. *Agriculture, Ecosystems and Environment*, *137*(1–2), 108–112. https://doi.org/10.1016/j.agee.2010.01.008

Dotzauer, M., Daniel-Gromke, J., & Thrän, D. (2019). Drivers of risks for biodiversity and ecosystem services: Biogas plants development in Germany. In M. Schröter, A. Bonn, S. Klotz, R. Seppelt, & C. Baessler (Eds.), *Atlas of ecosystem services* (pp. 113–117). Springer. https://doi.org/10.1007/978-3-319-96229-0_18

EEG. (2017). *EEG 2017—German renewable energies act*. https://www.bmwi.de/Redaktion/EN/Downloads/renewable-energy-sources-act-2017.pdf?__blob=publicationFile&v=3

Emmerling, C. (2014). Impact of land-use change towards perennial energy crops on earthworm population. *Applied Soil Ecology*, *84*, 12–15. https://doi.org/10.1016/j.apsoil.2014.06.006

Ende, M. L., Knöllinger, K., Keil, M., Fiedler, A. J., & Lauerer, M. (2021). Possibly invasive new bioenergy crop *Silphium perfoliatum*: Growth and reproduction are promoted in moist soil. *Agriculture*, *11*(1), 1–13. https://doi.org/10.3390/agriculture11010024

Ende, M. L., & Lauerer, M. (2020). Spontanvorkommen der Silphie im Bayreuther Raum: Birgt diese neue Bioenergiepflanze ein Invasionspotenzial? *Natur Und Landschaft*, *20*(7), 310–315. https://doi.org/10.17433/7.2020.50153819.310-315

Englund, O., Börjesson, P., Berndes, G., Scarlat, N., Dallemand, J. F., Grizzetti, B., Dimitriou, I., Mola-Yudego, B., & Fahl, F. (2020). Beneficial land use change: Strategic expansion of new biomass plantations can reduce environmental impacts from EU agriculture. *Global Environmental Change*, *60*, 101990. https://doi.org/10.1016/j.gloenvcha.2019.101990

European Commission. (2018). Commission delegated regulation (EU) 2018/1784 of 9 July 2018 amending Delegated Regulation (EU) No 639/2014 as regards certain provisions on the greening practices established by Regulation (EU) No 1307/2013 of the European Parliament and of the Council. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018R1784&from=EN

FAO. (2015). World reference base for soil resources 2014. International soil classification system for naming soils and creating legends for soil maps. Update 2015. World soil resources reports no. 106. FAO.

Feldwisch, N. (2011). *Umweltgerechter Anbau von Energiepflanzen*. Schriftenreihe Des LfULG, Heft.

FNR, & BMEL. (2022a). Anbau und Verwendung Nachwachsender Rohstoffe in Deutschland. https://www.fnr.de/ftp/pdf/berichte/22004416.pdf

FNR, & BMEL. (2022b). Anbauflächen nachwachsender Rohstoffe in Deutschland. https://statistik.fnr.de/anbauflaechen.php

Frank, T., & Reichhart, B. (2004). Staphylinidae and Carabidae overwintering in wheat and sown wildflower areas of different age. *Bulletin of Entomological Research*, *94*(3), 209–217. https://doi.org/10.1079/ber2004301

Franzaring, J., Holz, I., Kauf, Z., & Fangmeier, A. (2015). Responses of the novel bioenergy plant species *Sida hermaphrodita* (L.) Rusby and *Silphium perfoliatum* L. to CO2 fertilization at different temperatures and water supply. *Biomass and Bioenergy*, *81*, 574–583. https://doi.org/10.1016/j.biombioe.2015.07.031

French, B. W., Elliott, N. C., Berberet, R. C., & Burd, J. D. (2001). Effects of riparian and grassland habitats on ground beetle (Coleoptera: Carabidae) assemblages in adjacent wheat fields. *Environmental Entomology*, *30*(2), 225–234. https://doi.org/10.1603/0046-225X-30.2.225

Frölich, W., Brodmann, R., & Metzler, T. (2016). Die Durchwachsene Silphie (*Silphium perfoliatum* L.)—ein erfolgsbericht aus der praxis. *Journal Fur Kulturpflanzen*, *68*(12), 351–355. https://doi.org/10.1399/JFK.2016.12.01

Gallandt, E. R., Molloy, T., Lynch, R. P., & Drummond, F. A. (2005). Effect of cover-cropping systems on invertebrate seed predation. *Weed Science*, *53*(1), 69–76. https://doi.org/10.1614/ws-04-095r

Gansberger, M., Montgomery, L. F. R., & Liebhard, P. (2015). Botanical characteristics, crop management and potential of *Silphium perfoliatum* L. as a renewable resource for biogas production: A review. *Industrial Crops and Products*, *63*, 362–372. https://doi.org/10.1016/j.indcrop.2014.09.047

Ganser, D., Knop, E., & Albrecht, M. (2019). Sown wildflower strips as overwintering habitat for arthropods: Effective measure or ecological trap? *Agriculture, Ecosystems & Environment*, *275*, 123–131.

Gardiner, M. A., Tuell, J. K., Isaacs, R., Gibbs, J., Ascher, J. S., & Landis, D. A. (2010). Implications of three biofuel crops for beneficial arthropods in agricultural landscapes. *Bioenergy Research*, *3*(1), 6–19. https://doi.org/10.1007/s12155-009-9065-7

Geiger, F., Wäckers, F. L., & Bianchi, F. J. J. A. (2009). Hibernation of predatory arthropods in semi-natural habitats. *BioControl*, *54*(4), 529–535. https://doi.org/10.1007/s10526-008-9206-5

Gevers, J., Høye, T. T., Topping, C. J., Glemnitz, M., & Schröder, B. (2011). Biodiversity and the mitigation of climate change through bioenergy: Impacts of increased maize cultivation on farmland wildlife. *GCB Bioenergy*, *3*(6), 472–482. https://doi.org/10.1111/j.1757-1707.2011.01104.x

Glover, J. D., Culman, S. W., DuPont, S. T., Broussard, W., Young, L., Mangan, M. E., Mai, J. G., Crews, T. E., DeHaan, L. R., Buckley, D. H., Ferris, H., Turner, R. E., Reynolds, H. L., & Wyse, D. L. (2010). Harvested perennial grasslands provide ecological benchmarks for agricultural sustainability. *Agriculture, Ecosystems and Environment*, *137*(1–2), 3–12. https://doi.org/10.1016/j.agee.2009.11.001

Haughton, A. J., Bohan, D. A., Clark, S. J., Mallott, M. D., Mallott, V., Sage, R., & Karp, A. (2016). Dedicated biomass crops can

enhance biodiversity in the arable landscape. *GCB Bioenergy*, *8*(6), 1071–1081. https://doi.org/10.1111/gcbb.12312

Holland, J. M., Birkett, T., & Southway, S. (2009). Contrasting the farm-scale spatio-temporal dynamics of boundary and field overwintering predatory beetles in arable crops. *BioControl*, *54*(1), 19–33. https://doi.org/10.1007/s10526-008-9152-2

Holland, J. M., & Luff, M. L. (2000). The effects of agricultural practices on Carabidae in temperate agroecosystems. *Integrated Pest Management Reviews*, *5*(2), 109–129. https://doi.org/10.1023/A:1009619309424

Holland, J. M., Oaten, H., Southway, S., & Moreby, S. (2008). The effectiveness of field margin enhancement for cereal aphid control by different natural enemy guilds. *Biological Control*, *47*(1), 71–76. https://doi.org/10.1016/j.biocontrol.2008.06.010

Holland, J. M., Thomas, C. F. G., Birkett, T., & Southway, S. (2007). Spatio-temporal distribution and emergence of beetles in arable fields in relation to soil moisture. *Bulletin of Entomological Research*, *97*(1), 89–100. https://doi.org/10.1017/S0007485307004804

Home, R., Balmer, O., Jahrl, I., Stolze, M., & Pfiffner, L. (2014). Motivations for implementation of ecological compensation areas on swiss lowland farms. *Journal of Rural Studies*, *34*, 26–36. https://doi.org/10.1016/j.jrurstud.2013.12.007

Honěk, A., & Jarošík, V. (2000). The role of crop density, seed and aphid presence in diversification of field communities of Carabidae (Coleoptera). *European Journal of Entomology*, *97*(4), 517–525. https://doi.org/10.14411/eje.2000.080

Huk, T., & Kühne, B. (1999). Substrate selection by *Carabus clatratus* (Coleoptera, Carabidae) and its consequences for offspring development. *Oecologia*, *121*(3), 348–354. https://doi.org/10.1007/s004420050938

Huth, E., Paltrinieri, S., & Thiele, J. (2019). Bioenergy and its effects on landscape aesthetics—A survey contrasting conventional and wild crop biomass production. *Biomass and Bioenergy*, *122*, 313–321. https://doi.org/10.1016/j.biombioe.2019.01.043

Immerzeel, D. J., Verweij, P. A., van der Hilst, F., & Faaij, A. P. C. (2014). Biodiversity impacts of bioenergy crop production: A state-of-the-art review. *GCB Bioenergy*, *6*(3), 183–209. https://doi.org/10.1111/gcbb.12067

Iuliano, B., & Gratton, C. (2020). Temporal resource (dis)continuity for conservation biological control: From field to landscape scales. *Frontiers in Sustainable Food Systems*, *4*(September), 1–15. https://doi.org/10.3389/fsufs.2020.00127

Kemmann, B., Wöhl, L., Fuß, R., Schrader, S., Well, R., & Ruf, T. (2021). N$_2$ and N$_2$O mitigation potential of replacing maize with the perennial biomass crop *Silphium perfoliatum*—An incubation study. *GCB Bioenergy*, *13*(10), 1649–1665. https://doi.org/10.1111/gcbb.12879

Kiritani, K. (2006). Predicting impacts of global warming on population dynamics and distribution of arthropods in Japan. *Population Ecology*, *48*(1), 5–12. https://doi.org/10.1007/s10144-005-0225-0

Kromp, B. (1999). Carabid beetles in sustainable agriculture: A review on pest control efficacy, cultivation impacts and enhancement. *Invertebrate Biodiversity as Bioindicators of Sustainable Landscapes*, *74*(1–3), 187–228. https://doi.org/10.1016/b978-0-444-50019-9.50014-5

Labruyere, S., Ricci, B., Lubac, A., & Petit, S. (2016). Crop type, crop management and grass margins affect the abundance and the nutritional state of seed-eating carabid species in arable landscapes. *Agriculture, Ecosystems and Environment*, *231*, 183–192. https://doi.org/10.1016/j.agee.2016.06.037

Leather, S. R., Walters, K. F. A., & Bale, J. S. (1995). *The ecology of insect overwintering*. Cambridge University Press.

Leingärtner, A., Krauss, J., & Steffan-Dewenter, I. (2014). Elevation and experimental snowmelt manipulation affect emergence phenology and abundance of soil-hibernating arthropods. *Ecological Entomology*, *39*(4), 412–418. https://doi.org/10.1111/een.12112

Lenth, R., Singmann, H., Love, J., Buerkner, P., & Herve, M. (2018). Emmeans: Estimated marginal means, aka least-squares means. *R Package Version*, *1*(1), 3.

Lovei, G. L., & Sunderland, K. D. (1996). Ecology and behaviour of ground beetles (Coleoptera: Carabidae). *Annual Review of Entomology*, *41*, 231–256. https://doi.org/10.1146/annurev.en.41.010196.001311

Lövei, G. L., & Sunderland, K. D. (1996). Ecology and behavior of ground beetles (Coleoptera: Carabidae). *Annual Review of Entomology*, *41*(1), 231–256. https://doi.org/10.1146/annurev.en.41.010196.001311

Luff, M. L. (1965). The morphology and microclimate of *Dactylis glomerata* tussocks. *The Journal of Ecology*, *53*, 771–787.

Luff, M. L. (1966). Cold hardiness of some beetles living in grass tussocks. *Entomologia Experimentalis et Applicata*, *9*, 191–199.

Luff, M. L. (1994). Starvation capacities of some carabid larvae. In K. Desender, M. Dufrêne, M. Loreau, M. L. Luff, & J. P. Maelfait (Eds.), *Carabid beetles: Ecology and evolution*. Series Entomologica (Vol. *51*, pp. 171–175). Springer. https://doi.org/10.1007/978-94-017-0968-2_26

Magnusson, A., Skaug, H., Nielsen, A., Berg, C., Kristensen, K., Maechler, M., Van Bentham, K., Sadat, N., Bolker, B., & Brooks, M. (2019). Package 'glmmTMB': Generalized linear mixed models using template model builder. *The Comprehensive R Archive Network*.

Maudsley, M., Seeley, B., & Lewis, O. (2002). Spatial distribution patterns of predatory arthropods within an English hedgerow in early winter in relation to habitat variables. *Agriculture, Ecosystems and Environment*, *89*(1–2), 77–89. https://doi.org/10.1016/S0167-8809(01)00320-6

Mestre, L., Schirmel, J., Hetz, J., Kolb, S., Pfister, S. C., Amato, M., Sutter, L., Jeanneret, P., Albrecht, M., & Entling, M. H. (2018). Both woody and herbaceous semi-natural habitats are essential for spider overwintering in European farmland. *Agriculture, Ecosystems and Environment*, *267*, 141–146. https://doi.org/10.1016/j.agee.2018.08.018

Michalko, R., Pekár, S., & Entling, M. H. (2019). An updated perspective on spiders as generalist predators in biological control. *Oecologia*, *189*(1), 21–36. https://doi.org/10.1007/s00442-018-4313-1

Möller, K., Schulz, R., & Müller, T. (2011). Effects of setup of centralized biogas plants on crop acreage and balances of nutrients and soil humus. *Nutrient Cycling in Agroecosystems*, *89*(2), 303–312. https://doi.org/10.1007/s10705-010-9395-z

Mueller, A. L., Berger, C. A., Schittenhelm, S., Schoo, B., & Dauber, J. (2020). Water availability affects nectar sugar production and insect visitation of the cup plant *Silphium perfoliatum* L. (Asteraceae). *Journal of Agronomy and Crop Science*, *2020*, 1–9. https://doi.org/10.1111/jac.12406

Mueller, A. L., & Dauber, J. (2016). Hoverflies (Diptera: Syrphidae) benefit from a cultivation of the bioenergy crop *Silphium*

perfoliatum L. (Asteraceae) depending on larval feeding type, landscape composition and crop management. *Agricultural and Forest Entomology*, *18*(4), 419–431. https://doi.org/10.1111/afe.12175

Nazli, R. I., Kusvuran, A., Tansi, V., Ozturk, H. H., & Budak, D. B. (2020). Comparison of cool and warm season perennial grasses for biomass yield, quality, and energy balance in two contrasting semiarid environments. *Biomass and Bioenergy*, *139*(April), 105627. https://doi.org/10.1016/j.biombioe.2020.105627

Ni, J., Cheng, Y., Wang, Q., Ng, C. W. W., & Garg, A. (2019). Effects of vegetation on soil temperature and water content: Field monitoring and numerical modelling. *Journal of Hydrology*, *571*(February), 494–502. https://doi.org/10.1016/j.jhydrol.2019.02.009

Pfiffner, L., & Luka, H. (2000). Overwintering of arthropods in arable fields and adjacent semi-natural habitats. *Verhandlungen Der Gesellschaft Fur Ökologie*, *31*(July), 275–222.

Platen, R., Konrad, J., & Glemnitz, M. (2017). Novel energy crops: An opportunity to enhance the biodiversity of arthropod assemblages in biomass feedstock cultures? *International Journal of Biodiversity Science, Ecosystem Services and Management*, *13*(1), 162–171. https://doi.org/10.1080/21513732.2017.1289244

Pywell, R. F., James, K. L., Herbert, I., Meek, W. R., Carvell, C., Bell, D., & Sparks, T. H. (2005). Determinants of overwintering habitat quality for beetles and spiders on arable farmland. *Biological Conservation*, *123*(1), 79–90. https://doi.org/10.1016/j.biocon.2004.10.010

R Core Team. (2021). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing.

Rand, T. A., Tylianakis, J. M., & Tscharntke, T. (2006). Spillover edge effects: The dispersal of agriculturally subsidized insect natural enemies into adjacent natural habitats. *Ecology Letters*, *9*(5), 603–614. https://doi.org/10.1111/j.1461-0248.2006.00911.x

Ruf, T., & Emmerling, C. (2017). Impact of premature harvest of Miscanthus x giganteus for biogas production on organic residues, microbial parameters and earthworm community in soil. *Applied Soil Ecology*, *114*, 74–81. https://doi.org/10.1016/j.apsoil.2017.02.020

Ruf, T., & Emmerling, C. (2022). The effects of periodically stagnant soil water conditions on biomass and methane yields of *Silphium perfoliatum*. *Biomass and Bioenergy*, *160*, 106438.

Sauerbrei, R., Ekschmitt, K., Wolters, V., & Gottschalk, T. K. (2014). Increased energy maize production reduces farmland bird diversity. *GCB Bioenergy*, *6*(3), 265–274. https://doi.org/10.1111/gcbb.12146

Schittenhelm, S., Panten, K., & Gabriel, D. (2021). Converting perennial energy crops cup plant and field grass to arable cropping affects weed infestation, soil nitrogen mineralization and subsequent silage maize yield. *GCB Bioenergy*, *13*(8), 1232–1246. https://doi.org/10.1111/gcbb.12837

Schoo, B., Schroetter, S., Kage, H., & Schittenhelm, S. (2017). Root traits of cup plant, maize and lucerne grass grown under different soil and soil moisture conditions. *Journal of Agronomy and Crop Science*, *203*(5), 345–359. https://doi.org/10.1111/jac.12194

Schoo, B., Wittich, K. P., Böttcher, U., Kage, H., & Schittenhelm, S. (2017). Drought tolerance and water-use efficiency of biogas crops: A comparison of cup plant, maize and Lucerne-grass. *Journal of Agronomy and Crop Science*, *203*(2), 117–130. https://doi.org/10.1111/jac.12173

Schorpp, Q., Müller, A. L., Schrader, S., & Dauber, J. (2021). Agrarökologisches Potential der Durchwachsenen Silphie (*Silphium perfoliatum* L.) aus Sicht biologischer Vielfalt. *Journal of FÜR Kult*, *68*(12). https://doi.org/10.1399/jfk.2016.12.12

Sharratt, B. S., Benoit, G. R., & Voorhees, W. B. (1998). Winter soil microclimate altered by corn residue management in the northern Corn Belt of the USA. *Soil and Tillage Research*, *49*(3), 243–248. https://doi.org/10.1016/S0167-1987(98)00181-0

Song, Y. T., Zhou, D. W., Zhang, H. X., Di Li, G., Jin, Y. H., & Li, Q. (2013). Effects of vegetation height and density on soil temperature variations. *Chinese Science Bulletin*, *58*(8), 907–912. https://doi.org/10.1007/s11434-012-5596-y

Sotherton, N. W. (1984). The distribution and abundance of predatory arthropods overwintering on farmland. *Annals of Applied Biology*, *105*(3), 423–429. https://doi.org/10.1111/j.1744-7348.1984.tb03068.x

Speight, M. R., & Lawton, J. H. (1976). The influence of weed-cover on the mortality imposed on artificial prey by predatory ground beetles in cereal fields. *Oecologia*, *23*, 211–223.

Sutter, L., Amato, M., Jeanneret, P., & Albrecht, M. (2018). Overwintering of pollen beetles and their predators in oilseed rape and semi-natural habitats. *Agriculture, Ecosystems and Environment*, *265*(June), 275–281. https://doi.org/10.1016/j.agee.2018.06.030

Symondson, W. O. C., Sunderland, K. D., & Greenstone, M. H. (2002). Can generalist predators be effective biocontrol agents? *Annual Review of Entomology*, *47*, 561–594.

Thomas, M. B., Wratten, S. D., & Sotherton, N. W. (1991). Creation of "Island" habitats in farmland to manipulate populations of beneficial arthropods: Predator densities and emigration. *Journal of Applied Ecology*, *28*(3), 906–917. https://doi.org/10.2307/2404216

Thorbek, P., & Bilde, T. (2004). Reduced numbers of generalist arthropod predators after crop management. *Journal of Applied Ecology*, *41*(3), 526–538. https://doi.org/10.1111/j.0021-8901.2004.00913.x

Tudge, S. J., Purvis, A., & De Palma, A. (2021). The impacts of biofuel crops on local biodiversity: A global synthesis. *Biodiversity and Conservation*, *30*(11), 2863–2883. https://doi.org/10.1007/s10531-021-02232-5

Tymchuk, K., Polchaninova, N., Zhuk, A., Leheta, U., Voloshyn, V., & Fedornak, M. (2021). Spiders (Araneae) as a component of ground-dwelling animal assemblages of the energy crop fields in northern Bukovyna (Ukraine). *Ekologia Bratislava*, *40*(3), 240–247. https://doi.org/10.2478/eko-2021-0026

Vogel, E., Deumlich, D., & Kaupenjohann, M. (2016). Bioenergy maize and soil erosion—Risk assessment and erosion control concepts. *Geoderma*, *261*, 80–92. https://doi.org/10.1016/j.geoderma.2015.06.020

Von Cossel, M., Wagner, M., Lask, J., Magenau, E., Bauerle, A., Von Cossel, V., Warrach-Sagi, K., Elbersen, B., Staritsky, I., van Eupen, M., Iqbal, Y., Jablonowski, N. D., Happe, S., Fernando, A. L., Scordia, D., Cosentino, S. L., Wulfmeyer, V., Lewandowski, I., & Winkler, B. (2019). Prospects of bioenergy cropping systems for a more social-ecologically sound bioeconomy. *Agronomy*, *9*(10). https://doi.org/10.3390/agronomy9100605

Werling, B. P., Dickson, T. L., Isaacs, R., Gaines, H., Gratton, C., Gross, K. L., Liere, H., Malmstrom, C. M., Meehan, T. D., Ruan, L., Robertson, B. A., Robertson, G. P., Schmidt, T. M., Schrotenboer, A. C., Teal, T. K., Wilson, J. K., & Landis, D. A. (2014). Perennial grasslands enhance biodiversity and multiple

ecosystem services in bioenergy landscapes. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(4), 1652–1657. https://doi.org/10.1073/pnas.1309492111

Westerman, P. R., Liebman, M., Menalled, F. D., Heggenstaller, A. H., Hartzler, R. G., & Dixon, P. M. (2005). Are many little hammers effective? Velvetleaf (*Abutilon theophrasti*) population dynamics in two- and four-year crop rotation systems. *Weed Science*, *53*(3), 382–392. https://doi.org/10.1614/ws-04-130r

Wickham, H., Chang, W., & Wickham, M. H. (2016). Package 'ggplot2.' *Create elegant data Visualisations using the grammar of graphics. Version*, 3(3.5), 1–189.

Williams, C. M., Henry, H. A. L., & Sinclair, B. J. (2015). Cold truths: How winter drives responses of terrestrial organisms to climate change. *Biological Reviews*, *90*(1), 214–235. https://doi.org/10.1111/brv.12105

Yang, Q., Men, X., Zhao, W., Li, C., Zhang, Q., Cai, Z., Ge, F., & Ouyang, F. (2020). Flower strips as a bridge habitat facilitate the movement of predatory beetles from wheat to maize crops. *Pest Management Science*, *77*(4), 1839–1850. https://doi.org/10.1002/ps.6209

SUPPORTING INFORMATION

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

How to cite this article: Häfner, B., Dauber, J., Schittenhelm, S., Böning, L. M., Darnauer, M., Wenkebach, L. L., & Nürnberger, F. (2023). The perennial biogas crops cup plant (*Silphium perfoliatum* L.) and field grass pose better autumn and overwintering habitats for arthropods than silage maize (*Zea mays* L.). *GCB Bioenergy*, *15*, 346–364. https://doi.org/10.1111/gcbb.13027