Agriculture, Ecosystems and Environment 278 (2019) 61–71

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Design, implementation and management of perennial flower strips to promote functional agrobiodiversity in organic apple orchards: A pan-European study

Lukas Pfiffner[a,*], Fabian Cahenzli[a], Beatrice Steinemann[a], Laurent Jamar[b], Mona Chor Bjørn[c], Mario Porcel[d,1], Marco Tasin[d], Josef Telfser[e], Markus Kelderer[e], Jerzy Lisek[f], Lene Sigsgaard[c]

[a] Research Institute of Organic Agriculture (FiBL), Department of Crop Sciences, Ackerstrasse 113, 5070 Frick, Switzerland
[b] Walloon Agricultural Research Center (CRA-W), Department of Life sciences, Rue de Liroux 4, 5030 Gembloux, Belgium
[c] University of Copenhagen (UCPH), Department of Plant and Environmental Sciences, Thorvaldsensvej 40, DK-1871 Frederiksberg, Denmark
[d] Swedish University of Agricultural Science, Department of Plant Protection Biology – Unit of Integrated Plant Protection, P.O. Box 102, SE - 230 53, Alnarp, Sweden
[e] Research Center Laimburg, Department of Fruit Growing, Laimburg, 6, 39040 Auer, Italy
[f] Research Institute of Horticulture (InHort), Department of Horticultural Crops Management and Nutrition, Konstytucji 3, Maja 1/3, 96-100 Skierniewice, Poland

ARTICLE INFO

Keywords:
Diversified orchard
Ecological infrastructure
Habitat manipulation
Plant diversity
Sustainable apple production

ABSTRACT

Orchards, as intensive cropping systems, often have low diversity of plant species, which limits the promotion of natural enemies for pest control. The implementation of agri-environmental schemes, such as flower strips, could enhance biological control. We developed perennial, multifunctional flower strips with native plant species. In the second and third year after sowing, plant diversity and ground cover between flower strips (FS) in the drive alleys and the spontaneous orchard vegetation in control plots (Cont) were compared in 19 experimental blocks of eight organic apple orchards in six European countries. On average 73.7% of the sown plant species were established and plant diversity of FS was on average 43% higher than in Cont. Multivariate analysis further revealed significant dissimilarities in the plant communities of the two treatments. Intensive mulching of flower strips also affected the plant community: species richness and ground cover by forbs and plants, which especially promote functional agrobiodiversity (FAB plants), decreased significantly. We show that perennial FS with native plants are a valuable approach to enrich plant diversity in orchards in different European countries. Limitations and recommendations for the implementation and management of FS in orchards are discussed.

1. Introduction

The intensification of agriculture in recent decades due to the high use of synthetic pesticides and deterioration, fragmentation and destruction of natural habitats has led to an unfavourable homogenisation of the agricultural landscape throughout Europe and a loss or significant decline in biodiversity (Tscharntke et al., 2005; Geiger et al., 2010). Large net losses of biodiversity can impair ecosystem functions and services (Hooper et al., 2012; Newbold et al., 2016). The European agricultural policy therefore encourages farmers to reduce the negative effects of agriculture through the implementation of agri-environmental schemes (AES) (European Commission, 2005, 2009; European regulation No 1307, 2013). For example, the use of flower strips to promote conservation biological control was introduced as an AES in several European countries, but primarily in annual crops and much less in perennial crops such as orchards (Batáry et al., 2015).

Recent studies have shown many potential benefits of increased plant diversity in agroecosystems (Geneau et al., 2012; Batáry et al., 2015; Tschumi et al., 2016; Isbell et al., 2017). Selected plant communities can improve soil fertility, tree nutrition, weed suppression, or several of these ecosystem functions simultaneously (Uyttenbroeck et al. 2016; Demestihas et al., 2017). Furthermore, sown flower strips offer shelter, nectar, pollen and alternative prey to natural enemies or pollinators. This improves ecosystem services, such as biological control (Pfiffner and Wyss, 2004; Uyttenbroeck et al., 2016; Gurr et al., 2017) and pollination (Garibaldi et al., 2014; Feltham et al., 2015). Therefore, functional agrobiodiversity is a way to potentially reduce insecticide use (Tittonell, 2014; Demestihas et al., 2017). In addition, the implementation of flower strips may also improve the landscape's aesthetic value and help to support sustainable agriculture marketing

* Corresponding author.
E-mail address: lukas.pfiffner@fibl.org (L. Pfiffner).
[1] Current address: Corporación Colombiana de Investigación Agropecuaria (Agrosavia), C. I. La Libertad, Vía Puerto López km 17, Meta, Colombia.

https://doi.org/10.1016/j.agee.2019.03.005
Received 25 October 2018; Received in revised form 7 March 2019; Accepted 8 March 2019
0167-8809/

Table 1
Site characteristics of orchards in different countries.

Country	Site	North	Altitude (m)	Precipitation (mm)*	Temperature (°C)*	pH	SOM (%)	Soil type	Soil texture
BE	Gembloux-Penteville	50° 33' 7"	162	710	10.6	6.5	2.9	Haplic Luvisol	Heavy loam
DK	Ventegoodgaard	55° 31' 07"	24	650	8.7	6.5	3.1	Eutric Cambisol	Heavy clay
IT	Laimburg	46° 22' 59"	222	815	11.5	7.3	2.8	Rendzic Leptosol	Silty loam
IT	Laimburg	46° 22' 59"	222	815	11.6	7.2	2.1	Rendzic Leptosol	Silty loam
PL	Maków	51° 54' 59"	129	520	8.4	6.0	1.6	Eutric Fluvisol	Sandy loam
SE	Tomelilla-Helenlust	55° 36' 23"	94	614	7.6	6.7	3.0	Eutric Cambisol	Silty loam
SE	Kivik	55° 40' 2"	20	587	7.7	6.9	3.5	Eutric Cambisol	Silty loam
CH	Pupikon	47° 33' 0"	445	950	10.3	7.6	4.7	Dystric Cambisol	Heavy clay
CH	Hauptwil	47° 29' 28"	540	950	10.3	6.7	2.8	Dystric Cambisol	Heavy clay

*Annual mean values, SOM = soil organic matter.

strategies (Paar et al., 2008; Wratten et al., 2012).

Orchards have a certain plant diversity and multi-strata vegetation, but they generally lack the specific functional agrobiodiversity to meet the needs of beneficial arthropods (Simon et al., 2010; Demestihas et al., 2017; Daniel et al., 2018). Furthermore, sown flower strips in orchards are rarely kept longer than one season, as annual and non-durable plant mixtures are selected (Marliac et al., 2016). As a consequence, natural populations of beneficial arthropods, which depend on the continuity of plant resources in time and space (Sigsgaard, 2010; Blaauw and Isaacs, 2012; Campbell 2017), lack the adequate composition or abundance to provide the necessary ecosystem services (Bostanian et al., 2004; Porcel et al., 2018). However, the integration of ecosystem services to improve the resilience of orchards without compromising the quantity and quality of fruits is an important component of sustainable apple production (Zehnder et al., 2007; Demestihas et al., 2017). Innovative approaches are therefore needed to mitigate the shortcomings of current apple production systems. For instance, the use of perennial plant species to maintain flower strips over several seasons would not only facilitate the establishment of strong populations of beneficial arthropods in the orchard, but would also prevent further costs for reseeding. Native plant species (ecotypes and wild forms) are not only better adapted to the local climate than cultivated forms, but also correspond to the idea of promoting local biodiversity (Bischoff et al., 2006). Moreover, cultivated forms are generally less competitive with the spontaneous flora in apple orchards than ecotypes and wild forms (Keller, 1999; Bischoff et al., 2010). Unfortunately, knowledge about the quality and durability of sown perennial flower strips under orchard management is currently very limited, but highly relevant for their future implementation (Simon et al., 2010). Previous studies have focussed mainly on the effects of flower strips on arthropods, but have not assessed how the flower strips themselves, which are expected to promote the beneficial arthropods, could be optimised (e.g. Campbell et al., 2017). Therefore, we have designed perennial and multi-functional flower strips with native plant species adapted to regional soil and climate conditions. Thirty perennial and biennial forb and eight grass species were selected. Nine main criteria for implementing flower strips in the drive alleys of apple orchards were considered, as flower strips must meet several conditions to be optimal for the enhancement of natural enemies and biological control (van Rijn and Wäckers, 2016; Dib et al., 2016; Balzan et al., 2014). The selected plant species had to be (i) attractive to the natural enemies in focus, (ii) not attractive to pest insects and voles, (iii) sequentially flowering throughout the crop season, (iv) rosette or hemi-rosette plants to tolerate repeated mulching, (v) tolerant of machine traffic (vi) biennial to perennial life cycle, (vii) tolerant of nutrient rich orchard soil conditions, (viii) competitive against weeds and (ix) tolerant of shady light conditions. This study is the first European transnational field trial assessing the implementation of sown flower strips in orchards from Southern Sweden to Northern Italy. The mixture was established in organically managed apple orchards in six European countries (Belgium, Denmark, Italy, Poland, Sweden and Switzerland). Since broad-spectrum pesticides as used in conventional farming harm populations of beneficial arthropods (Geiger et al., 2010; Uyttenbroeck et al., 2016), organic production systems may be favourable for the implementation of flower strips for pest control (Porcel et al., 2018; Cahenzli et al., 2019 in press AGEE). In two consecutive years after sowing, we evaluated how mulching regime, seasonality, climate (temperature and precipitation), pH and organic matter influenced plant species richness, ground cover and plant community as compared to the spontaneous local orchard vegetation.

2. Material and methods

2.1. Study design and orchard characteristics

The study was conducted from 2015 to 2017 in 19 experimental blocks of eight organic apple orchards in six European countries (Table 1). Apple orchards (for commercial production and at research stations) had to be (i) organically managed, (ii) large enough for the implementation of the flower strips under real conditions (at least half a hectare in size) and (iii) had to include similar areas with spontaneous orchard vegetation. Furthermore, the farmers were required to have access to appropriate machinery for management of the flower strips. Each block involved flower strips on half of the length (28 to 40 m, depending on orchard size) of the drive alleys between seven or eight tree rows. Therefore, every block consisted of a control plot (intensively mulched under current vegetation cover management practices) and a plot with sown flower strips. The low stem trees, grafted on dwarf M9, M26 or semi-dwarf MM106 rootstocks, were in the yield phase. Pruning and fertilisation of the trees was performed according to regional management practices. The orchards were all planted before 2014.

The main orchard site characteristics are shown in Table 1. Soil type was classified according to the international soil classification system (IUSS Working Group Wrb., 2015). We have applied the Harmonized World Soil Database, 2012 HWSD Viewer, based on WRB (World Reference Base for soil resources). Precipitation and temperature data were provided by local weather services (closest official meteorological station) and local thermologgers. Annual mean values of precipitation and temperature were used due to their significant effect upon local plant communities. For chemical soil analyses, soil cores were taken in the drive alleys at a depth of 0–25 cm. For each orchard, a mix of 20 samples was analysed. The samples were sieved before analysis with a sieve of 2 mm mesh width. Soil pH and organic matter were measured according to the standard guidelines (ISO 10694:1995 resp. DIN EN 15933:2012). The pH of dried samples (60 °C, 24 h) was measured in a soil suspension with deionised water (1:10, w/v). Soil organic carbon was measured after wet oxidation of 1 g dry soil in 20 ml concentrated H_2SO_4 and 25 ml 2 M $K_2Cr_2O_7$ in accordance with standard protocols (FAL et al., 1996). Soil pH and organic matter are important parameters to characterise orchard soil quality.

Table 2
Forb species and grass species sown in the flower strips in the six European countries.

Taxonomic group	Species	CH	IT	BE	PL	DK	SE
Forb species	*Achillea millefolium* L. *	■	■	■	■	■	■
	Ajuga reptans L.	■	■	■	□	□	□
	Bellis perennis L.	■	■	■	■	■	■
	Campanula rotundifolia L.	■	■	■	■	■	■
	Cardamine pratensis L. *	■	■	■	■	□	□
	Carum carvi L. *	■	■	■	■	■	■
	Centaurea jacea L. *	■	■	■	■	■	■
	Crepis capillaris (L.) Wallr.	■	□	■	■	■	■
	Daucus carota L. *	■	■	□	■	■	■
	Galium mollugo L.	■	■	■	□	■	■
	Geranium pyrenaicum Burm. fil.	■	■	■	■	■	■
	Hieracium aurantiacum L.	■	□	■	□	□	□
	Hieracium lactucella Wallr.	■	□	■	□	□	□
	Hieracium pilosella L.	■	■	■	■	□	□
	Hypochaeris radicata L.	■	■	■	■	■	■
	Lathyrus pratensis L.	■	■	■	■	■	■
	Leontodon autumnalis L.	■	■	■	■	■	■
	Leontodon hispidus L.	■	■	■	■	■	■
	Leontodon saxatilis Lam.	■	□	■	□	□	□
	Leucanthemum vulgare Lam. *	■	■	■	■	■	■
	Lotus corniculatus L. *	■	■	■	■	■	■
	Medicago lupulina L. *	■	□	■	■	■	■
	Myosotis scorpioides L.	■	■	■	■	■	■
	Primula elatior (L.) Hill	■	□	■	■	■	■
	Prunella vulgaris L.	■	■	■	■	■	■
	Silene dioica (L.) Clairv.	■	■	■	■	■	■
	Silene flos-cuculi (L.) Greuter & Burdet	■	■	■	■	■	■
	Trifolium pratense L. *	■	■	■	■	■	■
	Veronica chamaedrys L.	■	■	■	■	□	□
	Vicia sepium L. *	■	■	■	■	■	■
Grass species	*Anthoxanthum odoratum* L.	■	■	■	■	■	■
	Cynosurus cristatus L.	■	■	■	■	■	■
	Festuca guestfalica Boenning. ex Rchb.	■	■	■	■	■	■
	Festuca rubra rubra Mit.	■	□	■	□	■	■
	Lolium perenne L.	■	■	■	■	■	■
	Poa nemoralis L.	■	■	■	■	■	■
	Poa pratensis L.	■	■	■	■	■	■
	Poa trivialis L.	■	□	■	■	■	■
Additional species	*Cichorium intybus* L.	□	□	□	□	■	■
	Gallium album Mill.	□	□	□	■	□	□
	Plantago lancelota L.	□	□	■	□	□	□
	Plantago media L.	□	□	■	□	□	□
	Sanguisorba minor Scop.	□	□	□	□	■	■
	Festuca nigrescens Lam.	□	□	□	■	□	□
Total number of species		38	30	39	34	33	33

Note: * indicate FAB plants, which specifically meet the criteria for the promotion of functional agrobiodiversity. The Swiss mixture was the reference. Grey squares = species included in the seed mixture, open squares = not included in the seed mixture.

2.2. Flower strip design and establishment

Perennial flower strips were designed to provide high durability, flower resources and structural diversity throughout the entire cropping season. Thirty forb species that meet the specific criteria were selected for the mixture (Table 2). According to the BiolFlor data-base (Kühn et al., 2004), flowers of the selected plants have a short corolla and offer easily accessible nectar and pollen in order to support aphid predators (e.g. Chrysopidae, Syrphidae, Coccinellidae, Anthocoridae, Miridae, Araneae) and parasitoids of *Dysaphis plantaginea* (Passerini) and *Cydia pomonella* (L.). Since annual plant species have no chance to persist under the mulching regime in orchards, only bi-annual to perennial plants were included focussing on a long-lasting plant community. Furthermore, in order to increase the tolerance of flower strips to machine traffic, to stabilise the plant community in the medium-term and to minimize the invasion of the strip by local pioneer plants, eight grass species being not too competitive against the forbs were also included in the mixture. In the majority of cases ecotypes (wild forms) of selected forbs and grass species were selected for the flower strips in order to ensure its long-term survival (Bischoff et al., 2010). Additional species to the Swiss reference mixture were included in Belgium, Denmark, Poland and Sweden and/or replaced by similar species adapted to biogeographic conditions. This was also a consequence of the differing availability of seeds of wild plant species in the different countries. These additional species are typically present in agricultural landscapes in the countries mentioned. Save for *Trifolium pratense* L. in Denmark and Sweden, which has been widely cultivated for centuries, only native, wild plant species were sown. Ten plant species specifically meet the criteria for the promotion of beneficial arthropods and pollinators (Table 2). These are hereafter referred to as functional agrobiodiversity (FAB) plants. Flowers of these plants bear nectaries, which are attractive for beneficial insects like Syrphidae (van Rijn and Wäckers, 2016), Tachinidae (Al Dobei et al. 2012), Coccinellidae (Walton and Isaacs, 2011) and parasitic wasps (Balmer et al., 2013). Seeds were supplied by local companies specialised in growing native plant species and locally adapted ecotypes.

For the establishment of the flower strips, after spading or the use of rotocultivator, the soil was harrowed several times to initiate the germination of the spontaneous orchard vegetation. The spontaneous vegetation was then completely removed in several steps to prepare the seedbed in the drive alleys. The seed mixture (4 g per m^2, in a weight ratio of 18%: 82% forbs to grasses) was sown in spring to early summer 2015 four weeks after the first soil treatment. After sowing a land roller was used to enable a good ground connection of the seeds. A mixture of 1:1 vermiculite-, barley or soy grist was applied to guarantee and facilitate an even distribution of the seeds. Flower strips were sown with a width from 0.6 to 1.0 m. The final width varied from 0.5 m to 1.0 m (mean width 0.72 m +/- 0.18 SD) across the orchards due to the specific orchard dimensions and the usable width between tractor wheels. In the first year of establishment, flower strips were mulched (8 cm cutting height) two to four times at approximate intervals of eight weeks according to their vegetation development. Cutting helps light germinating forbs to establish.

2.3. Flower strip management

The flower strips were not fertilised. Although the selected wild plant species can grow on nutrient-rich orchard soils, nutrient-poor soil conditions are preferable for these plants. To guarantee blooming flowers throughout the crop season, the flower strips were mulched (8–10 cm cutting height) three to four times a year in 2016 and 2017. The mulching of the pruned branches had to be performed early in spring in order not to destroy the forbs. The first mulching was performed before the flowering of apple trees. The second mulching in spring corresponded to the development stage of the FAB plants (2–6 weeks after beginning of flower strip bloom) and apple trees (BBCH 67–72) (Biologische Bundesanstalt für Land und Forstwirtschaft, 2010) when all apple flower petals have fallen or small fruits are visible. The third mulching was carried out during the summer break (end of July/ August) or before harvest and the fourth at the end of the season in October. This last intervention is, if necessary, for vole control, as voles may reach damaging population sizes under uncut drive alleys.

Depending on local conditions, the mulching regime used was either intensive (more than three mulches per year, cutting height below 8 cm) or moderate (three mulches per year, cutting height above 8 cm). In order to keep the spontaneous vegetation at a low level, as it is common practice in commercial orchards, the drive alleys in the control plots without flower strips were mulched more intensively, up to six times a year with a cutting height of 3–5 cm. The vegetation in drive alleys next to the flower strips was also mulched intensively. Mechanical weed control within the tree rows was carried out three to four times a year.

2.4. Botanical assessment

Botanical assessments were conducted three times a year, in spring (April), summer (June) and autumn (August) of the second (2016) and third year (2017) after the flower strips were sown. The vegetation was assessed in six samples of $1.2\,m^2$ plots ($2\,m \times 0.6\,m$) in the central drive alleys of each treatment (with and without flower strips). Percentage of ground cover by all sown and spontaneously growing plant species was estimated. The mean establishment rate as percentage of ground cover was calculated for each plant category and species over six sampling periods to assess the flower strip evolution in the two-year succession. An overall mean of the ground cover by the sown species was calculated to document their establishment rates in the flower strips during the study period.

The plant species were grouped under categories 'all plants,' forbs', 'FAB plants' (for species see Table 2) and 'grasses' for univariate analysis. Forbs are herbaceous flowering plants that are not graminoids (grasses, sedges and rushes). Since the plant communities were dominated by perennial plants with clonal growth (hemicryptophytes) and only a few, not sown annuals (therophytes) with a low percentage of ground cover, 'annuals' were not included as a separate category.

2.5. Statistical analysis

Mixed effects models were used to analyse the difference in the number of species and ground cover between flower strips and control plots (Table A.1). Generalised linear mixed models (GLMM) with Poisson distributed errors were used to analyse the number of all plant species, forb species and FAB plant species, whereas linear mixed models (LMM) were used to analyse the number of grass species and ground cover by all categories. The number of grass species was transformed with the natural logarithm. The models used the random factors *block* and *assessment period*. Due to the small number of grass species, the number of grass species was pooled within treatment blocks. There was no fitting statistical model to analyse the difference in ground cover by FAB plants between flower strips and control plots. Because of temporal autocorrelation of the residuals, the model analysing the number of all plant species included a rational correlation structure (Zuur et al., 2009). The temporal autocorrelation of the residuals in the models analysing the number of forb and FAB plant species and ground cover by all plants, forbs and grasses were structured using the best fitting number of auto-regressive parameters and moving average parameters (Table A.1) (Zuur et al., 2009).

All explanatory continuous variables were standardised by subtracting the mean and dividing them by their standard deviation. Generalised additive mixed models (GAMM) were used to analyse species richness and ground cover in flower strips. Additive modelling allows for the implementation of non-linear relationships between the response variable and one or more predictors of the model (Wood, 2006). The full models included the random effects *block* and *assessment period* and the fixed effects *season, year* and *mulching regime*. In addition, a smoothing curve for the best fitting covariate *pH, organic matter, precipitation* or *temperature* was included based on the Akaike information criterion (AIC) (Table A.1) (Zuur et al., 2009). As these four variables correlated with each other, only the best fitting explanatory variable was used in the model. The model analysing the number of all plant species used Poisson distributed errors, whereas all other models used a Gaussian error distribution. Ground cover by all plants and FAB plants were transformed with the natural logarithm. Due to the small number of grass species, this variable was pooled within blocks. Different variances along the fitted values within seasons were implemented for the ground cover by FAB plants (Zuur et al., 2009). Non-significant variables were removed in a combination of forward and backward step-wise model selection based on AIC to achieve the best fitting fixed effects structure for each model. Because of temporal autocorrelation of the residuals, the models analysing the number of all plant species, forb species and FAB plant species and ground cover by forbs, FAB plants and grasses included specific correlation structures (Table A1) (Zuur et al., 2009). The temporal autocorrelation of the residuals in the models analysing ground cover by all plants was structured by using three auto-regressive parameters (Table A1) (Zuur et al., 2009). Visual inspection of residual plots was applied to test for any obvious deviations from homoscedasticity or normality and temporal autocorrelation.

For multivariate analysis, the data from the three assessment periods was pooled by year. Permutational analyses of variance (PERMANOVA), with the function 'adonis', was used to test the difference in plant community between the flower strip and the control treatments (main term). The model included *year*, *pH, organic matter, precipitation* and *temperature* as covariables. A second PERMANOVA was run, using the FS data alone and including the same covariables, to establish the effect of the mulching regime (intense vs. moderate) upon the FS plant community. The Bray-Curtis dissimilarity measure was adopted as distance metric with 999 permutations for the probability tests. All variables were tested for equal multivariate dispersion using the function 'betadisper'. The results of the analyses were represented graphically in the multivariate space using nonmetric multidimensional scaling (NMDS) with the Bray-Curtis distance and transforming the data previously with a Wisconsin double standardisation. The Bray-Curtis dissimilarity measure was adopted as the distance metric with 999 permutations for the probability tests (Tables A.2, A.3). The influence of individual plant species on the differences detected with PERMANOVA were analysed with the random feature selection methodology from the 'Boruta' package (Kursa and Rudnicki, 2010). For the analyses, each main term was set as response variable and the plant species as features. The Boruta algorithm uses a highly robust permutation-based approach to identify all the features that are relevant to the outcome of interest (Degenhardt et al., 2017). We used the default random forest setting of 500 trees (ntree) and 4 variables per level (mtry). All the analyses were conducted with R 3.3.1 (R Development Core Team, 2016) using the packages 'mgcv', 'nlme', 'lme4', 'vegan' and 'Boruta'.

3. Results

3.1. Species level

A total of 110 plant species, 108 in the flower strips and 77 in the control plots, were found in the two years after sowing (Table A.4). Thirty-nine species were rather constantly recorded (> 0.5% ground cover) in flower strips across all countries. Of the sown species, 17 forb and eight grass species had established themselves with ground cover > 0.5% (Table 3). The most frequently found species were the forbs *Trifolium pratense* L., *Achillea millefolium* L., *Geranium pyrenaicum* Burm.fil., *Lotus corniculatus* L., and *Gallium mollugo* L. as well as the grasses *Lolium perenne* L. (very abundant), *Poa trivialis* L., *P. pratensis* L., *Cynosurus cristatus* L., and *Anthoxanthum odoratum* L. Seven out of the ten sown FAB plants became well established in the flower strips (Table 3).

Table 3
Mean establishing rates of sown plant species in flower strips at nine sites in the 2nd and 3th year (mean values ± standard error of mean (SEM) of six sampling dates).

Establishment category	Species	Mean		SEM
poorly (> 0 - 0.3 %)	*Campanula rotundifolia* L.	0.02	±	0.01
	Cardamine pratensis L. *	0.03	±	0.01
	Ajuga reptans L.	0.04	±	0.01
	Leontodon saxatilis Lam.	0.08	±	0.05
	Myosotis scorpioides L.	0.08	±	0.03
	Crepis capillaris (L.) Wallr.	0.18	±	0.1
	Silene flos-cuculi (L.) Greuter & Burdet	0.21	±	0.07
	Hieracium lactucella Wallr.	0.23	±	0.2
moderate (> 0.3 - 1 %)	*Bellis perennis* L.	0.38	±	0.08
	Leontodon autumnalis L.	0.40	±	0.13
	Hieracium pilosella L.	0.44	±	0.14
	Silene dioica (L.) Clairv.	0.49	±	0.16
	Cichorium intybus L.	0.51	±	0.07
	Poa nemoralis L.	0.57	±	0.19
	Vicia sepium L. *	0.63	±	0.22
	Lathyrus pratensis L.	0.65	±	0.3
	Festuca rubra rubra L.	0.70	±	0.23
	Veronica chamaedrys L.	0.71	±	0.19
	Leontodon hispidus L.	0.71	±	0.2
	Carum carvi L. *	0.82	±	0.27
	Hieracium aurantiacum L.	0.82	±	0.33
	Hypochaeris radicata L.	0.92	±	0.26
well (> 1 - 2 %)	*Prunella vulgaris* L.	1.05	±	0.32
	Medicago lupulina L. *	1.46	±	0.38
	Festuca guestfalica Boenning. ex Rchb.	1.50	±	0.82
	Leucanthemum vulgare Lam. *	1.70	±	0.68
	Daucus carota L. *	1.81	±	0.37
very well (> 2 %)	*Poa pratensis* L.	2.02	±	0.51
	Galium mollugo L.	2.19	±	0.42
	Lotus corniculatus L. *	2.43	±	0.63
	Centaurea jacea L. *	2.64	±	0.95
	Anthoxanthum odoratum L.	2.84	±	0.6
	Geranium pyrenaicum Burm. fil.	2.86	±	0.82
	Achillea millefolium L. *	3.14	±	0.72
	Trifolium pratense L. *	4.00	±	0.48
	Cynosurus cristatus L.	4.21	±	1.29
	Poa trivialis L.	4.64	±	1.12
	Lolium perenne L.	12.08	±	1.99

* Plants that especially promote functional agrobiodiversity (FAB plants).

3.2. Group level

3.2.1. Species richness

There were significantly more plant species (Fig. 1A), forb species (Fig. 2A), FAB plant species (Fig. 3A) and grass species (Fig. 4A) in flower strips than in control plots. The number of plant species (Fig. 1B) and forbs (Fig. 2B) in flower strips was significantly reduced by intensive mulching (mulching intensity and cutting height) as compared to moderate mulching. The intensity of mulching had no significant effect on the number of FAB plant species (Fig. 3B) and grasses (Fig. 4B). The number of plant species (Fig. 1D), forbs (Fig. 2D) and FAB plant species (Fig. 3D) in flower strips increased with increasing temperature. The number of grasses in flower strips was significantly affected by soil pH (Fig. 4D). The number of all plant species (Fig. 1B), forbs (Fig. 2B) and FAB plant species in flower strips (Fig. 3B) did not differ significantly between seasons. However, there were significantly fewer grasses recorded in autumn than in summer (Fig. 4B). There were significantly fewer forbs ($t_{1,83}$ = -3.10, P = 0.004), but more grasss in flower strips ($t_{1,82}$ = 6.65, P < 0.001) in the third year after sowing as compared to the second year.

3.2.2. Ground cover

Ground cover by all plants (Fig. 1E) and forbs (Fig. 2E) was significantly higher in flower strips than in control plots. In contrast, ground cover by grasses was significantly lower in flower strips as compared to control plots (Fig. 4E). Ground cover by forbs (Fig. 2G) and FAB plants in flower strips (Fig. 3F) was significantly reduced by intensive mulching as compared to moderate mulching. The applied mulching regime in flower strips had no significant effect on ground cover by all plants (Fig. 1F) and grasses (Fig. 4F). Ground cover by all plants decreased significantly with increasing precipitation (Fig. 1H). Grass cover in the flower strips was significantly affected by soil pH (Fig. 4H). Ground cover by all plants (Fig. 1F), forbs (Fig. 2F) and FAB plants (Fig. 3F) in flower strips was significantly lower in spring as compared to autumn. In contrast, ground cover by grasses did not differ significantly between spring and autumn (Fig. 4F). Ground cover by all plants (Fig. 1F) and FAB plants (Fig. 3F) did not differ significantly between summer and autumn. Ground cover by forbs (Fig. 2F) was significantly lower in summer than in autumn, whereas ground cover by grasses was higher in summer than in autumn (Fig. 4F). In the third year after sowing, ground cover by all plants ($t_{1,82}$ = 3.77, P < 0.001) and grasses in flower strips ($t_{1,82}$ = 2.74, P = 0.007) was significantly higher as compared to the second year.

3.3. Plant community level

The sown flower strips presented statistically significant dissimilarities in the plant community in comparison with the control plots (Pseudo-$F_{1,35}$ = 10.0, P < 0.001, Fig. 5A). The random forest feature selection revealed that 20 plants, most of them from the sown mixtures and all associated to the flower strip treatment, were influential in the differences observed (Fig. 5A). The most informative plants were, in order of importance, *G. mollugo* L., *G. pyrenaicum,* L. *corniculatus* L., *L. vulgare* Lam., *C. cristatus* L., *A. odoratum* L., *T. pratense* L., *L. hispidus* L. and *C. jacea* L. (Table S1). *Mulching regime* affected the plant community level in flower strips (Pseudo-$F_{1,17}$ = 2.3, P = 0.021, Fig. 5B) with *P. pratense* L. and *G. molle* L. as main drivers of the differences and found exclusively under moderate mulching. All the covariates tested were found to be significant in both PERMANOVA models (P < 0.050).

4. Discussion

4.1. Plant diversity and ground cover in flower strips compared to the traditional orchard vegetation

Sowing flower mixtures in the drive alleys of organic apple orchards increased plant diversity in the second and third year after sowing on average by 43% compared to the spontaneous orchard vegetation. Out of the 110 recorded plant species, 108 were found in flower strips and 77 in control plots. Plant communities were dominated by perennial plants at all sites. The multivariate analysis revealed important differences in the flower strip plant community in relation to the spontaneous vegetation. These were strongly related to the sown species in the flower strips. The most distinguishing species of the plant community were forbs including two legumes species and only one grass species. Although sowing of plants may cause a suppression of natural colonising species (Lepš et al., 2007), species richness of forbs, grasses and FAB plants were significantly higher within flower strips as compared to the traditional orchard vegetation. This was also shown for arable fields (Lepš et al., 2007) and vegetable crops (Balmer et al., 2013; Kang et al., 2013). We show that local diversity at orchard level can greatly benefit from sowing native plant mixtures that may ensure the long-term survival of sown plants (Bischoff et al., 2010). In contrast to flower strips, the vegetation in the control plots was dominated by grass species, as it is often the case in managed orchards due to more intensive management practices (Miñarro, 2012), such as intensive mulching (Granatstein and Sanchez, 2009). In general, a diversification of species-poor grass communities in nutrient-rich sites is difficult to achieve (Kirmer et al., 2018). Also, grassy margins are known to suppress mesotrophic grassland forbs (Critchley et al., 2006).

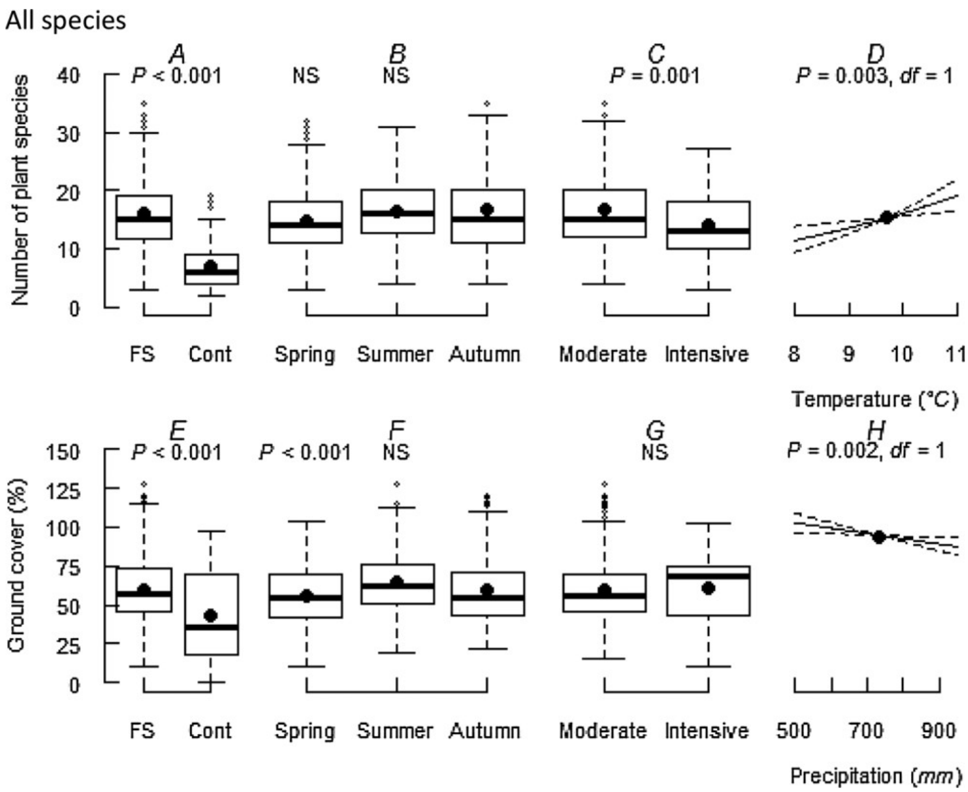

Fig. 1. Number of plant species (A–D) and ground cover (E–H) by all plants. Figures A and E show the difference between flower strips (FS) versus control plots (Cont), whereas figures B–D and F–H show effects of different factors on flower strip vegetation. The boxes represent the interquartile range from the first to the third quartile, the lines across the boxes indicate the median, filled circles show the mean, the whiskers represent the quartiles ± (1.5 × the interquartile distance) and the open circles indicate outliers. The vegetation in spring and summer is compared to the vegetation in autumn (figures B and F). The dashed lines in figures D and H indicate the 95%-confidence interval of the smoothing curves.

A high species richness adapted to local conditions is crucial for the resilience and competitiveness of a plant community against dominant plant species (van der Putten et al, 2000). Sowing (native) plants can suppress dominant, spontaneously growing plant species (Lepš et al., 2007).

Flower strips dominated by only a few species may lose their seasonal functionality due to a possible lack of succession in flower resources throughout the season. Different pests occur at different times and their specific antagonists must be able to build up high populations in advance of pest presence in order to prevent outbreaks and damage (Sigsgaard, 2010; Satar et al., 2015; Porcel et al., 2017; Daniel et al., 2018). In addition, different groups of beneficial arthropods have different needs, which cannot all be met by individual plant species (Uyttenbroeck et al., 2016; Cahenzli et al., 2019, in press AGEE), emphasising the importance of a diverse plant community. A broad spectrum of plant species can also better absorb the development dynamics of the flower strips in the first years after sowing (De Cauwer et al.,

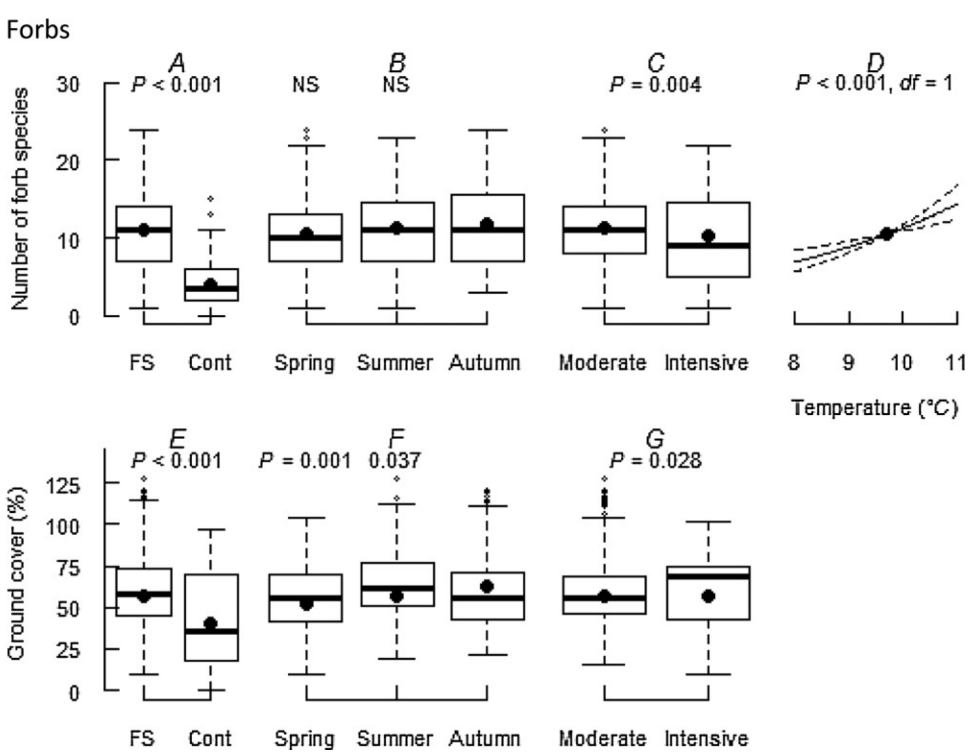

Fig. 2. Number of forb species (A–D) and ground cover (E–G) by forbs. Figures A and E show the difference between flower strips (FS) versus control plots (Cont), whereas figures B–D and F–G show effects of different factors on flower strip vegetation. The boxes represent the interquartile range from the first to the third quartile, the lines across the boxes indicate the median, filled circles show the mean, the whiskers represent the quartiles ± (1.5 × the interquartile distance) and the open circles indicate outliers. The vegetation in spring and summer is compared to the vegetation in autumn (figures B and F). The dashed lines in figure D indicates the 95%-confidence interval of the smoothing curve.

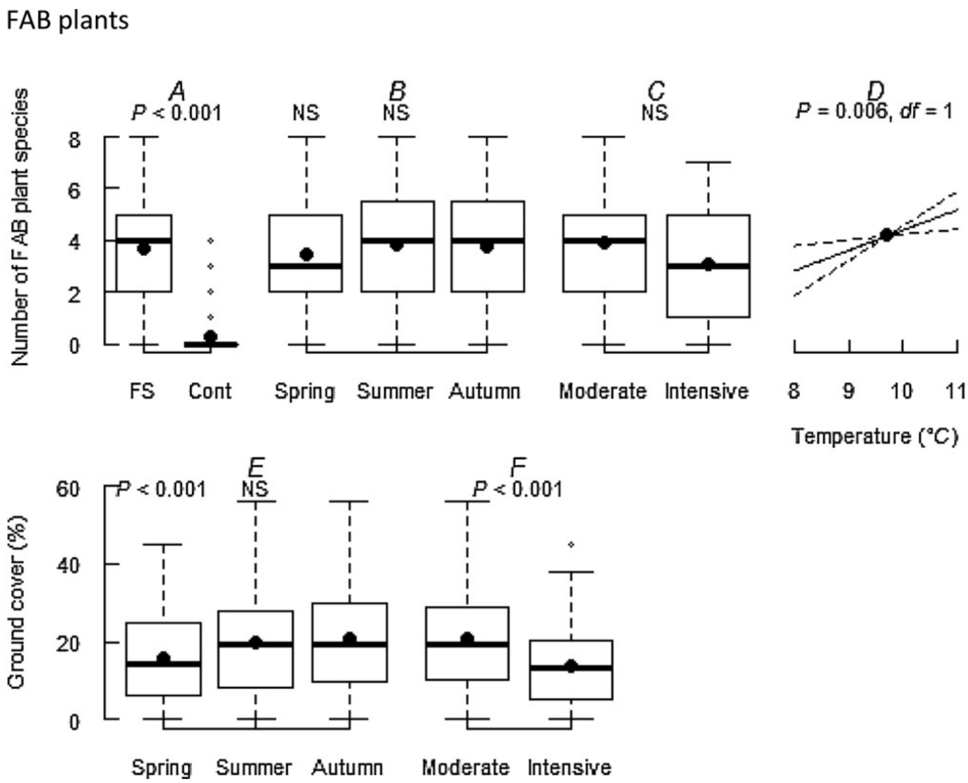

Fig. 3. Number of FAB plant species (A–D) and ground cover (E–F) by FAB plants. Figure A shows the difference between flower strips (FS) versus control plots (Cont), whereas figures B–D and F show effects of different factors on flower strip vegetation. The boxes represent the interquartile range from the first to the third quartile, the lines across the boxes indicate the median, filled circles show the mean, the whiskers represent the quartiles ± (1.5 × the interquartile distance) and the open circles indicate outliers. The vegetation in spring and summer is compared to the vegetation in autumn (figures B and E). The dashed lines in figure D indicates the 95%-confidence interval of the smoothing curve.

2005) and thus create in the medium term stable conditions for the promotion of beneficial arthropods. Therefore, populations of resident natural enemies may increase over the years, potentially also increasing pest control (Bostanian et al., 2004). The seed mixture used in this study did not only increase total plant diversity, but significantly increased the number of flowering forb species. Moreover, the number of FAB plant species, which specifically meet the criteria for the promotion of beneficial arthropods, was significantly increased as compared with the spontaneous orchard vegetation. For instance, wild carrot (*Daucus carota* L.), a biennial plant that requires disturbance to the soil in order to persist in the flower strip, established well in all countries. This makes wild carrot ideal to cope with orchard conditions. The

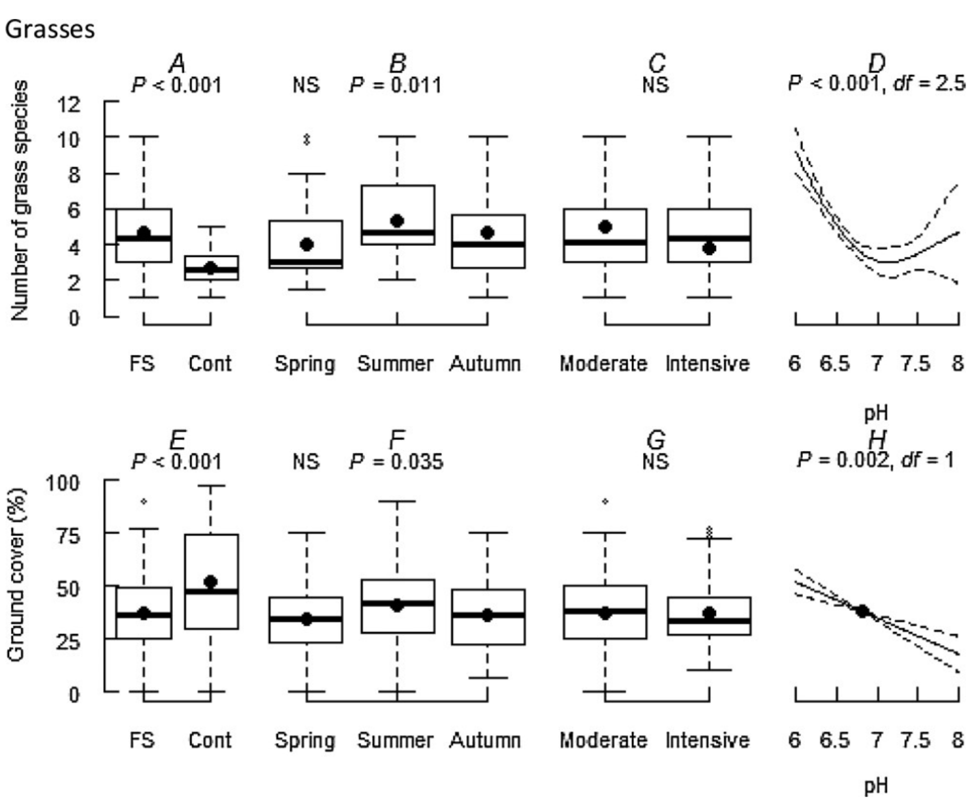

Fig. 4. Number of grass species (A–D) and ground cover (E–H) by grasses. Figures A and E show the difference between flower strips (FS) versus control plots (Cont), whereas figures B–D and F–H show effects of different factors on flower strip vegetation. The boxes represent the interquartile range from the first to the third quartile, the lines across the boxes indicate the median, filled circles show the mean, the whiskers represent the quartiles ± (1.5 × the interquartile distance) and the open circles indicate outliers. The vegetation in spring and summer is compared to the vegetation in autumn (figures B and F). The dashed lines in figures D and H indicate the 95%-confidence interval of the smoothing curves.

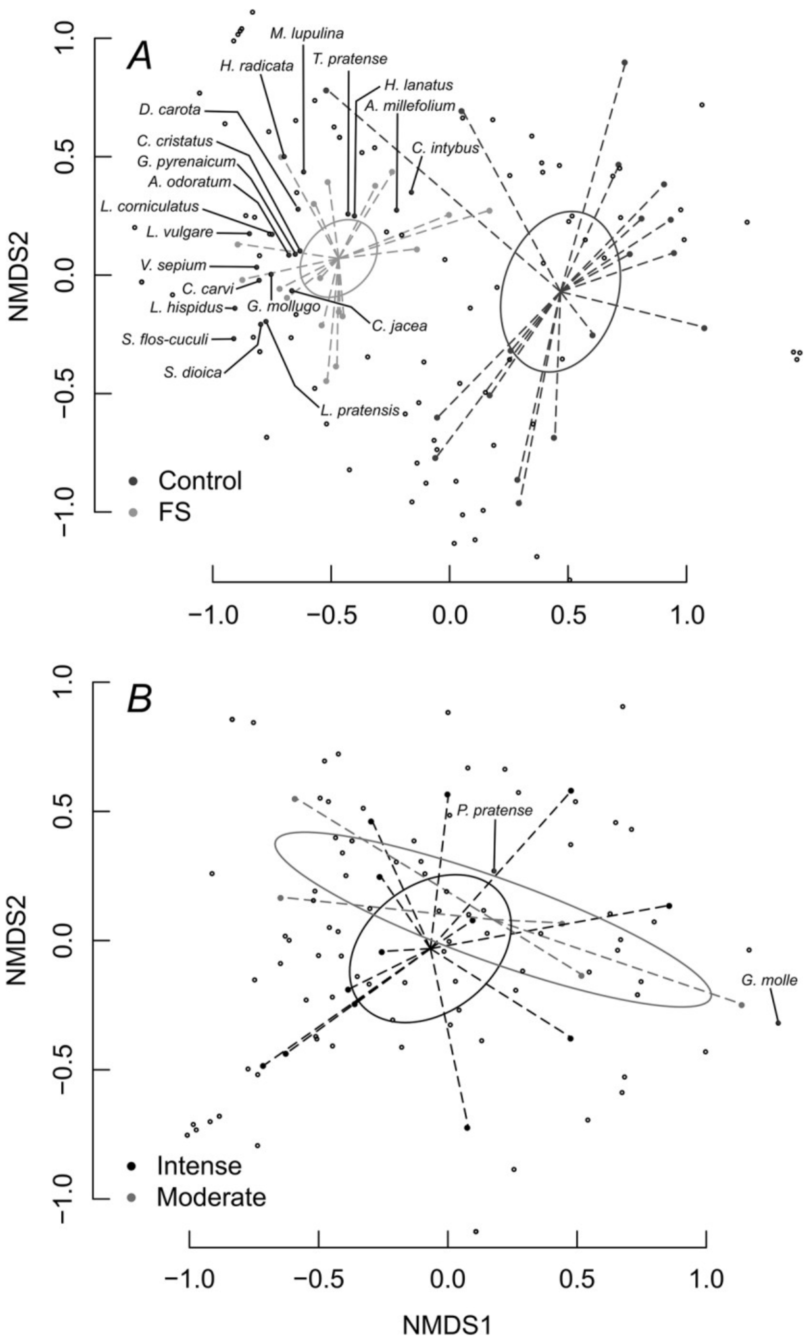

Fig. 5. Non-metric multidimensional scaling (NMDS) representation in two dimensions of (A) the plant community associated to the flower strips and the control orchard vegetation (Stress = 0.115) and (B) the plant community associated to intense and moderate mulching of flower strips (Stress = 0.173). The Bray-Curtis distance was used a dissimilarity measure. Bigger circles indicate the position of individual plots and smaller circles the position of the plant species. Plots belonging to the same group are connected by dashed lines that intersect at the centroid. Ovals represent the standard deviation of plots from the same group. Plant species represented with red circles and labelled with their name were detected with the Boruta algorithm as important in the separation of the groups represented. The plant communities represented were significantly different (PERMANOVA, $P < 0.050$) (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

flower of this plant bears open nectaries, which are very attractive for beneficial insects like Syrphidae (van Rijn and Wäckers, 2016; Földesi et al., 2016), Tachinidae (Al Dobei et al. 2012), Coccinellidae (Walton and Isaacs, 2011) and parasitic wasps (Balmer et al., 2013; Geneau et al., 2012). Furthermore, wild carrot has quite an extended flowering period (especially after one cut), thus serving as FAB plant during the whole summer. In contrast, half of the ground in the control plots was covered with a few grass species, as is often the case in orchards (Miñarro, 2012). Many grass species in orchards (e.g. *Lolium multiflorum* L.*)* are very competitive because they can efficiently use the high amounts of nutrients from the fertile soils (Granatstein and Sanchez, 2009) and their abundance is enhanced by frequent mulching (Uehlinger et al., 2005; Miñarro, 2012). A grass-dominated orchard vegetation with few flowers has only limited potential to promote beneficial arthropods. However, forbs were more dominant in the flower strip plots than in the control plots, which provides a promising approach to enhance natural pest control and pollination in orchards (Albert et al., 2017; Cahenzli et al., 2017; Campbell et al., 2017; Demestihas et al., 2017).

4.2. *Abiotic and anthropogenic factors affecting the flower strips*

Multiple biotic, abiotic and anthropogenic factors affect plant communities in orchards (Granatstein and Sanchez, 2009; Miñarro, 2012). A limiting factor for the establishment of flowering forbs in orchards is frequent mulching. The multivariate analysis revealed a significant influence of the mulching regime on the plant community in flower strips. As compared with moderate mulching, intensive mulching in the flower strips significantly decreased species richness and ground cover by all plants. Specifically, the number of forb species and ground cover by forbs, as well as the number of FAB plants were reduced For instance, the reduction in forb diversity (including FAB-species) due to mulching can be caused by the increase in nitrophilous species such as nettles (*Urtica dioica* L.) and willowherbs (*Epilobium* sp.), which displace other forbs due to their aggressive clonal growth. With novel mulching devices (e.g. Humus OMB®, Germany and Aedes®, Italy and a prototype developed at InHort, Poland), areas along the flower strips may be mulched more often than the flower strips themselves, due to an adjustable cutting height of more than 8 cm of the middle cutting tools. Such a differentiated mulching reduces the competitive pressure from the adjacent spontaneously grown orchard vegetation and conserves the flowering plants in the flower strips. Furthermore, these mulching devices can dump remains from the flower strips into the treeline (Pfiffner et al., 2018). This reduces organic matter content in the flower strips, thus preventing the enhancement of nitrophilous plant species, while improving the nutrition of the trees. However, especially for light germinating species, mulching or mowing of older plants in the flower strip is necessary to ensure good light conditions to facilitate the growth of the following flowers of subsequent species (Pfiffner and Wyss, 2004). Mulching may also reduce the growth of unwanted weeds in flower strips (Granatstein and Sanchez, 2009). Kirmer et al. (2018) showed that mowing in early summer resulted in higher cover of sown target species and less competition by grasses as compared to mowing in autumn in grassland. An excessively reduced mowing regime can lead to an increase in grasses and ultimately to a reduction in plant diversity (Kirmer et al., 2018). For a successful implementation of flower strips in the midterm, it is therefore crucial to apply a site-adapted mulching intensity. However, the frequency and timing of mulching flower strips must be carefully aligned with the stage of development of beneficial arthropods so that they will not be physically harmed and their habitat and food resources will remain intact (Buri et al., 2016). The right time for mulching must be decided by observing the population cycle of beneficial arthropods over the years or by using available data on life cycles (Dib et al., 2010).

The orchards in this study were located across a climate gradient between Southern Sweden and Northern Italy. Short vegetation periods in higher latitudes might hamper a successful development of species-rich flower strips, as the number of forb and FAB plant species significantly decreased with decreasing temperature. Ground cover by all plants slightly decreased with increasing precipitation. This suggests that the selected wild plant species, which naturally occur mainly in dry meadows, are better able to cope with drier conditions. In view of the increased occurrence of drier conditions due to climate change, this could be an advantage in the future. However, sufficient water availability is crucial for the establishment of flower strips in spring.

Soil pH is one of the main factors determining plant community composition in grassland (Ellenberg and Leuschner, 2012). In this study, the number of grass species and ground cover by grasses decreased with increasing soil pH. This is in accordance with the findings of Köhler et al. (2016), who also found a negative correlation between soil pH and grass cover in a wide range of grassland types. However, the effect of soil pH on plant species richness is complex, as it depends on climatic factors like precipitation and temperature (Palpurina et al., 2017). Similarly, precipitation, temperature, soil pH and organic matter all were correlated in this study, but species richness of forbs and FAB plants were best explained by temperature, whereas grasses significantly depended on soil pH.

4.3. Performance and limits of the flower strips

The establishment rate of 73.7% of the sown plant species across all countries showed that the selection of plant varieties for the seed mixture was adequate for apple orchards in different climatic regions in Europe. Although not all sown plant species germinated in the first two years after sowing, a continuous flower supply for beneficial arthropods was achieved. Of note, access to regional native seed mixtures is a bottleneck in some European countries, as for instance in Poland and Italy. Due to the increasing interest of farmers in flower strips and other elements targeting functional agro-biodiversity, various initiatives for the production of native wild flowers have started in Europe (Penvern et al., 2019). Apart from the right plant species, adequate management practices adapted to local climate conditions and access to specific machinery are decisive for the successful implementation of flower strips. For example, with sufficient precipitation, some of the plants sown in April or May germinate before summer drought. Others germinate in the course of the following months or years. For practical reasons, all flower strips in this study were sown in spring. However, sowing in autumn would probably lead to a better plant establishment in Sweden and Denmark, as water availability is higher in autumn than in spring. Generally, management of flower strips should be further adapted to local plant succession in the northern countries. The general guidelines for the management of flower strips were based mainly on experience from mild climate conditions in Switzerland (Pfiffner and Wyss, 2004; Uehlinger et al., 2005). Additionally, the mid-term survival of the sown plant species is not yet known and further adjustments in management may be necessary in the future. Flower strips in the drive alleys of orchards could pose a potential risk of attracting and propagating voles due to increased food supply and protection from birds of prey (Granatstein and Sanchez, 2009). However, we did not observe an increase in vole activity in the flower strips plots, possibly due to mulching after harvest. Regular assessment of the flower strips by the farmer seems essential in order to prevent voles in the flower strips. The key to acceptance by farmers and successful integration of FAB practices in orchards is the availability of technical guides regarding plant selection, the establishment and management of flower strips and the agro-ecological role of flower strips in orchards (Pfiffner et al., 2018).

5. Conclusions

In this study, carried out in different climatic regions of Europe, we show that sowing perennial flower strips consisting of native plants can significantly increase plant diversity and ground cover in the drive alleys of apple orchards. Specifically, the number of FAB plant species, which are important for the promotion of agrobiodiversity, as well as pollen and nectar-providing forbs, significantly increased as compared to the spontaneous orchard vegetation. Due to the favourable establishment of flower strips in the first three years, we recommend the specially tailored seed mixture as a promising, sustainable and long-lasting approach to promote agrobiodiversity in apple orchards. This diversification scheme is worth consideration for national agri-environmental programs. Further research should be carried out to establish locally adapted management strategies in order to ensure the long-term survival of the flower strips and sequential flowering throughout the growing season.

Author contributions

LP, LS conceived the study and designed methodology, BS, LP, LS, MCB, MP, LJ, JL, JT collected the field data; BS carried out data collection and preparation; FC and MP analyzed the data; LP coordinated the drafts of the manuscript, which was written by LP and FC and supplemented by all coauthors.

Declaration of interests

None.

Acknowledgments

We greatly acknowledge A. Herz and W. Świergiel for fruitful comments on the draft, F. Weibel, I. Giordano, A. Jorion, M. Lateur, S. K Jacobsen, Ian Dublon and J. Pålsson for their assistance and all apple growers for their participation. The study was supported by the project “Innovative design and management to boost functional bio-diversity of organic orchards (ECOORCHARD)" provided by FP7 ERA-net project partners, CORE Organic Plus, and the co-financing from the European Commission. National funding bodies were Swiss Federal Office for Agriculture FOAG, the Swedish Research Council for Sustainable Development (Formas, 2014-01905 and 2013-934), the Green Development and Demonstration Programme under the Ministry of Environment and Food of Denmark (GUDP j.nr: 34009-14-0906), Ministero delle politiche agricole e alimentari e forestali (62515), Walloon government for agriculture (D31-1317).

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.agee.2019.03.005.

References

Albert, L., Franck, P., Gilles, Y., Plantegenest, M., 2017. Impact of agroecological infrastructures on the dynamics of Dysaphys plantaginea Passerini (Hemiptera: aphididae) and its natural enemies in apple orchards in northwestern France. Environ. Entomol. 46, 528–537.

Balmer, O., Pfiffner, L., Schied, J., Willareth, M., Leimgruber, A., Luka, H., Traugott, M., 2013. Noncrop flowering plants restore top-down herbivore control in agricultural fields. Ecol. Evol. 3 (8), 2634–2646 1-13.

Balzan, M.V., Bocci, G., Moonen, A.C., 2014. Augmenting flower trait diversity in wildflower strips to optimise the conservation of arthropod functional groups for multiple agroecosystem services. J. Ins. Cons. 18 (4), 713–728. https://doi.org/10.1007/s10841-014-9680-2.

Batáry, P., Dicks, L.V., Kleijn, D., Sutherland, W.J., 2015. The role of agri-environment schemes in conservation and environmental management. Cons. Biol. 29, 1006–1016.

Biologische Bundesanstalt für Land und Forstwirtschaft, 2010. BBCH-Skala. Julius Kühn-Institut (2018-08-24). https://ojs.openagrar.de/index.php/BBCH/issue/view/160.

Bischoff, A., Vonlanthen, B., Steinger, T., Müller-Schärer, H., 2006. Seed provenance matters—effects on germination of four plant species used for ecological restoration. Basic Appl. Ecol. 7, 347–359.

Bischoff, A., Steinger, T., Müller-Schärer, H., 2010. The importance of plant provenance and genotypic diversity of seed material used for ecological restoration. Restor. Ecol. 18, 338–348.

Blaauw, B.R., Isaacs, R., 2012. Larger wildflower plantings increase natural enemy density, diversity, and biological control of sentinel prey, without increasing herbivore density. Ecol. Entomol. 37 (5), 386–394.

Bostanian, N.J., Goulet, H., O'hara, J., Masner, L., Racette, G., 2004. Towards insecticide free apple orchards: flowering plants to attract beneficial arthropods. Biocont. Sci. Technol. 14, 25–37.

Buri, P., Humbert, J.Y., Stańska, M., Hajdamowicz, I., Tran, E., Entling, M.H., Arlettaz, R., 2016. Delayed mowing promotes planthoppers, leafhoppers and spiders in extensively managed meadows. Ins. Cons. Div. 9 (6), 536–545.

Cahenzli, F., Pfiffner, L., Daniel, C., 2017. Reduced crop damage by self-regulation of aphids in an ecologically enriched, insecticide-free apple orchard. Agron. Sustain. Dev. 37 (6), 65.

Cahenzli, F., Sigsgaard, L., Daniel, C., Herz, A., Jamar, L., Kelderer, M., Kramer Jacobsen, S., Kruczyńska, S., Matray, S., Porcel, M., Małgorzata Sekrecka, M., Świergiel, W., Tasin, M., Telfser, J., Pfiffner, L., 2019. Perennial flower strips for pest control in organic apple orchards-A pan-European study. Agric. Ecosyst. Environ (in press).

Cahenzli F., Sigsgaard L., Daniel C., Herz A., Jamar L., Kelderer M., Kramer Jacobsen S., Kruczyńska S., Matray S., Porcel M., Małgorzata Sekrecka M., Świergiel W., Tasin, M., Telfser J., Pfiffner, L., Perennial flower strips for pest control in organic apple orchards - A pan-European study. Agric. Ecosyst. Environ. (in press 2019). Campbell, A.J., Wilby, A., Sutton, P., Wäckers, F.L., 2017. Do sown flower strips boost wild pollinator abundance and pollination services in a spring-flowering crop? A case study from UK cider apple orchards. Agric. Ecosyst. Environ. 239, 20–29.

Critchley, C.N.R., Fowbert, J.A., Sherwood, A.J., Pywell, R.F., 2006. Vegetation development of sown grass margins in arable fields under a countrywide agri-environment scheme. Biol. Conserv. 132, 1–11.

Daniel, C., Matray, S., Stoeckli, S., Niggli, U., 2018. Pest management in organic apple, pear and stone fruit. In: Vacante, V., Kreiter, S. (Eds.), Handbook of Pest Management in Organic Farming. CAB International, pp. 130–150.

De Cauwer, B., Reheul, D., D'hooghe, K., Nijs, I., Milbau, A., 2005. Evolution of the vegetation of mown field margins over their first 3 years. Agric. Ecosyst. Environ. 109 (1-2), 87–96.

Degenhardt, F., Seifert, S., Szymczak, S., 2017. Evaluation of variable selection methods for random forests and omics data sets. Brief. Bioinf pmid:29045534.

Demestihas, C., Plénet, D., Génard, M., Raynal, C., Lescourret, F., 2017. Ecosystem services in orchards. A review. Agron. Sustain. Dev. 37 (2), 12.

Dib, H., Simon, S., Sauphanor, B., Capowiez, Y., 2010. The role of natural enemies on the population dynamics of the rosy apple aphid, *Dysaphis plantaginea* Passerini (Hemiptera: aphididae) in organic apple orchards in south-eastern France. Biol. Cont. 55 (2), 97–109.

Dib, H., Sauphanor, B., Capowiez, Y., 2016. Effect of management strategies on arthropod communities in the colonies of rosy apple aphid, Dysaphis plantaginea Passerini (Hemiptera: aphididae) in south-eastern France. Agric. Ecosyst. Environ. 216, 203–206.

Ellenberg, H., Leuschner, C., 2012. Vegetation Mitteleuropas Mit Den Alpen. 6. Verlag Eugen Ulmer, Stuttgart UTB 8104.

European Commission, 2005. Agri-environment Measures: Overview on General Principles, Types of Measures and Application. European Commission, Directorate General for Agriculture and Rural Development.

European Commission, 2009. Sustainable Use of Pesticides Directive 2009/128/EC.

European regulation No 1307, 2013. Regulation (EU) No 1307/2013 of the European Parliament and of the Council of 17 December 2013 Establishing Rules for Direct Payments to Farmers Under Support Schemes Within the Framework of the Common Agricultural Policy and Repealing Council Regulation (EC) No 637/2008 and Council Regulation (EC) No 73/2009.

FAL, RAC, FAW, 1996. Schweiz. Referenzmethoden der Eidg. Landwirtschaftlichen Forschungsanstalten. Agroscope FAL Reckenholz, RAC Changins, FAW Wädenswil, Zürich-Reckenholz.

Feltham, H., Park, K., Minderman, J., Goulson, D., 2015. Experimental evidence that wildflower strips increase pollinator visits to crops. Ecol. Evol. 5 (16), 3523–3530.

Földesi, R., Kovács-Hostyánszki, A., Kőrösi, Á., Somay, L., Elek, Z., Markó, V., Sárospataki, M., Bakos, R., Varga, Á., Nyisztor, K., Báldi, A., 2016. Relationships between wild bees, hoverflies and pollination success in apple orchards with different landscape contexts. Agric. For. Entomol. 18, 68–75.

Garibaldi, L.A., Carvalheiro, L.G., Leonhardt, S.D., Aizen, M.A., Blaauw, B.R., Isaacs, R., Kuhlmann, M., Kleijn, D., Klein, A.M., Kremen, C., Morandin, L., 2014. From research to action: enhancing crop yield through wild pollinators. Front. Ecol. Environ. 12, 439–447.

Geiger, F., Bengtsson, J., Berendse, F., Weisser, W.W., Emmerson, M., Morales, M.B., Ceryngier, P., Liira, J., Tscharntke, T., Winqvist, C., Eggers, S., 2010. Persistent negative effects of pesticides on biodiversity and biological control potential on European farmland. Basic Appl. Ecol. 11 (2), 97–105.

Geneau, C.E., Wäckers, F.L., Luka, H., Daniel, C., Balmer, O., 2012. Selective flowers to enhance biological control of cabbage pests by parasitoids. Basic Appl. Ecol. 13/1, 85–93.

Granatstein, D., Sanchez, E., 2009. Research knowledge and needs for orchard floor management in organic tree fruit systems. Int. J. Fruit Sci. 9, 257–281.

Gurr, G., Wratten, S.D., Landis, D.A., 2017. Habitat management to suppress pest populations: progress and prospects. Annu. Rev. Entomol. 2017, 91–109.

Harmonized World Soil Database, 2012. HWSD Viewer, Based on WRB (World Reference Base for Soil Resources). Version 1.2. http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/.

Hooper, D.U., Adair, E.C., Cardinale, B.J., Byrnes, J.E., Hungate, B.A., Matulich, K.L., O'Connor, M.I., 2012. A global synthesis reveals biodiversity loss as a major driver of ecosystem change. Nature 486 (7401), 105–108.

Isbell, F., Adler, P.R., Eisenhauer, N., Fornara, D., Kimmel, K., Kremen, C., Letourneau, D.K., Liebman, M., Polley, H.W., Quijas, S., Scherer-Lorenzen, M., 2017. Benefits of increasing plant diversity in sustainable agroecosystems. J. Ecol. 105 (4), 871–879.

IUSS Working Group Wrb, 2015. World Reference Base for Soil Resources 2014, Update 2015 International Soil Classification System for Naming Soils and Creating Legends for Soil Maps. World Soil Resources Reports No. 106. pp. 192.

Kang, W., Hoffmeister, M., Martin, E.A., Steffan-Dewenter, I., Han, D., Lee, D., 2013. Effects of management and structural connectivity on the plant communities of organic vegetable field margins in South Korea. Ecol. Res. 28, 991–1002.

Keller, M., 1999. The Importance of Seed Source in Programmes to Increase Species Diversity in Arable Systems. Geobotanisches Institut, Zürich, ETH, pp. 90.

Kirmer, A., Rydgren, K., Tischew, S., 2018. Smart management is key for successful diversification of field margins in highly productive farmland. Agric. Ecosyst. Environ. 251, 88–98.

Köhler, I.H., Macdonald, A.J., Schnyder, H., 2016. Last-century increases in intrinsic water-use efficiency of grassland communities have occurred over a wide range of vegetation composition, nutrient inputs, and soil pH. Plant Physiol. 170, 881–890.

Kühn, I., Durka, W., Klotz, S., 2004. BiolFlor: a new plant-trait database as a tool for plant invasion ecology. Divers. Distrib. 10 (5/6), 363–365.

Kursa, M.B., Rudnicki, W.R., 2010. Feature selection with the Boruta package. J. Stat. Softw. 36, 1–13.

Lepš, J., Doležal, J., Bezemer, T.M., Brown, V.K., Hedlund, K., Igual, A.M., Jörgensen, H.B., Lawson, C.S., Mortimer, S.R., Peix Geldart, A., Rodríguez Barrueco, C., 2007. Long-term effectiveness of sowing high and low diversity seed mixtures to enhance plant community development on ex-arable fields. Appl. Veg. Sci. 10 (1), 97–110.

Marliac, G., Mazzia, C., Pasquet, A., Cornic, J.F., Hedde, M., Capowiez, Y., 2016. Management diversity within organic production influences epigeal spider communities in apple orchards. Basic Appl. Ecol. 216, 73–81.

Miñarro, M., 2012. Weed communities in apple orchards under organic and conventional fertilization and tree-row management. Crop Prot. 39, 89–96.

Newbold, T., Hudson, L.N., Arnell, A.P., Contu, S., De Palma, A., Ferrier, S., Hill, S.L.L., Hoskins, A.J., Lysenko, I., Phillips, H.R.P., 2016. Has land use pushed terrestrial biodiversity beyond the planetary boundary? Global Assess. Sci. 353, 288–291.

Paar, P., Röhricht, W., Schuler, J., 2008. Towards a planning support system for environmental management and agri-environmental measures—the Colorfields study. J. Environ. Manage. 89 (3), 234–244.

Palpurina, S., Wagner, V., von Wehrden, H., Hájek, M., Horsák, M., Brinkert, A., Hölzel, N., Wesche, K., Kamp, J., Hájková, P., Danihelka, J., 2017. The relationship between plant species richness and soil pH vanishes with increasing aridity across Eurasian dry grasslands. Global Ecol. Biogeol. 26 (4), 425–434.

Penvern, S., Fernique, S., Cardona, A., Ahrenfeldt, E., Grébeau, D., Jamar, L., Kruczyńska, D., Matray, S., Ozolina-Pole, L., Porcel, M., Ralle, B., Steinemann, B., Świergiel, W., Tasin, M., Telfser, J., Warlop, F., Dufils, A., Korsgaard, M., Herz, A., Sigsgaard, L.,

2019. Farmers Management of Functional Biodiversity Goes Beyond Pest Management in European Organic Apple Orchards. Submitted. .
Pfiffner, L., Wyss, E., 2004. Use of Sown Wildflower Strips to Enhance Natural Enemies of Agricultural Pests. Ecological Engineering for Pest Management - Advances in Habitat Manipulation for Arthropods. pp. 165–186.
Pfiffner, L., Jamar, L., Cahenzli, F., Korsgaard, M., Swiergiel, W., Sigsgaard, L., 2018. Perennial Flower Strips – A Tool for Improving Pest Control in Fruit Orchards. 2018, Technical Guide Nr. 1096, 16p. Edts. FiBL, SLU, CRAW, VKST, UCPH. www.fibl-shop.org.
Porcel, M., Cotes, B., Campos, M., Castro, J., 2017. The effect of resident vegetation cover on abundance and diversity of green lacewings (Neuroptera: Chrysopidae) on olives trees. J. Pest Sci. (2004) 90 (1), 195–206.
Porcel, M., Andersson, G.K.S., Pålsson, J., Tasin, M., 2018. Organic management in apple orchards: higher impacts on biological control than on pollination. J. Appl. Ecol. 0, 1–11. https://doi.org/10.1111/1365-2664.13247.
R Development Core Team, 2016. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna.
Satar, S., Raspi, A., Özdemir, I., Tusun, A., Karacaoğlu, M., Benelli, G., 2015. Seasonal habits of predation and prey range in aphidophagous silver flies (Diptera Chamaemyiidae), an overlooked family of biological control agents. Bull. Insect. 68 (2), 173–180.
Sigsgaard, L., 2010. Habitat and prey preferences of the two predatory bugs Anthocoris nemorum (L.) and A. nemoralis (Fabricius) (Anthocoridae: Hemiptera-Heteroptera) Biol. Cont. 53, 46–54.
Simon, S., Bouvier, J.C., Debras, J.F., Sauphanor, B., 2010. Biodiversity and pest management in orchard systems. A review. Agron. Sust. Dev. 30 (1), 139–152.
Tittonell, P., 2014. Ecological intensification of agriculture—sustainable by nature. Curr. Opi. Environ. Sust. 8, 53–61.
Tscharntke, T., Klein, A.M., Kruess, A., Steffan-Dewenter, I., Thies, C., 2005. Landscape perspectives on agricultural intensification and biodiversity – ecosystem service management. Ecol. Lett. 8, 857–874.
Tschumi, M., Albrecht, M., Bärtschi, C., Collatz, J., Entling, M.H., Jacot, K., 2016. Perennial, species-rich wildflower strips enhance pest control and crop yield. Agric. Ecosyst. Environ. 220, 97–103.
Uehlinger, G., Schaffner, D., Pfiffner, L., 2005. Does soil tillage or cutting regime improve the quality of wildflower strips? Agrarforschung 12, 332–337.
Uyttenbroeck, R., Hatt, S., Paul, A., Boeraeve, F., Piqueray, J., Francis, F., Danthine, S., Frederich, M., Dufrene, M., Bodson, B., Monty, A., 2016. Pros and cons of flowers strips for farmers. A review. Biotechnol. Agron. Soc. Environ. 20, 225–235.
Van der Putten, W.H., Mortimer, S.R., Hedlund, K., Van Dijk, C., Brown, V.K., Lepä, J., Rodriguez-Barrueco, C., Roy, J., Len, T.D., Gormsen, D., Korthals, G.W., 2000. Plant species diversity as a driver of early succession in abandoned fields: a multi-site approach. Oecologia 124, 91–99.
van Rijn, P.C.J., Wäckers, F.L., 2016. Nectar accessibility determines fitness, flower choice and abundance of hoverflies that provide natural pest control. J. Appl. Ecol. 53, 925–933.
Walton, N.J., Isaacs, R., 2011. Survival of Three Commercially Available Natural Enemies Exposed to Michigan Wildflowers. Environ. Entomol. 40, 1177–1182.
Wood, S.N., 2006. Generalized Additive Models: an Introduction With R. Chapman & Hall/CRC, Boca Raton, Florida.
Wratten, S.D., Gillespie, M., Decourtye, A., Mader, E., Desneux, N., 2012. Pollinator habitat enhancement: benefits to other ecosystem services. Agric. Ecosyst. Environ. 159, 112–122.
Zehnder, G., Gurr, G.M., Kühne, S., Wade, M.R., Wratten, S.D., Wyss, E., 2007. Arthropod pest management in organic crops. Annu. Rev. Entomol. 52, 57–80.
Zuur, A.F., Ieno, E.N., Walker, N.J., Saveliev, A.A., Smith, G.M., 2009. Mixed Effects Models and Extensions in Ecology With R. Springer Science + Business Media ISBN 978-0-387-87457-9.