Establishment of permanent weed strips with autochthonous nectar plants and their effect on the occurrence of aphid predators

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Abstract

Weed strips with flowering plants in orchards can enhance the number of predatory arthropods, especially those predators with adults requiring nectar and pollen. The weeds used in such trials usually are very attractive nectar plants with high flowering density. In this study, weed strips mostly containing autochthonous perennial plants that should succed in establishing in the alleys of the orchards were tested in on-farm trials in two regions of Southern Germany. The plant mix used is sown only once in the life of an orchard, and can be mulched two to three times a year. Achillea millefolium, Galium album, Carum carvi, Crepis capillaris *and* Picris hieriacoides *could be established in several orchards. Even if the density of flowering plants attractive for syrphids in the perennial weed strips was not very high, a significant effect on the occurrence of syrphid eggs and larvae was observed on bait trees with aphid colonies exposed in June/July 2012 and 2013. For other aphid predators, the effect was more variable. These first results indicate that permanent weed strips can be a sustainable way to enhance functional biodiversity in orchards even if the density of flowers is not as high as in strips renewed periodically. Further studies are needed to optimize plant species composition and the mulching regime. If biodiversity management is extended to all arthropod species, then plant species composition should focus not only on nectar plants for aphid predators but also on plants that are essential for other species such as wild bees, bumblebees and butterflies.*

Keywords: weed strips, orchard, nectar plants, aphid predators

Introduction

The idea to establish weed strips with flowering plants in orchards to enhance predator densities has a very long tradition in organic fruit growing. In 1986, a grower in the Lake Constance region started to sow nectar plants in the alleys of his orchards (Kienzle, 1988). Some years later, first trials were published with sown weed strips that could be mulched (Kienzle & Straub, 1991), with natural vegetation and extensive mulching (Kienzle *et al*., 1995) and with rather unmulched sown weed strips (Wyss, 1994). Since the enhancement of predatory arthropods failed to control key pests such as the Rosy apple aphid and, on the other hand, the flowering plants in the weed strips did not establish in time and problems with voles and field mice occurred, weed strips were never introduced as a common practice (Kienzle *et al*., 1997). Within the frame of the BOELN-project 03OE178 and 06OE100, a group of interested fruit growers and experts again started to discuss the feasibility of the weed strip idea (Kienzle, 2008).

Ever since fruit growers began to understand the importance of diversified plant protection strategies, they are focusing on the augmentation of aphid predators. In June and July, when temperatures are higher and plants start flowering, predators can contribute considerably to control aphid populations that occur during this period. In a project financed by

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Deutsche Bundesstiftung Umwelt, fruit growers and scientists from different disciplines have been collaborating on a concept of permanent weed strips for the enhancement of aphid predators in Southern Germany. The establishment of different **nectar plants with open flowers** which in the following will be abbreviated as "**ONP"** was tested and the effects of these strips on aphid predators were investigated.

Material and Methods

The **design** of these trials requires considerably sized sampling plots. As a consequence, many external factors may impact the results. Thus, a high number of replicates is needed to support the results. On-farm trials and several farms participating are required to generate robust results. If different treatments are performed in just one orchard, then concentration effects have to be considered. Arthropods and voles may be attracted by the weed strips and may migrate from parts without flowering plants to the part with flowering plants and higher vegetation. On the other hand, if treatments are spread over different farms, then external factors such as the surrounding landscape may have an overriding effect. This study provides a combination of different treatments in a small area with large scale treatments involving different farms (table 1). Thus, the advantages and disadvantages of both trial designs may be addressed. Furthermore, the number of replicates was as high as technically possible.

Table 1: Trial design (ORD = orchards are distant, ORC = orchards are close, PL = 2 plots in the same orchard) in the regions Lake Constance (LC) and Neckar valley (NE). Each different area is coded with a letter.

Region	Re-plicate	Trial design	Area	Strips	Hail net	Variety	Size of the plot/orchard	Dates of assessment of aphid predators
LC	1	ORD	A	+	+	Topaz	1.2 ha	25.6. 2013 2.7. 2013 9.7.2013 17.7.2013
			B	-	+	Topaz	Plot of 0.5 ha in > 10 ha	
	2	ORD	A	**+**	+	Topaz	1.7 ha	
			B	**-**	+	Topaz	ca. 2 ha	
	3	ORD	A	**+**	+	Topaz	Plot of 0.3 in 2 ha	
			B	**-**	+	Santana	ca. 3 ha	
NE	1	PL	C	+	+	Topaz	1 ha in 3 ha	22.6.2012 26.6.2012 11.7.2013 18.7.2013 22.7.2013 27.7.2013
			C	-	+	Topaz	1 ha in 3 ha	
	2	ORC	D	+	-	Elstar	0,7 ha	
			D	-	-	Opal	0,4 ha	

For all trials certified autochthonous seeds (Rieger-Hofmann) were used. In the region of Lake Constance (LC) new weed strips were sown between the tractor lanes in summer of 2012 in alternating tree rows. In the other rows, weed strips sown in summer of 2011 already existed (seed mixtures see table 2, ONP were mixed with other species to achieve a well balanced vegetation). Additionally, this grower started to establish weed strips at the farm boundary with *Anthemis tinctoria* as dominating flowering species. The distance of these strips to the bait trees was always more than 70 m, except for replicate 1 where one strip was located at the front end of the orchard and horizontally to the tree lines(ca. 45 m distance to the bait trees). In the Neckar valley region (NE) orchards with existing weed strips were used (table 2). In two other orchards weed strips were sown in 2012 and only the establishment of the sown plants was recorded (table 3). In the LC region orchards the

strips were mulched once during apple bloom whereas in the NE region the strips were not mulched before the end of the assessment period. The rest of the alley in both regions was mulched at shorter intervals. In NE, in 2013 the rest of the alley was mulched just after the bait trees had been set up. Due to the roll following this mowing machine the plants were borne down.

The **botanical assessment** in each orchard was done in 3 plots of 1 m² (2 m x 0,5 m). Occurrence of all plant species in the seed mixture was assessed counting the number of individuals and flowering individuals per species.

Table 2: Important ONP species tested in the different seed mixtures

Species	Colour of blossom	ONP	Month of blossom	Mix 1 2006, 2007	Mix 2, 2011	Mix 3, 2011	Mix 4, 2012
Achillea millefolium	white	+	6-9	+	+	+	+
Anthemis tinctoria	yellow	+	6-8		+		+
Ajuga reptans	blue		4-7	+			
Bellis perennis	white	+	3-8	+			
Carum carvi	white	+	6-7		+		+
Cichorium intybus	blau		7-9		+		+
Crepis capillaris	yellow	+	6-8		+	+	+
Daucus carota	white	+	7-9		+		+
Dianthus deltoides	red	+	6-8	+			
Galium album	white	+	5-9	+	+	+	+
Geranium pyrenaicum	rose	+	6-8	+	+	+	+
Hypochoeris radicata	yellow	+	6-10	+		+	
Knautia arvensis	blue	+	6-8	+	+		+
Leontodon autumnalis	yellow	+	6-9	+			
Leontodon hispidus	yellow	+	6-10	+	+	+	+
Leucanthemum ircutianum	Yell.white	+	6-9		+		+
Lotus corniculatus	yellow		6-8	+	+	+	+
Medicago lupulina	yellow		6-9	+	+	+	+
Myosotis arvensis	blue	+	4-10	+	+		+
Onobrychis viciifolia	rose		5-8		+		+
Origanum vulgare	rose	+	7-10		+		+
Picris hieracioides	yellow	+	7-10		+	+	+
Prunella vulgaris	violet		6-10	+	+	+	+
Sanguisorba minor	brown		5-8	+	+	+	+
Saponaria officinalis	rose	+	6-9	+	+		+
Scabiosa columbaria	violet	+	6-9		+		+
Silene vulgaris	white		5-10		+		+
Thymus pulegioides	violet	+	6-9		+		
Trifolium campestris	yellow		6-8		+	+	+
Trifolium dubium	yellow		5-8		+	+	+
Trifolium pratense	violet		6-10		+		+

The **occurrence of aphid predators** was assessed using bait trees. In 2012, 20 2-year old trees of the Topaz variety were exposed in pots (diameter 30 cm) in each orchard. Pots were buried in the tree rows with 6 regular trees between the potted trees. In 2013, 24 pots (diameter 13 cm) containing small trees of the Topaz variety were exposed in each orchard. These trees were provided with a wick and put on the top of vases filled with water hanging in the trees in the middle of the orchard (fig. 1). There were always 3

Figure 1: bait trees exposure

regular trees between the potted bait trees. Once a week, the water in the vases was refilled to ensure sufficient water supply.

The bait trees were provided with large amounts of N-fertilizer and artificially infected with green apple aphids (mainly *Aphis pomi* De Geer) collected previously in the field. During the period of colony establishment, the trees were protected by nets to prevent access for predatory arthropods. The nets were removed after the bait trees had been exposed in orchards with developed aphid colonies (average more than 50 aphids per shoot). Ants could reach the trees and were busy in attending the aphid colonies, but earwigs seemed to have problems to access.

Subsequently, the shoots of the small trees were controlled for aphids and predators at regular intervals (table 1). All developmental stages (eggs, larvae, pupaer parasitized aphids, adults) of predators were recorded. Egg clusters of ladybirds were counted as one occurrence.

In each orchard, natural infestation was monitored starting at at the second assessment date of the bait trees by counting aphid colonies on 2,000 randomly selected shoots. The prevalent aphid species was *A. pomi,* only very few colonies of *Dysaphis plantaginea* Pass. were present. Natural aphid infestation depended mainly on the vigour of the shoots. The higher abundance of aphids in the orchard with strips in replicate 1 of LC and in the orchard without strips in replicate 1 of NE was evidently due to a higher vigour of the trees. In all orchards studied, control of diseases was achieved with copper, sulphur, potassium hydrogencarbonate and lime sulphur. Before and during fading blossom NeemAzal-T/S was applied against the Rosy apple aphid. In summer, granulovirus was applied to control codling moth. In the LC region in March 2013 an unexpected infestation of *Anthonomus pomorum* L. occurred. A part of the whole farm, especially the plots with the variety Topaz where the samples were taken, had to be treated with Pyrethrum on 16.4.2013.

Results

Establishment of the ONP species

Figure 2: Five year old weed strip in replicate 1 the region NE

The ONP species tested are typical for the regional ground vegetation in extensively cultivated old orchards that are typically mulched or mowed twice per year. However, not all species successfully established in the strips. Table 3 provides results for the long term development of ONP species that successfully established at least in some orchards. Establishment of some attractive ONP species such as *Knautia arvensis* and *Scabiosa columbaria* was generally not successful.

Table 3: Summary of establishment of selected species of open nectar plant species sown in the strips in the region of Neckar valley (Soil type loess loam, sown in spring) and Lake Constance (soil type sand loam, sown in summer). The letter indicates the initial establishment, the arrow indicates the establishment after the third year after sowing sowing (ne = not established, C = Corresponding, R = reduced in relation to the number expected from the quantity in the seed; ↓ reduced, ↑ = increased → constant in relation to the initial number; ↡ = vanished, - = not part of the seed mixture tested in this orchard)

Region Neckar valley						
Test Nr.	1	2	3	4	5	6
Sun irradiation	high	high	High	High	high	high
Mulching	2-3 x	2-3 x	2-3 x	2-3 x, since 2012 4-5 x	2-3 x, since 2012 4-5 x	no mulching
Species/Year of seed	2006	2007	2009	2007	2007	2012
Achillea millefolium	C→	C↑	C↓	C↓	C→	ne
Anthemis tinctoria	C↓	-	C↓	-	-	C
Carum carvi	C↑	C→	Ne	R↡	C↡	ne
Cichorium intybus	-	-	C↓	-	-	R
Crepis capillaris	C↓	C↓	-	C→	C→	ne
Daucus carota	C↓	-	C↓	-	-	C
Galium album	C→	C↑	C↓	C↑	C↑	R
Geranium pyrenaicum	C→	C→	C→	C→	C→	ne
Hypochoaeris radicata	C↓	-	-	-	-	-
Leucanthemum ircutianum	-	-	C↓	-	-	ne
Picris hieracioides	-	-	-	-	-	ne

Region Lake Constance							
Test-Nr.	1	2	3	4	5	6	7
Sun irradiation	low	low	medium	medium	medium	high	medium
Year an season of seed	2011	2012	2012	2011	2012	2012	2012
Mulching	Not in 2012, 2 x in 2013	1 x	1 x	Not in 2012, 2 x in 2013	1 x	1 x	4-5 x
Species/Year of Seed	2011	2012	2012	2011	2012	2012	2012
Achillea millefolium	R↓	R	R	C→	C	R	C
Anthemis tinctoria	-	ne	R	-	R	C	ne
Carum carvi	ne	ne	Ne	Ne	ne	ne	C
Cichorium intybus	C↓	C	R	C↓	C	R	C
Crepis capillaris	R↓	R	C	-	C	C	R
Daucus carota	C↓	C	C	C→	C	C	ne
Galium album	R↓	R	R	R↓	R	ne	R
Geranium pyrenaicum	R→	C	R	C→	C	ne	ne
Hypochaeris radicata	C↓	-	-	-	-	-	-
Leucanthemum ircutianum	C↓	RR	C	C→	C	R	R
Picris hieracioides	ne	ne	C	Ne	C	R	R

Nectar plant species flowering during the period of aphid predator assessment

While ONP flowers were visible everywhere in the orchard in comparatively small numbers, cover by ONP was also rather small in the seeded strips (figure 2, table 4).

Table 4: Occurence and abundance of ONP flowering in the different orchards with weed strips at the assessment date of the bait trees with highest predator abundance (region LC at 9. July 2013, region NE at 22. July 2013): Number of flowering individuals per m² at the assessment date with the highest abundance of aphid predators

Region	LC			NE 2012		NE 2013	
Replicate	1	2	3	1	2	1	2
Achillea millefolium	2.3	1.6	6	13	15	2.7	4
Anthemis tinctoria	-	-	3	-	0.1	-	0.1
Crepis capillaries	1	4	4	-	-	-	0.1
Cichorium intybus	2.3	3	2	-	0.1	-	-
Galium album	-	-	-	>50	> 50	>50	>50
Geranium pyrenaicum	1.7	0.1	-	0.1	0.1	0.3	0.1
Hypochoaeris radicata	0,1	-	-	-	-	-	-
Leucanthemum ircutianum	3.7	6	11	-	0.1	-	0.1
Lotus corniculatus	5	4.3	5	2	2	0.3	-
Picris hieriacioides	0,5	1	0,5	-	-	-	-
Most abundant other species	*Grass, T. dubium, T. pratense*	*T. dubium, T. pratense*	*T. dubium, T. pratense, R. acetosa*	*T. re-pens*, grass, *T. pratense*	*T. repens,* grass	*T. repens,* grass, *T. pratense*	*T. repens,* grass

In the control orchards, the grass was mulched frequently. In the LC region, flowering mainly was restricted to *Bellis perennis* blooming shortly after mulching. In the NE region, few *Galium album* and *Crepis biennis* were flowering in the mulched orchards. During the period of arthropod assessment, the tree rows were processed mechanically (NE, LC no strips) or covered with mulched grass (LC, strips). As a consequence, the vegetation was not assessed.

Abundance of aphid predators

Arthropod abundance was very low during the first assessments in the LC region. In the first half of July, a syrphids oviposition peak was observed. Some syrphid larvae drowned in the irrigation vases. Therefore, the number of larvae recorded is less than the real number. However, significantly more syrphid eggs and larvae were found in orchards with strips.

Due to heat damage affecting the bait trees in Hohenheim in June 2013, in the NE region bait trees could be exposed only starting mid July when the oviposition period of the syrphids nearly came to an end. Syrphids were significantly more abundant in the orchards with strip s (table 5). In 2012, the number of syrphid eggs and larvae was higher in the orchards with strips, however, no significant difference could be shown due to a high concentration on few shoots yielding a high variance in the data set.

For Coccinellidae (mainly *Harmonia axyridis* Pallas) results are less distinct. In the LC region the population in two orchards with strips was even lower as compared to orchards without strips. Apparently the ladybird population in this area was generally very low. In the NE region, where the orchards are situated at close distance, the abundance was higher in the orchards with strips, but this was significant only for all replicates in 2013 and for the second replicate in 2013 (table 5). For the number of parasitized aphids (aphid parasitoids) and *Aphidoletes aphidimyza* the situation is similar: In the LC region abundance of parasitoides and *A. aphidimyza* is very variable**.**

In the NE region all replicates considered there is a significantly higher abundance in the orchards with strips in 2013 and for aphid parasitoids also in 2012 (table 5). In the orchard with strips in replicate1 in the LC region and in the control in replicate 1 in the NE region, the aphid population was much higher as compared to the other orchards. There is no evidence that results in these replicaters differ from the results in the other orchards.

Table 5: Occurrence of the most abundant families of aphid predators (n per 10 aphid colonies) in the orchards with and without weed strips during the whole period of assessment in 2012 and 2013: The orchards of the single replicates and all replicates of one region were analized with the Wilcoxon-Wilcox or Kruskal-Wallis test. Different letters mean significant differences (α = 0.01). Letters with * are significantly different at α = 0.05. Trial design (ORD = orchards are distant, ORC = orchards are close, PL = 2 plots in the same orchard)

Region/ Year	Re-plicate	Trial De-sign	N of assess-ments	Strips	Natural aphid infestation level in %	N of aphid colonies assessed	Coccinel-lidae	Syr-phids	Antho-coridae	*A. aphidi-myza*	Para-sitoids
LC 2013	1	ORD	4	+	2,5	94	0,10 a	15,88 a	0,00 a	1,03 a	13,09 a
				-	0,5	141	0,43 a	1,99 b	0,00 a	0,00 a	6,67 b
	2	ORD	4	+	0,5	122	0,00 a	16,99 a	0,00 a	0,00 a	0,33 a
				-	0,4	102	1,37 a	2,55 b	0,59 b	1,54 b	0,00 a
	3	ORD	4	+	0,8	158	0,25 a	12,85 a	0,13 a	0,44 a	0,00 a
				-	0,3	126	0,00 a	2,14 b	0,00 a	0,71 a	2,86 b
	All replicates		**4**	**+**	**1,2**	**1,2**	**0,13 a**	**14,97 a**	**0,05 a**	**0,95 a**	**3,47 a**
				-	**0,4**	**0,4**	**0,54 a**	**2,20 b**	**0,16 a**	**0,24 a**	**3,52 a**
NE 2013	1	PL	4	+	0,6	85	2,47 a	2,94 a*	7,18 a	6,82 a	11,17 a
				-	6,5	164	1,58 a	0,91 b*	0,73 a	0,91 b	1,64 b
	2	ORC	4	+	0,0	68	16,17 a	3,67 a	2,50 a	8,38 a	3,38 a
				-	0,0	122	1,88 b	0,41 b	0,59 b	3,60 a	0,00 b
	All replicates		**4**	**+**	**153**	**0,3**	**8,56 a**	**3,27 a**	**5,03 a**	**7,51 a***	**7,71 a**
				-	**286**	**3,3**	**1,71 b**	**0,69 b**	**0,70 b**	**2,06 b ***	**0,94 b**
NE 2012	1	ORC	2	+	0	78	3,71 a	9,87 a	0,51 a	0,26 a	3,01 a*
				-	0	96	3,23 a	1,35 a	0,42 a	0,31 a	0,94 b*

Discussion

It has been shown previously that strips with ONP can enhance the activity of beneficial arthropods (Wyss, 1994; Vogt *et al*., 1999, Marko *et al*., 2012, Campbell *et al*., 2013), especially of aphid predators. In previous trials the weeds were very attractive ONP with high flowering density. The idea behind the trials presented here, however, was to establish weed strips with native perennial plants that must be sown only once in the life of an orchard and can be mulched two or three times a year.

Thus, the first criterion for the selection of suitable ONP was their capacity to establish permanently in the orchards. In the NE region the plants that were most successfully established and have a rather early flowering period include *Achillea millefolium, Galium album* and *Carum carvi*. The same species did not establish in the LC region, probably due to a lower radiation in the orchard and to a more extensive mulching regime. *Crepis biennis,* and *Picris hieriacoides* were the main ONP in the LC region. *Geranium pyrenaicum* and *Leucanthenum ircutianum* successfully established in both regions. Other attractive ONP such as *Scabiosa columbaria* or *Knautia arvensis* did not establish in the strips. This may be caused by factors such as the rather high nutrient level of the soils, the lower radiation in the orchards or the mulching strategy. Generally, the preparation of the sowing bed is highly important for successful establishment of the ONP. If strips are to be established in an existing sward, the sod must be broken up with a milling machine. This has to be replicateed at least two times after drying of the soil. The last time the milling should be very superficial so that no new seeds are brought up to the surface. The seed has to be deposited superficially and consolidated with a roll without burying the seed in the ground (most species need light to germinate). In tests where these recommend-dations were not followed the establishment of the plants failed partially or even com-pletely. These tests were not included in the assessments presented here. Mulching is an important factor for the long term establishment of the strips. Without mulching, species such as *Galium album* are not competitive. Suitable mulching strategies for the con-servation of the strips still have to be developed.

The density of ONP flowers in the permanent weed strips was rather low. However, the effect on the abundance of syrphids was significant in all replicates.

The weed strips with *Anthemis tinctoria* at the farm boundary in the LC region may have attracted syrphids from more distant places to this area. Such an effect could partly explain the very high syrphid population in these orchards. Optimum combinations of boundary and alley strips should be further investigated.

In the NE region, for all predators and all replicates considered, the effect of the weed strips was significant. In the LC region, the picture was more variable. This may be due to the experimental design in this region encompassing different farms and different, more distant sites, or it may be due to the different plant species in the strips. For Anthocoridae, the March 2013 treatment with pyrethrum in the LC region may have caused considerable variation in the data, as Anthocorids usually immigrate into orchards during this time

Ladybirds are attracted by certain ONP (Kranz, 2002) and also by the aphids that can be found on the weeds. Thus, an effect of the strips could be possible and should be further investigated.

The only site without hailnet showed the highest effect of the strips. However, since there is no replicate it is difficult to draw conclusions on hailnet effects.

The behaviour of voles and field mice was also assessed. The according data are not presented here. However, these findings will be important for the development of the mulching strategies.

Our results indicate that permanent weed strips can be a sustainable way to enhance functional biodiversity in orchards even if the density of flowers is not as high as in strips renewed periodically. There is a need for additional studies in order to optimize the plant species combination and the mulching regime. If biodiversity management is extended to all arthropod species, the plant species combination should focus not only on ONP but also on plants that are essential for other species such as wild bees, bumblebees and butterflies.

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