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Research article

Effect of light and botanical species richness on insect diversity

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Abstract – Composition and diversity of flying insects was assessed within and along one-year-old sown/unsown field margin strips installed along both the shaded and unshaded side of an old lane of beeches. Investigated factors were light regime, plant community and monitoring position. Both insect composition and spatial preference of insect families was strongly dependent on light regime, field margin type and monitoring position. The number of insect families preferring the shaded side was fivefold higher than the number of families preferring the unshaded side. Particularly, insect families associated with moist conditions (*Haliplidae*, *Dolichopodidae*, etc.) were preferably or exclusively found on the shaded side characterised by higher soil moisture content. Some families (*Bibionidae*, *Scatopsidae*, *Proctotrupoidea*, etc.) showed higher abundance in the unsown field margin whilst others (*Cicadellidae*, *Chalcidoidea*, etc.) preferred the sown field margins. Similarly, some families (*Lygaeidae*, *Cantharidae*, etc.) occurred preferably in the field margin strip whilst others (*Chironomidae*, *Empididae*, *Cicadellidae*, etc.) preferred the adjacent field crop. Differential habitat preference might be explained by differences in botanical composition and structure of the vegetation. Insect diversity was significantly higher near the margin strip richest in botanical species (i.e. the unsown margin strip), reflecting the highest Shannon diversity index (2.57). Furthermore, insect diversity was significantly higher on the shaded side, irrespective of monitoring position, with Shannon diversity indices between 2.59 and 2.70.

insect composition / family richness / botanical diversity / shannon index / shade

1. INTRODUCTION

During the last few decades, biodiversity in agricultural landscapes in northern and western Europe has declined considerably owing to the intensification of agriculture from the 1950s on. Next to the impact on plant species (Marshall and Arnold, 1995), the impact of modern agriculture on animal species has been significant. Regular mechanical disturbance, increased chemical weed control and pesticide use, drift of agrochemicals into remnant field boundary habitats, field enlargement and the general simplification of crop rotations have contributed to the impoverishment of many insect groups on arable land (Sotherton and Self, 2000; Morris and Webb, 1987). Consequently, organisms downstream the food web are affected.

Field boundaries have become the dominant remnant refugia for biodiversity in agricultural landscapes. In many countries, support mechanisms have been installed to encourage farmers to buffer or expand existing boundaries by means of botanically diverse margin strips. A species-rich flowering vegetation with a high structural diversity has been shown to increase the associated family richness (Lagerlöf and Wallin, 1993; Kirkham et al., 1994; Huusela-Veistola, 1998; Frank, 1999; Thomas and Marshall, 1999; Marshall and Moonen, 2002; Meek et al., 2002). In particular, field margins may play an important role in conserving pollinators (Mänd et al., 2002) and generalist predators and parasitoids, allowing a natural control of agricultural pests in adjacent field crops (e.g. Thomas et al., 1992; Collins et al., 2002; Meek et al., 2002).

However, the impact of field margin type and, in particular, field margin composition on insect fauna remains poorly documented despite the increased interest in using field margin strips as a management instrument to attract antagonists for biological pest suppression. Furthermore, knowledge is lacking concerning insect fauna under shaded conditions. Indeed, many field margin strips on ex-arable land are installed along tree rows and hedges, because crops growing in these areas are less productive due to the decreased availability of light and water and due to a potentially higher weed and disease pressure (Brenner, 1996; Nuberg, 1998).

This research studies the impact of different field margin strips, installed along the shaded and unshaded side of a tree lane, on insect fauna. In particular, the following question was addressed: what is the effect of light regime and plant community on insect number, insect composition and insect diversity both in the margin strip and in the adjacent field crop?

2. MATERIALS AND METHODS

In September 2001, a field margin experiment was established on nutrient-rich arable land in a strip split-plot design with two light regimes (the vertical treatments) and three plant

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Table I. Sown seed mixtures: composition, dose of commercial (MIXT1) and native (MIXT2) seed mixture.

Functional group	MIXT1			MIXT2		
	Dose g ha^{-1}	N[1]	Origin	Dose g ha^{-1}	N[1]	Origin
Non-nitrogen-fixing dicots	5000	59	Barenbrug (NL)	6560	45	Pleijboza (NL)
native wildflowers				6560	45	
commercial wildflowers	5000	59				
Legumes	9200	6		9200	6	
Medicago sativa	1800		Feldsaaten Freudenberger (G)	1800		Feldsaaten Freudenberger
Trifolium incarnatum	1500		Feldsaaten Freudenberger	1500		Feldsaaten Freudenberger
Trifolium pratense	2000		Barenbrug	2000		CLO-DvP[2] (B)
Trifolium repens	1400		Barenbrug	1400		CLO-DvP
Trifolium resupinatum	1500		Feldsaaten Freudenberger	1500		Feldsaaten Freudenberger
Vicia sativa	1000		Feldsaaten Freudenberger	1000		Pleijboza
Monocots	26500	12		26500	12	
Agrostis tenuis	2000		Barenbrug	2000		collected[3]
Anthoxanthum odoratum	600		Feldsaaten Freudenberger	600		Pleijboza
Arrhenatherum elatius	3000		Feldsaaten Freudenberger	3000		Pleijboza
Cynosurus cristatus	1200		Feldsaaten Freudenberger	1200		Pleijboza
Festuca arundinacea	3600		Barenbrug	3600		collected
Festuca pratensis	3000		Barenbrug	3000		CLO-DvP
Festuca rubra	5000		Barenbrug	5000		CLO-DvP
Holcus lanatus	1000		Feldsaaten Freudenberger	1000		Pleijboza
Lolium perenne	3000		Barenbrug	3000		CLO-DvP
Phleum pratense	1400		Barenbrug	1400		CLO-DvP
Poa trivialis	700		Barenbrug	700		collected
Dactylis glomerata	2000		Barenbrug	2000		collected

[1] N = number of species (spp.).
[2] CLO-DvP: Department of Plant Genetics and Breeding, Agricultural Research Centre Merelbeke (Belgium).
[3] Collected in the neighbourhood of the trials.

communities (the horizontal treatments) in three replicates. The two light regimes were established by installing the field margin strip along both the southern and the northern side of a tree lane consisting of two rows of very uniform 50-year-old beeches, perfectly east-west oriented. Consequently, the vegetation development of the field margin plots occurred under a high light regime on the sunny southern side and under a low light regime on the northern shady side. The length and width of the margin strip were 180 m and 10 m, respectively. Within the strip, plant communities installed in plots of 20 m length were arranged in a split-plot design with three replicates. The trial was installed in Belgium on a humus sandy soil (pH-KCl 5.7, 2.9% C) in Beernem (51°09N, 3°20E). The previous crop was Italian ryegrass. Analysis of the topsoil (0–30 cm) showed that, per 100 g soil, extractable P and K were 65 mg and 25 mg, respectively; total mineral N was 98 kg ha^{-1}.

Apart from an unsown spontaneously evolving plant community (CONTR), two different sown communities were studied (MIXT1 and MIXT2). MIXT1 was established with a commercially available seed mixture (77 species) comprising species completely unrelated to the sowing region; for MIXT2 a seed mixture (63 species) comprising native seeds of local provenance was used. Plant species (Tab. I) in MIXT1 and MIXT2 were selected from a wide range of vegetation types: annual and perennial forbs from dry to moist grassland and perennial forbs which thrive in nutrient-rich soils.

In the installation year 2001, the field margin was not cut. In 2002, prior to insect monitoring, the mowing date was fixed at 15 June to allow the seed set of a major part of the plant species. Cutting height was 5 cm and the cuttings were removed immediately after mowing.

Vegetation succession occurred under zero fertilisation and no herbicides or pesticides were used in the margin strips or in the adjacent crops, since the experiment was conducted on an organic farm. Effects of light regime cannot be confounded with field effects since the fields on both sides of the tree lane were very similar: on both sides of the tree lane, the crop adjacent to the field margin strips was a mixture of red clover (*Trifolium pratense* L.) and Italian ryegrass (*Lolium multiflorum* Lamk.) During the monitoring period of flying insects the grass/clover vegetation did not flower.

Abiotic conditions in the margin strips were characterised by measurement of the soil water status and light availability. During the period from 27 June to 6 September 2002, soil moisture content of the uppermost soil profiles (0–10 cm) was assessed every two weeks within the centre of every plot. For the first sampling, undisturbed soil samples were taken in soil sample rings of known volume (100 cm^3). After drying the samples for 24 h at 105 °C, the volumetric moisture content (vol%) and the apparent specific gravity (i.e. dry weight of soil (g) divided by the ring volume) was calculated. The next samplings were taken with an auger with a diameter of 3 cm. The volumetric soil moisture content was calculated by multiplying the gravimetric moisture contents with the apparent specific gravity of the soil.

On complete sunny days (3 September 2002) photosynthetic active radiation (P.A.R., in $\mu mol.m^{-2}.s^{-1}$) above the field margin canopy (i.e. incident P.A.R.) and P.A.R. within the field margin canopy (i.e. transmitted P.A.R.) was measured every hour and a half with the Sunscan Canopy Analysis System SS1 (Delta-T Devices).

During the monitoring period of insects, presence and abundance of plant species was recorded on 20 August 2002 on a Tansley scale (Tansley, 1954) within the central 8 m × 4 m area of each plot. The abundance of plant species was expressed as dominant, codiminant, abundant, frequent, occasional, rare or sporadic. Prior to insect monitoring, the percentage of uncovered area was estimated on 20 July 2002 in sixteen randomly placed quadrats (80 cm × 80 cm) within the central plot area. The Sunscan Canopy Analysis System SS1 (Delta-T Devices) calculated the canopy leaf area index (L.A.I.) of the plant communities on 3 September 2002.

The insect fauna was monitored during a four-week period from 7 August to 3 September 2002. Fauna was caught on yellow biosignal sticky traps (BUGSCAN-BIOBEST) sized 20 cm × 40 cm. These sticky traps were made of recyclable plastic with a long-lasting water-repellent adhesive. The yellow colour is highly attractive to insects due to its high reflection properties (Bernays and Chapman, 1994). The trapping method with yellow traps is particularly representative for mobile canopy-dwelling insects. Traps were installed on both the shaded and unshaded sides along twelve transects perpendicularly centred on the field margin community plots. Along each transect, traps were placed verticularly 30 cm above the crop canopy at five monitoring positions: 4 m inside the margin strip, upon the edge between the margin strip and crop and at three positions in the crop 4, 8 and 16 m away from the margin edge. These positions are further indicated as –4 m, 0 m, 4 m, 8 m and 16 m. The traps were replaced weekly. Prior to determination of trapped insects, collected traps were temporarily stored in a refrigerator at 2 °C. Captured insects were determined according to Elsevier's Insect Guide (Chinery, 1982) using a trinocular microscope (120×). Per trap, all insects were determined to family level, some to superfamily or order level, and counted per family, superfamily or order. The total number of insects (hereafter called insect number) in the period from 7 August to 3 September 2002 was calculated by adding the weekly counts per position. Family richness was expressed as the number of occurring insect families. The Shannon diversity index (Magurran, 1988) was used to determine the biological diversity of insects (insect diversity) in the margin strips. The Shannon index is related to species richness but is also influenced by the underlying proportional abundances of species and evenness. In this study, the Shannon index was calculated as $-3\ p_i \ln p_{\rm i}$: p_i is the proportion of individuals found in the ith family divided by the total number of trapped insects. The Berger-Parker index (Berger and Parker, 1970) was used to determine whether there was any change in the dominance of insect families in the plant communities. The Berger-Parker index as a dominance measurement expresses the proportional importance of the most abundant species and was calculated as the number of trapped insects in the most abundant family divided by the total number of trapped insects. In this paper, the reciprocal form of the Berger-Parker index (hereafter simply called Berger-Parker index) was used so that an increase in the value of the index accompanies a reduction in dominance and an increase in diversity (Magurran, 1988).

To determine preferential presence of insect families on either the shaded or unshaded side or preferential presence within either the margin strip or the adjacent field crop, independent t-tests (SPSS10.0 program for Windows) were used at a significance level of 5%. Similar t-tests were used to compare differences in insect composition of sown and unsown margin strips. Family richness and insect numbers were statistically analysed with S-plus 2000 for Windows according to a strip split-plot design (Gomez and Gomez, 1984) with three factors (light regime, plant community and monitoring position). Abiotic factors were analysed according to a strip plot design with two factors (light regime and plant community).

3. RESULTS AND DISCUSSION

3.1. Soil water status and P.A.R. availability

Averaged over the monitoring period from 27 June to 6 September 2002, the soil moisture content in the profile 0–10 cm was significantly determined by light regime ($P = 0.000$). The unshaded side revealed a significantly higher soil moisture content in the profile (unshaded, 32.3 vol% versus shaded, 37.3 vol%; LSD = 2.4 vol%). The impact of plant community on soil moisture content was not significant despite the slightly higher soil moisture content in CONTR compared with sown communities.

On 3 September 2002, average incident P.A.R. above the canopy on the unshaded side (1158.3 $\mu mol.m^{-2}\ s^{-1}$) was significantly higher than incident P.A.R. on the shaded side (526.1 $\mu mol.m^{-2}\ s^{-1}$; LSD=174.7 $\mu mol.m^{-2}\ s^{-1}$). Transmitted P.A.R. under the canopy was significantly higher in CONTR (unshaded, 269.4 $\mu mol.m^{-2}\ s^{-1}$; shaded, 85.4 $\mu mol.m^{-2}\ s^{-1}$) than in the sown communities (unshaded 15.2–18.4 $\mu mol.m^{-2}\ s^{-1}$; shaded 3.7–5.4 $\mu mol.m^{-2}\ s^{-1}$) irrespective of light regime (LSD within light regime = 38.7 $\mu mol.m^{-2}\ s^{-1}$). CONTR revealed significantly higher transmitted P.A.R. on the unshaded side (269.4 $\mu mol.m^{-2}\ s^{-1}$) than on the shaded side (85.45 $\mu mol.m^{-2}\ s^{-1}$; LSD = 97.0 $\mu mol.m^{-2}\ s^{-1}$).

3.2. Botanical composition of plant communities

Species composition was clearly affected by light regime. The shaded side revealed several plant species associated with humid conditions such as *Glyceria fluitans* R. Br., *Ranunculus lingua* L., *Juncus effusus* L., *Juncus bufonius* L., *Myosotis palustris* L. and *Ranunculus repens* L. Contrary to the sown communities with many tall-growing grasses, only low-growing plant species occurred in CONTR: the most abundant species were *Alopecurus geniculatus* L. and *Agrostis stolonifera* L. on the unshaded side and *Poa trivialis* L. and *Glyceria fluitans* R. Br. on the shaded side. Contrary to the unsown community, the sown communities revealed a high abundance of *Trifolium* spp. The most abundant species in the sown communities, both on the unshaded and shaded sides, were the sown legumes *Trifolium pratense* L. and *Trifolium repens* L. and the sown grasses *Arrhenatherum elatius* J. and C. Presl, *Lolium perenne* L., *Phleum pratense* L. and *Dactylis glomerata* L.

Botanical diversity in August 2002 was significantly determined by plant community ($P = 0.002$) and not by light regime: no significant interaction was found. CONTR had a higher diversity compared with the sown communities (CONTR, 20.6 spp. versus MIXT1, 15.2 spp. and MIXT2, 14.1 spp.; LSD = 3.6 spp.). Species diversity was comparable on both sides of the tree lane (unshaded, 16.5 spp. versus shaded, 16.7 spp.).

The percentage of uncovered area at the end of July showed significant interaction between plant community and light regime ($P = 0.001$). On the shaded side, CONTR revealed a significantly higher percentage of uncovered area than the sown communities (CONTR, 35.2% versus MIXT1, 8.1% and MIXT2, 7.9%; LSD within light regime = 5.6%). On the unshaded side, no significant differences were found. Within CONTR, the percentage of uncovered area was significantly higher on the shaded side (unshaded, 14.2% versus shaded, 35.2%; LSD otherwise = 10.3%).

L.A.I. on 3 September 2002 was significantly determined by plant community ($P < 0.001$) and not by light regime; no significant interaction was found. L.A.I. of CONTR (2.3) was significantly lower than L.A.I. of the sown communities (7.6–7.7) (LSD = 0.7). These results correspond with the significantly higher transmitted P.A.R. in CONTR compared with the sown communities.

3.3. Analysis of flying insects

3.3.1. Insect composition

The distribution of total numbers of trapped insects over their corresponding insect families is shown in Table II. During the monitoring period, 78 insect families were trapped on the shady and sunny sides of a tree lane. This huge diversity might be partly attributed to the structural diversity of the woody landscape in Beernem. Bommarco (1999) accentuated the beneficial effects of structurally diverse surroundings on family richness.

The insect orders with the highest number of trapped insects were the order of *Diptera*, and the orders of *Thysanoptera* and *Hymenoptera*. The order of *Diptera* accounted for half the total number of trapped insects (185 288 insects). Within this order, no less than 32 insect families were represented. The order of *Diptera* was also the most significant order in grassy field margin strips according to the findings of Canters and Tamis (1999). Some representatives of insect families which can hardly fly (*Nepidae, Psyllidae)* were trapped. *Nepidae*, an aquatic family which usually inhabits the bottoms of freshwater ponds, must have accidentally flown onto the traps at night. *Psyllidae* must have jumped onto the sticky traps.

The preferential presence of insect families on either the unshaded or shaded side of the tree lane is shown in Table III. Some families were exclusively trapped on either the unshaded or shaded side. However, most families occurred on both sides. Aside from 45 indifferent families (not shown) and with the exception of the families of *Cecidomyiidae* and *Ectopsocidae*, all the other insect families were trapped in significantly higher numbers on the shaded side. Families associated with moist conditions (*Haliplidae*, *Dolichopodidae*, *Dryomyzidae*, *Empididae*, *Lauxaniidae* and the superfamily of *Dascilloidea*) or decaying material (*Asilidae*, *Calliphoridae*, *Otitidae, Sepsidae*, etc.) were caught in larger numbers on the shaded side since soil moisture content was significantly higher on the shaded side of the tree lane.

In Table IV, families are classified according to their preference for either the field margin strip (monitoring positions – 4 m and 0 m) or the adjacent crop. Some representative trapped species are shown in Figure 1. A small number of insect families occurred exclusively in either the field margin strip or in the adjacent field crop. However, most occurring families were trapped in both areas. On the shaded side, aside from indifferent families (not shown), 13 families were preferentially trapped above the field crop whilst the family of *Phoridae* and order of *Mecoptera* were preferentially trapped above the field margin strip. On the unshaded side, 8 families showed preference for the field margin strip whilst 5 families showed preference for the field crop. Families preferring the field margin strip differed on both sides of the tree lane, indicating different habitat preferences. Some families such as *Empididae*, *Chironomidae* and *Cicadellidae* preferred the field crop independently of light regime. Others such as the family of *Phoridae* showed preference for the field crop on the unshaded side but preferred the field margin strip on the shaded side. The order of *Thysanoptera* showed preference for the field margin on the unshaded side but was indifferent on the shaded side.

Within the field margin strip at the monitoring position – 4 m, insect composition differed between sown and unsown communities on both the unshaded and shaded sides. At both light regimes, sown communities showed higher insect numbers of *Thysanoptera*, *Cicadellidae* and *Chalcidoidea*, (significant at both light regimes) and of *Ichneumonoidea*, *Caeciliidae*, *Aleyrodidae* and *Berytidae* (significant on the unshaded side). At both light regimes, CONTR showed higher insect numbers of *Bibionidae*, *Aphidoidea*, *Proctotrupoidea* and *Scatopsidae* (significant at both light regimes) and of *Dolichopodidae, Lauxaniidae*, *Mycetophilidae, Oestridae*, and *Psyllidae* (significant on the shaded side). Families preferring the unsown community were probably more attracted by the low-growing open vegetation instead of the dense and tall vegetation in the sown communities, hampering flying, feeding and hunting. Also, the higher soil moisture content in the unsown communities might have attracted some specific families.

3.3.2. Family richness and insect number

Family richness was significantly determined by light regime ($P = 0.007$) and not by plant community or monitoring position.

Table II. Insect composition along the tree lane: invertebrate number and share (%) of occurring invertebrate families. Monitoring period from 7 August to 2 September 2002 (F, Family; SF, superfamily).

Invertebrate composition

Taxa[1]		Trapped insects Number	Share
Order *Coleoptera*		**1866**	**1.01**
F. *Anobiidae*	P[2]	15	0.01
F. *Cantharidae*	A	78	0.04
F. *Carabidae*	A	63	0.03
F. *Cerambycidae*	P	4	0.00
F. *Chrysomelidae*	P	40	0.02
F. *Coccinellidae*	A	192	0.10
F. *Curculionidae*	P	6	0.00
F. *Haliplidae*		47	0.03
F. *Scarabaeidae*	P	3	0.00
F. *Staphylinidae*	A	691	0.37
SF. *Dascilloidea*		727	0.39
Order *Diptera*		**92114**	49.71
F. *Anisopodidae*		163	0.09
F. *Asilidae*	A	61	0.03
F. *Bibionidae*	F	1135	0.61
F. *Borboridae*		4	0.00
F. *Calliphoridae*		98	0.05
F. *Cecidomyiidae*	P, A	26386	14.24
F. *Chamaemyiidae*	A	13	0.01
F. *Chironomidae*		15380	8.30
F. *Chloropidae*	P	8	0.00
F. *Conopidae*	F	5	0.00
F. *Dolichopodidae*	A	5562	3.00
F. *Dryomyzidae*		177	0.10
F. *Empididae*	A	1234	0.67
F. *Heleomyzidae*		417	0.23
F. *Lauxaniidae*		8164	4.41
F. *Lonchopteridae*		950	0.51
F. *Micropezidae*	A	270	0.15
F. *Mycetophilidae*		16072	8.67
F. *Oestridae*		440	0.24
F. *Otitidae*		156	0.08
F. *Phoridae*		3532	1.91
F. *Platystomidae*		48	0.03
F. *Psychodidae*		5847	3.16
F. *Ptychopteridae*		149	0.08
F. *Rhagionidae*	A	6	0.00
F. *Scatopsidae*		4912	2.65
F. *Sciomyzidae*		130	0.07
F. *Sepsidae*		442	0.24
F. *Stratiomyidae*		32	0.02
F. *Syrphidae*	A	193	0.10
F. *Tabanidae*		29	0.02
F. *Tipulidae*	P	99	0.05
Order *Dermaptera*	**P, A**	**3**	**0.00**

Invertebrate composition (continued)

Taxa[1]		Trapped insects Number	Share
Order *Hemiptera*		**8706**	**4.70**
F. *Acanthosomatidae*		7	0.00
F. *Aleyrodidae*	P	653	0.35
F. *Berytidae*		61	0.03
F. *Cercopidae*		41	0.02
F. *Cicadellidae*	P	3294	1.78
F. *Delphacidae*		30	0.02
F. *Lygaeidae*		6	0.00
F. *Miridae*	A	73	0.04
F. *Nabidae*	A	2	0.00
F. *Nepidae*	A	2	0.00
F. *Piesmatidae*		84	0.05
F. *Psyllidae*	P	211	0.11
F. *Reduviidae*	A	228	0.12
F. *Rhopalidae*		24	0.01
F. *Saldidae*	A	5	0.00
F. *Stenocephalidae*		6	0.00
SF. *Aphidoidea*	P	3902	2.11
Order *Hymenoptera*		**36901**	**19.92**
F. *Tenthredinidae*	P	489	0.26
SF. *Chalcidoidea*	A	20522	11.08
SF. *Formicoidea*	F, A	152	0.08
SF. *Ichneumonoidea*	A	11789	6.36
SF. *Proctotrupoidea*	A	3947	2.13
SF. *Sphecoidea*	A	1	0.00
SF. *Vespoidea*	F	1	0.00
Order *Lepidoptera*		**75**	**0.04**
F. *Micropterigidae*	F	66	0.04
F. *Notodontidae*		7	0.00
F. *Nymphalidae*		1	0.00
F. *Pieridae*	P	1	0.00
Order *Mecoptera*		**60**	**0.03**
Order *Neuroptera*		**83**	**0.04**
F. *Chrysopidae*	A	11	0.01
F. *Hemerobiidae*	A	72	0.04
Order *Psocoptera*		**4967**	**2.68**
F. *Caeciliidae*		475	0.26
F. *Ectopsocidae*		4310	2.33
F. *Peripsocidae*		170	0.09
F. *Stenopsocidae*		12	0.01
Order *Strepsiptera*	**A**	**1**	**0.00**
Order *Trichoptera*		**132**	**0.07**
Order *Thysanoptera*	**P, A**	**40380**	**21.79**

[1] Feeding habit: A, antagonist (predator, parasitoid); P, plant-damaging (pest); F, flower-visiting.

Table III. Preferential presence of trapped invertebrate families on either the unshaded or shaded side (indifferent families are not shown) (F = Family, SF = Superfamily, O = Order). Monitoring period from 7 August to 2 September 2002.

Solely unshaded side	Unshaded > Shaded[1]	Shaded > Unshaded[1]	Solely shaded side
O. *Dermaptera*	F. *Cecidomyiidae* (D)	F. *Cantharidae* (C)	F. *Nymphalidae* (L)
F. *Acanthosomatidae* (He)	F. *Ectopsocidae* (P)	F. *Carabidae* (C)	F. *Pieridae* (L)
SF. *Sphecoidea* (Hy)		F. *Chrysomelidae* (C)	
SF. *Vespoidea* (Hy)		SF. *Dascilloidea* (C)	
O. *Strepsiptera*		F. *Haliplidae* (C)	
		F. *Staphylinidae* (C)	
		F. *Bibionidae* (D)	
		F. *Mycetophilidae* (D)	
		F. *Asilidae* (D)	
		F. *Calliphoridae* (D)	
		F. *Dolichopodidae* (D)	
		F. *Dryomyzidae* (D)	
		F. *Empididae* (D)	
		F. *Lauxaniidae* (D)	
		F. *Oestridae* (D)	
		F. *Otitidae* (D)	
		F. *Platystomidae* (D)	
		F. *Sciomyzidae* (D)	
		F. *Sepsidae* (D)	
		F. *Reduviidae* (He)	
		F. *Aleyrodidae* (He)	
		F. *Cicadellidae* (He)	
		F. *Psyllidae* (He)	
		SF. *Formicoidea* (Hy)	

[1] Families assigned to either shaded or unshaded side according to the independent t-test at $\alpha = 5\%$.
[2] Order: He, *Hemiptera*; C, *Coleoptera*; D, *Diptera*; L, *Lepidoptera*; Hy, *Hymenoptera*; P, *Psocoptera.*

On the shaded side, a significantly higher number of insect families occurred (shaded, 43.5 families versus unshaded, 37.9 families; LSD = 1.95 families). At the position –4 m within the field margin strip, CONTR showed the highest family richness compared with the sown communities irrespective of light regime.

The insect number showed a significant interaction between light regime and position ($P < 0.001$), between light regime and plant community ($P = 0.049$) and between plant community and monitoring position ($P = 0.047$). On the unshaded side, significantly higher numbers of insects occurred near CONTR than near sown communities (CONTR, 1746 insects per trap versus; MIXT1, 1505; MIXT2, 1349 and LSD = 239). On the shaded side, the numbers near sown/unsown communities were comparable (CONTR, 1531 insects per trap; MIXT1, 1614; MIXT2, 1580; LSD = 239). Furthermore, within the plant community, the insect number was not significantly altered by light regime, although near CONTR a higher number was found on the unshaded side (unshaded side, 1746 insects per trap versus 1531 insects on the shaded side; LSD = 327).

The insect number on both sides of the tree lane was significantly determined by monitoring position. Similar distribution patterns over monitoring positions were found on both the shaded and unshaded sides. In the field margin strip, insect numbers were highest at the position 0 m. Within the crop, the numbers increased up to the position 16 m. On the shaded side, the significantly highest insect number occurred at the position 16 m (2255 insects per trap versus 1658 at 8 m, 1311 at 4 m, 1411 at 0 m and 1239 at –4 m; LSD = 215). The insect number was lowest at the most shaded positions: at positions –4 m, 0 m and 4 m. Insects are cold-blooded and adopt the prevailing temperature of their environment. All processes such as growth, development and activities of insects are dependent on their surrounding temperature (Speight et al., 1999). Insects attain their optimal body temperature faster under sunny conditions and are thus activated faster (Bernays and Chapman, 1994). The higher the temperature, the higher the activity of insects and thus the higher the chance of being trapped on the sticky traps.

On the unshaded side, the insect number at the positions 16 m and 0 m were significantly higher than the numbers captured at the other positions (1906 insects per trap at 16 m, 1819 at 0 m, 1420 at 8 m, 1245 at 4 m, 1277 at –4 m; LSD = 215). Within the monitoring positions, insect numbers were not significantly altered by the light regime except at the position 0 m (unshaded, 1819 insects per trap versus shaded, 1411; LSD = 351).

Compared with the sown communities, CONTR revealed higher insect numbers both at the position –4 m (CONTR, 1362 insects per trap versus MIXT1, 1267, MIXT2, 1143) and at the position 0 m (CONTR, 1952 insects per trap versus MIXT1,

Table IV. Distribution profile of trapped invertebrate families according to their preferential presence in the field margin strip or the adjacent field crop on both shaded and unshaded sides of a tree lane (F = Family; SF = Superfamily; O = Order). Monitoring period from 7 August to 2 September 2002.

	Shaded side		Unshaded side	
Margin strip solely	F. *Chloropidae* (D)[3]	A[2]	F. *Aleyrodidae* (He)	P
	F. *Sphaeroceridae* (D)		F. *Lygaeidae* (He)	
	F. *Nabidae* (He)	A	F. *Stenocephalidae* (He)	
	F. *Nepidae* (He)	A	SF. *Sphecoidea* (Hy)	A
			SF. *Vespoidea* (Hy)	F
			O. *Strepsiptera*	A
Margin strip > Field crop[1]	F. *Phoridae* (D)		F. *Cantharidae* (C)	A
	O. *Mecoptera*		SF. *Dascilloidea* (C)	
			F. *Staphylinidae* (C)	A
			O. *Mecoptera*	
			F. *Ectopsocidae* (P)	P
			F. *Caeciliidae* (P)	
			F. *Peripsocidae* (P)	
			O. *Thysanoptera*	A/P
Field crop > Margin strip[1]	F. *Chironomidae* (D)		F. *Chironomidae* (D)	
	F. *Mycetophilidae* (D)		F. *Ptychopteridae* (D)	
	F. *Empididae* (D)	A	F. *Empididae* (D)	A
	F. *Heleomyzidae* (D)		F. *Phoridae* (D)	
	F. *Lauxaniidae* (D)		F. *Cicadellidae* (He)	P
	F. *Lonchopteridae* (D)			
	F. *Aleyrodidae* (He)	P		
	F. *Cicadellidae* (He)	P		
	F. *Psyllidae* (He)	P		
	SF. *Chalcidoidea* (Hy)	A		
	SF. *Ichneumonoidea* (Hy)	A		
	SF. *Proctotrupoidea* (Hy)	A		
	F. *Hemerobiidae* (N)	A		
Field crop solely	F. *Anobiidae* (C)	P	F. *Curculionidae* (C)	P
	F. *Cerambycidae* (C)	P	F. *Scarabaeidae* (C)	P
	F. *Nymphalidae* (L)		F. *Conopidae* (D)	F
	F. *Pieridae* (L)	P	F. *Rhagionidae* (D)	A
			F. *Nabidae* (He)	A
			F. *Nepidae* (He)	A
			F. *Saldidae* (He)	A

[1] Families assigned to the field crop or the field margin strip according to the independent t-test at $\alpha = 5\%$.
[2] Feeding habit: P, plant-damaging (Pest); A, antagonists (predator, parasitoid); F, flower-visiting.
[3] He, *Hemiptera*; C, *Coleoptera*; D, *Diptera*; L, *Lepidoptera*; Hy, *Hymenoptera*; P, *Psocoptera*; N, *Neuroptera.*

1506, MIXT2, 1387; LSD = 295). So, in the field margin strip, CONTR showed both the highest family richness and the highest numbers of insects.

3.3.3. Diversity indices

The Shannon diversity index was significantly determined by plant community ($P = 0.02$) and revealed a significant interaction between light regime and monitoring position ($P = 0.03$). The Shannon index near CONTR (2.57) was significantly higher than near the sown communities (2.49 for both MIXT1 and MIXT2) (LSD = 0.06). Probably, both insect diversity and number were affected by the botanical diversity of the plant community since the highest Shannon diversity index and insect number was found in the community richest in species (i.e. CONTR). The lowest diversity and lowest numbers of insects were found in the community poorest in species (i.e. MIXT2). Thomas and Marshall (1999) and Lagerlöf and Wallin (1993) also found a positive correlation between botanical diversity and invertebrate diversity. In addition to the botanical diversity, insects might show a preference for the open vegetation structure (significant share of uncovered soil) of the unsown community, characterised by a low L.A.I., an abundance of low-growing plant species and a higher P.A.R. transmittance in the canopy offering better opportunities to warm up, fly, feed and hunt. Kirby (1992) highlighted the importance of bare ground for insects for hunting, basking, burrowing or nesting.

On the shaded side, the Shannon indices of all monitoring positions were not significantly different (2.59, 2.59, 2.66, 2.61 and 2.70 for position –4, 0, 4, 8 and 16 m, respectively; LSD within side = 0.12). On the unshaded side, the Shannon index of the position 0 m was significantly lower than all other positions (2.46, 2.21, 2.48, 2.46 and 2.45 for position –4, 0, 4, 8 and 16 m, respectively; LSD within light regime = 0.12). Within each monitoring position, the Shannon index was significantly higher on the shaded side than on the unshaded side (data above; LSD otherwise = 0.13). Apparently, the moist conditions on the shaded side were more attractive to a lot of insect families either directly or indirectly by the impact of shading on the botanical composition of the margin strip.

The Berger-Parker index revealed a significant interaction between plant community and monitoring position ($P = 0.02$). The Berger-Parker index at the position –4 m (CONTR, 5.26; MIXT1, 3.36; MIXT2, 3.51) and at the position 0 m (CONTR, 4.42; MIXT1, 3.08; MIXT2, 3.13) was significantly higher for CONTR than for the sown communities (LSD within position = 1.18). So, CONTR revealed the lowest degree of dominance in insect families (which means the highest evenness of insect families). At positions 4, 8 and 16 m no significant differences between plant communities were found. Berger-Parker indices at the field crop positions 4, 8 and 16 m were significantly higher than at the positions –4 and 0 m near MIXT1 (3.36, 3.08, 4.84, 4.95 and 5.41 for positions –4, 0, 4, 8 and 16 m, respectively) as well as near MIXT2 (3.51, 3.13, 5.25, 5.90 and 4.62 for positions –4, 0, 4, 8 and 16 m, respectively) (LSD within plant community = 1.20). Near CONTR, no significant differences were found between monitoring positions.

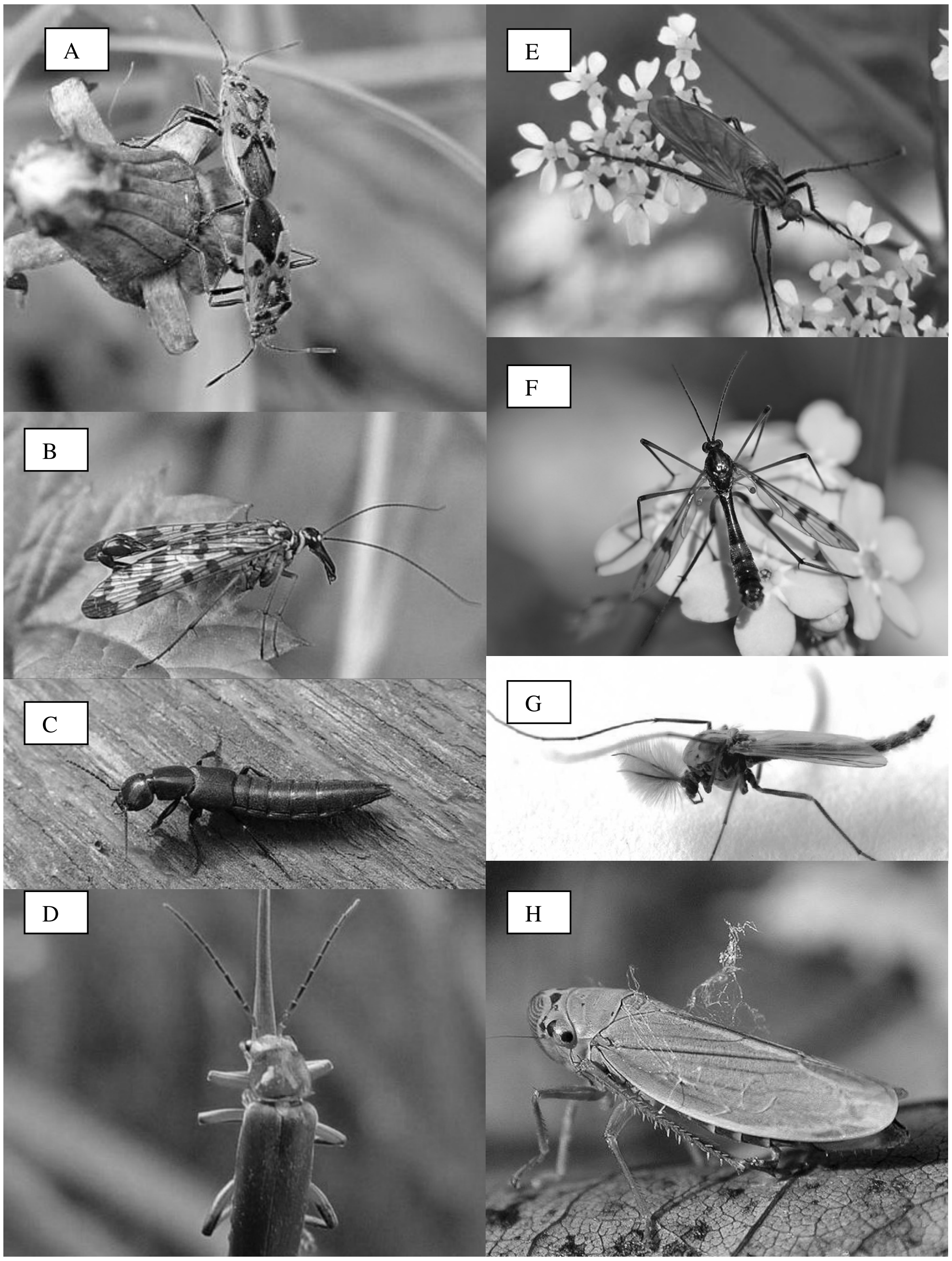

Figure 1. Preferential presence of some monitored insect species on the unshaded side of a tree lane: species A–D preferred the margin strip; species E–H preferred the adjacent field crop. Insect species: A *Lygaeus saxatilis* (F. *Lygaeidae*), B *Panorpa communis* (O. *Mecoptera*), C *Staphylinus olens* (F. *Staphylinidae*), D *Cantharis livida* (F. *Cantharidae*), E *Empis tessellata* (F. *Empididae*), F *Ptychoptera contaminata* (F. *Ptychopteridae*), G *Chironomus plumosus* (F. *Chironomidae*), H *Cicadella viridis* (F. *Cicadellidae*).

4. CONCLUSION

In conclusion, our results revealed the positive effect of botanical diversity on insect number and diversity. Insect diversity was significantly more diverse within and in the vicinity of the plant community richest in botanical species (i.e. the unsown community) as reflected by the significantly higher Shannon diversity index. The effects of botanical diversity on insect number were mediated by light regime. The composition of the caught insects and the abundance of some insect families were dependent on the composition of the vegetation. The effects of plant communities were more pronounced at high light availability. Light availability significantly influenced insect diversity as well as the spatial distribution of families. The shaded side was significantly more diverse than the unshaded side. Similarly, significantly more insect families were found on the shaded side.

Field margin strips installed to enhance floristic diversity might thus be beneficial to overall insect diversity and insect densities. In common agricultural practice, many field margin strips are preferentially installed along the shady sides of tree rows and hedges because the area closest to tree rows is less productive. From the viewpoint of nature conservation, this practice is no obstacle since faunistic diversity might be benefited. For the same reason, unsown margin strips might be preferred to sown communities, particularly on the unshaded side because of their open vegetation structure and/or higher botanical diversity. However, this might conflict with the agricultural viewpoint that unsown field margin strips might increase the potential risk of weed infestations in both the field margin and adjacent crops (Smith et al., 1999; West et al., 1997). An argument in favour of the unsown strips is the knowledge that a higher family richness entails a higher number of antagonist families which may be useful in biological control of emerging pests in adjacent crops. Indeed, several authors (Letourneau, 1990; Marino and Landis, 1996; Samu, 2003) reported beneficial effects of structurally and floristically diverse plant communities on the diversity and presence of predator insects directly by the availability of niches, nectar and pollen and indirectly by the higher availability of prey insects. Further research is necessary to find out if we are able to design field margins that deliver enough antagonists introgressing far enough into the crop to lean upon them as instruments to manage pests in crops.

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