

Can field-scale habitat diversification enhance the biocontrol potential of spiders?†

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Abstract: The study investigated the effect of strip management in alfalfa on the abundance and diversity of spiders. In strip management, narrow strips were left unmown in the crop, which were then shifted at next mowing. In an experimental field, out of the six 50 × 50-m blocks, three received strip management and three were managed traditionally (ie the whole block was mown). Our main hypothesis was that unmown strips will contain a more diverse and abundant spider assemblage, which will increase spider numbers in the mown parts of the crop. Over the 3 years of the study, unmown strips contained a spider assemblage of more than 50% higher abundance than in control alfalfa. Species diversity was also greater in the strips, and the presence of specific indicator species could be shown. We found that five dominant species comprised over 75% of spiders in the strips, and they were the same species as those that are dominant in alfalfa, where they represent 85% of all spiders. In contrast, a neighbouring meadow, which was a control in the study, also had high diversity, but different dominant species. The main result of the experiment was negative in that elevated abundance of spiders in unmown strips did not raise spider numbers in the mown strips of alfalfa, where abundance was only marginally higher than in the control alfalfa. We can speculate that better ecological conditions in unmown strips attract and conserve spiders from neighbouring areas and from the crop at mowing. We suggest that if diversification is more interspersed within the crop, we have a higher chance of increasing the number of natural enemies and bringing them closer to pests, so that they can interact more intensively.

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Keywords: strip management; alfalfa; habitat management; biological control; generalist predator; Araneae

1 INTRODUCTION

Generalist predators are important stabilising elements of agroecosystems.¹ Their influence on pest species often reaches the extent at which they can be considered to be significant biocontrol agents. A review of manipulative field studies showed that in *ca* 75% of cases generalist predators reduced pest numbers significantly.²

Spiders are amongst the most dominant generalist predators in agricultural fields,³ and a number of studies indicate their effectiveness in biological pest control.^{4–6} Although it is highly unlikely that using spiders as a biopesticide (ie releasing them in mass) would be a viable technique in the field, there are many options to enhance the natural density of spider and other natural enemy populations by habitat management, ie by altering various characters of the agricultural habitat.⁷ Habitat diversification, as one such technique, can result in reduced pest populations.⁸ It is proposed that the scale of diversification is an important element of the success of natural enemy

enhancement.⁹ A literature survey on the effect of various techniques showed that spatially segregated diversification (eg hedgerows and diverse field boundaries) had relatively little impact on spider populations as compared to interspersed diversification (eg undersowing, mulching, reduced tillage), which significantly increased spider density in 80% of the studies,¹⁰ in some cases by more than tenfold.¹¹

Creating interspersed diversification in agricultural fields often requires special techniques, such as the undersowing of a second crop, or spreading mulch on the soil under the crop,⁸ leading many farmers to adhere to traditional management. In the present study we intended to examine the effect of a simple, yet effective, diversification technique on spider populations. The technique is the 'strip management' of alfalfa, originally developed by Schilinger and Dietrick,¹² whereby, during mowing, some strips of the field are left unmown. The original method used 15- to 45-m-wide strips, mown alternately at two-weekly intervals. By this technique, an overall increase of

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† One of a collection of papers on various aspects of current research on pest management in Hungary, collated by Dr István Ujváry

Contract/grant sponsor: OTKA; contract/grant number: T32209

Contract/grant sponsor: Ministry of Environmental Protection, Hungary

Contract/grant sponsor: Hungarian Academy of Sciences

Contract/grant sponsor: NKFP; contract/grant number: 3B/0008/2002

(Received 5 June 2002; revised version received 24 August 2002; accepted 16 September 2002)

natural enemies in strip-managed fields was achieved.¹² Strip-managed alfalfa fields planted near to cotton fields successfully reduced infestation by Lygus bugs (*Lygus vosseleri* Popp) in the adjacent, more susceptible crop.¹³ In the present experiment we only intended to diversify the field, and used much narrower unmown strips, along with an unaltered mowing and hay collecting schedule for the crop.

Our hypotheses concerned the effect of strip management on spider populations in alfalfa. The specific questions that the study aimed to answer were (1) whether unmown strips could harbour an elevated spider density; (2) if there were such an increase of spider abundance in the unmown strips, could that serve as a source of extra spider abundance in the mown parts of the blocks; (3) does species composition differ in the unmown strip from that in normal (mown) alfalfa and/or in the adjacent meadow; and (4) does the species composition in strip-managed blocks differ from that in normal management blocks?

2 MATERIALS AND METHODS

The 1.6-ha experimental field was located at Julianna-major (47°32'52" N, 18°56'6" E), Nagykovács, Hungary, in a hilly region, near the north-west border of Budapest. The field was divided into six 50 × 50-m blocks. To separate the blocks, 3-m-wide paths were created between them and around the border of the field (Fig 1). The soil surface of these paths was kept weed-free throughout the experiment. Alfalfa was sown mid-April 1995, and a post-emergent herbicide treatment was applied in May. The field received no other chemical treatment during the rest of the experiment. The field was first mown on 5 July 1995. Treatments were implemented with this mowing, by designating three blocks as strip management, and the other three as normal management (control) blocks. A meadow (an old field) with rich grass vegetation was adjacent to the experimental field. Apart from sampling, this meadow was completely undisturbed throughout the experiment. We used the meadow as an 'outgroup' control. In alfalfa, mowing in both kinds of management blocks took place three or four times per year, usually when *ca* 10% of the alfalfa was in flower. Strip-blocks were mown, so that four 1-m-wide strips were left uncut. In these unmown strips alfalfa could continue flowering and maturing. However, during the next mowing, unmown strips were cut, and new strips, adjacent to the previous ones, were left uncut. By shifting the unmown strips we prevented weed growth and the ageing of alfalfa, but could still provide a structurally diverse and protected environment for the spiders. The implemented treatments and controls created four habitat types: unmown strip and mown strip of alfalfa, normal management alfalfa and meadow. Later on we refer to them either as 'habitats' or 'treatments'.

Sampling of the spider population started after the first mowing, and lasted until 11 December 1997.

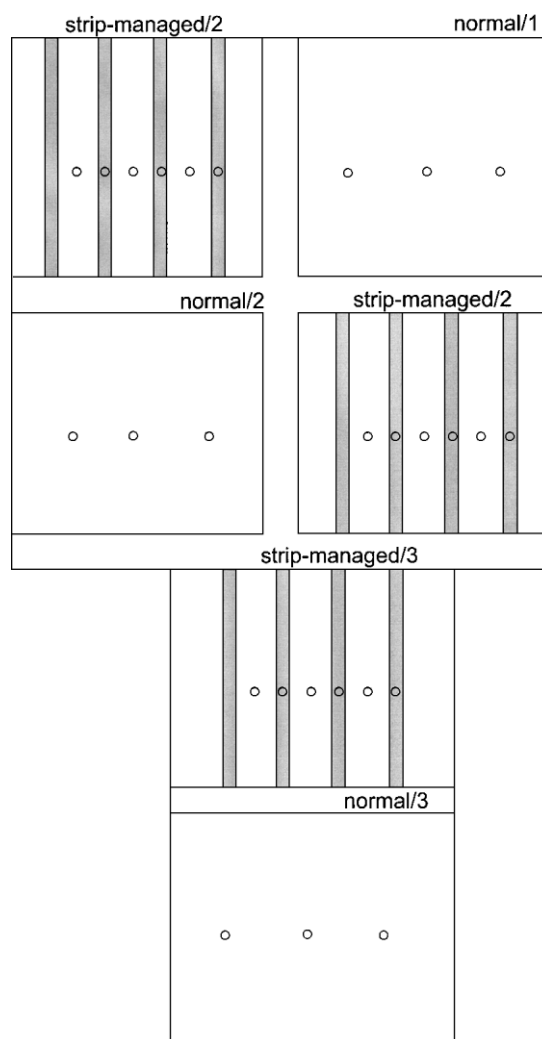


Figure 1. Schematic representation of the experimental blocks. Blocks were arranged in a 'T-shaped' structure. Small circles denote pitfall trap locations. Within each strip-managed block (50 × 50 m²), unmown strips (shaded areas) were 1 m wide, mown strips (unshaded areas) were 9 m wide.

During this period there were 64 sampling dates. We applied two methods in parallel: pitfall trapping and suction sampling. In normal blocks three pitfalls were placed per block, in strip-managed blocks three pitfalls were in the mown strips of alfalfa, and three in the unmown strips (when strips were shifted, pitfalls were moved with them). In the meadow we applied pitfalls (planted in linear transect, traps placed at a distance of 10 m). In the first year we had one transect of five traps, in the second year there was one transect of nine traps, while in the third year two transects were planted in the meadow (*ca* 100 m apart) each consisting of nine pitfalls. Suction sampling both in the alfalfa blocks and in the meadow took place in exactly the same spatial arrangement as that of the pitfalls, by applying one unit of suction sampling close to each pitfall trap location.

As pitfalls we used 300-ml plastic cups of 75 mm upper diameter, filled with ethylene glycol + water (40% + 60% by volume) as preservative. In pitfall

trapping the catch of one pitfall over an emptying period constituted a sampling unit. Suction samples were taken at a distance of 10 m from each pitfall, thus suction sampling and pitfall trap transects were parallel. One sampling unit consisted of 10 suction units by a 0.01-m² nozzle in a 10-m-long transect.¹⁴

We have quantified spider abundance by using the measure catch/unit sampling effort. For suction samples this was calculated by dividing the total catch by the actual number of sampling units for a given block on a given sampling date. For pitfall trapping we have standardised this measure for unit time by dividing it by the number of days that had elapsed since last trap emptying. In calculating spider abundance, all individuals were taken into account, while for diversity indices only adults were considered, since only adults could be identified according to species.

The effect of treatment was analysed with a complex ANOVA design, by controlling for method, sampling year, block (nested within treatment) and the treatment–method interaction. The response variable, catch per unit sampling effort, showed heteroscedasticity, which was successfully corrected with $\log_{10}(n+1)$ transformation,¹⁵ after which the homogeneity of variances test was non-significant (Bartlett's $\chi^2 = 4.058$, $df = 3$, $P = 0.255$).¹⁶ The diversity of spiders was measured by the Shannon diversity index,¹⁷ which was calculated for each habitat in each block, based on one year's cumulated data. Species composition relationships between habitat types were explored with principal components analysis (PCA) ordination, using the correlation method.¹⁸ The habitat specificity of species was quantified by the Indicator Species Analysis.¹⁹ The method calculates Indicator Values, which can signify whether a species is consistently more likely to occur in one habitat type than in others, considering the given analysis. Significance of Indicator Values was calculated by comparing the actual values to those obtained by randomised species distributions from 1000 Monte Carlo simulation runs.¹⁸

3 RESULTS

During the experiment we obtained data from 1730

sampling units, in which 23 958 spider specimens were collected. The spiders belonged to 163 species; those from the alfalfa (non-meadow) blocks represented 118 spider species.

We have tested whether spider abundance was greater in unmown strips than in normal alfalfa, by comparing catch per unit sampling effort values in the respective treatments, obtained by the two sampling methods. A complex ANOVA design showed that, after controlling for method, for block and for the effect of sampling year, unmown strips contained on average 53.2% more spiders than normal alfalfa, which difference in the specific contrast was highly significant (Table 1). However, this elevated spider abundance in the unmown strips did not influence spider numbers in the mown strips of alfalfa, where average spider abundance was only marginally higher, and not significantly different from spider abundance in normal blocks (Table 1). Method and treatment had a significant interaction in the model, most probably due to the differential efficiency of the methods in structurally different vegetations, which were sampled in the various treatments. There was no significant block effect in the model.

Not only spider abundance, but also the diversity of spiders was significantly different among the habitat types. However, *post hoc* comparisons revealed that diversity was not significantly different between normal alfalfa *versus* mown strips of alfalfa, and unmown strips *versus* meadow habitat types (Fig 2).

Habitats also showed particular differences in species composition. An ordination by PCA revealed that normal and between-strip alfalfa were occupied by virtually the same species, while the composition of spider assemblages inhabiting the strips and those in the meadow were quite distinct from them (Fig 3). Thus, it seemed that spiders distinguish between three main habitat types: mown alfalfa (in mown strips and in normal management blocks), unmown strips and meadow. Indicator Values were calculated for species for these three main habitat types (Table 2). There were two significant indicator species in mown alfalfa, five in unmown strips, and 36 in the meadow (Table 2). It is notable, that in unmown strips most indicator

Table 1. ANOVA model and planned comparisons of the effect of treatments (four habitat types) on spider abundance: the response variable (catch per unit sampling effort) is $\log_{10}(n+1)$ transformed

Source	df	Sum of squares	F	P
Model effects				
Treatment	3	2.734	6.9389	0.0001
Method	1	102.738	782.3409	0.0001
Year	3	1.161	2.9466	0.0324
Method * Treatment	3	3.773	9.5771	0.0001
Block[Treatment]	7	1.017	1.1068	0.3572
Error	531	69.731		
Contrasts				
Treatment: norm-alf ^a <i>versus</i> um-strip ^b	1	2.463	18.7547	0.0001
Treatment: norm-alf <i>versus</i> m-strip ^c	1	0.415	3.1602	0.076

^a Alfalfa in normal management plots.

^b Unmown strips of alfalfa in strip-managed plots.

^c Mown strips of alfalfa in strip-managed plots.

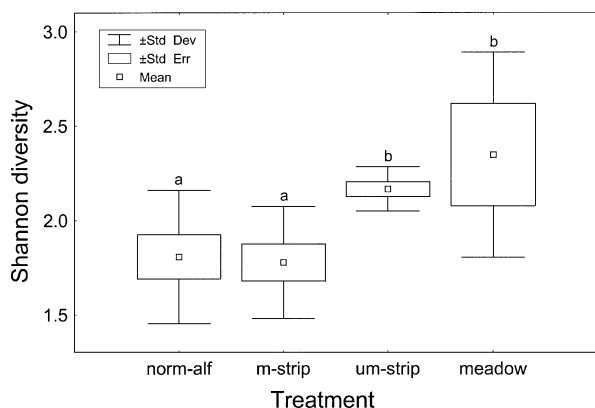


Figure 2. Shannon species diversity in the examined habitats, calculated for each block in each year. Diversity significantly differed between habitat types: one-way ANOVA, $F_{3,27}=4.964$, $P=0.007$. Treatments with the same letter were not significantly different (Duncan's multiple range test, at $P=0.05$) (um-strip=unmown strips of alfalfa; m-strip=mown strips of alfalfa; norm-alf=normal management alfalfa).

species were not among the dominant species (Table 3). In fact, dominant species composition was almost identical in mown and unmown alfalfa. Dominant species in the meadow, however, were distinctly different (Table 3).

4 DISCUSSION

Unmown strips of alfalfa proved to be a very good spider habitat, where we found 50% more spiders than in mown parts of the crop. Thus we were able to produce a diversified environment, which was potentially a good source of spiders for the rest of the alfalfa field. Root's enemies hypothesis²⁰ in general predicts natural enemies to be more abundant in diversified agricultural systems. A further important conclusion of many case studies reviewed by Samu *et al*⁹ was that

the more interspersed the diversification with the crop, the more positive its effect on natural enemies. The establishment of strips in a field creates a diversification that is more interspersed than the often used and studied hedgerows,^{21,22} but less interspersed than, for instance, mulching or undersowing.^{4,23} When designing the experiment, it was an open question whether such a partially segregated, but technically very simple, management type could enhance spider abundance in the crop. The conclusion of our 3-year experiment was that, at least at this scale and using this particular strip-generating method, strip management could not enhance spider populations in the crop. Even so, this negative result is important, because, by analysing further details of the experiment, we might be able to advise more effective ways to increase natural enemies by habitat diversification.

What reasons can we find, why spiders in the strips did not penetrate into the crop? One reason could have been that, in many ways, different species find their optimal ecological conditions in different habitats, such as an unmown strip and mown alfalfa. Dissimilarity between crop spider fauna and that of nearby habitats is not uncommon.^{24,25} The potential reasons include the sensitivity of spider species to structure,^{26,27} to micro-climate and disturbance,¹¹ and to prey availability.^{28,29} In the present experiment we compared the spider assemblages of alfalfa and an adjacent meadow. Even though one cannot make far-reaching conclusions from a comparison with one particular meadow, our tentative results indicated a nearly complete dissimilarity of meadow and alfalfa spider assemblages. However, dissimilarity was only partly found between unmown strips and mown alfalfa; although unmown strips had a higher species diversity and had specific indicator species, the first five dominant species, accounting for 75% and 85%, respectively, of all spiders in the two habitat types, were identical. So, unmown strips represent a special habitat type in alfalfa, with largely the same dominant spider species, but in greater numbers.

Thus we must conclude that unmown strips are a more favourable habitat type for spiders. Following this reasoning, we could even expect that unmown strips will deplete spiders from mown parts of crops, contrary to our starting hypothesis. The results showed that this was not the case. Mown strips of alfalfa contained marginally more, but statistically the same abundance of spiders. Accordingly, as a result of elevated spider density in unmown strips, strip-managed blocks in total contained more spiders than normal blocks. The potential reasons can be that strips provided better conditions (more food, shelter) for survival and reproduction, and/or strips attracted and retained more aerially or otherwise migrating spiders by their presumably more favourable micro-climatic, structural conditions. Migrants can originate from outside habitats, but periodic harvest of alfalfa is also likely to generate migratory fluxes, and if strips can conserve some of these animals, they can successfully

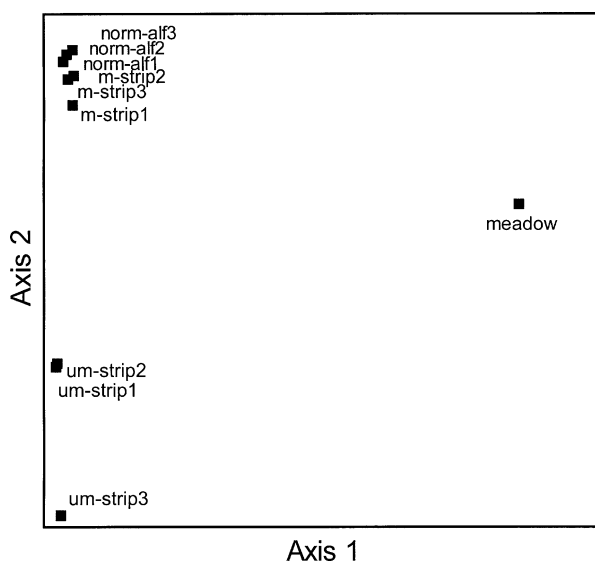


Figure 3. Ordination plot of blocks by PCA on spider species catches. First two axes represent 54.45% of the total variance. (um-strip=unmown strips of alfalfa; m-strip=mown strips of alfalfa; norm-alf=normal management alfalfa).

Table 2. Indicator species of the three main habitat types. In mown alfalfa and unmown strips all significant species are listed, while in the meadow only the first five out of 36 (see text for further details of the analysis)

Habitat	Species	Family	Indicator value	Simulation runs		
				Mean	SD	P
Mown alfalfa	<i>Erigone dentipalpis</i> (Wider, 1834)	Linyphiidae	60.7	40.6	5.56	0.001
	<i>Pardosa agrestis</i> (Westring, 1861)	Lycosidae	59.5	39.5	5.78	0.003
Unmown strips	<i>Lepthyphantes tenuis</i> (Blackwall, 1852)	Linyphiidae	66.6	37.6	8.08	0.001
	<i>Dicymbium nigrum</i> (Blackwall, 1834)	Linyphiidae	52.9	19.9	9.91	0.012
	<i>Pardosa pullata</i> (Clerck, 1757)	Lycosidae	43.4	19.1	9.89	0.020
	<i>Pachygnatha degeeri</i> Sundevall, 1830	Tetragnathidae	55.3	39.5	7.30	0.029
	<i>Mangora acalypha</i> (Walckenaer, 1802)	Araneidae	58.7	43.2	8.16	0.040
Meadow	<i>Aulonia albimana</i> (Walckenaer, 1805)	Lycosidae	99.7	28.4	11.79	0.001
	<i>Episinus truncatus</i> Latreille, 1809	Theridiidae	72.6	20.7	9.77	0.001
	<i>Evarcha arcuata</i> (Clerck, 1757)	Salticidae	75.0	14.1	7.40	0.001
	<i>Marpissa nivoyi</i> (Lucas, 1846)	Salticidae	97.1	17.5	9.09	0.001
	<i>Ozyptila atomaria</i> (Panzer, 1801)	Thomisidae	75.0	14.2	7.76	0.001

contribute to the overall increase of spider abundance of fields. Another possibility is that, when unmown strips eventually become mown strips, their spider population, at least in part, may remain in the mown part, and enhance the spider population there. Whatever the mechanism, perhaps the unmown strips will start to act as a 'source' reservoir for the region, and keep a longer term capacity of natural enemies to occupy the periodically disturbed/destroyed agricultural habitats.

In summary, the introduction of unmown strips in alfalfa first of all generated a high abundance of spiders within these strips. Although the spider fauna in unmown strips had a higher species diversity than in the crop, it contained the same dominant species. This is important, because alfalfa has a very conservative species composition,³ and if any nearby habitat contains different species, there will be only a negligible mutual effect between the faunas. Second, the higher abundance in unmown strips did not deplete spiders in the mown parts of the crop, so that

for the whole strip-managed field spider abundance increased. Third, unmown strips did not elevate spider abundance in comparison with the mown strips of the crop. From these findings we draw the conclusion that other, more interspersed ways of field diversification might be more effective in enhancing spider populations, and thus the application of interspersed diversification techniques may be generally a more effective strategy of biological control by natural enemies.

ACKNOWLEDGEMENTS

Mrs Erika Botos and József Németh gave valuable help in the collection, determination and data entry of the material. Thanks are due to Keith D Sunderland and Balázs Kiss for reading and commenting on the manuscript. The project was financed by OTKA Grant No T32209, the co-operative program between the Ministry of Environmental Protection and the Hungarian Academy of Sciences, and the NKFP program, grant No 3B/0008/2002.

Table 3. The first five most dominant species in the main habitat types, given as percentage of all individuals

Habitat type	Species	Family	Dominance (%)	Cumulative dominance (%)
Mown alfalfa	<i>Pardosa agrestis</i> (Westring, 1861)	Lycosidae	45.7	
	<i>Meioneta rurestris</i> (CL Koch, 1836)	Linyphiidae	19.0	
	<i>Erigone dentipalpis</i> (Wider, 1834)	Linyphiidae	11.2	
	<i>Oedothorax apicatus</i> (Blackwall, 1850)	Linyphiidae	7.6	
	<i>Tibellus oblongus</i> (Walckenaer, 1802)	Philodromidae	2.1	85.6
Unmown strips	<i>Pardosa agrestis</i> (Westring, 1861)	Lycosidae	35.0	
	<i>Meioneta rurestris</i> (CL Koch, 1836)	Linyphiidae	18.7	
	<i>Oedothorax apicatus</i> (Blackwall, 1850)	Linyphiidae	9.8	
	<i>Erigone dentipalpis</i> (Wider, 1834)	Linyphiidae	7.6	
	<i>Tibellus oblongus</i> (Walckenaer, 1802)	Philodromidae	4.1	75.2
Meadow	<i>Aulonia albimana</i> (Walckenaer, 1805)	Lycosidae	35.0	
	<i>Tibellus oblongus</i> (Walckenaer, 1802)	Philodromidae	23.0	
	<i>Pardosa hortensis</i> (Thorell, 1872)	Lycosidae	6.6	
	<i>Meioneta rurestris</i> (CL Koch, 1836)	Linyphiidae	6.3	
	<i>Pisaura mirabilis</i> (Clerck, 1757)	Pisauridae	4.4	75.1

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