SPIDERS (ARANEAE) AS A COMPONENT OF GROUND-DWELLING ANIMAL ASSEMBLAGES OF THE ENERGY CROP FIELDS IN NORTHERN BUKOVYNA (UKRAINE)

KATERYNA TYMCHUK^{1,2}, NINA POLCHANINOVA³, ALINA ZHUK¹, ULIANA LEHETA¹, VOLODYMYR VOLOSHYN², MARIIA FEDORIAK ✉¹

¹Yuriy Fedkovych Chernivtsi National University, Kotsiyubynski Street 2, 58012, Chernivtsi, Ukraine; e-mail: m.fedoriak@chnu.edu.ua

²Bukovinian State Medical University, Theater Square 2, 58000, Chernivtsi, Ukraine; e-mail: katerynagavryliak@gmail.com

³V.N. Karazin Kharkiv National University, Svobody Square 4, 61022, Kharkiv, Ukraine; e-mail: n.polchaninova@karazin.ua

✉ Corresponding author

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Abstract

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Energy cropping has positive effect only if considering and mitigating potential biodiversity loss in agroecosystems. While investigating ground-dwelling animal assemblages in experimental fields of miscanthus and switchgrass in comparison with a legume-grass mixture and an abandoned field, we found low abundance and taxon diversity of the energy crops assemblages. Spiders comprised 3.3–3.8% of collected arthropods in the switchgrass and miscanthus and 8.3–10.1% in the abandoned field and grass mixture. Forty-seven spider species were collected: 14 species in the miscanthus field, 18 in the switchgrass, 23 in the grass mixture and 31 in the abandoned field. Spider diversity was the lowest in the miscanthus, while the number of specimens was minimal in the switchgrass. According to our findings, energy crops hosted poor spider assemblages with no species found exclusively in these habitats. To mitigate the negative impact of biofuel production on biodiversity, we recommend preserving areas of semi-natural vegetation in the agricultural landscape.

Key words: spider diversity, habitat preference, bioindicators, biofuel, agroecosystems.

Introduction

Biomass crop production has advantages in terms of cost-effectiveness and carbon footprint and is seen as a mechanism for reducing climate risks (WWF Living Planet Report, 2016). However, the negative impact on biodiversity casts doubt on the resilience of such agroecosystems (Cook et al., 1991; Webb, Coates, 2012; Williams, Feest, 2019). The negative impact of energy crop cultivation on biodiversity depends on many abiotic and biotic factors and has spatial peculiarities. In particular, wood energy crops cause less impact on biodiversity than the arable ones; polycultural cultivation of native perennial species is likely to have a less significant negative impact on biodiversity than monocultural cultivation of annual energy crops (Groom et al., 2008; Dauber et al., 2010). Miscanthus (*Miscanthus × giganteus* JM Greef.) and switchgrass (*Panicum virgatum* L.) are among the most promising energy crops. They have wide adaptive capacity, can be grown effectively in various soil and climatic conditions of moderate latitudes, and provide high yields at minimal costs (Groom et al., 2008; Eggers et al., 2009; Energy Strategy of Ukraine..., 2017). Initially, energy crops were expected to become a relatively environmentally be-

nign crop, since they require less fertilizers, pesticides and mechanical disturbances during a growing season (Lewandowski et al., 2003). Studies on vertebrate animals did not confirm it (Eggers et al., 2009), while the studies of the influence of perennial grassy energy crop production on individual arthropod groups or ground-dwelling animals in general are not sufficient for final conclusion (Holguin et al., 2010; Schaeffer et al., 2011; Dauber et al., 2015; Snelick, 2018; Williams, Feest, 2019).

Ukraine's Energy Strategy implies a dynamic growth in the use of biomass energy. However, associated zoological diversity on the plantations of energy crops in Ukraine remains outside the scope of researchers. Sporadic invertebrate researches in bioenergetic plantations relate, first of all, to the formation of agricultural pest entomocomplexes (Stefanovska et al., 2011, 2012; Sabluk et al., 2018). Taking into account the need to increase the area under cultivation of energy crops to achieve bioenergy goals, biodiversity analysis should be an important part of risk assessment measures (Dauber et al., 2010). The impact of second-generation bioenergetic plants on animal diversity in Ukraine is unstudied and belongs to the issues of significant relevance.

Spiders are numerous generalist predators playing an important role in biological control in agroecosystems (Maloney et al., 2003; Benhadi-Marin et al., 2016; Michalko et al., 2019). They are widely used as bioindicators since their assemblage structures reflect anthropogenic and/or natural changes in environmental conditions (Cole et al., 2005; Blaum et al., 2009; Zhukov et al., 2018). Thus, they are a convenient group for the evaluation of ecosystem quality, which, in turn, promote biodiversity and ecosystem services.

The present research aimed at estimating diversity of spider assemblages in the miscanthus and switchgrass experimental fields in Northern Bukovyna in comparison with adjacent anthropogenic grasslands.

Material and methods

Study site and sample plots

The research was conducted on the lands of the Bukovyna State Agricultural Experimental Station of National Academy of Agrarian Sciences of Ukraine, located within administrative limits of the Ukraine's regional centre of Chernivtsi (48.360717 N, 25.933435 E). According to physiographic subdivision (National Atlas, 2007), Chernivtsi is situated on the border of two physiographic zones of Ukraine: the Ukrainian Carpathians and the deciduous forest zone.

We investigated two experimental fields of energy crops and two neighbouring fields with grassy vegetation for the comparison:

1. Study plot 1 – *Control* – an area that has not been cultivated since 2001, that is, an area of natural overgrowth. Poaceae predominate: *Poa pratensis* L., *Dactylis glomerata* L.; the other herbs are abundant – *Trifolium repens* L., *Lotus corniculatus* L., *Stenactis annua* (L.) Cass. ex Less. and *Taraxacum officinale* (L.) Weber ex F.H. Wigg; 0.25 ha.
2. Study plot 2 – *Grass-legume mixture* – a plot sown with a mixture of grasses for cattle and sheep feeding: *Trifolium pratense* L. + *Medicago sativa* L. + *Bromus inermis* Leyss. in the first year of cultivation without fertilizer; 0.2 ha.
3. Study plot 3 – *Miscanthus* – *Miscanthus* × *giganteus* J. M. Greef, Deuter ex Hodk., Renvoize in the fifth year of cultivation; planting rate of 1–3 rhizomes/m²; 0.1 ha.
4. Study plot 4 – *Switchgrass* – *Panicum virgatum* L. in the fourth year of cultivation; 0.05 ha.

Material collection

The material was collected by pitfall trapping. The traps with a diameter of 7 cm were set up in a line at a distance 10 m from each other and filled on one third with ethylene glycol as a preservation. Traps were opened from April 5 to September 29, 2016, and were emptied twice a month.

This paper presents the results of analysis of spider assemblages during the entire time of trap exposure (176 days) and ground-dwelling animals during the early spring period (22 days, April 5–27, 2016). A total of 2224 individuals of vertebrate and invertebrate animals were collected in April 2016 and 3694 individuals of spiders (of which 2973 were mature) during the study period.

Data analysis

We assessed dynamic density of ground-dwelling animals (mainly arthropods) as a number of individuals per 10 trap-days (individuals/10 trap-days). The total spider dynamic density was calculated for the entire number of individuals collected at the relevant site during the study period. However, in the following analysis, we considered only adult spiders, because most juvenile individuals cannot be identified to the species level.

Dominance classes were determined after Stöcker and Bergmann (1977): eudominants – 31.7–100% out of collected individuals, dominants – 10.1–31.6%, subdominants – 3.2–10.0%, reccedents – 1.1–3.1% and subreccedents – less than 1.0%.

Habitat fidelity indices for dominant species were calculated based on the proportion of individuals of a particular species in the samples at each plot and in total collection: $n_{ij}N - n_iN_j / (n_{ij}N + n_iN_j - 2n_{ij}N_j)$, where n_{ij} is the number of individuals of an i -species in the total sample (N_j) at the corresponding study plot, and n_i is the number of individuals of an i -species in the total collection of N individuals at all the plots studied (Pesenko, 1982).

Alpha-diversity of the spider assemblages was estimated based on Shannon index of species diversity, Pielou index of evenness and Simpson index of dominance (Magurran, 1991). These indices are widely used in ecological studies including biodiversity assessment of energy crops (Holguin et al., 2010; Platen et al., 2017; Williams, Feest, 2019), thus enabling consistent comparison with other researches. Calculations were performed in the program PAST (Hammer et al., 2001); differences between the index values were estimated by means of bootstrap analysis and visualized in the StatSoft Statistica 7.0 package.

Biocenotic similarity of the spider assemblages was assessed by the Renkonen index, $K_R = \sum \min(p_i, p_{i2})$, where p is the proportion of each species in the assemblage of N species (Jost et al., 2011). Faunistic similarity was assessed by the Sørensen index $K_s = 2C / A + B$, where C is the number of common species in two assemblages of A and B species (Magurran, 1991).

Detrended correspondence analysis (DCA) of spider assemblages of the study plots was based on the species individual abundance. Only species represented by three or more individuals at two compared plots were taken into account. We chose two dimensions with eigenvalues and ordinated the results in the program PAST.

Results

Spring assemblages of ground-dwelling animals

Ground-dwelling animals in April collection were represented by 4 phyla, 7 classes and 13 orders. The number of animal orders at the study plots was as follows: control – 10, grass-legume mixture – 11, miscanthus – 8 and switchgrass – 7 (Fig. 1).

Rodents and terrestrial mollusks were collected only from the control plot while earthworms fall in traps in the agricultural fields (Fig. 2). Arthropods were distributed more evenly, except two orders (Lepidoptera and Homoptera) found at one plot out of four.

Arthropods' dynamic density in April was the highest at Contr (32.3 individuals/10 trap-days) and the lowest at Miscant (11.7 individuals/10 trap-days). The most abundant were the or-

Fig. 1. Taxonomic structure of ground-dwelling animal assemblages at the study plots (April 2016).
Notes: 0 – no animals found; 1 – control plot; 2 – grass-legume mixture; 3 – miscanthus; 4 – switchgrass.

Fig. 2. Relative abundance of dominant orders of ground-dwelling arthropod assemblages at the study plots (April 2016).
Notes: Contr – control plot; GrLgMix – grass-legume mixture; Miscant – miscanthus; Switch – switchgrass.

Table 1. Faunistic and biocenotic similarity of spider assemblages at the study plots.

	Contr	GrLgMix	Miscant	Switch
Contr		0.42	0.36	0.29
GrLgMix	0.66		0.39	0.34
Miscant	0.39	0.66		0.50
Switch	0.43	0.69	0.87	

Notes: Renkonen index – left bottom part; Sorensen index – right upper part (for abbreviations, see Fig. 2).

ders Coleoptera, Araneae and Hymenoptera. The latter was represented mainly by Formicidae, Apidae and Vespoidea.

The Coleoptera dominated at each study plot; their relative abundance varied from 57.0% (Contr) to 88.9% (Miscant) of collected animals. The Hymenoptera proportion ranged from 0.4% (Miscant) to 20.1% (Contr) and that of the Araneae from 3.3% (Switch) to 10.7% (Contr). The arthropod community structure at Miscant was the most specific. It had an extremely low activity density of Hymenoptera and the extremely high proportion of Coleoptera (88.9%). The Araneae (3.8%) and Isopoda (2.6%) followed it, while the relative abundance of all the other orders in total accounted for only 4.7%.

Spider assemblages

Forty-nine spider species of 14 families were recorded from the study plots. The most diverse were the families Gnaphosidae (13 species, 26.5% of the species list) and Lycosidae (12 species, 22.5%). Species richness of spider assemblages at the study plots decreased in the following way: Contr (31), GrLgMix (23), Switch (18) and Miscant (14 species). Spider individual abundance was the highest at GrLgMix (1655 specimens) and the lowest at Switch (388 specimens) (Appendix, Table 1).

Shannon index of spider diversity was maximal at Contr, but its differences from the indices at GrLgMix and Switch were statistically insignificant (Fig. 3). The evenness grew from Contr to Switch, the Simpson index being statistically lower only at Miscant.

Spider dominant complexes included only two species: *Paradosa agrestis* and *Xerolycosa miniata*. Together they accounted

from 86.4% (Contr) to 96.4% (Miscant) of collected spiders at each plot. Other species had the statuses of recedents or subrecedents only. *Pardosa agrestis* preferred Switch and Miscant with the highest fidelity index at the latter plot, while *Xerolycosa miniata* was associated with Contr (Fig. 4; Appendix, Table 1). Both species had equal proportions at GrLgMix and their fidelity indices approached zero.

Six recedent species can be regarded as habitat specific within the study site. *Zelotes aeneus*, *Alopecosa cuneata*, *Phlegra fasciata* and *Zodarion rubidum* chose Contr; *Zelotes latreillei* and *Alopecosa pulverulenta* chose GrLgMix, but no specific species were found at Switch or Miscant. Five species (*Trochosa ruricola*, *Thanatus arenarius*, *Xysticus cristatus*, *X. kochi* and *Drassyllus praeficus*) occurred at the four study plots. Of these, only *Trochosa ruricola* showed no habitat specificity, while the others displayed lower or higher preferences for Contr (fidelity index 0.197–0.516).

Seasonal dynamics of dominant species varied depending on the plot (Fig. 5). *Pardosa agrestis* peaked in late July being most abundant at GrLgMix and Miscant. *Xerolycosa miniata* was numerous at Contr and GrLgMix from early June to late July. It had one peak at Miscant in early July and then dropped and disappeared at both Miscant and Switch.

Both faunistic and biocenotic similarities of spider assemblages were the highest between Miscant and Switch ($K_s = 0.50$, $K_R = 0.87$); the lowest were the faunistic similarity between Contr and Switch ($K_s = 0.29$) and biocenotic similarity between Contr and Miscant ($K_R = 0.39$) (Table 1).

DCA ordination shows the differences between the study plots based on the structure of spider assemblages (Fig. 6): GrLgMix occupies the middle position on Axis 1 between Contr and Miscant; the distances Switch-Miscant and Contr-GrLgMix are approximately equal on Axis 2, but in total, Switch is the most distant from the other study plots. Dominant spiders take middle position at the ordination plot, *Pardosa agrestis* being closer to Switch and Miscant. The *Xerolycosa miniata* low abundance at Switch defines the plot's higher extremity on Axis 2. All species included in the analysis are shared between Contr and GrLgMix, leaving the energy crop fields out of the 95% confidence area.

Discussion

In the course of our research, 47 spider species were recorded from the four experimental fields of the Bukovyna Agricultural Station. The majority (31) inhabited an abandoned field, while the switchgrass and miscanthus fields were populated by only 14 and 18 species, respectively. Spider individual abundance in the energy crops was also lower, but alpha diversity decreased significantly only in the miscanthus field. Early spring arthropod assemblages showed the similar traits, being the richest in abandoned field and the poorest in the miscanthus one.

Our data are consistent with the results of the long-term miscanthus studies in southeast England (Williams, Feest, 2019). Conclusions on the miscanthus benefits to biodiversity (Jodl et al., 2004; Semere, Slater, 2007) are based on its comparison with other biomass crops and/or investigation of young plantations. Miscanthus was also shown to host least divers and abundant invertebrate communities than switchgrass and abandoned fields in the USA (Snelik, 2018) that corresponds to our observations.

Fig. 3. Alpha-diversity indices of spider assemblages at the study plots. Whiskers indicate min and max bootstrap values (for abbreviations, see Fig. 2).

Fig. 4. Dominance structure of spider assemblages at the study plots (for abbreviations, see Fig. 2).

Spiders are known to have a high dispersal capacity; many species colonize cultivated fields from surrounding habitats (Öberg et al., 2008; Benhadi-Marín et al., 2016). Nevertheless, despite the close location and small areas, only *Trochosa ruricola* was distributed more or less evenly within the four study plots; 18 species preferred the abandoned field and/or grass mixture, while not a single species chose switchgrass, miscanthus or both. All the fields were dominated by two widespread grasslands species, numerous on arable and abandoned lands. *Pardosa agrestis* is reported to be the main eudominant in grain fields in the south of the East European Plain (Seyfulina, 2010; Zhuravel et

Fig. 5. Seasonal dynamic densities of the dominant spider species (*Pardosa agrestis* left and *Xerolycosa miniata* right) at the study plots (for abbreviations, see Fig. 2).

Fig. 6. DCA ordination of the study plots based on spider species composition and individual numbers. A 95% confidence ellipse is displayed (for abbreviations, see Fig. 2 and Appendix, Table 1).

al., 2012) and a second-rank dominant in the north (Seyfulina, 2005). Interestingly, that its dominance status in adjacent virgin steppes is not higher than recedent (Prokopenko, Savchenko, 2013). The high abundance of *Xerolycosa miniata* is typical of disturbed lands, like extensively grazed pastures, fallows or burnt grasslands (Prokopenko, Savchenko, 2013; Polchaninova et al., 2016). At our study site, it finds preferable conditions in both abandoned field and grass mixture being not numerous in

the energy crops.

Both dominants are photophylous species. In the study year, they reached their maximal abundance in mid or late July and then gradually declined. In the switchgrass and miscanthus, their individual numbers decreased dramatically after the peak due to the change in lighting conditions: grown plants shaded the ground and transformed open grasslands into a dark ‘jungle’. For the same reason, *Zelotes longipes*, a numerous autumnal dry grassland species (Polchaninova et al., 2019), was absent from the energy crops. Seasonal changes in macroclimatic conditions and insufficient fodder are, presumably, the main factors affecting spider communities in biofuel crops (Williams, Feest, 2019).

Conclusion

Except the dominance structure, spider assemblages of the miscanthus and switchgrass fields differed dramatically from those of the neighbouring grassy habitats. They were poorer in species diversity and individual abundance. An essential depletion of spiders and other arthropods in perennial biofuel crops affects biodiversity in agroecosystems. We recommend preserving small areas of natural or semi-natural vegetation between the cultivated fields for providing ecologically friendly agricultural management.

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Appendix

Spider species composition and individual abundance at the study plots of the Bukovyna State Agricultural Experimental Station of National Academy of Agrarian Sciences of Ukraine April 5 to September 29, 2016.

Species	Abbr	Study plots			
		Contr	GrLgMix	Miscant	Switch
Fam. Agelenidae					
Agelenopsis potteri (Blackwall, 1846)	-	-	-	-	1
Allagelena gracilens (C. L. Koch,1841)	-	-	1	-	-
Agelenidae sp. juv.	-	-	-	-	1
Fam. Araneidae					
Argiope bruennichi (Scopoli, 1772)	-	-	-	-	1
Fam. Clubionidae					
Clubiona diversa (O. P. Cambridge, 1862)	C. div	1	2	-	-
C. neglecta (O. P. Cambridge, 1862)	-	-	-	-	1
Fam. Dysderidae					
Harpactea rubicunda (C. L. Koch, 1838)	-	1	-	-	-
Fam. Gnaphosidae					
Callilepis nocturna (Linnaeus, 1758)	-	1	-	-	-
Drassodes cupreus (Blackwall, 1834)	-	1	-	-	-
Drassyllus praeficus (L. Koch, 1866)	D. pre	5	4	1	-
D. pusillus (C. L. Koch, 1833)	D. pus	1	3	-	-
Haplodrassus minor (O. P. Cambridge, 1879)	H. min	2	-	-	1
H. signifer (C. L. Koch, 1839)	-	-	1	-	-
Micaria formicaria (Sundevall, 1831)	-	-	2	-	-
Zelotes aeneus (Simon, 1878)	Z. aen	5	-	-	-
Z. apricorum (L. Koch, 1876)	-	-	-	1	-
Z. latreillei (Simon, 1878)	Z. lat	-	15	1	-
Z. longipes (L. Koch, 1866)	Z. lon	9	3	-	-
Z. petrensis (C. L. Koch, 1839)	-	1	-	1	-
Gnaphosidae sp. juv.	-	1	-	-	-
Fam. Linyphiidae					
Agyneta rurestris (C. L. Koch, 1836)	-	-	3	-	-
Diplostyla concolor (Wider, 1834)	-	-	-	-	1
Nematogmus sanguinolentus (Walck., 1841)	-	-	-	1	1
Trichopterna cito (O. P.-Cambridge, 1873)	-	1	-	-	-
Fam. Lycosidae					
Alopecosa cuneata (Clerck, 1757)	A. cun	5	-	-	-
A. farinosa (Herman, 1879)	-	1	-	1	-
A. pulverulenta (Clerck, 1757)	A. pul	13	7	-	1
Pardosa agrestis (Westring, 1861)	P. agr	171/-0.484	646/0.012	417/0.303	219/0.192
P. fulvipes (Collett, 1876)	-	-	1	-	-
P. lugubris (Walckenaer, 1802)	-	1	-	-	-
P. paludicola (Clerck, 1757)	-	1	-	-	-
P. palustris (Linnaeus, 1758)	P. pal	4	26	-	7
P. prativaga (L. Koch, 1870)	-	-	-	-	2
P. pullata (Clerck, 1757)	P. pul	2	1	1	-
Trochosa ruricola (De Geer, 1778)	T. rur	10	8	6	8
Xerolycosa miniata (C. L. Koch, 1834)	X. min	541/0.328	559/0.014	91/-0.468	64/-0.382
Lycosidae sp. juv.	-	212	338	80	67
Fam. Philodromidae					
Thanatus arenarius (L. Koch, 1872)	Th. ar	9	4	1	4
Tibellus oblongus (Walckenaer, 1802)	-	-	1	-	-
Fam. Phrurolithidae					
Phrurolithus festivus (C. L. Koch,1835)	-	1	-	-	-

Appendix - continue

Species	Abbr	Study plots			
		Contr	GrLgMix	Miscant	Switch
Fam. Pisauridae					
<i>Pisaura mirabilis</i> (Clerck, 1757)	-	-	-	-	2
Fam. Salticidae					
<i>Evarcha arcuata</i> (Clerck, 1757)	-	-	-	1	-
<i>Heliophanus auratus</i> (C. L. Koch, 1835)	-	1	-	-	-
<i>H. flavipes</i> (Hahn, 1832)	-	-	-	-	1
<i>Phlegra fasciata</i> (Hahn, 1826)	Ph. fa	19	1	-	-
Salticidae sp. juv.	-	-	1	-	-
Fam. Tetragnathidae					
<i>Pachygnatha degeeri</i> (Sundevall, 1830)	-	1	-	-	-
Fam. Theridiidae					
<i>Robertus arundineti</i> (O. Pickard-Cambridge, 1871)	-	-	1	-	-
Fam. Thomisidae					
<i>Spiracme striatipes</i> (L. Koch, 1870)	-	1	-	-	-
<i>Xysticus acerbus</i> (Thorell, 1872)	X. ace	2	1	-	-
<i>X. cristatus</i> (Clerck, 1757)	X. cri	4	1	3	3
<i>X. kochi</i> (Thorell, 1872)	X. koc	18	12	1	2
<i>Xysticus</i> sp. juv.	-	7	13	-	-
Fam. Zodariidae					
<i>Zodarion rubidum</i> (Simon, 1914)	Z. rub	4	-	-	-
Total number of individuals		1058	1655	607	388
Total number of families		12	9	6	10
Total number of species		31	23	14	18

Notes: Contr – Control plot; GrLgMix – Grass-legume mixture; Miscant – miscanthus; Switch – switchgrass; Abbr – abbreviation of the species names; - no data; number of individuals/fidelity index.