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EVALUATION OF THE DIVERSITY OF INVERTEBRATES ASSEMBLAGES IN SPRING WHEAT CULTIVATED IN DIFFERENT CROP PRODUCTION SYSTEMS

Summary

The aim of the study was to evaluate the diversity of invertebrate groups in spring wheat cultivated in different crop production systems. The field experiment was established in 1994 in experimental plot at Agricultural Experimental Station of IUNG-PIB Kępa in Osiny. The research was conducted in 2014-2016 on spring wheat fields in organic, conventional and integrated systems. At designated points in each year of research, biological material was collected, using two methods: sweep net and pitfall traps. The number of invertebrates in each order was determined and compared, as well as the variety of orders. Simpson's diversity index and Shannon-Wiener's index were used to assess their diversity. In spring wheat, about two times more spiders and pollinating insects were found in organic system than in conventional and integrated systems. Beetles (Coleoptera) were the dominant group of invertebrates in spring wheat in all crop production systems. The highest values of the Simpson and Shannon-Wiener's diversity indexes calculated for invertebrate orders were recorded in the organic system, while the smallest in the integrated system.
***Key words**: invertebrates, ecosystem services, spring wheat, crop production system*

OCENA RÓŻNORODNOŚCI ZGRUPOWAŃ BEZKRĘGOWCÓW W PSZENICY JAREJ UPRAWIANEJ W RÓŻNYCH SYSTEMACH PRODUKCJI ROŚLINNEJ

Streszczenie

Celem prowadzonych badań była ocena różnorodności zgrupowań bezkręgowców w pszenicy jarej uprawianej w różnych systemach produkcji roślinnej. Do przeprowadzenia badań wykorzystano doświadczenie polowe założone w 1994 r. w RZD IUNG-PIB Kępa w Osinach. Badania prowadzono w latach 2014-2016 na polach pszenicy jarej w systemie ekologicznym, konwencjonalnym oraz integrowanym. W wyznaczonych punktach w każdym roku badań zbierano materiał biologiczny czerpakiem entomologicznym oraz metodą pułapek ziemnych. Określono i porównano liczebność osobników bezkręgowców w poszczególnych rzędach, a także różnorodność rzędów. Do oceny wykorzystano wskaźnik różnorodności Simpsona oraz wskaźnik Shannona-Wienera. W pszenicy jarej uprawianej ekologicznie stwierdzono około dwa razy więcej pająków i owadów zapylających niż w systemach konwencjonalnym i integrowanym. Dominującą grupą organizmów bezkręgowych w pszenicy jarej we wszystkich systemach produkcji roślinnej były chrząszcze (Coleoptera). Najwyższe wartości wskaźników różnorodności Simpsona oraz Shannona-Wienera wyliczone dla rzędów bezkręgowców odnotowano w systemie ekologicznym, natomiast najmniejsze w systemie integrowanym.
***Słowa kluczowe**: bezkręgowce, usługi ekosystemowe, pszenica jara, systemy produkcji roślinnej*

1. Introduction

In recent years, attention has been paid to the direct economic benefits of biodiversity conservation. These benefits are called ecosystem services. So far few studies have shown that higher levels of biodiversity have a positive effect on the level of these services [10, 11], but the mechanisms underlying these dependencies are poorly recognized. The natural protection of plants from pests and pathogens is one of the most important ecosystem services in agrocenosis. It is based on specific quantitative relationships between harmful and useful organisms. Research and implementation programs in this area often take into account only the simple relationships between individual species of the victims and their natural enemies. It appears that the effectiveness of biological control is enhanced by the simultaneous interaction of the entire predator and parasitoid groups, whose abundance may be affected by the complexity of farmland and management intensity [9]. Unfortunately, estimation of such complex interaction is difficult and rarely undertaken, especially in different types of agricultural landscapes [11].

The purpose of the study was to assess the diversity of invertebrate groups in spring wheat cultivated in different crop production systems.

2. Materials and methods

The field experiment was established in 1994 at Agricultural Experimental Station of IUNG-PIB Kępa in Osiny (Lublin province) and the aim was to compare different systems of crop production. The research was conducted in 2014-2016 on spring wheat fields in organic, conventional and integrated systems. The experiment was conducted on the soil of the rye good complex. The organic system was represented by the following crop rotation: potato – spring wheat + seed – mixture of clover with grass – cereal and legume mixture – winter wheat + catch crop. In organic system no synthetic mineral fertilizers, pesticides and growth regulators were used. Organic fertilization included the application of compost once in rotation for potato crop in an amount of about 30 $t \cdot ha^{-1}$. Weed control mainly consisted of intensive mechanical procedures. Nitrogen needs of plants were primarily satisfied by the biological binding of this ingredient by the legume plants and the compost used once in rotation.

The conventional system was represented by 3-field rotation (rape – winter wheat – spring wheat. In this system intensive production technologies were implemented. Nitrogen fertilization was based on dose rates for yield maximization.

The integrated system of 4-field crop rotation (potato – wheat – faba bean – winter wheat + catch crop) was characterized by a moderate use of industrial means of production. Nitrogen fertilization was lower by about 30-40% lower than in the conventional system.

On spring wheat fields at designated points in each year of study, a collection of biological material was carried out using two methods: the sweep net and the pitfall traps.

Invertebrates (terrestrial) were caught using earth traps. Traps, or plastic containers of about 10 cm in diameter, were placed in a straight line along the designated transects at a distance of about 5 m from each other. In every field of area of one hectare, 5 traps were set. Traps were emptied every 2 weeks from about the beginning of May to harvest of the wheat for a period of three years from 2014 to 2016.

Plant inhabiting invertebrates were grasped with an sweep net. A heart-shaped net with two straight edges was used in the study. The collection consisted of a double-sided swing with a scoop of about 120 degrees. Each collection consisted of material derived from the passage of two parallel transects, in which a total of 50 sweeps were made, 25 in each transect. The collection was carried out at a distance of about 5 m from earth traps. Invertebrates were caught during the growing season at the same time as epigraphic invertebrates were collected.

All invertebrate individuals were counted and determined to order. The number of invertebrates in each order was determined and compared, as well as the variety of orders. Shannon-Weiner's and Simpson's diversity indexes were used to evaluate diversity of the orders [6].

The analyzed data were characterized by normal distribution. In order to assess the significance of the differences, a variance analysis was performed with using ANOVA and LSD test. Mean squares (MS) and statistic value F were calculated. Statistical tests were performed using STATISTICA 7, whereas diversity indexes were calculated using PAST 3.

3. Results and discussion

Significant differences in the number of individuals in particular orders of invertebrates between compared systems of spring wheat production were found (Table 1). In organic spring wheat, approximately twice as many spiders (Araneae) were recorded than in conventional and integrated systems. Spiders are considered as one of the most important groups of antagonistic organisms in relation to pests, especially in cereals, such as cereal aphid, cereal leaf beetle (Oulema melanopus and Q. gallaeciana*)* [2, 7, 8]. More than twice as many pollinators (Hymenoptera and Lepidoptera) were also found in the organic fields than in other fields. Numerous studies indicate that organic farming is characterized by a greater diversity of pollinator insects than conventional systems [1, 3]. This is mainly due to the greater diversity of segetal plants in organic crops, including a large group of flower plants [3]. The average number of invertebrates trapped with pitfall traps and sweep net in spring wheat is shown in Table 1.

Beetles (Coleoptera), flies (Diptera), bugs (Hemiptera) and spiders (Araneae) were on average the most abundant in all management systems. Among the beetles, the Chrysomelidae and Carabidae families constituted the largest group. Among the bugs the most abundant was the superfamily Aphidoidea. Spiders were mainly represented by families: Lycosidae, Linyphiidae and Araneidae.

Table 1. Average number and percentage share of individuals in orders in invertebrate groups in spring wheat cultivated in different crop production systems (2014-2016)

Tab. 1. Średnia liczba i procentowy udział osobników poszczególnych rzędów w zgrupowaniach bezkręgowców w pszenicy jarej uprawianej w różnych systemach produkcji roślinnej (2014-2016)

Invertebrate order	**System of crop production**					
	Organic		**Conventional**		**Integrated**	
	number of individuals	share %	number of individuals	share %	number of individuals	share %
Acari	117.3	3.2	291.0	8.2	88.3	2.5
Araneae	654.3	18.1	305.0	8.6	384.0	11.1
Coleoptera	957.7	26.4	979.3	27.6	1068.0	30.8
Collembola	176.7	4.9	267.0	7.5	276.0	8.0
Dermaptera	0	0	0	0	0.7	>0.1
Diptera	751.0	20.7	813.7	22.9	983.7	28.4
Hemiptera	581.7	16.1	569.7	16.0	430.3	12.4
Hymenoptera	304.7	8.4	156.0	4.4	143.3	4.1
Isopoda	0	0	0.3	>0.1	0	0
Lepidoptera	29.3	0.8	14.3	0.4	10.3	0.3
Haplotaxida	4.0	0.1	13.3	0.4	2.7	0.1
Mecoptera	0	0	0.3	>0.1	0	0
Lithobiomorpha	0	0	0.3	>0.1	2.3	0.1
Neuroptera	6.3	0.2	8.0	0.2	2.0	0.1
Opiliones	16.3	0.5	5.0	0.1	2.0	0.1
Orthoptera	3.0	0.1	2.7	0.1	5.0	0.1
Siphonaptera	1.3	>0.1	2.0	0.1	3.7	0.1
Thysanoptera	17.3	0.5	124.0	3.5	65.3	1.9
Total	**3620.9**	**100**	**3551.9**	**100**	**3467.6**	**100**

Source: own work / Źródło: opracowanie własne

The Simpson and Shannon-Wiener indexes were calculated on the basis of the number of individual orders. The average values of the indicators in the two collected methods were compared. In spring wheat, the largest number of invertebrates in the organic system were collected using pitfall traps. Samples collected from the sweep net also included, on average, more invertebrates in ecologically grown wheat (Table 2). The statistically significant differences are presented in Tables 3 and 4.

In samples collected using both methods: sweep net and pitfall traps, more invertebrates were found in organic spring wheat than in the other systems (Figure 1). On average, in organic wheat 577 specimens were collected in a net and 1085 specimens in the traps. In the conventional system, an average of 330 individuals were collected in the net and 631 in the traps. In the integrated system, the average number of individuals was 331 in the net and 658 in the traps, and it was approximately similar to the conventional system. On the basis of one-way analysis of variance, it was found that the plant production system was a factor differentiating the results obtained with both methods (Table 3). On the basis of the LSD test, a statistically significant difference was found between the mean of organic system and the conventional and integrated systems (Table 4).

In spring wheat, a total of 18 different invertebrate orders were identified. The number of orders ranged between 12 and 16 in different agricultural systems in 2014-2016. Both in vegetation and trap samples, the average number of orders was the highest in the ecological system (Figure 2). In the case of samples collected from vegetation in organic, conventional and integrated systems, the difference was not statistically significant. Mean values from the pitfall traps were significantly higher in organic system than in other crops (Table 4). There were no significant differences between the average number of orders in traps between conventional and integrated system. On the basis of the results obtained, the distinctness of organic farming compared to the other two management systems (Table 1, Figures 1 and 2) is highlighted. Organic farming is characterized by a higher ratio of beneficial invertebrates (Araneae, Opiliones, Hymenoptera) which plays an important role in the provision of ecosystem services than other plant production systems.

The highest values of Simpson's diversity indices (Si_{2014} = 0.80, Si_{2015} = 0.85, Si_{2016} = 0.83) and Shannon-Wiener's index values (H'_{2014} = 1.78, H'_{2015} = 2.03, H'_{2016} = 1.95) were found in organic system. The lowest values of diversity indices at the habitat level were characterized by crops in the integrated system (Figure 2). There were differences in the diversity indices between various farming systems in both sweep net and pitfall traps (Figures 3 and 4). In the samples from traps, the significantly higher values of the Simpson index and the Shannon-Wiener index were found in the organic management system of spring wheat compared to the conventional and integrated systems (Table 4). Significantly higher values of the Simpson and Shannon-Wiener's indices were also found in samples from pitfall traps between conventional and integrated production systems. In the sweep net samples the differences between production systems were not significant for both indicators (Table 4).

Table. 2. Average values of invertebrate diversity indices in spring wheat in different crop production systems for two collecting methods (2014-2016)

Tab. 2. Średnie wartości wskaźników różnorodności bezkręgowców w pszenicy jarej w różnych systemach produkcji roślinnej dla dwóch metod zbioru (2014-2016)

Method of collection	Farming system	Number of individuals	Number of orders	Simpson's index	Shannon-Wiener's index
Sweep net	Organic	577.0	7.5	0.7	1.5
	Conventional	330.4	7.1	0.7	1.3
	Integrated	331.8	7.4	0.7	1.4
Pitfall traps	Organic	1084.92	10.61	0.77	1.67
	Conventional	631.09	9.55	0.73	1.58
	Integrated	622.71	9.81	0.68	1.43

Source: own work / Źródło: opracowanie własne

Table 3. Results of variance analysis for 4 indices of invertebrate diversity in spring wheat in different cropping systems for two collecting methods *

*Tab. 3. Wyniki analizy wariancji dla 4 wskaźników różnorodności bezkręgowców w pszenicy jarej w różnych systemach produkcji roślinnej dla dwóch metod zbioru**

Method of collection	Indicator	MS	F	p
Sweep net	Number of individuals	147749.1	3.90	0.024
	Numer of orders	1.542788	1.06	0.351
	Simpson's index	0.010012	1.35	0.265
	Shannon-Wiener's index	0.050203	1.68	0.193
Pitfall traps	Number of individuals	283902.6	7.95	0.001
	Numer of orders	1.884776	5.55	0.005
	Simpson's index	0.003628	12.89	>0.001
	Shannon-Wiener's index	0.03095	11.99	>0.001

* Relatively significant correlations with p <0.05 were highlighted in red

Source: own work / Źródło: opracowanie własne

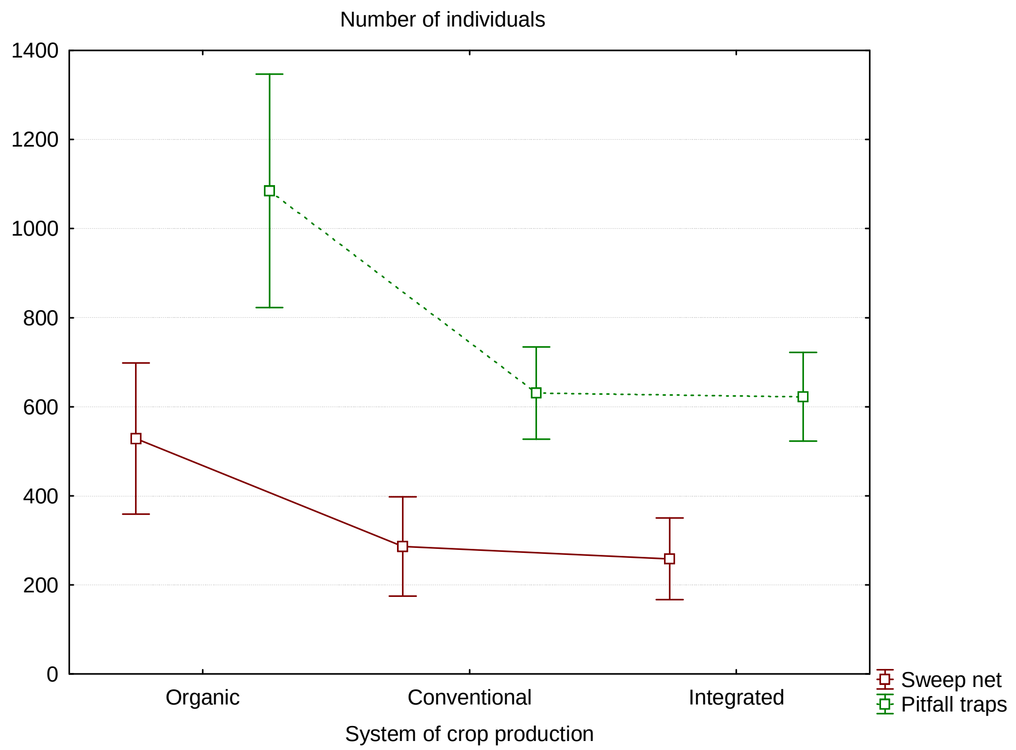
Table 4. Results of LSD test for 4 indices of invertebrate diversity in spring wheat in different cropping systems for two collecting methods *

*Tab. 4. Wyniki testu NIR dla 4 wskaźników różnorodności bezkręgowców w pszenicy jarej w różnych systemach produkcji roślinnej dla dwóch metod zbioru**

Method of collection	Indicator	Farming system	Organic	Conventional	Integrated
Sweep net	Number of individuals	Organic	-	0.013	0.044
		Conventional	0.013	-	0.991
		Integrated	0.044	0.991	-
	Number of orders	Organic	-	0.156	0.767
		Conventional	0.156	-	0.399
		Integrated	0.767	0.399	-
	Simpson's index	Organic	-	0.149	0.209
		Conventional	0.149	-	0.933
		Integrated	0.209	0.933	-
	Shannon-Wiener's index	Organic	-	0.074	0.346
		Conventional	0.074	-	0.610
		Integrated	0.346	0.610	-
Pitfall traps	Number of individuals	Organic	-	0.001	0.002
		Conventional	0.001	-	0.955
		Integrated	0.002	0.955	-
	Number of orders	Organic	-	0.002	0.036
		Conventional	0.002	-	0.493
		Integrated	0.036	0.493	-
	Simpson's index	Organic	-	>0.001	>0.001
		Conventional	>0.001	-	0.017
		Integrated	>0.001	0.017	-
	Shannon-Wiener's index	Organic	-	0.041	>0.001
		Conventional	0.041	-	0.003
		Integrated	>0.001	>0.003	-

* Relatively significant correlations with p <0.05 were highlighted in red

Source: own work / Źródło: opracowanie własne



Source: own work / Źródło: opracowanie własne

Fig. 1. Mean and standard error for the number of individuals collected by the sweep net method and pitfall traps in different spring wheat cultivation systems

Rys. 1. Średnia i błąd standardowy dla liczby osobników zebranych metodą czerpaka entomologicznego i pułapek ziemnych w różnych systemach gospodarowania w uprawie pszenicy jarej

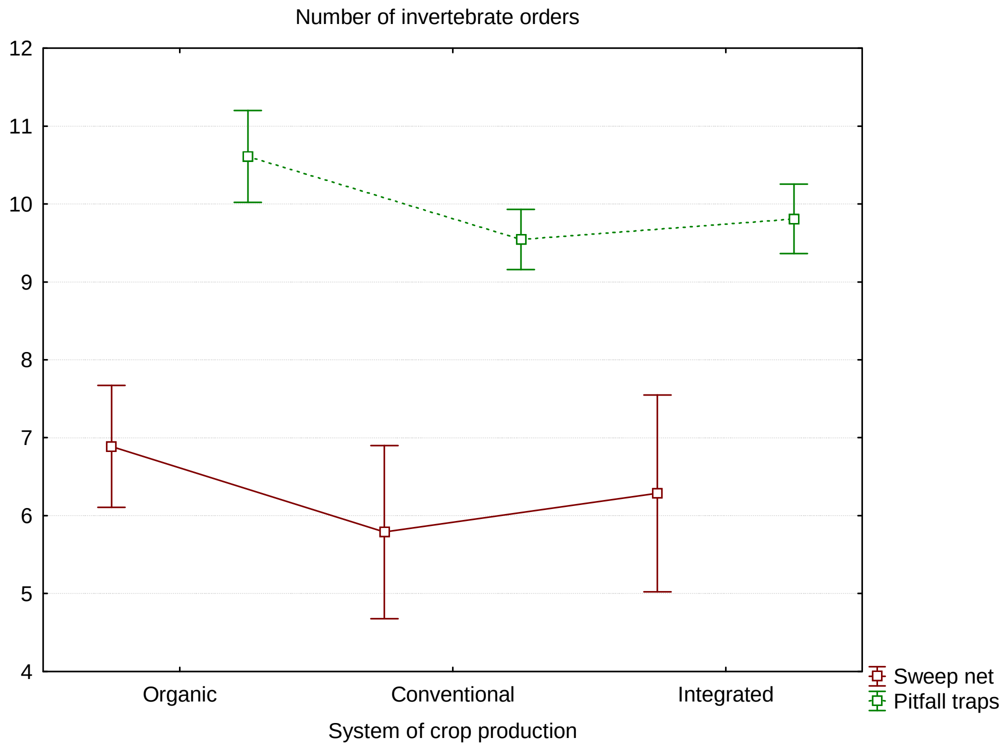


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Fig. 2. Mean and standard error of the number of orders of invertebrates in different spring wheat management systems in samples collected using sweep net and pitfall traps
Rys. 2. Średnia i błąd standardowy liczby rzędów w różnych systemach gospodarowania w pszenicy jarej w próbach zebranych za pomocą czerpaka entomologicznego i pułapek ziemnych

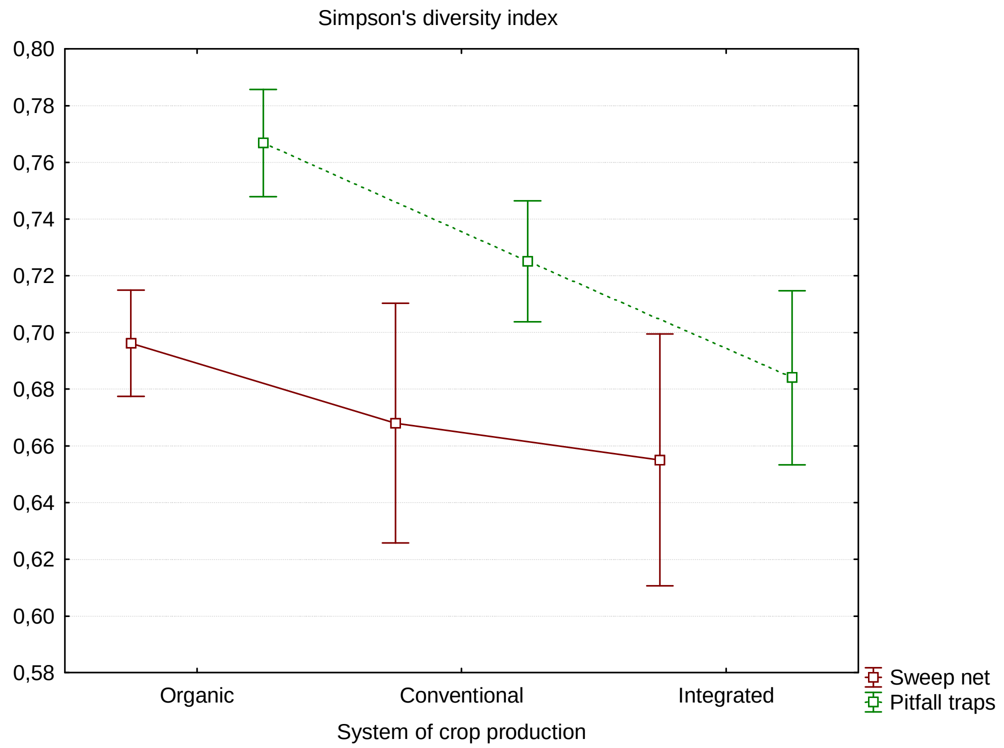

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Fig. 3. Mean and standard error of Simpson's diversity index in samples from pitfall traps and sweep net collected in different spring wheat management systems
Rys. 3. Średnia i błąd standardowy wskaźnika różnorodności Simpsona w próbach z pułapek ziemnych i czerpaka entomologicznego, zebranych w różnych systemach gospodarowania w pszenicy jarej

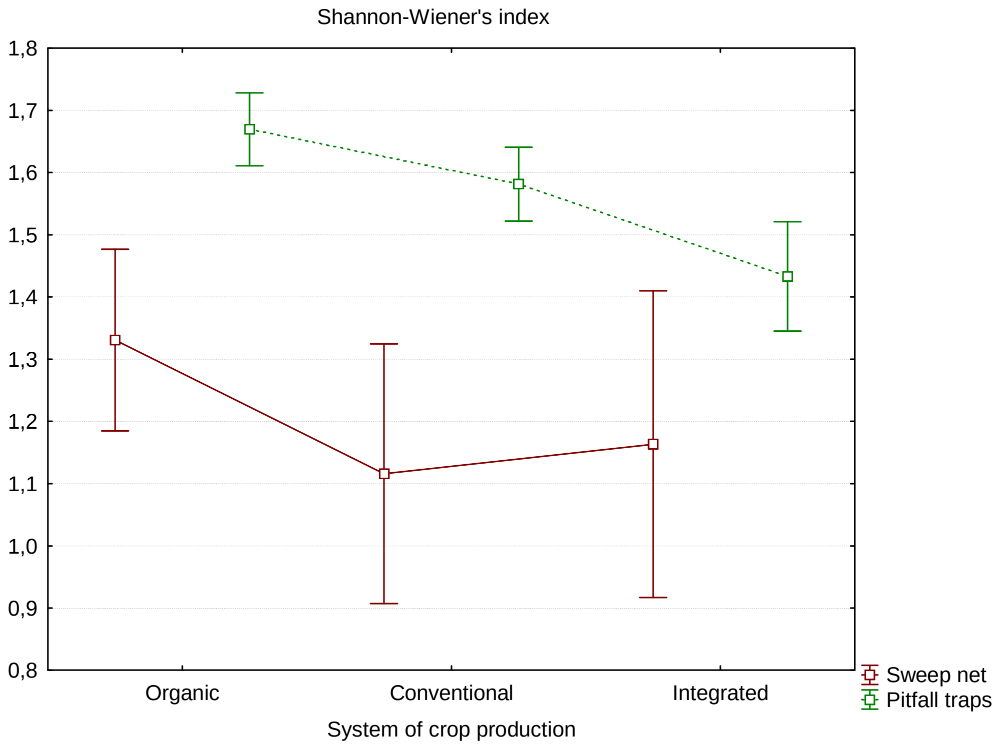

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Fig. 4. Mean and standard error of the Shannon-Wiener's diversity index in samples from pitfall traps and sweep net in spring wheat in different management systems
Rys. 4. Średnia i błąd standardowy wskaźnika różnorodności Shannona-Wienera w próbach z pułapek ziemnych i czerpaka entomologicznego w pszenicy jarej w różnych systemach gospodarowania

The results indicate that the production system has a greater effect on invertebrates that settle the soil surface in spring wheat than on plant-based organisms. The difference may be due to the density of the vegetation in particular crops. Conventional crops are typically densely planted and have a better coverage of vegetation, limiting the access of light to the soil, indirectly influencing thermophilic invertebrates. According to the results, the structure of the field vegetation resulting from the differences between the systems does not affect the diversity of the plant-based invertebrates. Another reason for the difference between the impact of systems on plant and terrestrial invertebrates can be the poor efficiency of sweep net sampling in dense vegetation [4].

Small differences between the conventional and integrated systems can be explained by the presence of intensive production in the integrated system (mineral fertilization, pesticides), which adversely affect biodiversity [5]. The presence of these factors, despite their limited use, can have a significant impact on invertebrate populations living in the wheat cultivated in this system. The results indicate that only complete abandonment of mineral fertilization and pesticide use in the organic system has a significant effect measured by higher diversity indicators values.

4. Conclusions

1. In winter wheat, approximately twice as many spiders and pollinating insects (Hymenoptera and Lepidoptera) were found in organic wheat than in conventional and integrated systems.
2. The dominant group of invertebrates in spring wheat in all plant production systems comprised beetles (Coleoptera). They accounted for about 30% of the total invertebrate groups.
3. On average, the largest number of invertebrates and their greatest diversity measured by the number of orders were found in the organic system.
4. The highest values of the Simpson and Shannon-Wiener diversity indices calculated for invertebrate orders were recorded in the organic system, while the lowest in the integrated system.
5. The results indicate that only complete abandonment of mineral fertilization and pesticide use in the organic system has a significant effect measured by higher diversity indicators values.

5. References

[1] Andersson G.K., Ekroos J., Stjernman M., Rundlöf M., Smith H.G.: Effects of farming intensity, crop rotation and landscape heterogeneity on field bean pollination. Agriculture, Ecosystems and Environment, 2014, 184, 145-148.
[2] Dinter A.: Microcosm studies on intraguild predation between female erigonid spiders and lacewing larvae and influence of single versus multiple predators on cereal aphids. Journal of Applied Entomology, 2002, 126 (5), 249-257.
[3] Gabriel D., Tscharntke T.: Insect pollinated plants benefit from organic farming. Agriculture, Ecosystems and Environment, 2007, 118: 43-48.
[4] Gardiner T., Hill J., Chesmore D.: Review of the methods frequently used to estimate the abundance of Orthoptera in grassland ecosystems. Journal of Insect Conservation, 2005, 9.3, 151-173.

[5] Isenring R.: Pesticides reduce biodiversity. Pesticides News, 2010, 88, 4-7.
[6] Krebs C.J.: Ecological Methodology. Harper and Row Publishers, New York, 1989.
[7] Mansour F., Heimbach U.: Evaluation of lycosid, micryphantid and linyphiid spiders as predators of Rhopalosiphum padi (Hom.: Aphididae) and their functional response to prey density-laboratory experiments. Entomophaga, 1993, 38(1), 79-87.
[8] Nyffeler M., Benz G.: Feeding ecology and predatory importance of wolf spiders (Pardosa spp.) (Araneae, Lycosidae) in winter wheat fields. Journal of Applied Entomology, 1988, 106(1-5): 123-134.
[9] Stoate C., Baldi A., Beja P., Boatman N.D., Herzon I., van Doorn A., de Snoo G.R., Rakosy L., Ramwell C.: Ecological impacts of early 21st century agricultural change in Europe – a review. J. Environ. Manage, 2009, 91, 22-46.
[10] Swift M.J., Izac A.M.N., van Noordwijk M.: Biodiversity and ecosystem services in agricultural landscapes – are we asking the right questions? Agr. Ecosyst. Environ., 2004, 104: 113-134.
[11] Tscharntke T., Klein A.M., Kruess A., Steffan-Dewenter I., Thies C.: Landscape perspectives on agricultural intensification and biodiversity – ecosystem service management. Ecol. Lett., 2005, 8, 857-874.

The study was conducted under the statutory projects of IUNG-PIB no 1.13 Biodiversity assessment of selected groups of invertebrates in different types of agricultural production (2014-2017).