AGRONOMY SCIENCE
wcześniej – formerly
Annales UMCS sectio E Agricultura

VOL. LXXVIII (4) 2023

https://doi.org/10.24326/as.2023.5266

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Biodiversity assessment of segetal flora, earthworms and terrestrial invertebrates in various agricultural production systems and crops

Różnorodność biologiczna chwastów, owadów i dżdżownic w różnych systemach rolniczych południowej Polski

Summary. The functioning of societies depends on a number of goods and services provided by the natural environment. Knowledge about the benefits that humans derive from it is an important issue in the era of current environmental and climate changes. Agricultural systems and management methods (e.g., tillage, weed and pest control, fertilization, field consolidation, crop specialization and monoculture) are important for biodiversity, the presence of which is of great importance for people and the environment. The aim of this study was to assess bioenvironmentalindicators such as weed flora, earthworms and terrestrial invertebrates biomass, in selected crops in an organic, integrated and conventional farming systems in southern Poland.
The results showed the highest biodiversity weeds, earthworms, and terrestrial invertebrates in crops grown in the organic system in comparison to the conventional or sustainable ones, where chemical herbicides were applied. Species diversity of weeds was, on average, twice as high in the organic system (21 species) compared to the integrated and conventional systems (10–11 species). In the organic system, the highest number of weeds (average 71 pcs m^{-2}) accompanied spring wheat and the lowest number of weeds was observed in legume-grass mixture in the first year of use (average 28 pcs m^{-2}). The highest biomass of earthworms in the soil was estimated under winter wheat and legume-grass mixtures. This indicator was half as much in the soil under plants grown in integrated and conventional systems. Terrestrial invertebrates were also most abundant in crops grown in the organic system, indicating that this agricultural production system is conducive to maintaining high

Citation: Harasim E., Feledyn-Szewczyk B., 2023. Biodiversity assessment of segetal flora, earthworms and terrestrial invertebrates in various agricultural production systems and crops. Agron. Sci. 78(4), 63–75. https://doi.org/10.24326/as.2023.5266

biodiversity in agroecosystems. For winter wheat cultivated in the conventional and integrated systems, the invertebrate richness index was 2.5–3 times lower than in the organic system.

Key words: farming systems, weeds, earthworms, terrestrial invertebrates

INTRODUCTION

The agroecosystem is a unique living environment for wild plant species (weeds), but also for other organisms, such as terrestrial invertebrates, soil organisms and higher organisms that, together with cultivated plants, create the biodiversity of agricultural lands. The concept of biological diversity in agriculture is a broad issue, as it covers species of plants, fungi and animals living wild in agricultural areas, but also all living organisms resulting from agricultural activity, including: species and varieties of cultivated plants, species and breeds of farm animals and related microorganisms. Thanks to this diversity, people have access to food and the ability to meet basic life needs such as: clothing, medicines, cosmetics, building materials and others [Rockström et al. 2017, Rasmussen et al. 2018].

Maintaining biodiversity of species and accompanying organisms depends, among others, on the type of farming systems, i.e., organic, integrated and conventional, and methods of management (cultivation, weed control, mineral fertilization, canopy protection, field consolidation, introduction of specialization, monoculture). In the aspect of preserving or renewing agricultural biodiversity, the preservation of field edges, trees, bushes, water reservoirs and other mid-field areas, i.e. the creation of the so-called mosaic structure of groups, is important [Pfiffner and Stoeckli 2023].

The agrotechnical measures associated with a specific farming system have a significant impact on the wild flora and fauna species found in the agricultural landscape and the organisms inhabiting the soil [Urmler 2010, Flohre et al. 2011]. Some of the agrotechnical treatments, in particular tillage or the fertilisation type, impose strong changes to the soil habitat. These treatments often lead to significant shifts in the soil species composition. According to draft publication of CropLife International [2004], weed eradication, regardless of the method used, changes the microclimate within the field. It affects light access, temperature, and soil and air humidity. That results in changes in the floristic composition of weed community and the accompanying fauna and microflora. Preserving vegetation of fields edges or creating plant strips between cultivated plants is important for various organisms and plays a positive role for them. For example, according to Twardowski and Pastuszko [2008], a greater diversity of plant species in marginal habitats directly adjacent to an agricultural field favors a greater occurrence of beetles from the carabid family – enemies of some plant insect-pests. Weed communities are subject to change under the influence of biotic and abiotic factors which shape them. Promotion of sustainable agriculture in the EU, and the introduction into practice the cultivation methods recommended for integrated and organic production, can prevent the loss of some weed species and have a positive impact on biodiversity [Zoschke and Quadranti 2002, Sanyal et al. 2008].

Soil quality assessment allows for recording changes in soil condition caused by natural factors and human activities [Jurys and Feizienė 2021]. Soil quality is influenced by a number of different abiotic and biotic factors, including its colonization by microorganisms and soil mesofauna. These organisms play a major role in processes such as decomposition of organic residues in the soil and increasing the nutrients availability to cultivated plants, formation of soil humus and soil aggregates, degradation of polluting substances (xenobiotics) in the soil, limiting the development of phytopathogens, atmospheric nitrogen fixation, etc. [Visser and Parkinson 1992, Schloter et al. 2018, Coonan et al. 2020]. Earthworms play a special role in shaping soil fertility and biological activity. Together with other soil-dwelling organisms, they perform many key-functions, increasing the sustainability of agricultural ecosystems. Earthworms have the ability to process up to 6 tons of organic matter per 1 ha per year into agricultural soils, thus contributing significantly to their fertility [Paoletti 1999]. Earthworms collect organic residues with different C:N ratios and process them into products with a narrower C : N ratio, thereby participating in the carbon sequestration and indirectly improve adaptation of agricultural systems to climate change, counteracting it [Eisenhauer et al. 2009, Phillips et al. 2019]. Despite many research, earthworms are still not well-recognized animals. There is a growing interest among farmers in the importance of these organisms in shaping soil fertility and quality and their role as an indicator of proper agricultural management. Preserving the biological diversity of terrestrial organisms (invertebrates), including organisms living in the soil, is a necessary condition for maintaining soil fertility and agricultural productivity. Increasing the number of beneficial organisms reduces crop pests. The protection of biodiversity pays off in terms of the size and quality of the crop [Eisenhauer and Hines 2021].

The research hypothesis assumed that the organic management system has the most beneficial effect on the studied determinants of biodiversity environment. The aim of the study was to assess soil environment indicators (segetal flora, earthworms and terrestrial invertebrates) in selected crops in an organic, integrated and conventional system.

MATERIAL AND METHODS

In 2011–2012, an assessment of the biodiversity of flora, invertebrates and earthworms occurring in agricultural fields was carried out in 3 different farming systems: organic (without the use of NPK mineral fertilizers and chemical plant protection products), integrated (with the use of NPK doses and recommended pesticides reduced by 50% for crop species) and conventional (using 100% of the doses of NPK and pesticides recommended for plant species). The research included the following plant species grown in pure sowing or in mixtures:

I. organic system: winter wheat, spring wheat, potato, white clover + grasses 1st year of use; white clover + grasses 2nd year of use;

II. integrated system: winter wheat, spring wheat, potato, legumes (faba bean);

III. conventional: winter wheat, spring wheat, winter rapeseed.

Sowing and harvesting of plant species was carried out at the dates recommended for the cultivation area. The soil was tilled in a conventional system (plowing).

The research was carried out in the model experiment of The Institute of Soil Science and Plant Cultivation-SRI in Osiny near Puławy, on Luvisol soil (heavy loamy sand as a dominant) [FAO 2015] in fields with an area of 1 ha each. As part of the biodiversity of weed assessment, the species composition and abundance were determined in 10 squares with an area of 1 m^2 each, randomly located on the diagonals of the field (frame method was used).

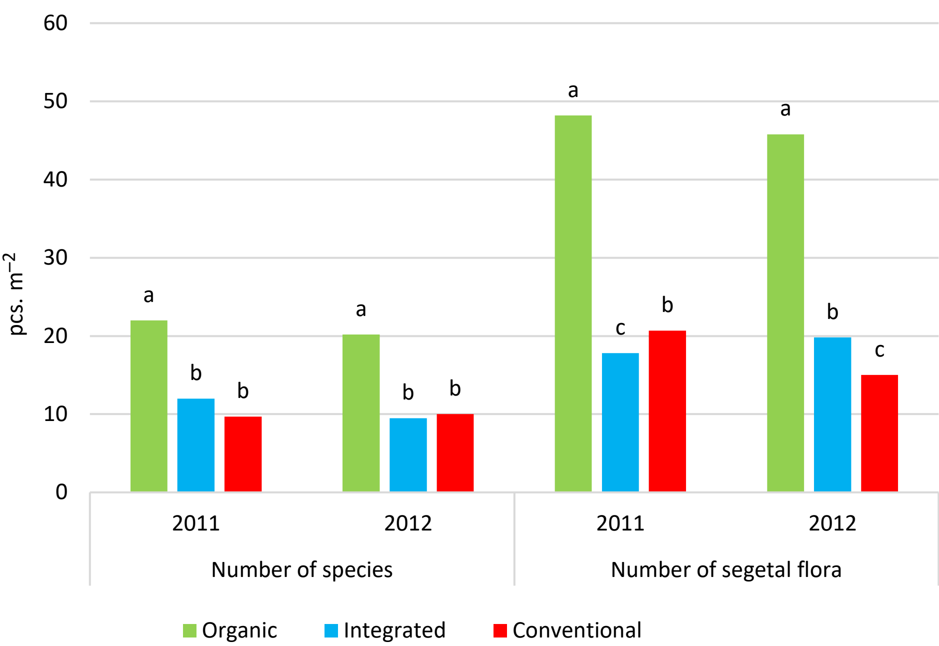
The assessment of earthworm biodiversity was carried out in two dates during the growing season: spring (May) and autumn (October). For this purpose, blocks of soil measuring 25 cm × 25 cm × 25 cm were dug, ten per each field. Each of them was spread on foil and the earthworms were counted. Then, the earthworms were transported to the laboratory, washed and weighed.

The biomass of invertebrates was carried out in spring-summer, and samples were collected continuously from May to July. For this purpose, 10 Barber traps filled with ethylene glycol were placed in each field. Insect samples were collected every 2–3 weeks [Szyszko 1985]. The insects from each trap were weighed. The study reported the total biomass of terrestrial organisms. This group was dominated by arthropods, while arachnids occurred sporadically.

Analysis of variance (ANOVA) was used to statistically analyze the results using Statistica PL 13.3, while HSD Tukey's test was applied to determine significant values at $p < 0.05$.

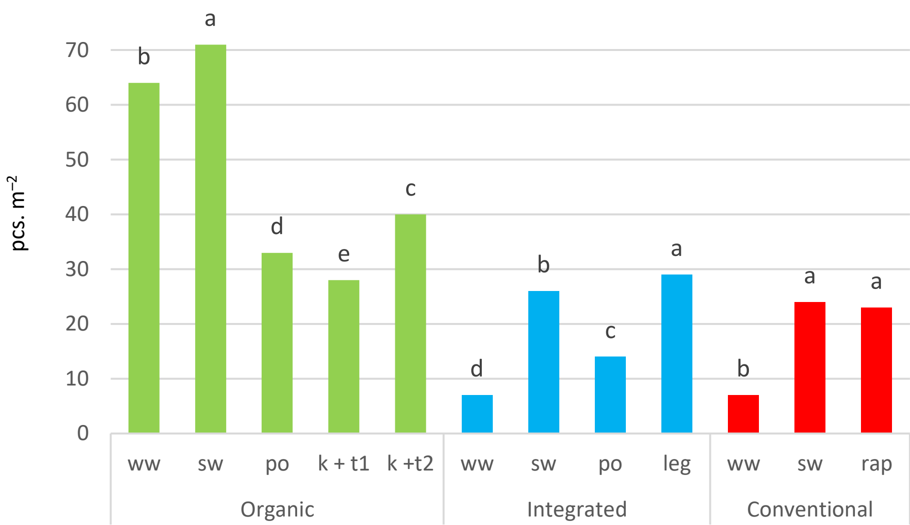
RESULTS

The results showed the greatest biodiversity of weeds, earthworms and terrestrial invertebrates in plants grown in an organic system (Fig. 1–6). The species diversity of segetal flora was on average twice as high in the organic system (21 species) compared to the integrated and conventional ones (10–11 species), in which chemical herbicides were used (Fig. 1). The number of weed species in the organic system, on average for 5 cultivated plants, was similar in both years of the study and amounted to 47 pieces m^{-2}, with the dominance of *Chenopodium album*, *Viola arvensis* and *Stellaria media* (Fig. 1). Significantly



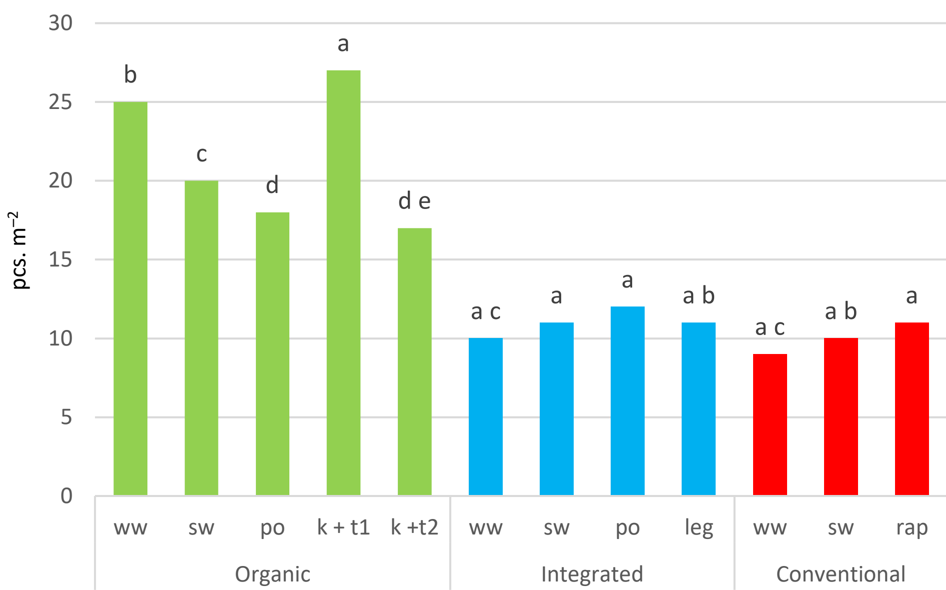
Means followed by various letter (a–c) are significantly different at p = 0.05

Fig. 1. Average number of species and abundance of segetal flora in various agricultural production systems



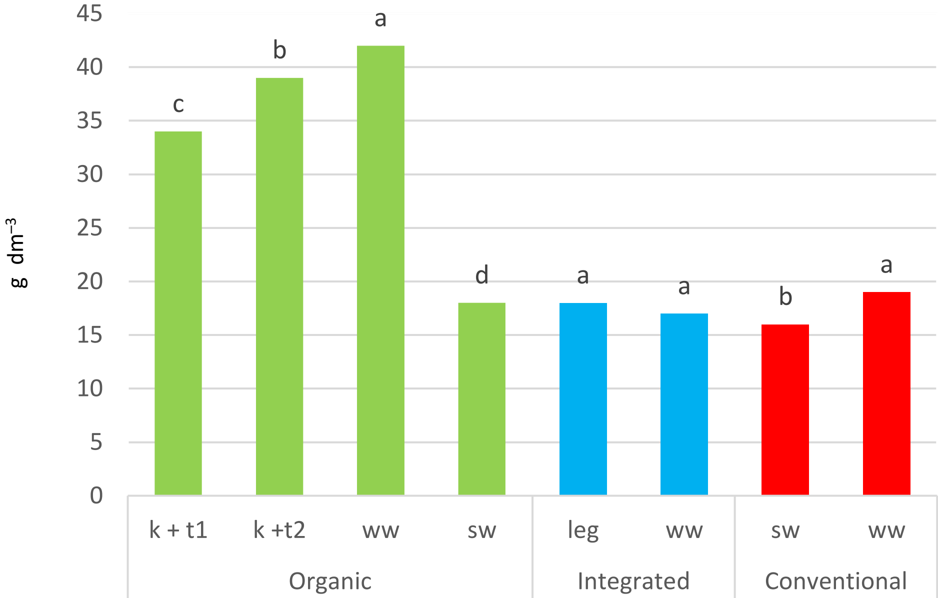
ww – winter wheat, sw – spring wheat, po – potato, k + t1 – clover + grass 1st year of use,
k + t2 – clover + grass 2nd year of use, leg – legumes (faba bean), rap – rapeseed
Means between plants within the farming system followed by various letter (a–d) are significantly different at $p = 0.05$

Fig. 2. Species diversity of segetal flora in plants grown in various agricultural production systems (average from 2011–2012)



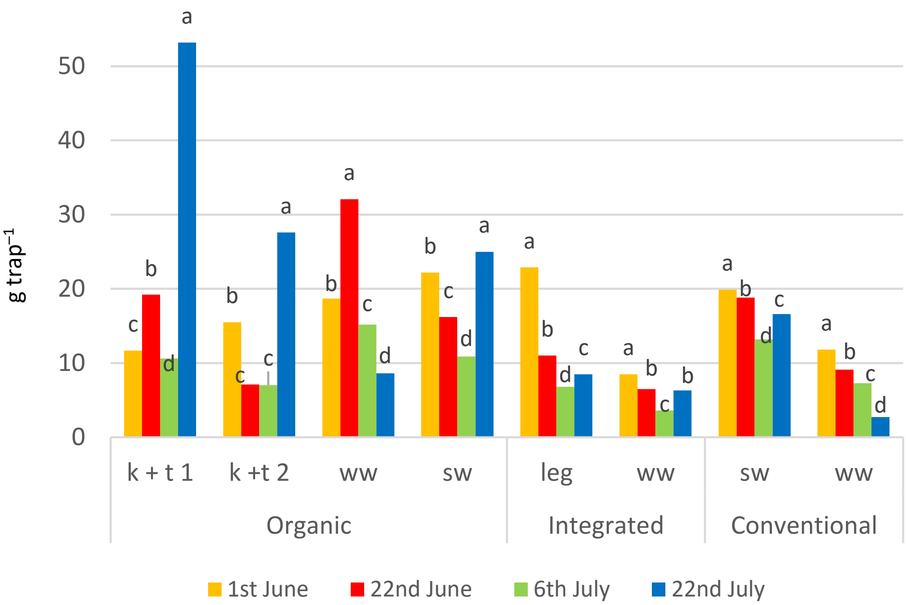
Explanations as in Fig. 2.

Fig. 3. The number of segetal flora in plants grown in various agricultural production systems (average from 2011–2012)



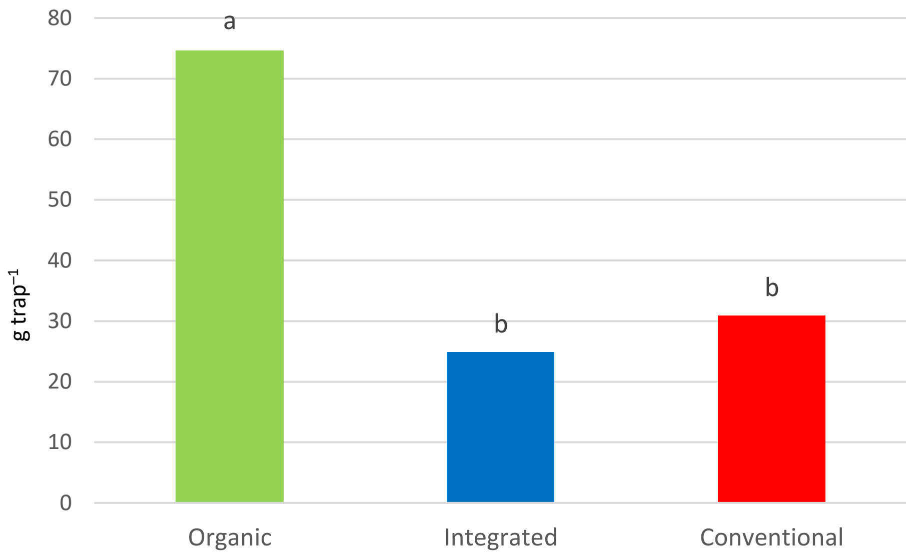
Explanations as in Fig. 2

Fig. 4. Average weight of earthworms in plants grown in various agricultural production systems in 2011–2012



* explanations as in Fig. 2

Fig. 5. Biomass of terrestrial invertebrates in plants grown in various agricultural production systems in 2011



Means followed by various letter (a–c) are significantly different at p = 0.05

Fig. 6. Biomass of terrestrial invertebrates in winter wheat grown in various agricultural systems in 2011 (sum of 4 research dates)

lower (by about 60%) weed number, of 18–19 pcs. m^{-2}, was found in the conventional and integrated systems.

Among the plants grown in the organic system, the highest number of weeds in both years of the study was found in spring wheat (average 71 pcs m^{-2}), and the lowest in grass-clover mixture in the first year of use (average 28 pcs m^{-2}) – Figure 2. At the same time, the mixture clover + grass 1st year of use was characterized by the highest weed species diversity (average 27 species), in spring wheat, however, 7 fewer species were recorded (Fig. 3). Chemical weed control in the conventional and integrated systems resulted in a significant reduction in the diversity and number of weeds in winter wheat crops, compared to other plant species (Fig. 1–3).

In the organic system, the highest biomass of earthworms was found, and they were most numerous in the soil under the cultivation of winter wheat and legume-grass mixtures (Fig. 4). This indicator was half as much in the soil under plants cultivated in the integrated and conventional systems.

Terrestrial invertebrates were most abundant in plants grown in the organic system, which indicates that this agricultural production system supports maintaining high biodiversity of agroecosystems (Fig. 5). Indeed, the highest invertebrate biomass was found on the last survey date of the study (22nd July) in all crops except winter wheat. In the integrated and conventional systems, significantly higher invertebrate biomass was estimated at the beginning of the study (1st and 22nd June) than at later dates.

For winter wheat grown in the conventional and integrated systems, the invertebrate richness index was 2.5–3 times lower than in the organic system (Fig. 6).

DISCUSSION

In recent years, more attention has been paid to preserving and developing biodiversity [Zhang et al. 2023]. It is assumed that species diversity is desirable for aesthetic, cultural and economic reasons and that it stabilizes the environment and prevents its unfavorable changes [Dobrzański and Adamczewski 2009].

In modern agriculture, weed flora is perceived not only as a competitor of crop plants or a habitat of crop pests, but also as an element that increases the biodiversity of agroecosystems [Smith 1976, Marshall et al. 2003]. Weeds are a source of food as well as habitats for animals, including pollinating insects and other beneficial insects (predators and pest parasites), thus supporting the biological protection of crops [Rosin et al. 2011]. From the point of view of crop yields, complete weed eradication is not necessary in all conditions and weed infestation can be limited to a level that does not pose a threat to crop plants, also taking into account economic reasons [Doğan et al. 2004, Deese 2010, Das et al. 2021]. This view of weed protection is adapted to the assumptions of pro-organic and integrated weed management, which considers the protection of biodiversity to be no less important than crops [Jones and Medd 2000, Buhler 2002].

The results of the biodiversity assessment in various agricultural production systems indicate that the organic system is more conducive to the preservation of biodiversity than the conventional and integrated systems. Management in this system can support the ecosystem services, such as: pollination, maintaining proper soil structure, protection against erosion, biological protection against pests, and aesthetic values. All these activities ultimately benefit people. The other authors also showed a positive impact of organic farming on the diversity of flora and fauna on arable land and permanent grassland [Azeez 2000, Stoate et al. 2001, Bengtsson et al. 2005, Marshall et al. 2003]. The analysis by Bavec and Bavec [2015] indicates that organic farming increases species richness by approximately 30%. This is the result not only of the exclusion of the synthetic fertilizers and chemical plant protection products, but also of other environmentally friendly practices. Many studies on the quantitative impact of agricultural management systems on crop biodiversity have shown that organic systems have both a greater richness of weed species in aboveground vegetation [Bengtsson et al. 2005, Hole et al. 2005, Roschewitz et al. 2005] as well as in the soil seed bank [Menalled et al. 2001] compared to conventional system. When considering agricultural systems in terms of biodiversity, it should be emphasized that the dominant method of farming is the so-called conventional system, in which, according to numerous studies, the development of biodiversity is significantly limited. Therefore, a very important role in preserving agrobiodiversity is assigned to an integrated (sustainable) system. By limiting the number of pesticides and fertilizers used, and by diversifying crop rotation, the number and biodiversity of weeds increases. In diversified crop rotations, due to different sowing dates, different crop life cycles and interchanging mechanical and chemical weed control, ecological niches are created for a wide range of weed species [Cardina et al. 2002, Légère and Samson 2004, Rasmussen et al. 2006].

Organic farming has a positive effect on the soil structure but also on its biodiversity [Tuck et al. 2014]. A very important group of soil organisms that influence multifaceted soil quality are earthworms. These organisms feed on organic residues, mainly of plant origin, mixed with soil particles. By drilling tunnels in the soil, they accelerate the soil water infiltration, limiting surface runoff and erosion [Coleman et al. 2004]. Additionally, earthworms promote the colonization of soil by beneficial bacteria and fungi. Their impact on soil fertility, and therefore on the development and yield of plants, is enormous. The agricultural production system may therefore favor or limit the populations of these organisms [Westernacher-Dotzler 1992, Pfiffner and Luca 2007, Urmler 2010, Mace et al. 2012, Johnston et al. 2014]. Hole et al. [2005] reviewed the effects of organic farming on earthworms and other animals. They revealed a general trend of higher earthworm abundance and biomass under organic management in comparison to conventional farming. This trend is supported by Curry et al. [2002] who found a drastic decline of earthworm abundance by intensive cultivation. However, some studies do not confirm such large differences between these systems [Foissner 1992, Nuutinen and Haukka 1990]. Filser et al. [1999] studied the earthworm biomass over a period of six years in organic and conventional fields and found an increase from 10 to 25 g DW m^{-2}. However, biomass was mainly influenced by climate conditions in the present study. Biomass was highest under medium rainfall regardless of organic and conventional farming practices.

Our own research has shown that management in a conventional and integrated system causes the loss of biodiversity of plants, invertebrates and earthworms, which is confirmed by research by other authors in relation to various groups of organisms: soil microorganisms, segetal flora, insects, spiders, birds and mammals [Ewald and Aebischer 1999, Benton et al. 2002, Hyvönen et al. 2003, Benton et al. 2003, Shah et al. 2003, Urmler 2010, Flohre et al. 2011]. Agricultural practices that favor the occurrence of earthworms and other soil organisms include: moving away from the use of harmful pesticides, using balanced fertilization with organic and natural fertilizers and conservation tillage [Singh et al. 2016, Briones and Schmidt 2017]. However, the cultivation of cereals, vegetables and other plants in intensive systems greatly reduces biodiversity, among other things, because intensive treatments carried out in these crops significantly reduce the production of seeds by weeds. There is an opinion that the introduction of cereals and other plants grown for seeds, as well as combine harvesters, had a greater impact on species diversity than many other agrotechnical procedures. Non-agriculturally used areas such as midfield afforestation and thickets, balks, forest islands and roadsides, play an important role in increasing the number and biotic diversity of various groups of beneficial arthropods, including carabids. This is confirmed by the research of Varchola and Dunn [1999] and Purtauf et al. [2005]. In our own research, the highest invertebrate biomass was found in various crops in the organic system. Also in the case of winter wheat cultivation, the species with the largest area in Poland, a significantly higher biomass of terrestrial invertebrates was estimated in this cultivation system. In a study by Pfiffner and Luka [2003], 36% fewer ground beetles and 8% fewer spiders were found in cereal crops in an integrated system than in an organic system. Intensive agriculture may therefore have an adverse impact on important ecosystem services: pollination, biological protection of crops, nutrient cycling, and resistance to invasive organisms [Donald 2004, Mace et al. 2012].

CONCLUSIONS

The biodiversity of segetal flora and various groups of aboveground and underground organisms depends not only on farming systems and related agricultural practices, but also on plant species cultivated in particular agricultural systems. The research results showed twice the species diversity and 60% greater abundance of segetal flora in the organic system, compared to the integrated and conventional one. In the organic system, the highest biomass of earthworms was found in the soil under the cultivation of winter wheat and legume-grass mixtures. The organic farming system also favored the occurrence of a significantly larger number of aboveground organisms (Carabids).

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Source of funding: This research was supported by the Ministry of Education and Science of Poland as the part of statutory activities of Department of Herbology and Plant Cultivation Techniques, University of Life Sciences in Lublin.

Received: 20.11.2023
Accepted: 5.12.2023
Online first: 28.03.2024
Published: 18.04.2024