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Effect of cropping systems on quantitative changes in prevailing weed species

Wpływ systemów uprawy na zmiany ilościowe
dominujących gatunków chwastów

Summary. A field experiment was established to evaluate quantitative changes in weed species prevailing in a crop rotation and a 30-year cereal monoculture. The subject of the study included cropping systems: a) crop rotation, and b) cereal monoculture. First (1989–1992) and second (1993–1996) rotation focused on weed infestation of winter triticale in crop rotation and monoculture; third (1997–2000) and fourth (2001–2004) focused on weed infestation of winter wheat; fifth (2005–2008), sixth (2009–2012), seventh (2013–2015) and eighth (2016–2018) focused on weed infestation of spring wheat. The prevailing weed species included: *Apera spica-venti*, *Avena fatua*, *Galium aparine*, *Fallopia convolvulus*, *Stellaria media*, *Viola arvensis*, *Anthemis arvensis*, *Veronica persica*, *Consolida regalis,* and *Papaver rhoeas*. Among these, *A. spica-venti* predominated in the winter cereals whereas *A. fatua* in the spring ones. Numbers of *A. spica-venti* and *A. fatua* plants were several times higher in the monoculture than in the crop rotation. The substitution of winter cereals with spring ones in cultivation decreased *A. spica-venti* population in the spring cereals, but increased the population of *A. fatua*, particularly in the monoculture.

Key words: crop rotation, monoculture, species composition of weeds, number of weeds

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INTRODUCTION

Crop cultivation in a monoculture leads to the emergence of a few prevailing weed species, eradication of which requires using increased doses of herbicides [Clarke et al. 2000, Young 2006, Boyette et al. 2008, Chauhan et al. 2012, Woźniak and Soroka 2018]. As proved in scientific research, this may lead to the selection of species not susceptible to the herbicides applied [Owen and Zelaya 2005, Collavo and Sattin 2014, Heap 2014]. This was the case with grassy weeds *Alopecurus myosuroides* and *A. spica-venti* common in cereal stand, that have become resistant to sulfonylurea herbicides [Bohren et al. 2006]. Also Van Gessel [2001] and Perez et al. [2004] proved the weed eradication with herbicides, especially with a non-selective glyphosate, to be highly effective but contributing to the development of weed biotypes resistant to this substance. Finally, investigations conducted by Heap [1997] and Koning et al. [2019] have shown that new species of weeds which developed resistance to herbicides are reported each year and that reasons behind this phenomenon should be searched in the inappropriate use of these weed control agents.

Weed eradication from specialist cereal crop successions is performed principally with herbicides, whereas in crop rotations including various plants the herbicides are only complementary to the non-chemical weed control methods [Moss et al. 2004, Poggio 2005, Hayden et al. 2012, Eslami 2014]. The appropriately adjusted crop sequence and diversified cropping systems are the factors which decrease the number of weeds and diversify their species composition, which prevents the prevalence of a few weed species [Poggio 2005, Woźniak and Rachoń 2019]. The substitution of winter cereals with the spring ones was demonstrated to eliminate *A. spica-venti* from a cereal monoculture [Woźniak and Soroka 2015]. In the study conducted by Melander et al. [2008], crop rotation had a stronger effect on *Apera spica-venti* population than soil tillage system. In that study, the greatest density of this weed species was reported on the plots where winter wheat was sown after itself, especially in the no-till system. Consistent results were also achieved by Pallutt [1999], who demonstrated a low efficacy of graminicides in eradicating *A. spica-venti* in the no-till system and in the continuous monoculture of winter wheat.

The following research hypothesis can be advanced based on the literature cited: continuous monoculture of cereals leads to the predominance of weed species best adapted to the developmental cycle of winter or spring cereals, whereas the high abundance of these weeds can be counteracted by crop rotation involving various groups of plants. Considering the above, the objective of this study was to evaluate quantitative changes in prevailing weed species occurring each year in a crop rotation and a 30-year monoculture.

MATERIAL AND METHODS

Localization and scheme of the experiment

Results presented in this manuscript originate from an exact field experiment conducted during 1989–2018 at the Uhrusk Experimental Station belonging to the University of Life Sciences in Lublin, south-eastern Poland (51°18'N, 23°36'E). The experiment was conducted in the system of randomized blocks (6 × 25 m), in three replications. The subject of the study included cropping systems: a) 4-field crop rotation, and b) cereal monoculture. The following crops were used in the first (1989–1992) and in the second (1993–1996) rotation: potato – winter triticale – peas – winter triticale, whereas winter triticale was sown in the monoculture. Weed infestation of winter triticale (after peas) was assessed in crop rotation and monoculture. In the third (1997–2000) and in the fourth (2001–2004) rotation, potato – winter wheat – peas – winter wheat were grown in the crop rotation, and winter wheat in the monoculture. Weed infestation of winter wheat (after peas) was assessed in crop rotation and monoculture. In the fifth (2005–2008) and in the sixth (2009–2012) rotation, spring wheat was sown after winter wheat in crop rotation and monoculture. Weed infestation of spring wheat was assessed in crop rotation (after peas) and monoculture. In the seventh (2013–2015) and the eighth (2016–2018) rotation, the 4-field crop rotations were simplified to 3-filed ones, and were sown with: peas – spring wheat – spring triticale: the same cereals were sown in the monoculture. Weed infestation of spring wheat was assessed in crop rotation and monoculture.

Habitat conditions, fertilization, and sowing density

The soil the experiment was established on was Rendzic Phaeozem [IUSS Working Group WRB 2015] with the following mineral fraction distribution: sand – 53%; silt – 24%; and clay – 23%. Total nitrogen content in the 0–25 cm soil layer was 0.69 g kg^{-1}, that of phosphorus was 120 mg P kg^{-1}, that of potassium was 211 mg K kg^{-1}, that of magnesium was 70 mg Mg kg^{-1}, and that of organic C was 11.5 g kg^{-1}.

The course of weather conditions in study years is presented in Figure 1. The annual sums of precipitation ranged from 413 mm in 2018 to 822 mm in 2009. The highest monthly sums of precipitation were recorded in May (70 mm on average), June (71 mm), and July (83 mm), whereas the lowest ones in December (26 mm), January (32 mm), and February (30 mm). Great differences were also noted in average annual air temperatures which ranged from 6.3°C in 1996 to 10.1°C in 2015. The highest daily air temperatures were recorded in May (14.1°C), June (17.3°C), July (19.5°C), and August (18.6°C), whereas the lowest ones in December (–1.0°C), January (–2.3°C), and February (–1.4°C). The growing season, expressed by the number of days with a daily temperature above +5°C, begins at the study area in the third week of March and lasts 210–220 days on average.

In both systems of plant sequence, soil was cultivated in the ploughing tillage system and crops were fertilized with the same doses of fertilizers. The following fertilizers were used in the cultivation of winter triticale and winter wheat: 150 kg N ha^{-1} (20 kg N ha^{-1} before medium ploughing; 70 kg N ha^{-1} at the tillering stage (22–23 in BBCH scale) [Meier 2001]; 40 kg N ha^{-1} at the shooting stage (32–33 BBCH); 20 kg N ha^{-1} at the ear formation stage (52–53 BBCH); and 30 kg P ha^{-1} and 85 kg K ha^{-1} before medium ploughing. In turn, the following fertilizers were used in the case of spring wheat: 140kg N ha^{-1} (50 kg N ha^{-1} before sowing, 40 kg N ha^{-1} at the tillering stage (22–23 BBCH), 30 kg N ha^{-1} at the shooting stage (32–33 BBCH), and 20 kg N ha^{-1} at the ear formation stage (52–53 BBCH) as well as 30 kg P ha^{-1} and 80 kg K ha^{-1} before sowing.

Sowing density of winter triticale was 400 seeds per square meter (m^2), that of winter wheat was 400 seeds/m^2, and that of spring wheat was 400 seeds/m^2. The winter cereals were sown in the last week of September, and the spring ones in the first or the second week of April. Weeds were removed mechanically by double harrowing: at the tillering stage (22–23 BBCH) and 10–14 days later.

Parameters analyzed and statistical analysis

Weed infestation was evaluated with the frame method at the waxy maturity stage of cereals (82–83 BBCH). This method consists in the determination of species composition and number of weeds per surface area of 1 m^2 of each plot. This area was determined at random twice using a frame (1 × 0.5 m). Based on data from 30 years of observations, 10 weed species were selected which occurred each year on plots with crop rotation and monoculture. Results obtained were subjected to the analysis of variance (ANOVA), whereas the significance of differences between mean values was evaluated using the Tukey's HSD test, at $P < 0.05$.

RESULTS

The most abundant weed species observed throughout the 30-year study included: *A. spica-venti*, *A. fatua*, *G. aparine*, *F. convolvulus*, *S. media*, *V. arvensis*, *A. arvensis*, *V. persica*, *C. regalis*, and *P. rhoeas*. Among these, *A. spica-venti* prevailed especially in winter triticale and *Avena fatua* in spring wheat.

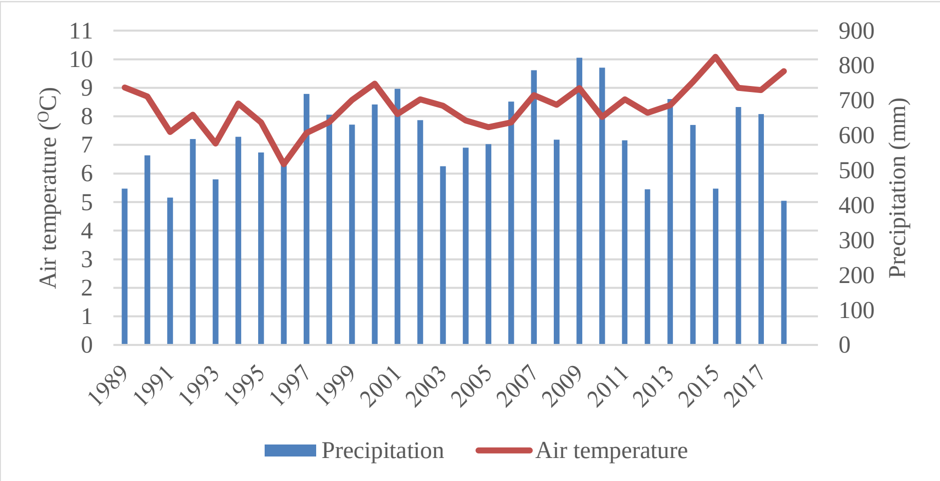
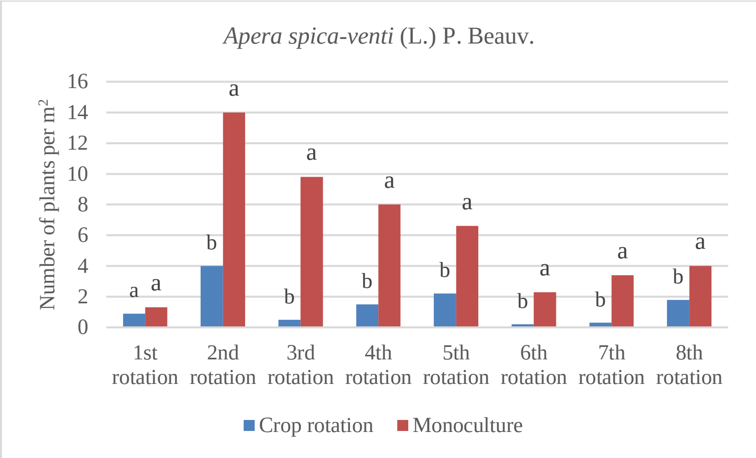


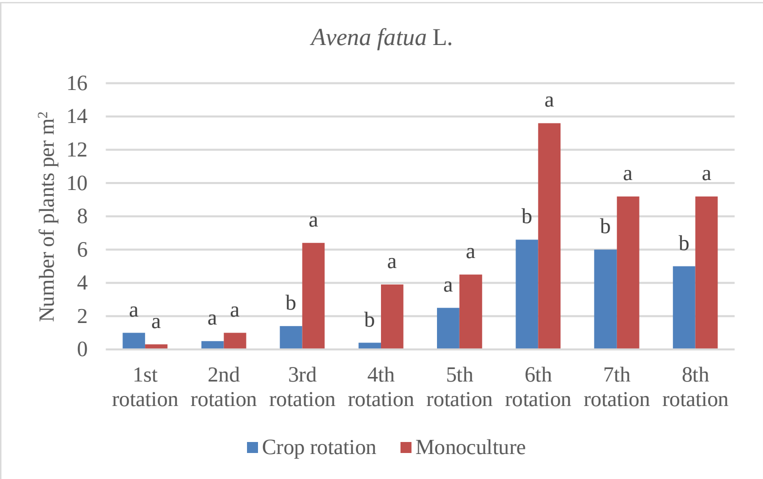
Fig. 1. Total sums of precipitation and average air temperatures

Both, crop sequence system and study years (particular rotations) caused differences in population numbers of the weed species studied. Stands of winter cereals sown in the monoculture were predominated by *A. spica-venti*, particularly in the second rotation of winter triticale (Fig. 2). Substitution of winter cereals with the spring ones in crop rotation and monoculture (since the fifth till the eighth rotation) significantly reduced the population of this weed species, however its smallest density per square meter was recorded in the sixth and in the seventh rotation. A few times more abundant population of *A. spica-venti* occurred in the monoculture of winter triticale (in the second rotation) and winter wheat (in the third and the fourth rotation) than in the crop rotation system. Another grassy weed abundant in the crops studied was *A. fatua* (Fig. 3). The substitution of winter cereals with spring ones in crop rotation and monoculture increased the population number of this weed species, with its greatest density per square meter recorded in the sixth, seventh, and eighth rotation.



a, b – mean values in a rotation denoted with the same letters do not differ significantly, $P < 0.05$

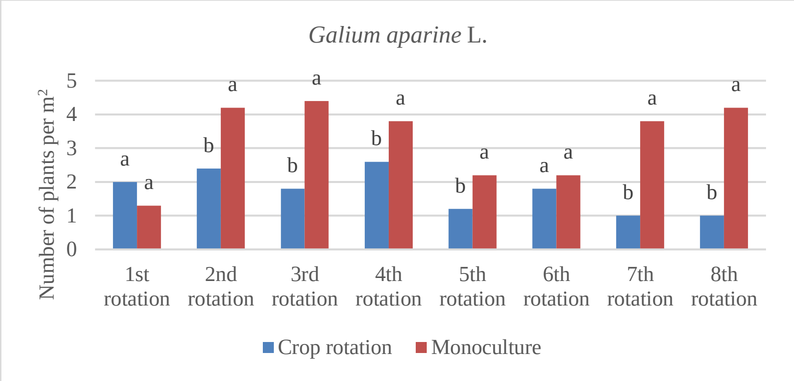
Fig. 2. Number of *Apera spica-venti* (L.) P. Beauv. plants per square meter in crop rotation and cereal monoculture



Explanations under Fig. 2.

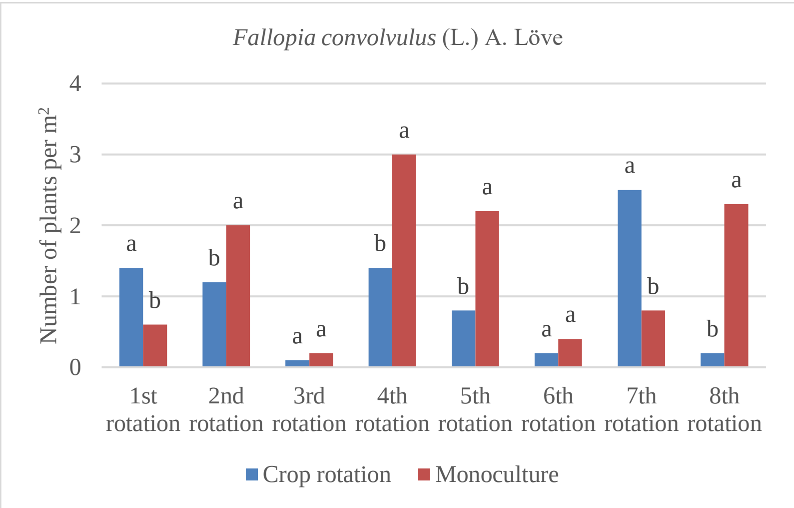
Fig. 3. Number of *Avena fatua* L. plants per square meter in crop rotation and cereal monoculture

The population of *G. aparine* was more abundant in the monocultures of winter triticale (in the second rotation) and winter wheat (in the third and in fourth rotation) than in the crop rotation system (Fig. 4). A significantly higher number of *G. aparine* plants was also observed in the monoculture of spring wheat (in the seventh and eighth rotation) than in the crop rotation system. Also *F. convolvulus* was more abundant in the monoculture than in the crop rotation, however significant differences were noted in the case of winter triticale (in the second rotation) and winter wheat (in the third rotation) – Figure 5.



Explanations under Fig. 2.

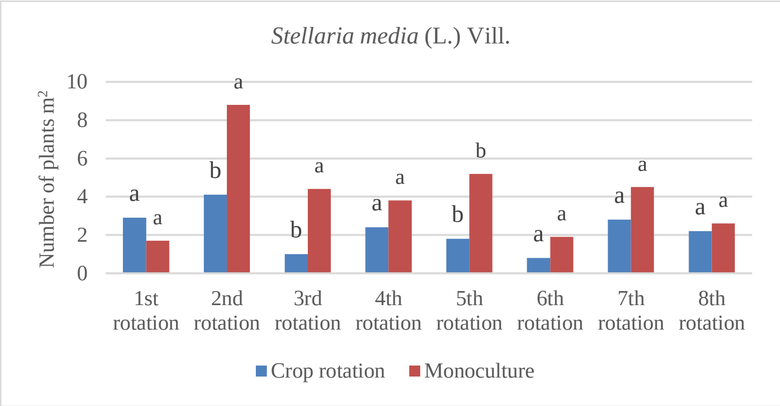
Fig. 4. Number of *Galium aparine* L. plants per square meter in crop rotation and cereal monoculture



Explanations under Fig. 2.

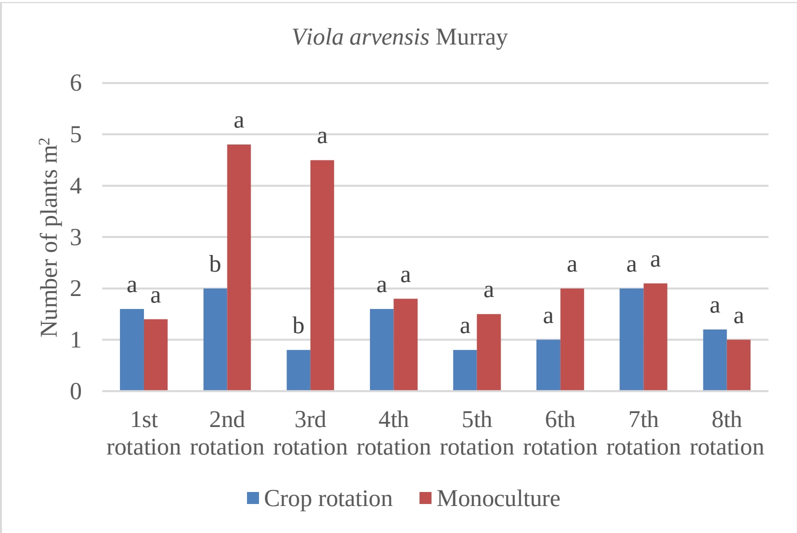
Fig. 5. Number of *Fallopia convolvulus* (L.) A. Löve plants per square meter in crop rotation and cereal monoculture

Significant differences were also observed between the sixth rotation of spring wheat monoculture and crop rotation. Another weed species more abundant in the monoculture than in the crop rotation turned out to be *S. media*, with differences noted in winter triticale (in the second rotation), winter wheat (in the third rotation), and spring wheat (in the fifth rotation) – Figure 6. Also *V. arvensis* developed a more numerous population in the cereal monoculture than in the crop rotation, but significant differences were demonstrated only in the second and third rotation (Fig. 7).



Explanations under Fig. 2.

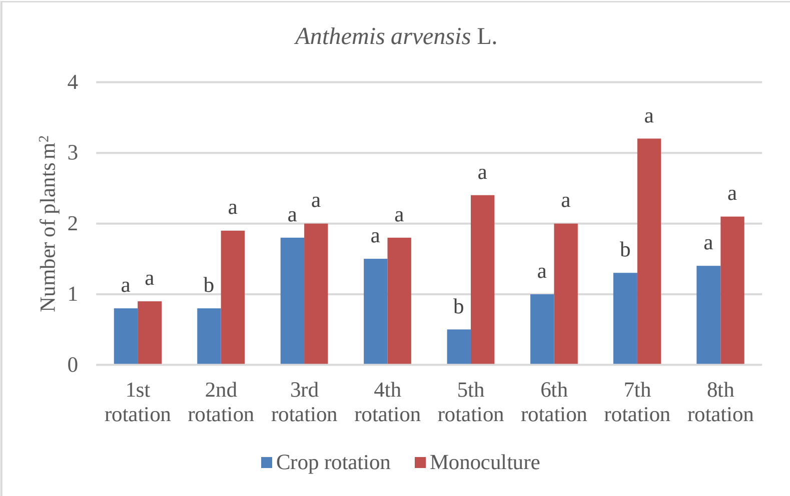
Fig. 6. Number of *Stellaria media* (L.) Vill. plants per square meter in crop rotation and cereal monoculture



Explanations under Fig. 2.

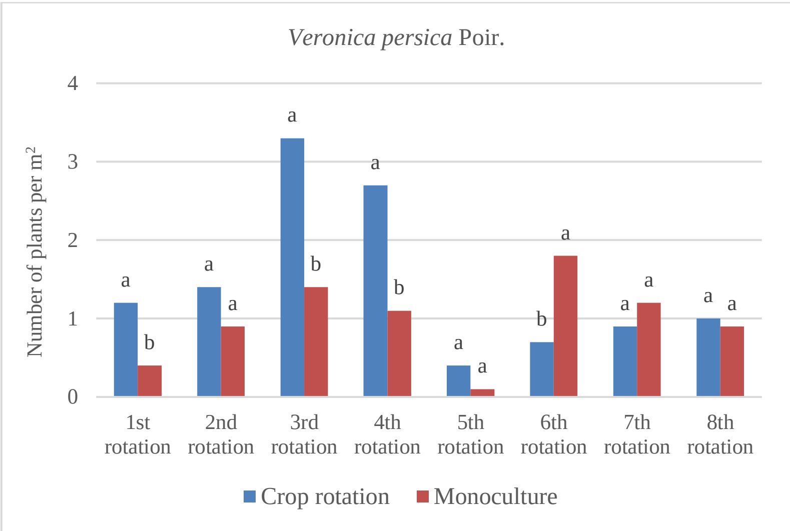
Fig. 7. Number of *Viola arvensis* Murray plants per square meter in crop rotation and cereal monoculture

The population of *A. arvensis* was more abundant in the cereal monoculture than in the crop rotation, with significant differences observed in the fifth and the seventh rotation (Fig. 8). In turn, the population number of *V. persica* was low (from 0.4 to 2.1 plants/m^2) in both systems of plant sequence, and significant differences were demonstrated only in the third and fourth rotation (Fig. 9).



Explanations under Fig. 2.

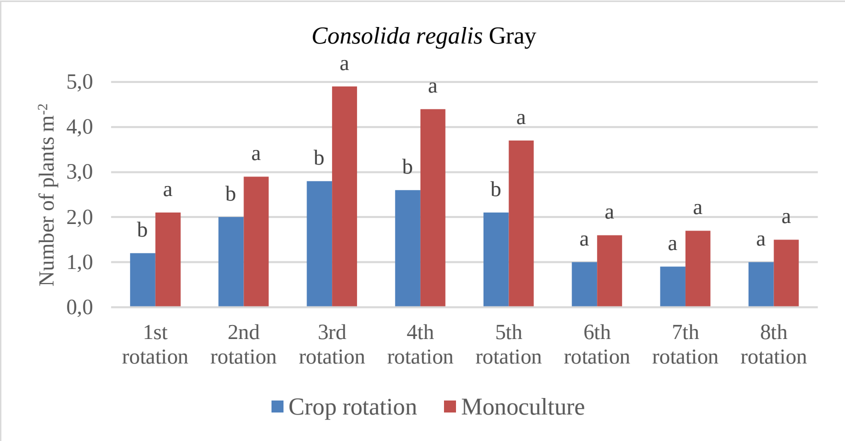
Fig. 8. Number of *Anthemis arvensis* L. plants per square meter in crop rotation and cereal monoculture



Explanations under Fig. 2.

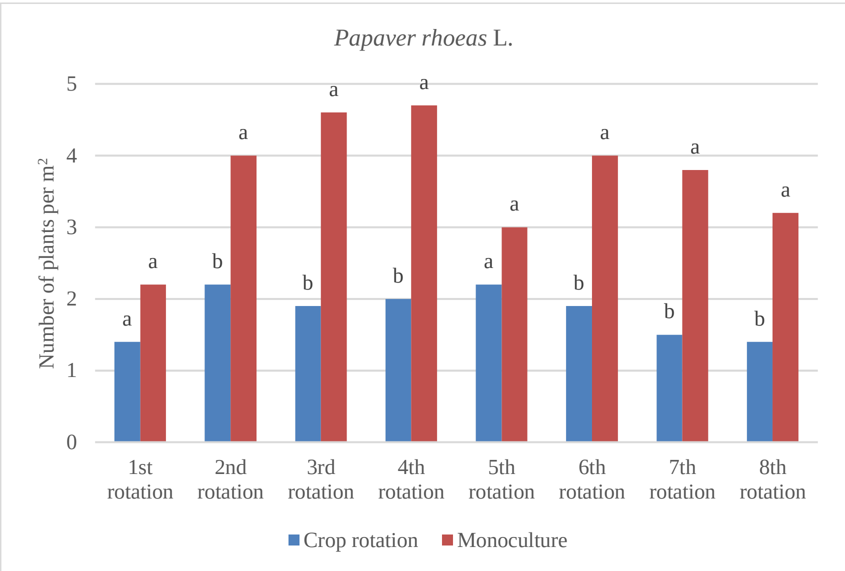
Fig. 9. Number of *Veronica persica* Poir. plants per square meter in crop rotation and cereal monoculture

The population of *C. regalis* was more abundant in the monoculture than in the crop rotation, with significant differences observed in the third, fourth, and fifth rotation (Fig. 10). Also *P. rhoeas* population was more numerous in the cereal monoculture than in the crop rotation, and differences occurred in the second, third, and forth rotation as well as in the sixth, seventh, and eighth rotation (Fig. 11).



Explanations under Fig. 2.

Fig. 10. Number of *Consolida regalis* Gray plants per square meter in crop rotation and cereal monoculture



Explanations under Fig. 2.

Fig. 11. Number of *Papaver rhoeas* L. plants per square meter in crop rotation and cereal monoculture

DISCUSSION

Cereal cultivation in the monoculture results in the increased number and weight of weeds as well as in the accumulation of a few weed species having biological characteristics and habitat requirements similar to the grown crop [Liebman and Dyck 1993, Demjanová et al. 2009, Martin et al. 2019, Farooq et al. 2019]. Stands of winter cereals are predominated by weed species which germinate in the autumn or spring, whereas these of spring cereals – by weed species germinating in the spring [Hald 1999]. As reported by Melander et al. [2008] and Woźniak [2018], the introduction of no-till systems to the agricultural practice and preponderance of winter cereals have contributed to the high prevalence of *A. spica-venti*, which is an annual grassy weed species, growing mainly in the winter. Its seeds germinate usually in the late summer and in the autumn [Melander et al. 2008], but also during warm winter and even in the springtime in spring cereals [Wallgren and Avholm 1978]. According to Northam and Callihan [1992], *A. spica-venti* is the most abundant on humid and light loamy soils, but is also a troublesome weed species on sandy soils. As claimed by Pallutt [1999], the high prevalence of *A. spica-venti* is facilitated by the cultivation of winter cereals in the monoculture and by the no-till system. Also in the present study the population number of this weed species was several times higher in the monoculture than in the crop rotation. It was, however, significantly reduced by the substitution of winter wheat with spring wheat. It may, therefore, be concluded that the alternate cultivation of winter and spring cereals (and/or the opposite) is an effective means for controlling species composition and population number of weeds. Also *A. fatua* can serve as an example in this case; within the 30-year study period it occurred sparsely in winter wheat, but its population number increased noticeably in the spring wheat grown after it. Also Hald [1999] demonstrated that the replacement of spring cereals into winter ones in cultivation resulted in a decreased number of plants and species of weeds, but also in the change of their species composition.

As reported by Woźniak and Soroka [2015], cereal stands are predominated by weeds from the class *Stellarietea media* with preponderance of annual and two-year species. Species typical of this class include *S. media* and *V. arvensis*. They are characterized by a high adaptation capability and high abundance in both winter and spring cereals as well as in other crops. This was confirmed also in our study, although these weed species were slightly more abundant in the monoculture than in the crop rotation as well as in the winter than in the spring cereals. Presumably, this may be due to the fact that they germinate throughout the growing season and even during warm winter. In turn, the developmental cycle of *A. spica-venti* resembles that of winter cereals, whereas the developmental cycle of *A. fatua* is similar to that of spring cereals, therefore the exchange of winter into spring cereals (or the other way round) in cultivation effectively reduces population numbers of these weeds [Wallgren and Avholm 1978, Bohren et al. 2006, Woźniak and Soroka 2015]. This was also confirmed in the present study. In turn, the substitution of winter cereals with spring cereals caused an insignificant effect on *A. arvensis* population, which is related to its germination capability in the autumn or in the spring. Also *G. aparine* can appear in high numbers in cereal stands [Woźniak and Soroka 2015]. In the present study, this species was more abundant in the monoculture than in the crop rotation, probably due to lesser competitiveness of cereals to weeds in the monoculture than in the crop rotation. In the stands of winter cereals, particularly in the monoculture, *C. regalis* was also abundant. This species germinates mainly in the autumn, hence a higher number of its plants is observed in the winter than in the spring cereals. It may also be concluded that *C. regalis* reveals higher competitiveness to cereals grown in the monoculture than in the crop rotation system, which results from a smaller cereal stand in the monoculture. In turn, *P. rhoeas* occurred at a similar density per 1 m^2 in winter and spring cereals, and also at a significantly higher density in the monoculture than in the crop rotation system. In addition, this species germinates equally effectively in the autumn, thereby infesting winter crops, and in the springtime causing infestation of spring crops.

CONCLUSIONS

Weed species prevailing in the 30-year study included: *A. spica-venti*, *A. fatua* L., *G. aparine*, *F. convolvulus*, *S. media*, *V. arvensis*, *A. arvensis*, *V. persica*, *C. regalis*, and *P. rhoeas*. Of these, *A. spica-venti* prevailed especially in winter triticale and *A. fatua* in spring wheat. The population of *A. spica-venti* was several times greater in the monoculture than in the crop rotation. The substitution of the winter cereals with the spring ones decreased *A. spica-venti* population in the spring cereals, but increased the population of *A. fatua* in the monoculture.

The alternate cultivation of winter and spring cereals allows for the effective control of species composition and number of weeds in a crop stand as well as prevents weed compensation in cereals.

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