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# The selected agrotechnical factors affecting the occurrence of black grass *Alopecurus myosuroides* in winter wheat crops in north-western Poland

Wybrane czynniki agrotechniczne wpływające na występowanie wyczyńca polnego *Alopecurus myosuroides* w uprawach pszenicy ozimej w północno-zachodniej Polsce

**Summary.** *Alopecurus myosuroides* of the family *Poaceae* is a highly competitive species for winter cereal crops, particularly for barley and wheat, less frequently for root vegetables or rapeseed. This study aimed to determine the predominant factor or group of factors affecting the cover of *A. myosuroides* in winter wheat field depending on the tillage systems, time, and amounts of herbicides used. The following variables differentiating the quantitative contribution of *A. myosuroides* in the analyzed fields were assumed: plough or no-plough tillage, date of biocidal application, and the total amount of herbicides (active substances) used. When spring-only herbicide was applied, the lowest *A. myosuroides* cover, not exceeding 25%, was observed in the margins of winter wheat fields. The coverage of *A. myosuroides*, reaching 25–100% of the winter wheat area, regardless of the tillage system, was found when the herbicides from the group of sulfonylurea derivatives (acetolactate synthase ALS inhibitors) were frequently used. Winter wheat infestation with *A. myosuroides* was significantly lower when ploughing was applied. The highest cover of *A. myosuroides*, reaching 50–100% of the area, was observed only in the central part of the analyzed winter wheat fields, following the application of herbicides in autumn and spring or in autumn only.

**Key words:** herbicide-resistance, weed control, blackgrass *Alopecurus myosuroides,* weed infestation of winter wheat

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## INTRODUCTION

One of the most important agrotechnical treatments necessary for high and good quality crops is protecting crops against weeds. Out of all the agricultural pests, weeds are the strongest contributors to crop losses, competing with the crop for nutrients, water, and light. Effective weed control should be based on detailed knowledge [Barbaś and Sawicka 2020]. Both scientific research and agricultural practice indicate a significant impact of a group of factors, e.g., the type of agrotechnical treatments, the type of herbicide (active ingredient) used, or the date of herbicide application, on the crop yield and weed infestation level. However, frequent use of the same herbicides develops resistance mechanisms among weeds. There are currently 522 unique cases (species × site of action) of herbicide resistant weeds globally, with 269 species (154 dicots and 115 monocots). Weeds have evolved resistance to 21 of the 31 known herbicide sites of action and to 166 different herbicides. Approximately 380 herbicide-resistant weed biotypes have been reported in 99 crops in 72 countries [Kubiak et al. 2022, Heap 2023]. The latest research indicates that the most effective approach in weed control applies integrated methods of weed management, including combined mechanical treatments and herbicides [Mohammadduost Chamanabad et al. 2011, Zarzecka et al. 2019].

Out of 675 registered herbicides in Poland, 149 are sulfonylurea herbicides, composed of 19 active ingredients, which mode of action is acetolactate synthase (ALS) inhibition. These herbicides account for over 20% of all herbicides used in Polish agrifield [Adamczewski et al. 2019]. A similar situation was observed in other countries practicing intensive agrifield. Sulfonylurea herbicides are very popular and widely used. However, due to their overuse, resistance to these herbicides evolved and is the most common type of resistance [Mahmood et al. 2016] in Europe, next to resistance to the group of acetyl-CoA carboxylase (ACCase) inhibitors [Menne and Hogrefe 2012, Heap 2014]. Many weed species are resistant to sulfonylurea herbicides because they affect plant growth at the beginning of its metabolic pathway. *Alopecurus myosuroides* Huds. (blackgrass) has been identified as resistant to sulfonylurea herbicides [Heap 2014] in England, France, Germany, Belgium, and the Netherlands.

Blackgrass from the *Poaceae* botanical family likely originates from the Mediterranean or South-East Asia. It is a rare example of an archaeophyte, which has spread over the last half of a century in numerous regions of the country, particularly on Żuławy Wiślane, West Pomerania, Greater Poland, Lower Silesia, and on the Krakowsko-Częstochowska Upland, locally reaching the status of invasive species [Naylor 1972, Moss 1990, Domaradzki 2006, Gamrat et al. 2006, Korniak 2007, Tokarska-Guzik et al. 2012, Dąbkowska et al. 2017, Moss 2017]. In Western Europe, *Alopecurus myosuroides* has been recognized as a problematic weed species in winter cereals. Globally it is ranked amongst the worst weeds that pose the highest risk to crops, affecting over 25 million hectares of cereal crops worldwide [Heap 2014]. Its occurrence has increased significantly in the last few decades due to, amongst others, crop rotations with a large share of winter cereals, reduced tillage, and early sowing dates in September and October, when most *A. myosuroides* seeds germinate [Lutman et al. 2013]. This species prefers compact, loam, and clay-wet soils with neutral or alkaline pH and moderate content of humus and nitrogen [Colbach and Durr 2003]. These conditions make blackgrass very competitive, which causes losses in the winter wheat yield of 15–20% at a density of 100 plants $m^{-2}$ [Lutman et al. 2013]. This species is characterized by a high seed production with high germination capacity, which is affected by numerous factors linked to, i.e., the cultivation technology and type of the crop [Domaradzki et al. 2010].

The lack of new effective herbicides makes growers dependent on using existing products in a new way. In addition, stricter registration and environmental regulations for herbicides have resulted in the loss of some herbicides, particularly in Europe. The lack of novel chemicals entering the market and the rapid growth of multiple weed resistance threaten crop production worldwide.

Therefore, this study aimed to determine the dominant factor or group of factors affecting the occurrence of *A. myosuroides* in winter wheat in variable herbicide application timing in the tillage systems. The results may also point to factors promoting the development of herbicide resistance in *A. myosuroides* in winter wheat in northwest Poland's climatic and soil conditions.

## MATERIAL AND METHODS

The study areas were established in winter wheat fields, with a potential occurrence of *A. myosuroides* herbicide-resistant biotypes, in Lubuskie and Zachodniopomorskie Voivodeships in seven selected agricultural holdings. The fields were chosen based on surveys conducted with the owners of holdings where sulfonylurea herbicides have been commonly used in recent years and the problem of widespread occurrence of *A. myosuroides* was observed. Moreover, the fields differed in tillage system – plow or no-plow. The margins of crop fields, a two-meters wide strip with limited use of herbicides, constituted the so-called reference area. The soils in all selected farms were arable soils of good or medium quality. The research was conducted during the vegetation seasons, between June and July 2018–2019.

All the herbicides against mono- and dicotyledonous weeds in winter wheat were summarized based on their active substances and listed in Tables 1 and 2.

The following variables affecting the quantitative contribution of *A. myosuroides* in the analyzed fields were included in the analyses: location of the sample plot in the random central (C) area or the reference (R) area (margin) of the field; plow (P), or no-plow (WP) tillage; term of herbicide application – spring (S) or autumn (A); and the total number of herbicides (active substances) used per each application term.

The measurements were performed within the sample plots of 25 $m^2$ each, located within each field's C or R areas, in 3 replications. The *A. myosuroides* frequency was assessed per each sample plot, based on the Braun-Blanquet method, using a 5-degree scale, reflecting the percentage contribution of this species in the winter wheat. Statistical analyses were performed on the values of the mean coefficient of the Braun-Blanquet scale for blackgrass in the examined sample plots (P) [Dzwonko 2007] – Table 3.

In 2018, 18 field observations were made in three locations, and in 2019 another 24 observations were made in four locations. A total of 42 samples in seven different winter wheat growing locations were collected, and the data were subject to statistical analysis. Each sample was tagged with a uniform code containing information on the field location (001–007), with replication number (1–3 for C, and 4–6 for R) provided, e.g., 002-1, 004-6.

A one-way analysis of variance was carried out, and the significance between the mean values was determined using the Tukey test at $p = 0.05$. The statistical analysis of the collected data also included discriminant analysis (DA).

Table 1. List of active substances used in the without plowing tillage system

| Variable | | | Active substances | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| sample number | season | controlled weeds | amino-phosphonates | phenoxy-nicotine-anilides | phenyl-pyrazolines | isoproturon | oxy-acetamides | sulphonyl-urea | triazinones | triazole-pirymidines |
| 001 | autumn | dicotyledonous and *Apera spica-venti* | | | | x | | | | |
| | spring | dicotyledonous and *Apera spica-venti* | | x | | | | | | |
| 002 | autumn | monocotyledonous and dicotyledonous | x | | | | | | | |
| | | dicotyledonous and *Apera spica-venti* | | | | | | x | | |
| | | monocotyledonous and dicotyledonous | | x | | | | | | |
| | | dicotyledonous and *Apera spica-venti* | | | | | x | | x | |
| 007 | autumn | dicotyledonous and *Apera spica-venti* | | | x | | | | | |
| | | monocotyledonous | | | | | | | | x |
| | spring | monocotyledonous | | | x | | | | | |

Table 2. List of active substances used in the plow tillage system

| Variable | | | Active substances | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| sample number | season | controlled weeds | amino-phosphonates | phenoxy-acids | phenoxy-nicotine-anilides | phenyl-pyrazolines | oxy-acetamides | derivative urea | sulphonyl-urea | triazole-pirymidines | triazinones |
| 003 | spring | dicotyledonous (*Galium sp.*) | | | | | | | x | | |
| | autumn | dicotyledonous and *Apera spica-venti* | | | x | | | | | | |
| | | monocotyledonous and dicotyledonous | | | | | x | | | | |
| | | dicotyledonous and *Apera spica-venti* | | | | | | | | x | |
| 004 | autumn | monocotyledonous and dicotyledonous | x | | | | | | | | |
| | | dicotyledonous and *Apera spica-venti* | | | | | | | x | | |
| | | monocotyledonous and dicotyledonous | | | x | | | | | | |
| | | dicotyledonous and *Apera spica-venti* | | | | | x | | | | |
| | spring | dicotyledonous (*Galium sp.*) | | | | | | | | x | |
| 005 | autumn | dicotyledonous and *Apera spica-venti* | | | | | | x | | | |
| | | dicotyledonous and *Apera spica-venti* | | | | | | | x | | |
| | spring | dicotyledonous | | x | | x | | | | x | |
| | | monocotyledonous | | | | x | | | | | |
| 006 | spring | monocotyledonous | | | | | | | | | x |
| | | dicotyledonous | | | | x | | | | | |

Table 3. Examined variables influencing the *A. myosuroides* coverage in winter wheat crops in the analyzed samples

| Specification | Sample number | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 001/1-3 | 001/4-6 | 002/1-3 | 002/4-6 | 003/1-3 | 003/4-6 | 004/1-3 | 004/4-6 | 005/1-3 | 005/4-6 | 006/1-3 | 006/4-6 | 007/1-3 | 007/4-6 |
| Coverage factor of *A. myosuroides* in the samples | 4583 | 1583 | 7083 | 336 | 5416 | 333 | 8750 | 336 | 7916 | 336 | 500 | 10 | 1333 | 500 |
| Quantity of *A. myosuroides* according to BB scale | 4;3;3 | 3;1;1 | 5;4;4 | 1;1;+ | 4;4;3 | 1;1;0 | 5;5;5 | 1;1;+ | 5;5;4 | 1;1;+ | 1;1;1 | +;+;+ | 2;2;1 | 1;1;1 |
| Cultivation system | WP | WP | WP | WP | P | P | P | P | P | P | P | P | WP | WP |
| Sample location | C | R | C | R | C | R | C | R | C | R | C | R | C | R |
| Treatment date | A/S | A/S | A | A | A/S | A/S | A/S | A/S | A/S | A/S | S | S | A/S | A/S |
| Number of treatments in autumn | 1 | 1 | 4 | 4 | 3 | 3 | 4 | 4 | 2 | 2 | 0 | 0 | 2 | 2 |
| Number of treatments in spring | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 1 |
| Amount of active substances used throughout the cultivation cycle (autumn and spring) | 2 | 2 | 5 | 5 | 4 | 4 | 5 | 5 | 6 | 6 | 4 | 4 | 3 | 3 |
| Amount of active substances used in autumn | 1 | 1 | 5 | 5 | 3 | 3 | 4 | 4 | 2 | 2 | 0 | 0 | 2 | 2 |
| Amount of active substances used in spring | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 4 | 4 | 4 | 4 | 1 | 1 |
| Amount of active substances for monocotyledonous weeds used in autumn | 1 | 1 | 5 | 5 | 3 | 3 | 4 | 4 | 2 | 2 | 0 | 0 | 1 | 1 |
| Amount of active substances for monocotyledonous weeds used in spring | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 1 | 1 | 1 | 1 |
| Amount of active substances used for dicotyledonous weeds in autumn | 1 | 1 | 5 | 5 | 3 | 3 | 4 | 4 | 2 | 2 | 0 | 0 | 1 | 1 |
| Amount of active substances used for dicotyledonous weeds in spring | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 1 | 1 |

Explanations: WP – without plowing, P – plowing, C – central area, R – residential area, A – autumn, S – spring

## RESULTS

Based on the *A. myosuroides* cover, expressed as the cover coefficient (P), the discriminant analysis (DA) indicated two main clusters of the samples characterized by a similar coverage of *A. myosuroides* (AM). The first cluster was composed mainly of the sample plots from the central C portion of the fields and the other for the reference R (margins of the fields) – Figure 1.

The first cluster (marked in red) was divided further into two sub-clusters:

1) 006/4, 004/4, 003/4 – *A. myosuroides* cover not exceeding 5% of the plot area, samples located in reference parts of winter wheat fields;

2) 002/4, 007/1, 007/4, 006/1, 005/4, 001/4 – *A. myosuroides* cover not exceeding 25% of the plot area, samples located in reference and central parts of winter wheat fields.

The second cluster (marked in green) was also composed of two sub-clusters:

1) 003/1, 001/1 – *A. myosuroides* cover not exceeding 25–50% of the plot area, samples located in central parts of winter wheat fields;

2) 004/1, 005/1, 002/1 – *A. myosuroides* cover not exceeding 50–100% of the plot area, samples located in central parts of winter wheat fields.

This analysis enabled distinguishing a group of samples characterized by the highest *A. myosuroides* cover and a similar location in the analyzed winter wheat fields.

In the first sub-cluster in the R area, of the lowest *A. myosuroides* cover (less than 5%) and the plow tillage, the number of active substances of herbicides used was from 4 to 5. The most commonly used herbicides in this cluster were the inhibitors of acetyl-CoA carboxylase and amino acid biosynthesis inhibitors.

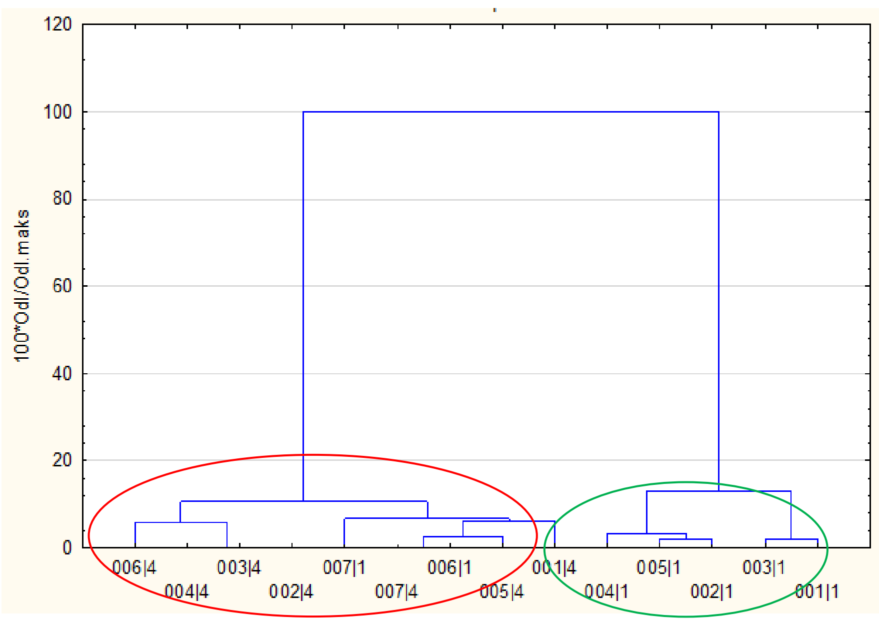


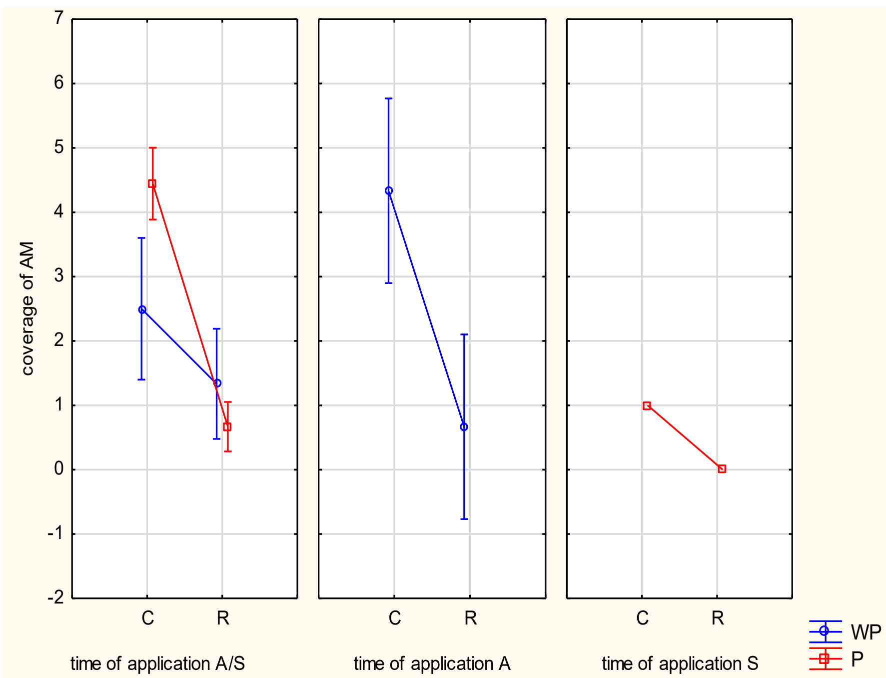

Fig 1. Discriminant analysis (DA) of *A. myosuroides* coverage variability in samples from the central (C) (001/1 – 007/1) and reference (R) (001/4 – 007/4) areas of winter wheat fields

In the second sub-cluster, low *A. myosuroides* cover was also determined in the R area in the no-plow system (001/4 and 002/4). In 001/4, a photosynthesis-inhibiting herbicide was used in the autumn, and a pigment-inhibiting herbicide was used in the spring. In the 002/4, five active substances from four herbicide groups were used in the autumn, with photosynthesis inhibitors as dominant. In the 005/4, located in the R, with the plow system, coverage of *A. myosuroides* reached 25%, and six active substances in four herbicides were used.

In the second green cluster, plots from the central parts of the winter wheat fields were concentrated. These plots also had a higher *A. myosuroides* coverage (25–50% for samples 001/1 and 003/1, and 50–100% for samples 002/1, 004/1, and 005/1). Such a high coverage of *A. myosuroides* was observed in the fields with plow (003/1, 004/1, and 005/1) and no-plow (001/1 and 002/1).

Significant differences ($p < 0.05$) were determined between the winter wheat fields with *A. myosuroides* in no-plow (WP) and plow (P) systems and between the central areas (C) and the reference areas (R) of the fields. Differences in the *A. myosuroides* cover were also observed when analyzing the herbicide application timings, i.e., autumn and spring (A/S), only autumn (A), and only spring (S) – Figure 2.

The above analysis indicated a significant impact of the herbicide application time and plot sample location on the share of *A. myosuroides* in winter wheat. The most pronounced infestation with *A. myosuroides* was determined in the central area of field




C – the central part of the field, R – margin area of the field, A – autumn, S – spring, WP – no-plow, P – plow

Fig. 2. Variability of *A. myosuroides* (AM) coverage according to the BB scale depending on the time of herbicide application, sample plot location, and the tillage system

(C) after herbicide application in autumn and spring (A/S) or autumn only (A). The lowest *A. myosuroides* cover was observed in the reference area of the winter wheat field (R) and following the spring-only herbicide application (S) – Figure 2. It was also found that in all the analyzed crops, both in the plow and no-plow system and with autumn and spring weed control, the most frequently used groups of herbicides were amino acid biosynthesis

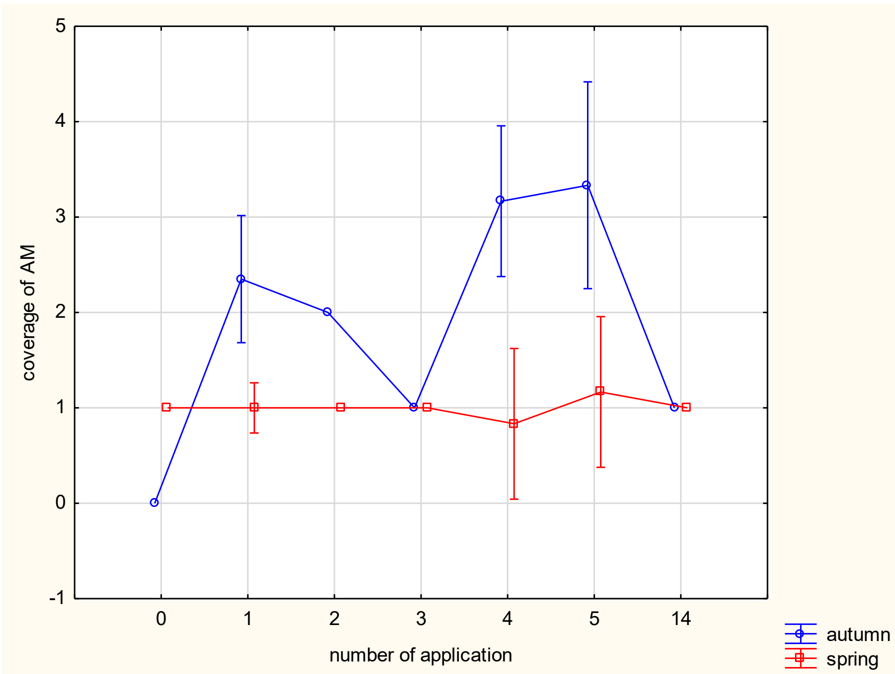



Fig. 3. Effect of the number of herbicide applications performed in autumn and spring on *A. myosuroides* (AM) cover

inhibitors, including acetolactate synthase (ALS) inhibitors and 5-enolpyruvylshikimate-3-phosphate (EPSP) synthase inhibitors. In addition, in all analyzed winter wheat fields, both in the plow and no-plow system, the greatest weed infestation was observed in those plots where sulfonylurea herbicides were used, i.e., samples 002/1, 003/1, 004/1 and 005/1, with a mean *A. myosuroides* cover was from 25% to 100%. The lowest *A. myosuroides* (<25%) cover was observed in samples 006/1 and 007/1, both in the plow and no-plow system where ACCase inhibitors instead of sulfonylurea herbicides were used. In the case of sample 007/1, only one application was made in the autumn, using an active substance from the triazolopyrimidine group.

Application of herbicides in the autumn limited the cover of *A.myosuroides* in winter wheat to a lesser degree than the same number of applications performed in spring (Fig. 3).

Correlation analysis revealed moderate, although statistically significant positive correlations between *A. myosuroides* cover and the number of herbicide applications in autumn, the number of active substances used in autumn, the number of active substances against monocotyledonous weed used in spring, and the number of active substances against

Table 4. Influence of the variables (*p*) on the participation of *A. myosuroides* in the analyzed samples and their mutual correlations (*r*)

| Variable | *p* | *r* |
|---|---|---|
| Number of treatments in autumn | 0,002* | 0,391* |
| Number of treatments in spring | 0,984 | 0,081 |
| Amount of active substances used throughout the cultivation cycle (autumn and spring) | 0,000* | 0,270 |
| Amount of active substances used in autumn | 0,007* | 0,360* |
| Amount of active substances used in spring | 0,143 | - 0,159 |
| Amount of active substances for monocotyledonous weeds used in autumn | 0,006* | 0,377* |
| Amount of active substances for monocotyledonous weeds used in spring | 0,985 | 0,126 |
| Amount of active substances for dicotyledonous weeds used in autumn | 0,006* | 0,377* |
| Amount of active substances for dicotyledonous weeds used in spring | 0,002* | –0,381* |

* significant difference

dicotyledonous weed used in autumn (Tab. 4). A moderate statistically significant negative correlation was recorded with the number of active substances against dicotyledonous weed used in spring, suggesting the higher efficacy of herbicides used that term.

## DISCUSSION

This study's results are confirmed by other authors' works, stating that plowing limits the phenomenon of weed herbicide resistance and, thus, the density of weed cover [Blair 1999, Hicks et al. 2018]. Based on the field history analyses, the present study found that plow tillage in spring limited winter wheat field infestation with *A. myosuroides*. However, in the case of *A. myosuroides*, with a higher tendency to develop herbicide resistance, the cultivation system has a lower impact on the species' frequency. Important, however, is the crop rotation, which enables the introduction of various herbicides for *A. myosuroides*, of a lower resistance threat [Maréchal et al. 2012, Menne and Hogrefe 2012, Adamczewski et al. 2016].

In all the analyzed samples, regardless of the cultivation system, the greatest weed infestation of *A. myosuroides*, reaching 25–100% coverage, was found on the plots where sulfonylurea herbicides were applied. The so-far-recognized phenomenon of herbicide-resistant *A. myosuroides* applies especially to herbicides containing sulfonylurea derivatives. The higher covers of *A. myosuroides* observed in our sample plots, where the application of sulfonylurea herbicides was frequent, may indicate that the cause of mass weed infestation was the presence of a resistant form to those herbicides, which is also confirmed in the literature [Adamczewski et al. 2016].

The obtained results demonstrated that the herbicide application time is the most significant for the *A. myosuroides* cover in winter wheat, independently of the number of active substances used. This species is distinguished by a long, extended seed germination period, observed in autumn and spring. Applying herbicides in spring was more efficient regarding *A. myosuroides* field infestation than the autumn application. Our finding may support that apart from the recommended variability of herbicides and their reduced doses [De Prado and Franco 2004, Hicks et al. 2018]. Also timing of herbicides application plays a role in reducing weed infestation. The lower cover of *A. myosuroides* in the field margins also supports the good agricultural practice of recommending leaving a buffer strip without using herbicides to maintain the biodiversity in agricultural ecosystems [Directive 2009/128/EC].

The analyzed variables affecting the *A. mysuroides* infestation of winter wheat may be considered factors significantly determining the cereal-weed interactions and be used to create models for the spread of weed on fields. Such a model, the ALOMYSYS devoted to *A. myosuroides*, was created by Colbach [2006]. Thanks to such models, it is possible to foresee the impact of agrotechnical and environmental factors on the growth and development of this weed species [Miziniak 2006, Maréchal et al. 2012, Freckleton et al. 2017, Zeller et al. 2018].

Studies indicate that apart from the agrotechnical factor, that is, the tillage system, fertilization, time and dose of herbicide used, other conditions significantly impact the distribution of *A. myosuroides* on cultivated fields and in their vicinity. Only assessing the impact of individual agrotechnical, weather, and soil factors may affect weed infestation level and resistance to herbicides.

## CONCLUSIONS

To summarize, the highest coverage of *A. myosuroides*, reaching 25–100% of the winter wheat area, regardless of the tillage system, was found when the herbicides from the group of sulfonylurea derivatives (acetolactate synthase ALS inhibitors) were frequently used. When plowing was applied, winter wheat infestation with *A. myosuroides* was significantly lower. The smallest cover of *A. myosuroides*, not exceeding 25%, was observed in the margin zone of the winter wheat field and following the springtime application of herbicides. The highest cover of *A. myosuroides*, reaching 50–100% of the area, was observed only in the central part of the analyzed winter wheat fields, following the application of herbicides in autumn and spring or in autumn only.

The analysis of the obtained results allows to formulate agrotechnical recommendations that may limit the expansion of *Alopecurus mysosuroides* in cereal crops and consist in interrupting plow cultivation and longer periods of no-plough cultivation. Moreover, it is recommended to introduce crop species other than just cereals into the crop rotation and to include the spring use of biocidal preparations in the cultivation cycle, regardless of their use in autumn.

The results also indicate the need to expand the research towards the synergy of active substances in the applied herbicides, often intended for different groups of weeds or repeated application.

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