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ECONOMIC EFFICIENCY OF WEED CONTROL METHODS IN WINTER WHEAT CULTIVATION ON LARGE-SCALE FARMS[1]

Key words: winter wheat, herbicides, weed resistance, chemical plant protection, profitability, large-scale farms

ABSTRACT. In modern agriculture, on large-scale farms using monoculture, reduced tillage and intense chemical protection, the phenomenon of herbicide resistance in weeds is the cause of ecological and economic losses. More and more attempts are made to answer the question about the profitability of reducing agrotechnical treatments and intensifying chemical methods of weed control with a simultaneous intensification of the problem of herbicide resistance in weeds occurring in winter wheat crops, which dominates the structure of cereal sowing in Poland. The main objective of the study was to evaluate the costs of weed control for winter wheat cultivation on large-scale farms where there was no problem of weed resistance and on farms where resistant biotypes were identified. The research was based on a survey conducted among owners of farms cultivating winter wheat in 2019. The collected data were elaborated using basic methods of descriptive statistics and economic analysis. Based on the research results, it was found that with an increase in the area of farms, reduced tillage and monoculture are used more frequently than conventional tillage and crop rotation. At the same time, the commonly used chemical weed control methods are more frequently applied than mechanical ones. Economic efficiency indicators for winter wheat protection against weeds indicate a decrease in this efficiency with an increase in farm size. This is because the larger the farms, the more frequently the occurrence of resistant weed biotypes, which was confirmed by laboratory tests, and farmers more often assumed that such a problem occurred on their farms.

INTRODUCTION

Wheat takes first place in the world's cereal production and is typical temperate grain. However, its cultivation is associated with changes in profitability, which results from, i.a., instability of purchase prices, an increase in cultivation costs, as well as the dynamics of

[1] The research is part of the project „Strategy against herbicide resistance in weeds as a significant factor in ensuring sustainable agroecosystem development"; BIOSTRATEG III programme [BIOSTRATEGIST III] (2017-2020) (task entitled „An analysis of economic losses caused by herbicide-resistant weed biotypes"). The project is funded by the National Centre for Research and Development as part of the strategic research and development programme „Environment, Agriculture and Forestry" – BIOSTRATEG [BIOSTRATEGIST], III contest (BIOSTRATEG3/347445/1/NCBR/2017).

changes in grain prices and production costs. Regarding the structure of sowing in Poland, cereals currently occupy over 70% of it and, for this reason, they are very frequently grown in monoculture [GUS 2020]. In modern agriculture, especially on large-scale farms with long-standing reduced tillage and monoculture, there is also a problem of weed resistance, which causes economic and ecological losses[2]. Usually, in the case of wheat cultivation, chemical weed control treatments are applied by using herbicides.

Fifty years ago, weed control for crops was mainly based on mechanical weed removal. Significant changes only occurred in the late 1950s, after the earlier discovery and then use of synthetic chemicals on an industrial scale. In following years, a dynamic development of chemical weed control methods, based on substances called herbicides, was observed. Unfortunately, the long-term use of herbicides has led to the occurrence of resistance [Rola 1988, Adamczewski 2000, Sekutowski 2012]. In Polish agriculture, the problem of herbicide resistance in weeds is not a common phenomenon yet, however, it is already receiving much attention [Golinowska et al. 2014, Kieloch, Marczewska-Kolasa 2015, Adamczewski 2017, Adamczewski et al. 2017, Głowicka-Wołoszyn et al. 2020]. Observing its scale in developed countries, where large quantities of herbicides have been used for years, it should be assumed that in Polish agriculture this problem will grow. In Poland, the second factor that contributes to the intensification of weed resistance, apart from the growing use of chemical plant protection products, including herbicides, are the changes in the area structure of farms – a growing number of large farms (area over 50ha[3]) that limit agrotechnical procedures, using, among other things, reduced tillage to reduce agricultural production costs. The rationale for research was the need to indicate that the occurrence of herbicide-resistant weeds will cause a reduction in profits from agricultural production. The costs of herbicide resistance in weeds should be considered in two aspects. Firstly, the phenomenon of weed resistance reduces yield due to the uncontrolled spread of weeds. Secondly, it generates additional costs for weed control and the introduction of alternative cultivation practices or systems. The indicated economic effects of weed resistance justify the necessity of introducing products to prevent its development.

The main objective of the study was to evaluate the costs of weed control for winter wheat crops on large-scale farms where there was no problem of weed resistance, and on farms where resistant biotypes were identified. An additional aim of the study was to evaluate the frequency of use of various cultivation methods and methods of selection of herbicides for weed control depending on farm size.

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[2] Resistance to herbicides is a hereditary ability of plants to survive and reproduce after applying a dose of herbicide, which usually causes their destruction [Adamczewski, Dobrzański 2012]. The issue of herbicide resistance in weeds mainly concerns the crops that occupy first place in terms of sown area, i.e. wheat cultivation. Resistant biotopes were the earliest observed in countries with many years of intense chemical protection, reduced rotation of plants and limited cultivation.

[3] The number of farms with an area of 50 ha and more amounted to 22.1 thousand in 2004 and 34.1 thousand in 2018, which means an increase in their number by more than 50% after Poland joined European structures [GUS 2008, 2019].

SOURCE MATERIAL AND RESEARCH METHODS

Empirical research was based on questionnaires collected in 2019, in Poland. The survey "Economic efficiency of the use of herbicide treatments for winter wheat cultivation" was conducted to carry out the task entitled "An analysis of economic losses caused by herbicide-resistant weed biotypes" as part of the BIOSTRATEG project "Strategies against herbicide resistance in weeds as a significant factor in ensuring agribusiness development". The survey was only conducted on farms where winter wheat was grown. It was mainly addressed to farmers running large-scale (in Polish conditions) farms ([4]area over 30 ha). A survey questionnaire was made available in both electronic version (information about it was published on various news websites) and a traditional one (e.g. during various training courses organised by agricultural advisory centres. Hence, the respondents were mainly farmers who availed of information activities and training courses conducted in agricultural advisory centres. More or less, 200 questionnaires were filled out, of which 169 were accepted after having entered the data and checked their completeness. Approximately 85% of farmers participating in the survey (143 questionnaires) ran large-scale farms (area over 30 ha)[5], whereas others (15%) – small- or medium-scale farms (in the survey, area from 1.3 ha to 28 ha).

The data obtained from the surveys made it possible to assess and compare the values of yield indicators and costs of herbicide protection for winter wheat crops on farms of different sizes. Methods of winter wheat cultivation, weed control methods and farmers' methods of herbicide selection used for weed control have also been analysed, which contributes to the indication of an overall strategy of farmer behaviour with regards to the protection of winter wheat against weeds. Moreover, the economic effects of herbicide use in a group of farms with the confirmed presence of resistant weed biotypes were compared to a group of farms where farmers suspected this problem or where they did not note it.

The collected data from the surveys were developed using statistical methods (measures of position and structural indicators) and economic analysis. The economic efficiency of wheat protection against weeds, i.e. the cost-efficiency of protection treatments, was presented using the following indices [Golinowska et al. 2014, Głowicka-Wołoszyn et al. 2020]:

– the average cost index for the protection of 1 ha of winter wheat crops: $E_1 = \frac{KC}{PU}$ [zł/ha],

– the average cost index for the protection of 1 tonne of winter wheat: $E_2 = \frac{KC}{PL}$ [zł/t],

4 According to CSO data (available in the Local Data Bank), in 2010-2016, the number of least profitable farms with an area of up to 30 ha decreased by approx. 8% and the number of farms with an area over 30 ha increased: in the 30-50 ha class by 13%, in the 50-100 ha class by 32% and in the class over 100 ha by 23%. These changes will continue in the coming years.

5 In the 30-50 ha class there were 18.2% of farms, in the 50-100 ha class – 32.9%, in the 100-500 ha class – 35.0%, and in the class over 500 ha – 14.0%.

– the coverage ratio for winter wheat crop protection costs, which informs what percentage of revenues (yield percentage) should be allocated to cover the costs of weed control: $E_3 = \frac{KC}{C \cdot PL} \times 100$ [%],

– the profitability index, which shows how much wheat yield per hectare covers the costs of weed control treatments: $E_4 = \frac{E_1}{C}$ $[t/ha]$,

– where: *KC* – total annual costs of herbicide protection treatments including the purchase costs of protection products and spraying [PLN], *PU* – cultivation area of winter wheat [ha], *PL* – winter wheat yield [t], *C* – the price of 1 tonne of winter wheat [PLN/t].

RESULTS OF EMPIRICAL RESEARCH

A survey on the economic efficiency of herbicide treatments was conducted among farms cultivating winter wheat. Winter wheat constitutes over 80% of wheat sown and occupies 23% of area for grain sown in Poland [GUS 2020]. Therefore, its economic significance is great. The surveyed farms used different methods of cultivation and weed control. It was noted that with an increase of large-scale farm area (over 30 ha), there was a decrease in the percentage of farms using the conventional method of cultivation (from 81% in the group 30-50 ha to 50% in the group of farms cultivating 500 ha and more) and crop rotation (from 57.7% to 40%, respectively). On the other hand, with an increase of farmland, there was an increase in the percentage of farms using reduced tillage (from 7.7% to 70%) and monoculture (from 0% on the smallest farms to 20% on farms cultivating 500 ha and more). Such changes in the methods of cultivation are justified by the need to reduce the costs of i.a., agrotechnical treatments on very large-scale farms, however, at the same time, they contribute to an increased risk of weed resistance (Table 1). Many studies have shown the importance of cultivation treatments in changing the state and level of weed infestation of fields under cultivation [Arshad et al. 1994, Keller et al. 2011, Hernández Plaza et al. 2015, Małecka-Jankowiak et al. 2015, Nichols et al. 2015]. Literature indicates an increase in weed infestation of winter wheat as a result of using monoculture as a cultivation method [Parylak 1998, Zawiślak, Kostrzewski 2000, Adamiak et al. 2003, Blecharczyk et al. 2007, Kieloch, Marczewska-Kolasa 2015]. However, according to the study by Irena Małecka-Jankowiak et al. [2015], direct seeding increases the number and weight of weeds in the field of winter wheat compared to ploughing. This phenomenon increased especially in conditions of winter wheat grown in monoculture.

Chemical methods of weed control are commonly used in all groups of large-scale farms under consideration (98-100% of farms). Frequently, herbicides are used in small- and medium-scale farms (96.2%) as well. A beneficial phenomenon concerns an increase in the percentage of large-scale farms applying integrated weed control methods as their area increases (Table 1).

Table 1. Percentage of farms using selected methods of cultivation and weed control

Farm size [ha]	Number of farms	Share of winter wheat sown in agricultural land [% of land area]	Total percentage of farms [%]						
			agricultural system		methods of cultivation/ tillage		main methods of weed control		
			conventional	reduced	monoculture	crop-rotation	mechanical	chemical	integrated
Small- and medium-scale farms									
Less than 30	26	40.5	69.2	7.7	11.5	46.2	50.0	96.2	11.5
Large-scale farms									
30-50	26	35.6	80.8	7.7	0.0	57.7	19.2	100.0	3.8
50-100	47	39.3	74.5	21.3	8.5	74.5	42.6	97.9	14.9
100-500	50	32.4	74.0	36.0	16.0	76.0	38.0	98.0	10.0
500 and more	20	26.3	50.0	70.0	20.0	40.0	30.0	100.0	15.0
Total	169	29.3	71.6	27.2	11.2	63.9	37.3	98.2	11.2

Source: own study based on the results of a survey conducted in 2019, entitled "Economic efficiency of the use of herbicide treatments for winter wheat crops"

Table 2. Incidence of selected weeds occurring in winter wheat crops

Farm size [ha]	Incidence of selected weeds [% of farms in a given class]			
	loose silky-bent (*apera spica-venti*)	slender meadow foxtail (*alopecurus myosuroides*)	corn poppy (*papaver rhoeas*)	cornflower (*centaurea cyanus*)
Less than 30	88.5	0.0	23.1	53.8
30-50	88.5	3.8	26.9	30.8
50-100	66.0	4.3	4.3	27.7
100-500	80.0	12.0	28.0	50.0
500 and more	85.0	15.0	20.0	55.0
Total	79.3	7.1	19.5	42.0

Source: as in Table 1

Table 3. Farmers' herbicide selection methods for weed control in winter wheat cultivation

Farm size [ha]	Herbicide selection methods for weed control [% of farms in a given class]							
	the same herbicide that worked best before	various herbicides, I pay attention to different mechanism	various herbicides, I pay attention to different active substances	my choice of herbicide was mainly determined by price	recommended by a sealer or inter-mediary	I use a non-selective herbicide	I use preemergent herbicides	I combine herbicides based on different mechanisms and use them in tank mixtures
Less than 30	19.2	46.2	57.7	0.0	19.2	3.8	26.9	19.2
30-50	42.3	38.5	46.2	11.5	11.5	0.0	3.8	15.4
50-100	14.9	42.6	66.0	4.3	21.3	0.0	40.4	46.8
100-500	40.0	46.0	44.0	4.0	26.0	4.0	32.0	46.0
500 and more	35.0	60.0	50.0	0.0	25.0	10.0	10.0	55.0
Total	29.6	45.6	53.3	4.1	21.3	3.0	26.6	38.5

Source: as in Table 1

The most common weed in winter wheat crops was loose silky-bent (*apera spica-venti*), which was found in more than 80% of farms, regardless of the group to which they belonged (groups differentiated by the number of hectares utilised by a farm). The exception was a group of farms utilising 50 to 100 ha, where 66% of the surveyed farms declared the presence of this weed. Loose silky-bent (*apera spica-venti*) is a common grass weed belonging to the *Poaceae* (*Gramineae*) family found in winter cereals (especially in wet years) in northern and central Europe [Adamczewski et al. 2017]. A slightly less frequent weed was cornflower (*centaurea cyanus*), which occurred in every second farm with an area of at least 100 ha and in less than every third farm with an area from 30 to 100 ha. Cornflower (*centaurea cyanus*) is a common weed found in winter cereals, canola, root crops and papilionaceous plants. This species has low habitat requirements and is found on almost all soils. As the pollen of this plant can easily be carried by bees, immunised species will likely spread more easily. Corn poppy (*papaver rhoeas*), on the other hand, was found in less than every fifth surveyed farm [most frequently on farms utilising 100 to 500 ha (28%), least frequently on those utilising 50 to 100 ha (4.3%)]. According to farmers, the occurrence of slender meadow foxtail (*alopecurus myosuroides*) in winter wheat crops (7.1% of all surveyed farms) is relatively rare

– the weed most frequently occurred in wheat crops on the largest farms utilising 500 ha and more (15%), while least frequently on the smallest ones, i.e. from 30 ha to 50 ha of farmland (less than 4%) (Table 2).

The relatively lower incidence of the above-mentioned weed species in the 50-100 ha class of farms may be a result of more frequent use of mechanical and integrated weed control methods in this class (Table 1). However, it is also the effect of the use of the same herbicide that has already proven itself before and its rare application, as well as the biggest attention of farmers from this group to active substances in the composition of protection products (Table 3).

On large-scale farms, when selecting herbicides, farmers most frequently pay attention to their mechanism and active substances. As farm size increases, the percentage of farmers combining herbicides with different mechanisms, using them in tank-mixtures (from 15.4 to 55% of farms) and applying non-selective herbicides (from 0 to 10%) increases as well. From 11.5 to 25% of the surveyed farms follow the recommendations of an intermediary when selecting a herbicide. On the other hand, as the size of a farm increases, the percentage of farmers selecting a herbicide based solely on price decreases (from 11.5% in the group of farms utilising 30 to 50 ha to 0% on farms with an area of at least 500 ha) (Table 3).

The average costs of crop protection of 1 ha of winter wheat (E_1) on large-scale farms were the lowest in the group of farms utilising from 30 to 50 ha and amounted to 149.2 PLN/ha, while the highest ones – 351.9 PLN/ha on the largest farms with an area over 500 ha. On large-scale farms with an area of 30-500 ha the economic efficiency indicator for winter wheat protection in question was lower than for small- and medium-scale farms (Table 4).

On farms with an area of 30-50 ha, 3.6% of revenues were to be allocated to the herbicide protection of winter wheat (E_3), which meant allocating 0.2 tonnes of yield per hectare for this purpose. The value of these indicators increased with farm size – in those with an area over 500 ha, 7.5% of revenues from wheat sales, which represented 0.5 tonnes of wheat yield per hectare, were to be used to cover the crop protection of wheat (Table 4).

Table 4. Economic efficiency indicators for wheat protection against weeds on farms

Farm size [ha]	Economic efficiency indicators for wheat protection against weeds			
	E_1 [PLN/ha]	E_2 [PLN/t]	E_3 [%]	E_4 [t/ha]
Small- and medium-scale farms				
Less than 30	228.3	35.0	5.3	0.3
Large-scale farms				
30-50	149.2	24.5	3.6	0.2
50-100	188.8	26.2	3.9	0.3
100-500	190.9	29.0	4.2	0.3
500 and more	351.9	53.3	7.5	0.5
Total	280.6	42.2	6.0	0.4

Source: as in Table 1

On large-scale farms, as their area increased, farmers more frequently assumed that weeds occurring in winter wheat crops could be herbicide-resistant. This opinion was expressed by 15.4% of farmers utilising 30-50 ha of farmland and as much as 40% of farmers with the largest farms of over 500 ha. Test-confirmed herbicide-resistant biotypes were noted in 15% of the largest farms (Table 5).

Farms with confirmed weed resistance constituted 7.1% of the sample. Almost one-third of the surveyed farmers (29%), based on their own experience and observations, assumed that such a phenomenon occurred on their farms. On the other hand, 64% of farmers were unable to address this problem or stated that there was no such problem on their farms (Table 5).

Table 5. Subjective assessment of farmers confirmed by studies concerning the occurrence of herbicide resistance in weeds

Farm size [ha]	Is there a problem with weed resistance to herbicides used in winter wheat cultivation on the farm?				
	no	I suppose so	yes and this was confirmed by laboratory tests	hard to say	total
Small and medium-scale farms [% of farms in a given class]					
Less than 30	34.6	15.4	7.7	42.3	100.0
Large-scale farms [% of farms in a given class]					
30-50	30.8	15.4	0.0	53.8	100.0
50-100	25.5	38.3	8.5	27.7	100.0
100-500	38.0	30.0	6.0	26.0	100.0
500 and more	25.0	40.0	15.0	20.0	100.0
Total	31.4	29.0	7.1	32.5	100.0

Source: as in Table 1

Comparing economic efficiency indicators for wheat cultivation, which have been presented in Table 6, a high convergence of their values in the group of farms with confirmed laboratory tests for weed resistance, as well as in the group in which farmers suspected the occurrence of this phenomenon, was observed. At the same time, these indicators confirmed significantly lower profitability of wheat protection in these groups compared to the group of farms where farmers did not notice such a problem. The costs of protection of wheat crops on farms with confirmed or suspected weed resistance amounted to PLN 296.1-307.6 per hectare or PLN 44-45 per tonne and constituted 6.3-6.4% of sales revenue, while in the second group these indicators were PLN 262, PLN 40.3 and 5.7%, respectively. To cover the costs of weed control, 0.4 tonnes of wheat per hectare should be allocated to each farm group.

Table 6. Economic efficiency of the herbicide protection of wheat crops depending on the occurrence of confirmed weed resistance and on the farmer's subjective assessment of the occurrence of such a phenomenon

Is there a problem with weed resistance to herbicides used in winter wheat cultivation on the farm?	Indicator values for the economic efficiency of crops			
	E_1 [PLN/ha]	E_2 [PLN/t]	E_3 [%]	E_4 [t/ha]
Not likely	262.2	40.3	5.7	0.4
I suppose so	307.6	45.0	6.4	0.4
Yes, and it was confirmed	296.1	43.7	6.3	0.4
Total	280.6	42.2	6.0	0.4

Source: as in Table 1

SUMMARY AND CONCLUSIONS

The conducted survey among farmers proved that, with an increase in farm size, a reduced tillage system and monoculture were used more frequently than a conventional tillage system and crop rotation. Bearing in mind the changes in the area structure of farms in Poland, manifested in an increase of farmland area, it can be assumed that they will contribute to the intensification of the phenomenon of weed resistance in winter wheat cultivation. Besides, commonly used chemical weed control methods (almost 100% of farms) and herbicides with a broad-spectrum mechanism (non-selective), which are more commonly used on the largest farms, as well as less frequently used mechanical methods, will contribute to the development of weed resistance. On the other hand, however, the more frequent use of integrated methods or selection of herbicides due to their different mechanism may be a factor limiting the development of weed resistance as farm area increases.

Economic efficiency indicators for the protection of winter wheat against weeds indicate a decrease in this efficiency as the farm size increases, while in groups of farms with 30-50 ha, 50-100 ha and 100-500 ha area this decrease is similar and much lower than in the class of the largest farms with an area over 500 ha. This is because the larger the farms, the more frequently the occurrence of resistant weed biotypes was confirmed by laboratory tests, and farmers more often assumed that such a problem occurred on their farms. Farmers' subjective opinions on the occurrence of weed resistance were confirmed by laboratory tests and indicators for the economic profitability of crops.

The economic effects of wheat cultivation in the form of crop protection expenditures per hectare and their coverage in terms of the size of revenues and yield were higher on farms where herbicide resistance in weeds was present or farmers assumed it might be present than on farms where farmers did not notice the problem of weed resistance.

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EKONOMICZNA EFEKTYWNOŚĆ METOD ZWALCZANIA CHWASTÓW W UPRAWIE PSZENICY OZIMEJ W OBSZAROWO DUŻYCH GOSPODARSTWACH ROLNYCH

Słowa kluczowe: pszenica ozima, herbicydy, zjawisko odporności chwastów, chemiczna ochrona roślin, opłacalność, wielkoobszarowe gospodarstwa rolne

ABSTRAKT

We współczesnym rolnictwie w gospodarstwach wielkoobszarowych stosujących monokulturę, uprawę uproszczoną oraz intensywną ochronę chemiczną, przyczyną strat ekologicznych i ekonomicznych jest zjawisko odporności chwastów na herbicydy. Coraz częściej podejmuje się próby odpowiedzi na pytanie, jaka jest opłacalność ograniczania zabiegów agrotechnicznych oraz intensyfikowania chemicznych sposobów zwalczania chwastów przy nasilaniu się problemu ich odporności na herbicydy w uprawie pszenicy ozimej, która dominuje w strukturze zasiewów zbóż w Polsce. Celem głównym badań była ocena kosztów zwalczania chwastów w uprawie pszenicy ozimej w dużych obszarowo gospodarstwach rolnych, w których nie występował problem odporności na chwasty oraz w gospodarstwach rolnych, w których zidentyfikowano odporne biotypy. Badania prowadzono na podstawie badań ankietowych wśród właścicieli gospodarstw rolnych uprawiających pszenicę ozimą w 2019 roku. Zebrane dane opracowano z wykorzystaniem podstawowych metod statystyki opisowej oraz analizy ekonomicznej. Na podstawie wyników badań stwierdzono, że wraz ze wzrostem powierzchni gospodarstw rolnych częściej stosowana jest uprawa uproszczona i monokultura, a rzadziej uprawa tradycyjna i płodozmian. Jednocześnie powszechnie stosowane są chemiczne metody ochrony przed chwastami, a rzadziej stosowane metody mechaniczne. Ekonomiczne wskaźniki efektywności ochrony uprawy pszenicy ozimej przed chwastami wskazują na spadek tej efektywności wraz ze wzrostem wielkości gospodarstw rolnych. Związane jest to z tym, że im większe gospodarstwa rolne, tym częściej badania laboratoryjne potwierdzały występowanie biotypów chwastów odpornych, a rolnicy częściej przypuszczali, że taki problem w ich gospodarstwach rolnych występuje.

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