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THE PROBLEM OF WEED RESISTANCE TO HERBICIDES AND THE ECONOMIC EFFICIENCY OF WHEAT PROTECTION ON THE EXAMPLE OF A LARGE-SCALE AGRICULTURAL FARM[1]

Key words: wheat, herbicides, weed resistance, weed control costs

ABSTRACT. The main purpose of the article is to assess the economic efficiency of wheat protection in conditions of the occurrence of weed resistance to herbicides in a selected large-scale farm (case study). In modern agriculture, especially in large-scale farms using monoculture, zero tillage and intensive chemical protection, the emerging phenomenon of weed resistance to herbicides is a cause of ecological and economic losses. In Poland, as well as the world, the problem of weed resistance is mainly noted in the case of wheat cultivation, which is ranked first in terms of sown area. Therefore, more and more often attempts are being made to answer the question, what is the profitability of performed weed control operations with the simultaneous occurrence of herbicide resistance. Empirical research was conducted on the basis of data recorded in the book of profits and losses recorded by the farm owner in 2014-2018. The collected data was developed using economic analysis and statistical methods. It was found that, in the examined period, due to the growing problem of the presence of resistant weeds, the use of products to control them increased and the costs of protecting wheat cultivation also increased. The low effectiveness of chemical weed control treatments resulted in a change in the structure of crops in the researched farm in the last year of the study.

INTRODUCTION

Wheat cultivation is of great economic importance, both in the world and Poland. In the world, it ranks first in terms of crop size and third (after corn and rice) in terms of harvest size. In turn, in Poland, wheat is the basic bread cereal, produced in the largest quantity and occupying the largest sown area. In 2017, the area of wheat sown in Poland was 2,392 thousand hectares, accounting for more than one-fifth of the agricultural area under sowing [GUS 2019 and BDL].

[1] The research was carried out as part of the project: "Strategy to prevent weeds becoming herbicides as an important factor in ensuring the sustainable development of the agroecosystem"; BIOSTRATEG III (2017-2020) (task entitled "Analysis of economic losses caused by herbicide-resistant weed biotypes"). The project is co-financed by the National Center for Research and Development as part of the strategic programme of scientific research and development work "Environment, agriculture and forestry" (BIOSTRATEG3/347445/1/NCBR/2017).

One of the important elements in cultivation technology, as noted by Maria Golinowska and her team [2014], which determine the size and quality of wheat yield, is treatment to reduce weeds[2]. In the case of wheat cultivation, chemical weed control is applied most often through the use of herbicides. In modern agriculture, especially large-scale farms using, among others, zero till cultivation and monoculture, however, the problem of weed resistance arises[3], which is a cause of economic and ecological losses. A lack of effectiveness of chemical protection treatments performed by farmers causes, on the one hand, losses in wheat yield and, on the other, the development of this phenomenon forces the intensification of protection, exerting a negative impact on the natural environment [IOR 2015].

In Poland, the main reason for the occurrence of the phenomenon of weed resistance to herbicides is increasing the area of arable fields on large-scale farms using intensive chemical protection and poor crop rotation dominated by regular cereal sowing. This problem particularly concerns the northern regions of Poland [Adamczewski et al. 2017]. Traditional tillage is gradually being replaced by new methods taking into account, on the one hand, progress in mechanization and, on the other hand, the need to reduce the labor intensity of cultivation operations. In large-scale farms, the simplified cultivation used results from the necessity to reduce costs and increase the area of crops of particular plants. Many studies [cf. Carvalho, Basch 1994, Idkowiak, Kordas 2007] show that simplified cultivation allows to reduce labor input without clearly reducing yield and its quality. However, such actions contribute to an increased risk of weeds becoming resistant to herbicides. Therefore, attempts are being made more frequently to answer the question, what is the profitability of performed weed control operations with a simultaneous occurrence of herbicide resistance. The main purpose of the article is, therefore, to assess the economic efficiency of wheat protection in conditions of the occurrence of weed resistance to herbicides in a selected large-scale farm.

MATERIAL AND RESEARCH METHODS

A large-scale farm, located in the Warmińsko-Mazurskie Voivodship, where weed resistance was observed, was deliberately selected for this research. Source material for the research came from data recorded in the book of profits and losses recorded by the farm owner in 2015-2018. The researched farm conducts plant production on an area of about 900 hectares of arable land, using simplified cultivation and before the phenomenon of weed resistance to herbicides appeared – also monoculture. The main production direction of the researched farm is plant production, in particular wheat cultivation. The phenomenon of cereal broom (*Apera spica-venti*) and the common foxtail (*Alopecurus myosuroides*) to herbicides from the group of acetolactate synthase inhibitors (ALS) was

[2] Research carried out by Maria Golinowska [2009] shows that the working surface for reducing weed infestation in tangible tasks of chemical plant protection accounts for over 50% of the working surface for controlling pests.

[3] Weed resistance is defined as the natural phenomenon of inheritance of the ability to survive herbicidal treatments, resulting in an increase in the number of resistant individuals in the population, initially showing no resistance to plant protection products. Herbicide resistance occurs when a weed is able to survive and produce seeds with a reproductive capacity [IOR 2015].

found on the researched farm. The collected data from the farm allowed, among others, to determine expenditure on the chemical reduction of weed infestation in wheat cultivation and estimate the profitability of performed treatments. The cost-effectiveness of the protective procedure was presented using the cost coverage index. The collected data was developed using economic analysis and statistical methods (positional measures, structure and dynamics indicators).

THE PHENOMENON OF WEED RESISTANCE TO HERBICIDES – THE SCALE OF THE PHENOMENON IN POLAND AGAINST A BACKGROUND OF EUROPE AND THE WORLD

One of the major problems of modern plant protection against weeds is the phenomenon of weed resistance to the chemicals used to control them – herbicides. This phenomenon is more and more common both in Poland and around the world. International research shows [ISHRW 2019, www.weedscience.org] that 480 cases of weed resistance to her-

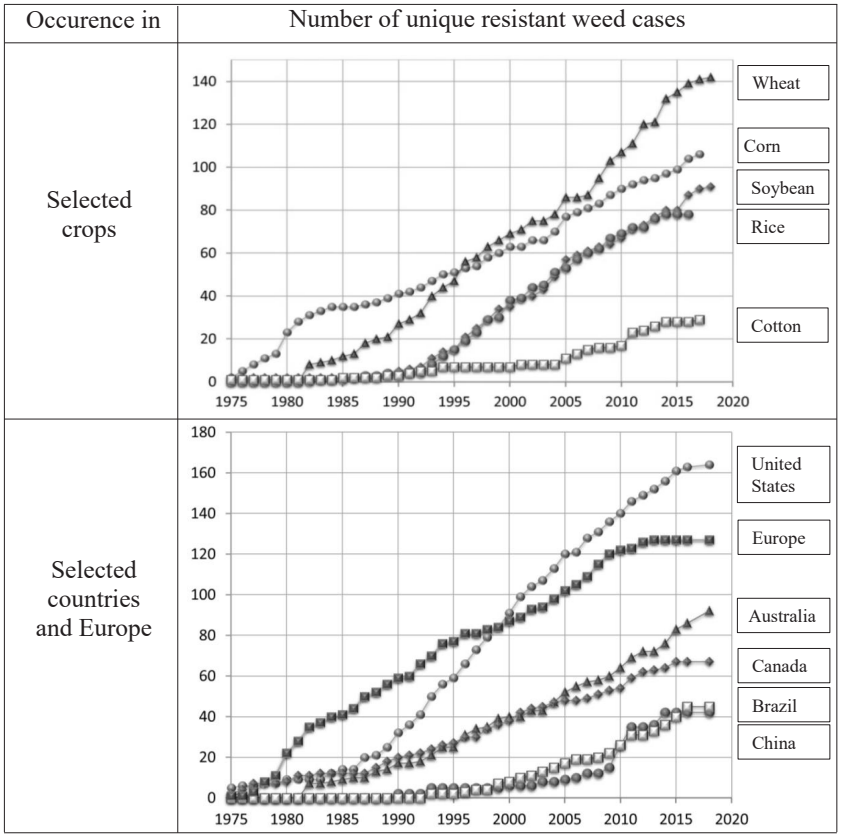

Figure 1. The increase in unique herbicide resistant weed cases in 1997-2019
Źródło: [Heap 2019]

bicides were noticed in 252 plant species worldwide. The problem of weed resistance to herbicides mainly concerns the cultivation of wheat, corn, rice and soybeans, i.e. crops occupying first places in terms of sown area. Since the beginning of the 80s, a pronounced intensification of weed resistance to herbicides in wheat cultivation is being observed, and since 2007 the dynamics of this phenomenon has clearly increased (Figure 1). Currently, over 140 unique cases of weed resistance to herbicides have been observed in wheat cultivation. The large problem of weed resistance to herbicides is also observed in maize cultivation (currently over 100 cases), rice and soybean cultivation (over 80 cases).

Resistant biotypes were first observed in countries that used intensive chemical protection for many years, simplified crop rotation and limited cultivation. The United States are at the forefront in this aspect (Figure 1), where, at the beginning of the eighties, 20 cases of weed resistance to herbicides were recorded, whereas currently over 160 are noticed. The high intensity of the studied phenomenon is also observed in Australia and Canada. Herbicide weed resistance is also a serious problem in European countries where there are over 120 confirmed cases of herbicide resistance to weeds. The highest number of herbicide resistant biotypes was mainly recorded in Western European countries, i.e. in France (52 recorded herbicide resistant biotypes), Spain (38), Germany (33) and Great Britain (28) (Figure 2).

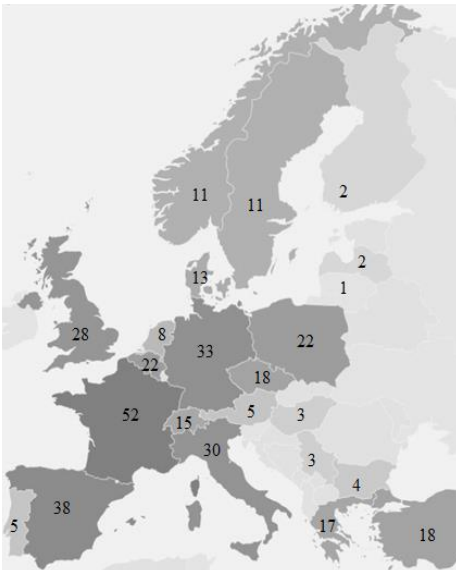

Figure 2. The number of unique herbicide resistant cases in Europe
Źródło: [Heap 2019]

So far, 22 biotypes of herbicide resistant weeds have been recorded in Poland (Figure 2), which indicates that the problem of weed resistance to herbicides is not yet a common phenomenon in Polish agriculture[4]. However, observing its scale in developed countries,

[4] However, it should be assumed that the problem of weed resistance is much more serious and broader than indicated by official data. The number of biotypes suspected of resistance increases every year. Currently, intensive research is being conducted in Poland to locate new herbicide-resistant weed sites. The accurate recognition of the severity of this phenomenon is only possible thanks to the cooperation of farmers, phytopharmaceutical companies and scientific units, which will allow for the development of an action strategy to prevent the emergence and spread of resistant biotypes. Research conducted as part of the project "Strategy to prevent weeds becoming herbicides as an important factor in ensuring the sustainable development of the agroecosystem" (BIOSTRATEG III, 2017-2020) concern 4 weed species mainly found in the cultivation of cereals, namely: the cereal broom (Apera spica-venti), the foxtail grass (Alopecurus myosuroides), the common poppy (Papaver rhoeas) and the cornflower (Centaurea cyanus). As part of the project, weed seed samples are taken from all over Poland to confirm their resistance, based on genetic testing. Currently, 1,791 samples have been taken, including: 1,203 cereal broom samples, 284 cornflower samples, 162 foxtail grass samples, 73 common poppy samples and 69 other weed samples.

where large amounts of herbicides have been used for years (its use in Poland is still increasing), it can be assumed that this problem will increase in the future in Polish agriculture.

The phenomenon of weed resistance to herbicides contributes to economic losses on farms where it occurs. Undamaged, herbicide resistant weeds not only compete with the crop, leading to a decrease in yield[5] and deterioration of their quality, but increase the seed supply in soil, thus contributing to the problem of weed infestation in further years of farming. This situation forces farms to give up the herbicide used thus far or even a whole group of these products and to choose other – usually more expensive weeding methods (including manual work). As a consequence, this can lead to increased work nuisance and reduced economic viability. In Poland, the problem of weed resistance to herbicides and serious economic losses are mainly recorded in the northern regions, such as Warmińsko-Mazurskie, Pomorskie and Zachodniopomorskie voivodships. Cereal broom (*Apera spica-venti*) is one of the most important grass weeds found in agricultural crops resistant to herbicides in Poland. According to the report of the Institute of Plant Protection of the Polish Academy of Sciences [IOR 2015], the resistance of cereal broom against herbicides from a local problem is becoming a regional problem.

ECONOMIC EFFECTIVENESS OF HERBICIDE TREATMENTS IN A LARGE-SCALE FARM (CASE STUDY)

In the studied large-scale farm, for many years until 2014, monoculture in wheat cultivation was used. In 2014, winter wheat was still 94.4% of total crop (Figure 3). As many authors show, cultivating cereals in monoculture leads to an increase in weeds resulting from the weakening competitiveness of spike plants against weeds [Małecka-Jankowiak et al. 2015, Pytlarz, Parylak 2015, Parylak et al. 2016]. Winter wheat, unfortunately, has a low competitive capacity in relation to weeds due to the long growing season (slow development in autumn) and such morphological features as short blades [Brzozowska, Brzozowski 2013]. Hence, in the cultivation of this cereal, it is necessary to use chemical weeding treatments [Woźnica et al. 2004]. One of the strategies for controlling weeds in wheat cultivation was the use of various active substances on the farm, the list of which is presented in Table 1.

Glyphosate was a commonly used herbicide in agriculture and annually on the surveyed farm[6]. In 2014, the average consumption of active substances was 2,916.4 g/ha, and glyphosate 1,839.8 g/ha (Figure 3). Reducing the average consumption of active substances by 46.2% in 2015 compared to 2014 (and glyphosate by 65.1%) resulted from the reduction of wheat growing area by 29.3%. In subsequent years, however, the phenomenon of weed resistance to herbicides intensified, which resulted in an increased use of herbicides,

[5] It is estimated that the mass occurrence of cereal broom in agricultural crops may contribute to a reduction in yield even by 40% [IOR 2015].

[6] Due to the increasing number of research results showing that this agent may endanger human and animal health in many ways, and may even have a carcinogenic effect, there is a discussion about its use. By the end of 2017, the 10-year license for its use in European countries expired. The European Parliament, under pressure from agricultural organizations, decided to extend the license for another five years, but on December 15, 2022, there will be a total ban on using glyphosate in the EU.

Table 1. Active substances used to control weeds on the surveyed farm

Active substance	Usage in years				
	2014	2015	2016	2017	2018
2,4-D			+		
Potassium aminopyralid	+	+	+		
Clopyralid	+				
Diflufenican	+	+	+	+	
Fenoxaprop-P-ethyl	+		+	+	
Florasulam	+	+	+		
Flufenacet			+	+	
Fluroxypyr			+		
Glyphosate	+	+	+	+	+
Isoproturon	+	+	+		
Iodosulfuron-methyl-sodium				+	
MCPA				+	
Metsulfuron methyl			+		
Metribuzin		+		+	
Mesosulfuron methyl			+		
Pendimethalin	+	+			
Pinoxaden	+	+		+	+
Piroxysulam	+	+		+	
Methyl tribenuron		+			
Sulfosulfuron			+		+

Source: own study based on data from the surveyed farm

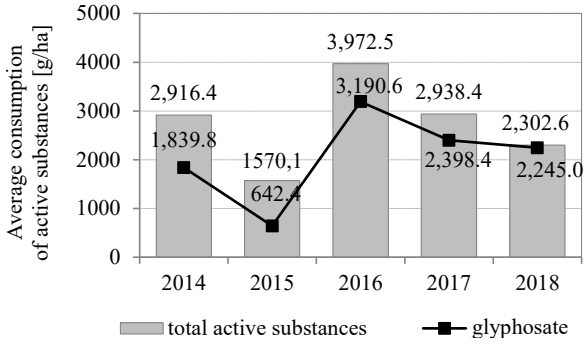

Figure 3. Average consumption of active substances and glyphosate

Source: own study based on data from the surveyed farm

and thus the amount of active substances. Between 2015 and 2017[7], when wheat cultivated area occupied around 70-80% of total sown area, the consumption of active substances in herbicides increased by 87.1% (to 2,938.4 g/ha) and glyphosate by as much as 273.3% (to 2,398.4 g/ha).

The problem of an increase in weed resistance to herbicides, in particular foxtail grass and cereal broom, together with the low

[7] The unusually high consumption of herbicides in 2016 was due to the fact that measures were first used to protect winter wheat, and after winter wheat freezing – to protect spring wheat.

effectiveness of chemical protection of wheat cultivation, required other actions. In 2018, a decision was made to introduce other crops, i.e. peas and corn, and the area of wheat cultivation was reduced to 25.9% of total sown area (Figure 4). In addition, spring wheat was introduced, due to lower resistance to herbicides of weeds emerging in spring, which results in more effective and cheaper crop protection. As a result, in 2018, there was a reduction in glyphosate consumption by 6.4% to 2,245 g/ha.

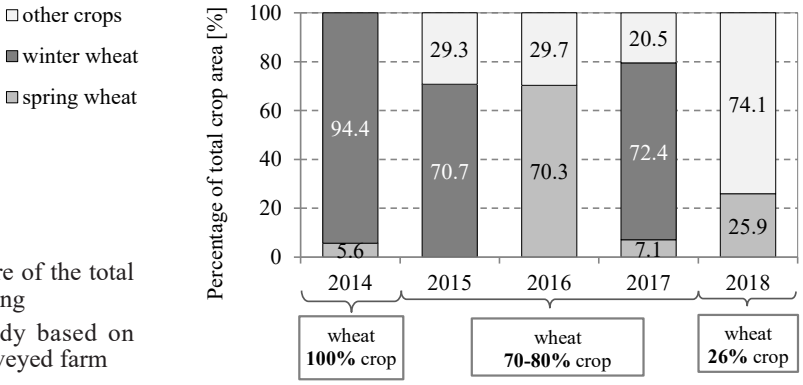

Figure 4. Structure of the total crop area by sowing

Source: own study based on data from the surveyed farm

Among the products intended for chemical plant protection, it is weeders that make up the greater part. According to research by Maria Golinowska and her team [2015], carried out for a 10-year period, the chemical reduction of weed infestation ranged from 56 to 100% in the structure of pesticide use. Thus, herbicidal treatments can significantly reduce the profitability of plant production on the farm. Based on approximate indicators of the economic efficiency of protection of spring wheat cultivation, presented in Table 2 at the large-scale farm in 2018, it can be stated that the cost of weeding 1 ha of cultivation was PLN 367.1. These costs constituted 13.7% of revenue from the sale of spring wheat, with the cost of purchasing funds constituting 9.9%, and the remainder being the costs associated with spraying. The determined value of the approximate profitability rate of protection informs that protecting wheat against weeds consumed 7.3% of its cultivation volume. The results obtained for the analyzed large-scale farm in Warmińsko-Mazurskie Voivodship are similar to the results of other studies. Leszek Majchrzak and Jerzy Pudełko [2009], analyzing the profitability of wheat and triticale crops in one of the farms in the Wielkopolskie Voivodship, estimated the cost of protecting wheat cultivation at PLN 306.7 per 1 ha in 2006 and PLN 285.4 per 1 ha in 2007 (which in constant prices from 2018 gives the values of PLN 387.5 per 1 ha and PLN 360.6 per 1 ha, respectively). Costs, estimated by Leszek Majchrzak and Jerzy Pudełko [2009] were, therefore, comparable with the results obtained in the surveyed farm, although slightly lower, as they also included other plant protection products.

In turn, the value of the approximate yield coverage ratio obtained for the surveyed farm, which amounts to 7.3%, is similar to the results of 10 years of research by Maria Golinowska et al. [2015], where in the years 2009-2013 this ratio was around 8-15%.

Table 2. Indicators of the economic profitability of herbicidal treatments at the farm in 2018

Specification		Unit	Level
Average spring wheat yield (III class soil)		t/ha	4
Revenue from spring wheat sales* according to the national average wheat price		PLN	588,348
Total costs of purchasing substances** for chemical protection of plants against weeds in wheat cultivation		PLN	58,123
Total costs of wheat herbicidal protection (purchase of substances + spraying)		PLN	80,588
Indicators of the economic effectiveness of herbicide protection	cost of wheat herbicidal protection per 1 ha of wheat cultivation	PLN/ha	367.1
	total costs of purchasing substances** for chemical protection of plants as a share of revenues from the sale of wheat	%	9.9
	the cost of wheat herbicide protection as a share of revenue from the sale of wheat	%	13.7
	the cost of herbicide protection as a percentage of yield	%	7.3

* according to the national average purchase price of wheat in the first half of 2018 [INFOR 2019]
** based on data from the surveyed farm
Source: own study based on data from the surveyed farm

SUMMARY AND CONCLUSIONS

The introduction of herbicides into agricultural practice has raised the hope that chemical weed control can replace other methods and allow the use of simplifications in soil and plant cultivation. Such belief often led to neglect in agricultural technology, which resulted in an increase in weed infestation instead of its decrease [Skrzypczak, Pudełko 2003] and the appearance of weed resistance to herbicides.

The obtained results of the profitability of weeding crops in the researched farm ,comparable to other studies, show that the occurrence of the problem of weed resistance does not cause an excessive increase in the costs of their control. However, plant protection against weeds is still a key problem in growing plants. The lack of the possibility of effective chemical crop protection against weeds makes it necessary to use other solutions – the use of other crops, a shift from monoculture back to crop rotation, or the use of other agrotechnical operations, which can translate into economic results from the farm. It seems necessary to look for solutions combining plant protection and the economic foundations of the farm with environmental protection and the health protection of farmers and consumers.

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PROBLEM ODPORNOŚCI CHWASTÓW NA HERBICYDY A EKONOMICZNA EFEKTYWNOŚĆ OCHRONY PSZENICY NA PRZYKŁADZIE WIELKOOBSZAROWEGO GOSPODARSTWA ROLNEGO

Słowa kluczowe: pszenica, herbicydy, odporność chwastów, koszty zwalczania chwastów

ABSTRAKT

Głównym celem artykułu jest ocena ekonomicznej efektywności ochrony pszenicy w warunkach występowania zjawiska odporności chwastów na herbicydy w wybranym wielkoobszarowym gospodarstwie rolnym (*case study*). We współczesnym rolnictwie, a zwłaszcza w gospodarstwach wielkoobszarowych, stosujących monokulturę, uprawę bezorkową oraz intensywną ochronę chemiczną, pojawiające się zjawisko odporności chwastów na herbicydy jest przyczyną strat ekologicznych i ekonomicznych. W Polsce, jak i na świecie problem odporności chwastów notuje się głównie w przypadku uprawy pszenicy, która zajmuje pierwsze miejsce w zakresie powierzchni zasiewów. Coraz częściej podejmuje się więc próby odpowiedzi na pytanie, jaka jest opłacalność wykonywanych zabiegów zwalczania chwastów przy występowaniu problemu ich odporności na herbicydy. Badania empiryczne przeprowadzono z wykorzystaniem danych z księgi przychodów i nakładów prowadzonej w gospodarstwie rolnym za lata 2014-2018. Stwierdzono, że w badanym okresie, ze względu na nasilający się problem występowania chwastów odpornych, zwiększało się zużycie środków do ich zwalczania i wzrastały koszty ochrony uprawy pszenicy. W ostatnim roku badania zbyt niska efektywność chemicznych zabiegów zwalczania chwastów skutkowała zmianą struktury zasiewów w badanym gospodarstwie rolnym.

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