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**THE COSTS AND INTENSITY OF CHEMICAL PROTECTION
IN THE PRODUCTION OF WINTER WHEAT IN POLAND
DEPENDING ON THE WHEAT PRODUCTION SCALE ON FARM**

Key words: farm size, pesticides cost, cost of crop protection, pesticide use, farmer behaviour, Green Deal

ABSTRACT. This paper aims at investigating pesticides used by farmers and their costs in Poland for winter wheat protection. Based on data collected in 2020 from the market survey among 1,299 growers, an analysis of how farm size determines pesticide usage, and their costs was conducted. A significant interrelationship was found. The average cost of pesticide used in wheat cultivation in 2020 was 85.61 EUR/ha, and the median was 77.24 EUR/ha. The average cost of herbicide was 28.62 EUR/ha with a median of 27.40 EUR/ha. Respectively, the cost for fungicide was 47.90 and 40.68 EUR/ha, while for insecticides farmers spent on average 2.28 EUR/ha. Along with the increased farm size, the protection cost and number of treatments increased, too. Farm size also had an impact on particular herbicide strategies. Smaller farms much more often chose spring herbicide to manage weeds, while bigger ones used herbicide in autumn. In the article, we showed the importance of farm size for the strategies adopted by them. This is particularly important in the era of limiting the use of pesticides and the EU's Green Deal policy.

INTRODUCTION

Pesticides in agriculture production have been widely used since the end of World War II. They allowed to increase plant yields and feed the growing human population [Sharma et al. 2019]. Chemical substances increased food security and the quality of life; however, the population is not fully protected from exposure to pesticides and its potentially negative health effects, therefore they have to be authorized and monitored by public bodies. Pesticides reduced the amount of human effort and energy devoted to

farming. They also impacted the economics of agricultural production and allowed to extend the productivity of land and changed the structure of production factors [Aktar et al. 2009]. Paradoxically, they may also contribute to environmental protection by increasing production per unit area and meeting the need to allocate further areas for agricultural production [Cooper et al. 2007].

According to the new Farm to Fork Strategy, the number of pesticides used in agriculture by 2030 has to be reduced by 50%, and the number of ecological farms will increase by up to 25% [EC 2021].

Achieving pesticide reduction goals can be particularly difficult due to the current characteristics of production. In Europe, in countries such as France and Germany, the dominant type of production is intensive farming, with heavy use of fertilizers and pesticides [FAOSTAT 2018, Eurostat 2019], and farms able to achieve wheat yields at a level of 8 t/ha [Brown 2012]. On average, the level of Polish agriculture is less intensive comparing to Western European countries, however a significant number of farms is able to achieve high yields and use intensive farming practices. The importance of plant protection products is especially significant in the production products that bring high profits [Burger et al. 2012].

Poland is the 5th country in Europe, after France, Spain, Italy and Germany, in terms of the number of pesticides sold. In 2018, over 20 million kilograms of them were sold [Eurostat 2018]. Eurostat divides pesticides into 6 groups: 1) bactericides fungicides 2) herbicides, haulm destructors and moss killers; 3) insecticides and acaricides; 4) molluscides; 5) plant growth regulators; 6) other plant protection products. In 2018, compared to 2011, the sales of fungicides in Poland increased from 6,081 to 7,992 tons. The sales of herbicides decreased from 12,408 to 11,371 tons in 2018. The sales of insecticides almost doubled, from 991 tons in 2011 to 1,770 tons in 2018. The sales of growth regulators also increased slightly. In 2011, 1,593 tons were sold, and in 2018, the sales amounted to 1,609 tons [Eurostat 2021]. As a result, Poland is one of the countries that recorded an increase in the sales and consumption of chemicals. Also, since 2010, an increase in fertilizer consumption has been recorded, both in Poland and in countries such as Latvia, Romania, the Czech Republic and Slovakia, which may be the result of pressure on the increase in yield [Zalewski 2020].

Wheat is one of the most important crops worldwide. In Poland, an increase in the production of winter wheat has been recorded in the last few years. In 2020, 10.3 million tons of such grain were produced in Poland [GUS 2020]. The popularity of wheat cultivation makes it a very good example of a model plant. Achieving a satisfactory crop quantity and quality depends on appropriate nutritional balance, weed control, pest and disease regulation and appropriate sowing density [Małecka-Jankowiak et al. 2015, Voss-Fels et al. 2019]. At the same time, Poland is one of the largest agricultural producers in Europe. The structure of agriculture in this country is unique in comparison to other

countries in Central and Eastern Europe. Family farms dominate in Poland, but, at the same time, there are also large farms with more than 1,000 ha and strongly developing farms with an area of 50-100 ha [Rowiński 2019]. Additionally, Polish agricultural markets are changing not only on a farm level but also with regard to input providers and raw material buyers. All these changes impact farmer behaviour in terms of market activity and farming practices [Gazdecki 2018]. Such a cross-section of farms places Poland in the position of an index country for various types of ongoing processes.

Plant protection practices are an important part of agricultural production with a substantial impact on the economic efficiency of farms, the environment and indirectly on food security and food safety. Much research [Rizzo et al. 2011, Rahman, Chima 2018, Damalas, Koutroubas 2018, Chèze et al. 2020, Piwowar 2021] has focused on the plant protection topic, however most deal with farmer behaviour related to pesticide use and its impact on the environment, while less attention is paid to economic issues, especially the costs of pesticide use. In this paper we intend to fill this gap; therefore, the aim of our research was to investigate the cost of pesticides used by farmers in Poland for winter wheat protection. Additionally, we focused on the differences of these factors in farm size categories. Size criterion can be an interesting way of diversifying farms and contribute to the further discussion on limiting the use of plant protection products. It may be important for the ongoing regulation of the pesticide market and the creation of rural areas in the European Union.

MATERIAL AND METHODS

The data used in the paper were collected by the market research company Kleffmann and Partner during crop panel studies conducted in 2020. Interviews were done personally using the PAPI (Paper and Pencil Interviewing) technique based on standardized questionnaires; when answering questions, farmers were able to use notes and field diaries. Field work was done in July and August 2020, i.e., at the end of the vegetation season, when all the treatments had been completed. Farmers provided information about the cost of all plant protection products used for winter wheat plantations during the whole vegetation season, starting in the autumn of 2019 and ending in the summer of 2020. Questions posed to farmers covered the time of use, the area of treatment, the type of pesticides and their cost.

The sample for the study covered 1,299 farms distributed across the whole of Poland, based on the distribution of cultivated area by region and crop size class. Thanks to this approach, the sample was representative for all producers of winter wheat. The R programme were used for data analysis. Descriptive statistics were used, and statistical differences were calculated using the parametric test. Tukey's test was used to compare the differences between farms.

The analysis based on the division of farms into groups depending on farm size. The split was made according to the others available scientific studies.

The costs of pesticides were declared by farmers in local currency – PLN, and then, were converted into EUR at an exchange rate of EUR 1 = PLN 4.4452.

RESULTS

The average area of a farm in the analysed group was 237.74 ha, and the average area of cultivated wheat was 72 ha (Table 1).

In the analysed farms, the number of treatments performed in individual size groups grew with the increase in farm area. The smallest number of treatments, below 2, were performed on farms with an area of up to 10 ha. In the largest farms, with an area of over 300 ha, the average number of treatments was near 4 and, at the same time, the spread was the greatest. There were statistically significant differences between farms of various areas, except for farms 10-30 and 30-50. In this case, no statistical differences were observed (Figure 1).

Table 1. Characteristics of the study group

Characteristic	Value
Sample size	1,299
Average area of farms [ha]	237.74
Median area of farms	60
Quartile 1	25
Quartile 3	200
Number of farms with an area up to 10 ha	77
Number of farms with an area of 10-29.99 ha	299
Number of farms with an area of 30-49.99 ha	187
Number of farms with an area of 50-99.99 ha	228
Number of farms with an area of 100-299.99 ha	253
Number of farms with an area over 300 ha and more	255
Average area of cultivated winter wheat [ha]	72
Average share of wheat in the crop structure [%]	30.40
Average cost of pesticide use [EUR/ha]	85.61
Average cost of herbicide use [EUR/ha]	28.61
Average cost of fungicide use [EUR/ha]	47.89
Average cost of insecticide use [EUR/ha]	2.28

Source: own study

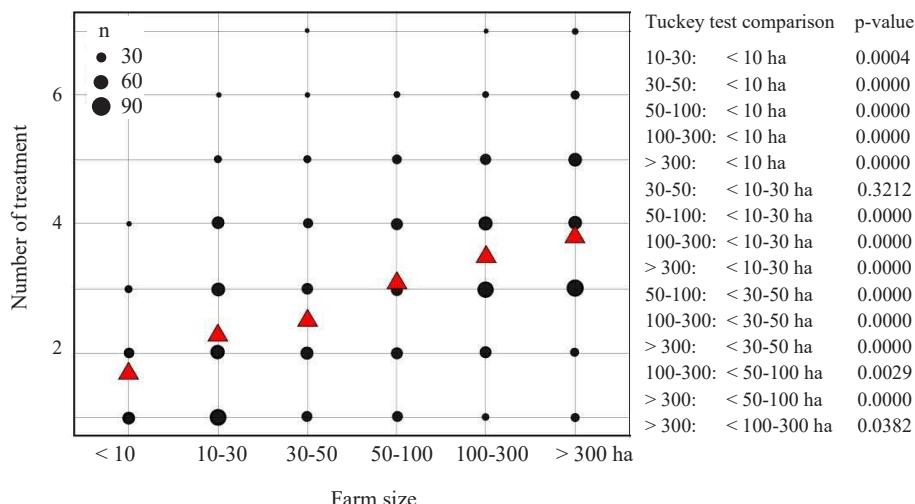


Figure 1. Number of plant protection treatments according to farm size

Source: own study

The smallest variation in the number of treatments took place among herbicides. The average number of treatments differed slightly between farms. A significant increase was observed in the group of fungicides. Farms with an area of up to 10 ha most often applied 1 or 2 fungicidal treatments during the entire vegetation period. The average number of treatments was 1.3. Along with the increase in the area, the number of treatments also increased. Farms over 300 ha most often used 2 or 3 antifungal treatments, with an average amounting to 2.5. The increase was also noticeable in the amount of insecticide treatments used. The smallest farms used no more than one such treatment, while the increase in the maximum number of treatments and the average number of treatments increased. Farms over 300 ha performed such treatments on average 50% more than the smallest farms (Figure 2).

Along with the increase in the area of analysed farms in Poland, the expenditure on pesticide protection increased. Farms in the area group up to 10 ha incurred the lowest expenses. The mean was 39.1 EUR/ha. This value systematically increased with farm size. Farms with an area of more than 300 ha paid the highest price for protection – 126 EUR/ha (Figure 3).

Figure 4 presents a detailed scheme of the cost of pesticides used for plant protection by product groups. The smallest differences in terms of pesticide costs are in the group of herbicides. Regardless of the farm size, the costs incurred for protection are similar. In the largest farms, however, the existence of outliers is visible. The average cost of herbicides was 28.61 EUR/ha and no statistical differences between different farms were indicated.

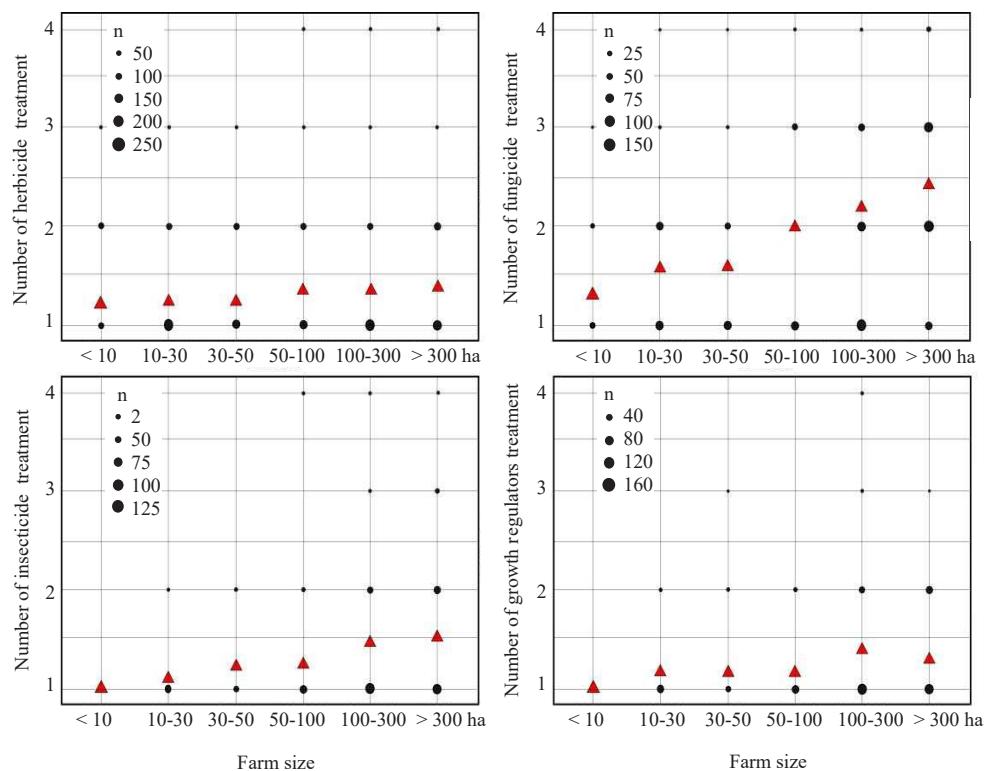


Figure 2. Number of treatments taking into account the groups of pesticides according to farm size

Source: own study

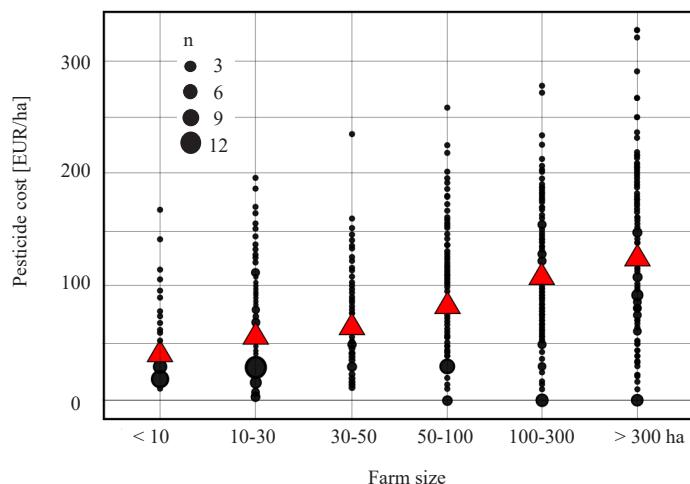


Figure 3. Total cost of pesticides used according to farm size

Source: own study

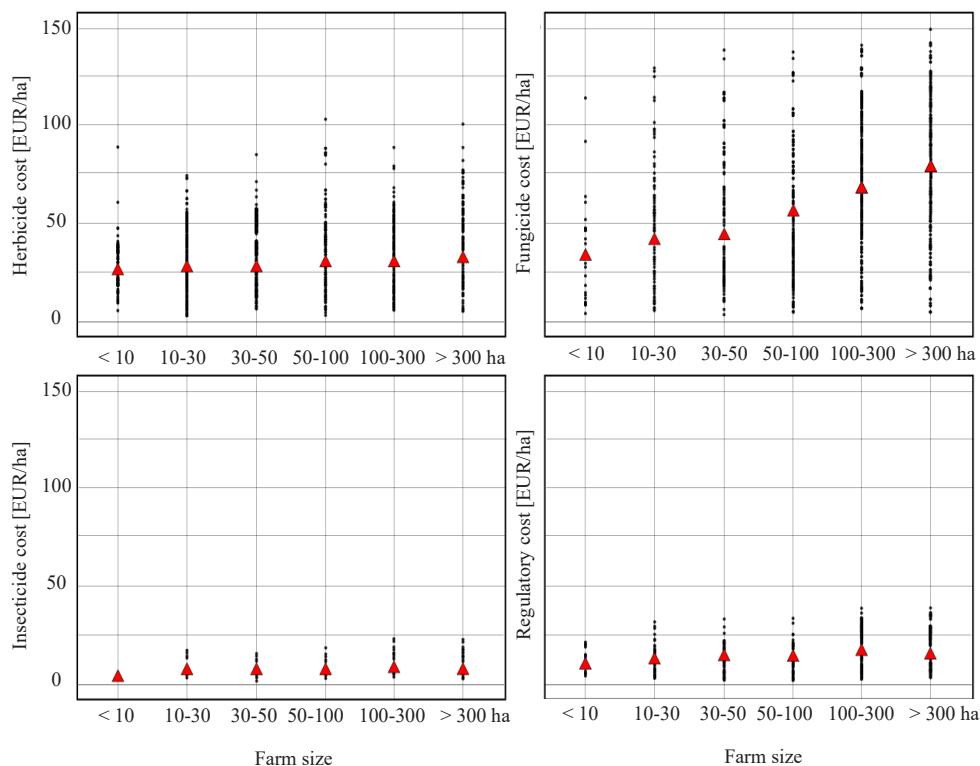


Figure 4. Pesticide cost in different chemical groups according to farm size

Source: own study

Fungicide protection had the strongest impact on higher product costs in large farms. Based on the analysed examples, the smallest farms incurred the lowest expenditure on fungicide protection. On farms up to 50 ha, the differences in incurred inputs were small between groups. Only in the group of 50 ha and above, with the transition to the next size group, the expenses of farms per 1 ha of wheat cultivation grew.

The costs of insecticides were similar in all farms, except for the smallest farms, where outlays were visibly lower. In farms up to 10 ha, significantly lower outlays were also incurred for plant growth regulations.

The size of the farm influenced the timing of the application of fungicides and herbicides. Along with the increase in farm area, the tendency to perform autumn herbicide treatment increased (Figure 5).

Despite the similar costs incurred by farms of different sizes on weed protection, differences are visible in the autumn-spring approach. The larger the farm, the higher the expenditure on herbicide protection in autumn, and the lower it is in spring. Farms

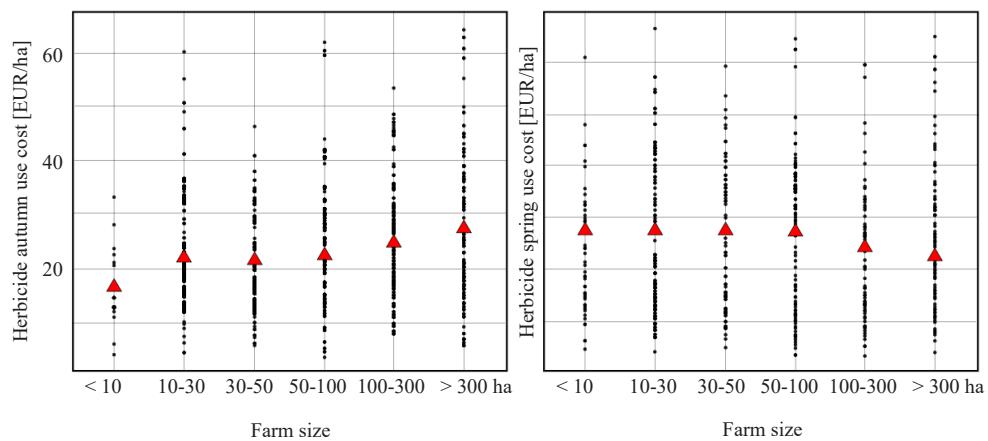


Figure 5. The cost of autumn and spring herbicide application according to farm size
Source: own study

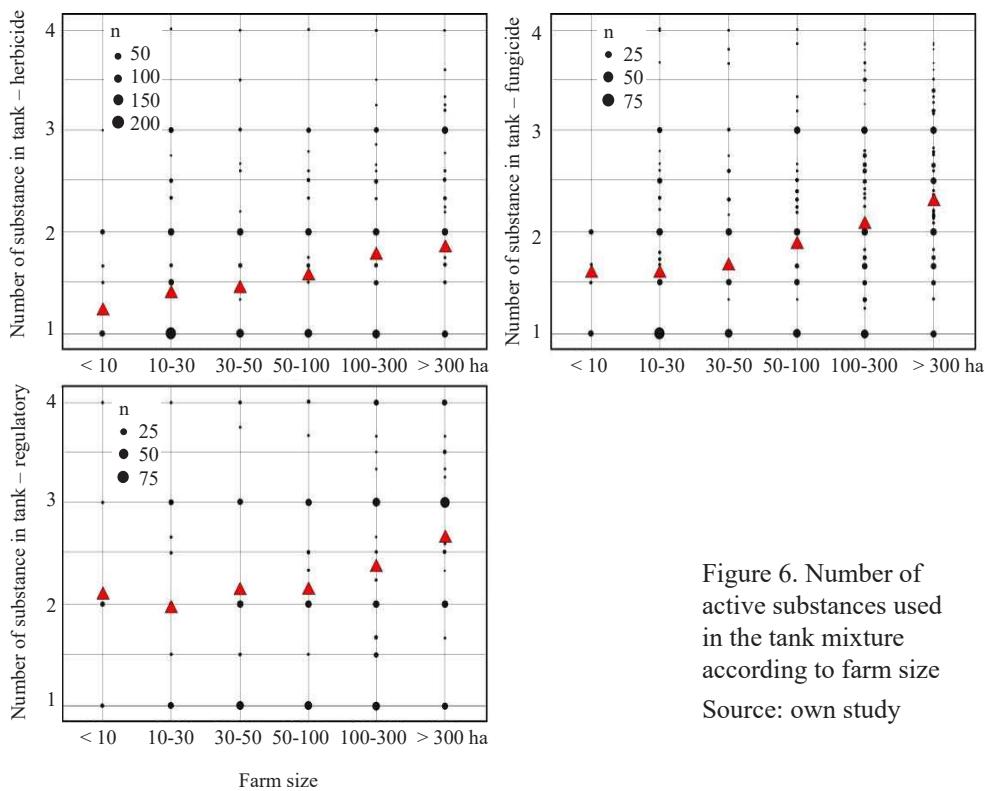


Figure 6. Number of active substances used in the tank mixture according to farm size
Source: own study

with an area of up to 10 ha spend an average of 16.4 EUR/ha on autumn protection, and 8.22 EUR/ha in spring, while the largest farms, with an area of over 300 ha, spend an average of 27.2 EUR/ha in autumn and 8.78 EUR/ha in spring. Such differentiation was not noticed for other groups of preparations.

The differentiation within the studied sample was also visible in terms of the number of active substances used in tank mixtures. In the case of herbicides, the average number of preparations used in the tank mixture ranges from 1 to 2. The smallest indicator is for the smallest farms, and the highest average, close to 2, was for the largest farms. It was similar to fungicides and growth regulators.

DISCUSSION

Our research showed differences in the use of plant protection products among farms with different agricultural areas – larger farms spend more on the pesticides used for wheat protection. Recent publications indicate that a large number of farms is able to reduce the use of plant protection products without a negative effect on the crop yield. Research confirms that, depending on the region or system of cultivation, pesticides are often used excessively [Zhang et al. 2015, Xu et al. 2008, Pereira et al. 2021] or in insufficient amounts. Therefore, the key question remains whether the protection costs incurred by large farms are overstated and can be reduced without a loss of yield, or is protection in small farms insufficient and causes yield reduction? Profitability for large farms is usually higher than for small farms, but it must, therefore, be done by reducing costs other than pesticide protection. Pesticide protection is also more intensive in large farms.

Increased pesticide use and costs may also be related to farmers' risk aversion, which might enhance pesticide use. In Chinese studies [Gong et al. 2016], it has been shown that greater risk anticipation increases pesticide use significantly. Their application was associated with the type of production methods.

A study in southern Sweden investigated the economics of using fungicides in the cultivation of winter wheat. The increase in yields and the resulting benefit from the use of fungicides varied between years, leaving it questionable when and how much fungicides should be used [Wiik, Rosenqvist 2010]. French studies show that it is possible to reduce pesticide use by 30% without reducing farmer income [Jacquet et al. 2011].

One of the factors determining farm profitability is the plant's yield and its quality. It is difficult to find solutions other than chemical weed control solutions, which will be both efficient and cheap. Large farms require reliable weed control. They look for solutions which provide the following factors: a fast effect, flexibility and efficiency [Rüegg et al. 2007]. This is confirmed by our research, which showed that the differences in the use of herbicides were small between farms with different areas. Additionally,

plant protection product use can contribute to the farm's profitability by reducing labour costs and machinery costs [Swinton, Deynze 2017]. Moreover, the further development of modern methods of agricultural production, like precision farming, might enable the continuation of cost saving strategies, and reduce the amount of product use and threats of agrichemical residuals [Finger et al. 2019].

In the cultivation of wheat, there are two times when herbicide treatments can be applied in autumn and spring. In practice, 3 options for protection are possible:

- 1) the treatment is performed only in autumn, without spring treatment,
- 2) the treatment is carried out in autumn and uncontrolled weeds are treated in spring,
- 3) the treatment is performed only in spring.

Autumn treatments are performed with the use of substances with foliar and soil action mechanisms. This type of strategy has been recommended for several years due to a lack of competition from weeds from the very beginning of the crop growth. They are used in low growth stages of weeds, which makes it possible to use lower doses of herbicides. Applying herbicides in the fall gives more time for other treatments in spring.

Spring treatments are usually performed with foliar substances. The treatment is performed on weeds in major development stages. If the treatment is carried out too late, the weeds are destroyed, they can take up nutrients and reduce yield [Jabran et al. 2017].

Our research shows that small farms were more focused on applying spring herbicide treatments. Autumn treatments were the domain of large farms. There is no research thus far showing such trends among farmers.

In the analysed farms, we noticed a progressive increase in the use of pesticides along with an increase in farm area. A similar increase was noticed on farms in the case of the use of insecticides.

Insecticides are among substances that are currently under greatest criticism and their use is being systematically inhibited. In the last few years, over a dozen active substances and preparations for plant protection have been withdrawn. Neonicotinoids have generated particular controversies [Walters 2016].

The farm size is associated with many behaviours of farmers and the way they run the farm. Stanisław Świtek and Zuzanna Sawinska described the way in which Polish farmers introduced greening on their farms. The size of the farm influenced the choice of EFA practices. The category of the smallest farms, up to 15 ha, was the most lagging behind in their management. In this group of farms, methods such as fallow land, hedges or forest area were not entirely chosen. Small farmers were reluctant to undertake actions that would result in the loss of their arable land [Świtek, Sawinska 2017].

The size of farms is an important factor of economic and environmental importance. The size of the farm is interrelated with other factors like economic ones (the bargaining power, market connections and business relations with other market entities) [Gazdecki 2018, Gazdecki, Szakály 2018, Gazdecki, Goryńska-Goldmann 2019, Ramos et al. 2021] and agricultural

ones, like e.g., implementing integrated pest management [Sawinska et al. 2020]. It affects the result of agricultural production, translating into the amount and method of using input.

The economic size of the farm is a factor of farm sustainability in an environmental and economic aspect. Higher economic potential enables agricultural production to be conducted at a higher level of sustainability. Wioletta Wrzaszcz [2012] study found that the largest farms (over 40 ESU) are the most hazardous to the environment, but also small farms (2-4 ESU). In non-specialized entities, the increase in economic size corresponded to higher values of the sustainability index. According to Polish FADN [2022], farm size also affects the wheat yields achieved there. On 10 ha farms they amounted to 47.5 dt/ha, on farms 30-55 dt/ha, with an area of 100 ha 56.5 dt/ha, and on farms with an area of over 300 ha it amounted to 63 dt/ha. The difference in yield between the highest and the lowest amounts to 32%. The increase in the economic size of farms increases the productivity of farmers. The smallest farms are characterized by low efficiency and dynamics of changes and increasing the area results in a better use of resources [Wicki 2019]. The profitability of wheat production mainly depends on the yield and price [Gołaś 2017].

In Chinese conditions, farm size has a positive effect on the economic capacity of farms, the farmer's net profit, technical and labour productivity. It has been shown that the increase in the area of farms is interrelated with a decrease in the number of fertilizers and pesticides used per hectare, which translates into positive environmental protection. This is also confirmed by the research of Wei Zhu and Ruimei Wang [2021], who show that farm size is significantly negatively correlated with the number of pesticides used. A 1% increase in area is associated with a 0.2% decrease in the number of pesticides applied per ha [Ren et al. 2019, Zhu, Wang 2021].

Our results provide a different picture of agricultural practices comparing to the Chinese, however, are similar to other research related to the Polish market. For instance, Arkadiusz Piwowar [2021] presented similar results showing that pesticide consumption is positively related to farm size. However, as farm management systems are more advanced in the case of bigger growers, we can consider whether such farmers will reduce pesticide consumption and, if so, what kind of factors can support such change. Identifying the key factor to change plant protection practices might have significant importance on a microlevel (farm economics) and macrolevel – the implementation of Green Deal resolutions and the impact of agricultural production on the environment.

European countries are taking different approaches to meet the requirement to reduce the use of pesticides and their impact on health and the environment. The actions taken so far on the example of the UK, show that there is a trend in which the quantities and use that are easily measurable are reduced, yet the move towards reducing effects that are more difficult to assess, require greater commitment [Barzman, Dachbrodt-Saaydeh 2011].

Existing scientific research shows that the application of the actions taken so far in the EU has not brought the intended results [Lee et al. 2019, Mohring et al. 2020].

CONCLUSIONS

The protection methods and expenses for crop protection products of Polish farms differ and depend on farm size. The smallest farmers perform the least amount of plant protection treatments and have the lowest cost of used products. Along with the increasing farm area, the expenditure on pesticides used increases. It should be stressed that differences in terms of treatment practices and costs of used pesticides are related to the products segment.

As farmers operating in larger areas seem to be more open to the higher costs of plant protection, it might have consequences regarding the development of plant protection products. The higher use of pesticides can be rational if they remain productive and translate into higher yields. Taking into account the upcoming reduction of pesticide usage, one of the possible scenarios might aim at introducing a product with a long-lasting protection effect, which would allow to reduce the number of treatments. As this concept was not directly investigated in the paper, it needs to be more carefully addressed in future research.

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KOSZTY I INTENSYWNOŚĆ OCHRONY PESTYCYDOWEJ PSZENICY OZIMEJ W POLSCE W ZALEŻNOŚCI OD WIELKOŚCI GOSPODARSTW

Słowa kluczowe: wielkość gospodarstw, koszt pestycydów, koszt ochrony roślin, zużycie pestycydów, zachowanie rolników, Zielony Ład

ABSTRAKT

Celem pracy jest określenie kosztów pestycydów stosowanych w ochronie pszenicy ozimej w Polsce. Na podstawie rynkowego sondażu przeprowadzonego w 2020 roku wśród 1299 producentów rolnych dokonano analiz i określono w jaki sposób wielkość gospodarstwa determinuje zużycie środków i ich koszt. Stwierdzono istotną zależność. Średni koszt pestycydów stosowanych w uprawie pszenicy w 2020 roku wyniósł 85,61 euro/ha, a mediana 77,24 euro/ha. Średni koszt herbicydu wyniósł 28,62 euro/ha przy medianie 27,40 euro/ha. Odpowiednio koszt fungicydu wyniósł 47,90 i 40,68 euro/ha, natomiast na ochronę insektycydową rolnicy ponieśli średnie wydatki w wysokości 2,28 euro/ha. Wraz ze wzrostem wielkości gospodarstwa zwiększała się liczba wykonywanych zabiegów i zwiększały się koszty ich stosowania. Wielkość gospodarstwa miała również wpływ na decyzje rolników co do sposobu odchwaszczania. Mniejsze gospodarstwa znacznie częściej stosowały herbicydy wiosną, podczas gdy większe stosowały herbicydy jesienią. Jest to szczególnie ważne w dobie ograniczania stosowania pestycydów i wprowadzanego w UE Zielonego Ładu.

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