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CHEMICAL PLANT PROTECTION AND ITS ENVIRONMENTAL IMPACT UNDER CONDITIONS OF RESOWING AFTER FROST KILLING OF WINTER CROPS

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Summary

The weather conditions in winter 2011/2012 in Poland caused severe frost killing of winter crops (in most areas up to 90%) requiring spring resowing. This brought about a considerable impact of chemical plant protection. The paper presents results from two farms, belonging to a State Treasury company, with intensive agricultural production, located in the Wielkopolska voivodship. The number of plant protection treatments increased due to resowing from 39.9 to 81.4%, depending on the farm, and the amount of used p.p.p.(plant protection products) increased from 51.9 to 153.7%. Costs of used p.p.p. increased overall by 28.5%. The value of multi-criteria index of pesticides negative impact on the environment increased from 18.8 to 39.8% in farms 1 and 2. Identifying extremes in plant protection will allow more accurate than only on the basis of average values, planning and calculation of effect in production, as well as projections of adaptation processes to the changing conditions of production caused by the on-going global climatic changes.

Key words: plant protection products, costs, environmental impact, toxicity index, intensive agricultural production

INTRODUCTION

In formation of agricultural policies and environment protection programs, both at the level of the entire European Union and the member states, in an increasingly formalized and rigorous manner it is required to rationalize the use of pesticides, especially from the point of view of their impact on the environment [Decision of the European Parliament…, 2002; Directive of the European Parliament and of the Council…, 2009]. Using of plant protection products (p.p.p.) may in fact occur threat to the health of humans, animals and the environment [Stobiecki *et al.*, 2010]. In the past, studies of pesticides in agriculture mainly focused on monitoring the level of their effectiveness in controlling certain pests and diseases of crop plants. The risk of environmental threats was compared to the amount of active ingredients doses. Consumption of active ingredients is no longer a sufficient monitoring indicator of biodiversity threats in agricultural agrocenosis after a new generation of pesticides, characterized by high efficiency at low dose levels, has come onto the market [Verhoeven multi-criteria index *et al.*,1994]. It is necessary to conduct comprehensive assessment of environmental pollution threats from pesticide residues. The developed indices of toxicity [Bockstaller *et al.*, 1997] serve this purpose. The studies have shown that with intensive application of p.p.p. increases the risk of its leakage into surface water and groundwater, air and food products [Oskam, 1998].

Currently, it must be emphasized and taken into account the increasing risk of threats from pesticide use resulting from the progressive, global climate change [Patterson *et al.* 1999, Easterling *et al.,* 2007; Diffenbaugh *et al.,* 2008; Jankowiak and Kędziora, 2009].

In addition to perpetuate climate changes (changes in average annual temperature, amount and distribution of precipitation) they carry increased frequency and severity of extreme weather events, such as short periods of very high and very low temperatures, severe drought, excessive rainfall [Easterling *et al.*, 2007; Jankowiak and Kędziora, 2007]. It will impinge on the occurrence of pathogens, the need for and impact of pesticide use [Ruszkowska, 2006; Diffenbaugh *et al.,* 2008].

For these reasons, it is necessary to study the effects of extreme weather events on the course and effectiveness of plant protection. Identifying extremes in plant protection will allow planning and calculation of final results and projections of adaptation processes to the changing conditions of production.

MATERIALS AND METHODS

The study was conducted on the basis of the applicable procedures and pesticides used in intensive agricultural production in two agricultural farms (Farm 1 and Farm 2) that belong to the a Company of State Treasury, managing on a total area of 3,100 ha of agricultural land, located in the Wielkopolska voivodship. The business year selected for the detailed study was 2011/2012 due to the occurrence in winter of this year extreme weather conditions, resulting, in most parts of Poland, in severe frost killing of winter crops sowings (up to 90%). This caused the need for spring resowing with other plant species, incurrence of substantial additional expenses and changes in plant protection programs. This situation has provided data for description and assessment of the effects of the weather extreme and extension of materials for projections and building models of adaptation to new climatic situation. This requires a separate analysis and should not be dispersed in the collections of data used to calculate and evaluate the means. The descriptions and quantifications of the effects of extreme events in plant protection are not found in the literature.

Detailed documentation in both agricultural farms of all production expenditures, technologies and the dates and duration of treatments was used for the study. Additionally, the prices of individual investments, including the purchase prices of p.p.p. were taken from the source documents. This helped to assess the cost of p.p.p. in the resowing conditions after frost killing of winter crops, including expenditures made for the crops in autumn.

There were also investigated effects of pesticides on the environment, including the resowing of crops. Evaluation was performed using the multi-criteria environmental risk assessment index, implemented in the EMA (Environmental Management for Agriculture) computer program, developed in the UK [Lewis and Tzilivakis, 1998]. In this program there was used the method of point assessment of environmental risk caused by a given p.p.p., resulting from the physical and chemical properties of active ingredients and their quantities. Mathematical form of this index represents the following formula:

$$EMA = \sum_{i=1}^{n} (E_i * Q_i)$$

where:

E_i - sum of points obtained by the *i*-th active ingredient on the basis of its physical and chemical properties, on a scale 0 - (-58),

Q_i - the amount of the *i*-th active ingredient used, in kg,

n – the number of active ingredients.

Physico-chemical properties of pesticides are characterized by four variables: Henry's constant, *GUS* index (Ground-water Ubiquity Score), K_{OW} - partition coefficient between octanol and water (octanol-water partition coefficient), the solubility in water. Henry's constant characterizes the ability of a substance to spread by volatilization, *GUS* index – compounds susceptibility to leaching and possibility of contamination of ground water, K_{OW} factor - the risk of accumulation in living organisms, the solubility in water - risk of surface waters pollution. The *GUS* index is calculated by the following formula [Gustafson, 1989]:

$$GUS = \log DT_{1/2}\left(4 - \log K_{OC}\right)$$

where:

$DT_{1/2}$ – half-life of the substance degradation in the soil,

K_{OC} – coefficient of adsorption by organic carbon compound.

RESULTS AND DISCUSSION

The farms in which studies were conducted run intensive agricultural production. Evidence of this, inter alia, is the structure of crops (Table 1). The share of cereals in plantings ranged from 53.8 to 55.8% (Farm 2 and Farm 1, respectively). The main part in cereal sowing was winter crops (33.7 and 38.4%). Large share in sowings had industrial plants (roots and oil), 10.6% in total in the Farm 2 and 18.3% in the Farm 1. Extent of area with these plants is an indicator of the intensive organization of production (the highest score in the evaluation by the Kopeć method [Kopeć, 1987]. However, indication of intensive management of cropland and, at the same time, a large degree of balance between production directions is relatively high proportion of forage plants, including perennials (in total 35.0% in Farm 1 and 26.0% in Farm 2), as compared to the average share of 6.3% for Poland [GUS 2012].

Table 1. Cropping pattern in the studied farms

Plant group	Farm 1		Farm 2	
	area [ha]	share [%]	area [ha]	share [%]
Cereals, of which:	257.7	55.8	234.5	53.8
- winter cereals	177.6	38.4	146.6	33.7
- spring cereals	80.2	17.4	87.8	20.2
Root crops	41.4	9.0	40.2	9.2
Oil plants	43.0	9.3	6.0	1.4
Annual fodder crops	71.4	15.5	124.0	28.5
Perennial fodder crops	48.3	10.5	30.9	7.1
Total	461.9	100.0	435.5	100.0

Source: own study

Table 2. Number of plant protection treatments in both farms in 2012 according to the plant groups (weighted averages)

Plant group	Farm 1			Farm 2		
	harvesting crop (without resowing effect)	with resowing	increase due to resowing in %*	harvesting crop (without resowing effect)	with resowing	increase due to resowing in %*
Cereals, of which:	1.7	2.7	158.8	2.8	3.4	121.4
- winter cereals	2.5	-	-	2.4	-	-
- spring cereals	1.3	2.8	215.4	3.5	5.0	142.9
Root crops	4.0	-	-	3.5	-	-
Oil plants	3.4	-	-	5.0	-	-
Annual fodder crops	1.0	1.7	170.0	1.8	2.8	155.6

* 100% – treatments for harvesting crop
Source: own study

Significant frost killing of winter crops sowings in winter 2011/2012 in the studied Farms (over 90% of the area) caused the necessity of resowing in the spring. Tables 2 and 3 show the effects resulting from the resowing in the chemical plant protection. They clearly reveal an increased number of plant protection procedures performed, on average by 81.4% in Farm 1 and 39.9% in Farm 2, and an increased amount of pesticides used, on average by 153.7% in Farm 1 and by 51.9% in Farm 2.

Table 3. Use of p.p.p. according to the farms and plant groups [kg a.i./ha]

Plant group	Farm 1			Farm 2		
	harvesting crop (without resowing effect)	with resowing	increase due to resowing in %*	harvesting crop (without resowing effect)	with resowing	increase due to resowing in %*
Cereals, of which:	1.10	2.22	201.8	1.79	2.29	127.9
- winter cereals	2.51	-	-	2.08	-	-
- spring cereals	0.47	2.08	442.6	1.31	2.66	203.1
Root crops	3.20	-	-	4.61	-	-
Oil plants	2.11	-	-	2.79	-	-
Annual fodder crops	2.15	2.51	116.7	2.99	3.73	124.7

* 100% – treatments for harvesting crop
Source: own study

As a consequence of the resowing, the increased costs of applied p.p.p. were incurred (Table 4), on average by 29.3% in the Farm 1 and by 27.7% in the Farm 2. They varied according to a crop rotation applied in the Farms. Three crop rotations were distinguished, which were characterized by the following features:

1. high proportion of perennial forage crops (alfalfa or grass mixtures with legume) and cereals,
2. large share of industrial crops and cereals,
3. large share of annual forage crops and cereals.

Table 5 shows the increase in the use of p.p.p. according to Farms and crop rotation. In the Farm 1, the largest relative increase occurred in the first crop rotation (at the lowest absolute value of the consumption), while in the

Farm 2 - the largest increase (in absolute and relative terms) in the third rotation. Similar trend of changes occurred in the cost of p.p.p. in different crop rotations (Table 6).

Table 4. Costs of used p.p.p.'s according to farms and plant groups [PLN/ha]

Plant group	Farm 1			Farm 2		
	harvesting crop (without resowing effect)	with resowing	increase due to resowing in %*	harvesting crop (without resowing effect)	with resowing	increase due to resowing in %*
Cereals, of which:	163.78	259.03	158.1	227.45	300.00	131.9
- winter cereals	322.44	-	-	241.69	-	-
- spring cereals	92.13	230.40	250.2	203.68	397.36	195.1
Root crops	722.56	-	-	806.69	-	-
Oil plants	297.37	-	-	454.86	-	-
Annual fodder crops	235.44	308.86	131.2	266.31	400.20	150.3
Average	220.26	284.76	129.3	278.96	356.13	127.7

* 100% – treatments for harvesting crop
Source: own study

Table 5. Use of p.p.p. according to the crop rotations [kg a.i./ha]

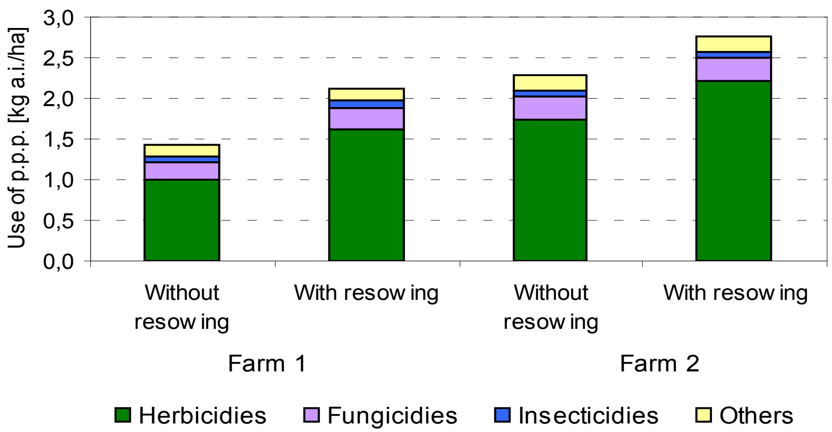
Crop rotation	Farm 1			Farm 2		
	harvesting crop (without resowing effect)	with resowing	increase due to resowing in %*	harvesting crop (without resowing effect)	with resowing	increase due to resowing in %*
1	1.02	2.00	196.1	2.12	2.49	117.5
2	1.54	2.16	140.3	2.39	2.84	118.8
3	2.02	2.23	110.4	3.12	3.93	126.0

* 100% – treatments for harvesting crop
Source: own study

Table 6. Costs of used p.p.p. according to the crop rotations [PLN/ha]

Crop rotation	Farm 1			Farm 2		
	harvesting crop (without resowing effect)	with resowing	increase due to resowing in %*	harvesting crop (without resowing effect)	with resowing	increase due to resowing in %*
1	209.40	292.94	139.9	305.61	346.60	113.4
2	219.73	274.70	125.0	236.83	302.58	127.8
3	239.13	281.41	117.7	316.09	483.52	153.0

* 100% - treatments for harvesting crop
Source: own study



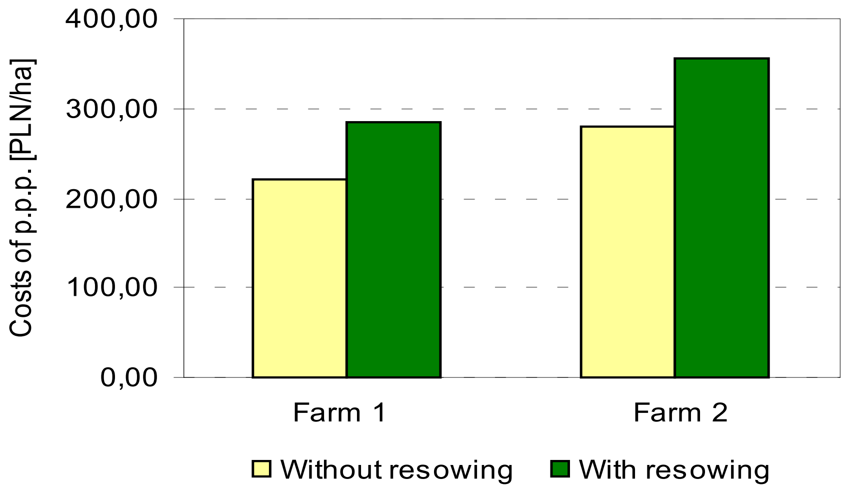
Source: own study

Figure 1. Differences in amounts and structure of p.p.p. use in the farms [kg a.i./ha] attributable to the occurrence of resowing

There were also significant differences between the studied Farms in the total amount of p.p.p. used. This is illustrated by Figure 1. Farm 2 used higher amounts of p.p.p., both for crops protection without and with resowing.

However, the structure of p.p.p. used was similar in all cases. The most consumed were herbicides, and fungicides among the plant protection agents. This is consistent with the general practices in the country and abroad [Wossink and Feitshans, 2000; Zalewski, 2007]. This was not changed even by the extreme situation related to resowing caused by frost killing of crops. A noticeable phenomenon in the studied case, in both Farms, was survival in extremely severe winter conditions, sowing of winter wheat plants (variety: Bogatka, Tonacja, Ozon) in the fields with rape as a preceding crop. This case demonstrates the importance of the role played by a proper sequence of crops and precrops) in plant production, emphasizing its role in particular in the extreme growing conditions. This species, as Zawiślak and Adamiak [1996] underline, has a particularly strong reaction to the yield-forming and yield-protection influence of crop rotation.

As a consequence of resowing, there was an increase in p.p.p. costs (Fig. 2), in the Farm 1 by 29.3% on average, and in the Farm 2 by 27.7% on average.



Source: own study

Figure 2. Changes of p.p.p. costs due to resowing [PLN/ha]

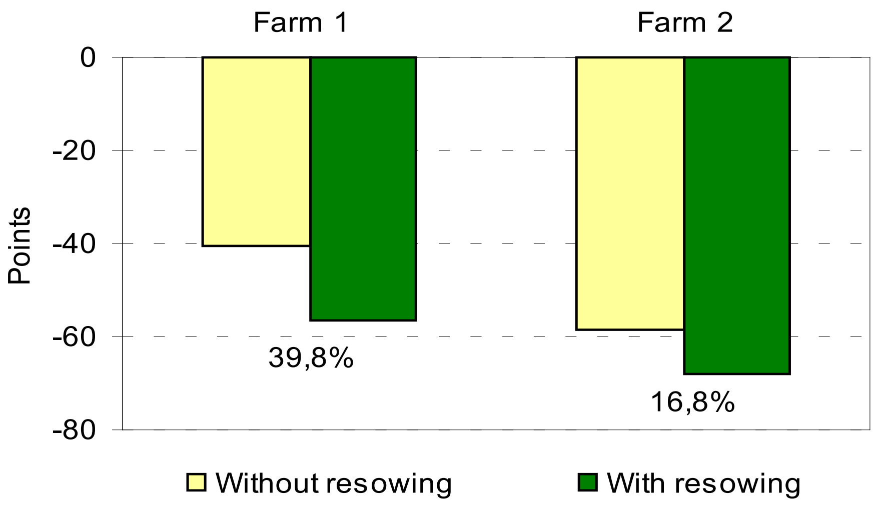
Table 7. Value of components of the multi-criteria index of pesticide impact on the environment

Farms	Cultivation variants	Crop rotations	K_{OW} coefficient	Solubility in water	Henry's constant	GUS index	Sum
1	without resowing	1	-3.1	-6.8	-7.5	-9.5	-26.8
		2	-7.8	-7.9	-14.1	-6.1	-35.9
		3	-13.8	-10.0	-22.9	-21.5	-68.2
	with resowing	1	-9.2	-9.6	-19.0	-13.4	-51.2
		2	-11.5	-9.8	-21.1	-8.3	-50.7
		3	-14.0	-11.5	-24.2	-22.3	-71.9
2	without resowing	1	-10.3	-19.3	-18.7	-9.1	-57.4
		2	-12.8	-15.0	-20.5	-21.1	-69.5
		3	-5.4	-14.0	-12.3	-16.5	-48.3
	with resowing	1	-14.7	-23.9	-26.4	-14.7	-79.7
		2	-14.7	-17.0	-24.6	-23.0	-79.3
		3	-5.6	-16.7	-13.5	-17.8	-53.6

Source: own study

Effects of resowing on plant protection intensity are measured not only by an increased amount of pesticides and rising costs, but also by an increase in the impact on the environment. It was assessed by the use of the multiple criteria index of pesticides impact on the environment, encompassing a wide spectrum of their different impacts on the agricultural habitat. The values of index components are shown in Table 7. As a result of resowing, the index values rose by 39.8% in Farm 1 and by 18.8% in Farm 2 (Fig. 3). Farm 2 applied generally more p.p.p. of high risk to the environment than the Farm 1, hence presumably lower, relative increase of the index as a result of resowing.

There were also significant differences in the value of the index in the maintained crop rotations (Fig. 4). In both Farms, the highest relative increases of the indexes occurred in rotation 1. These differences between crop rotations in the compared Farms were undoubtedly affected by the absolute values of the indexes, and could be linked to differences in the production types of Farms, as it was already noted in other studies [Bieńkowski *et al.*, 2005].



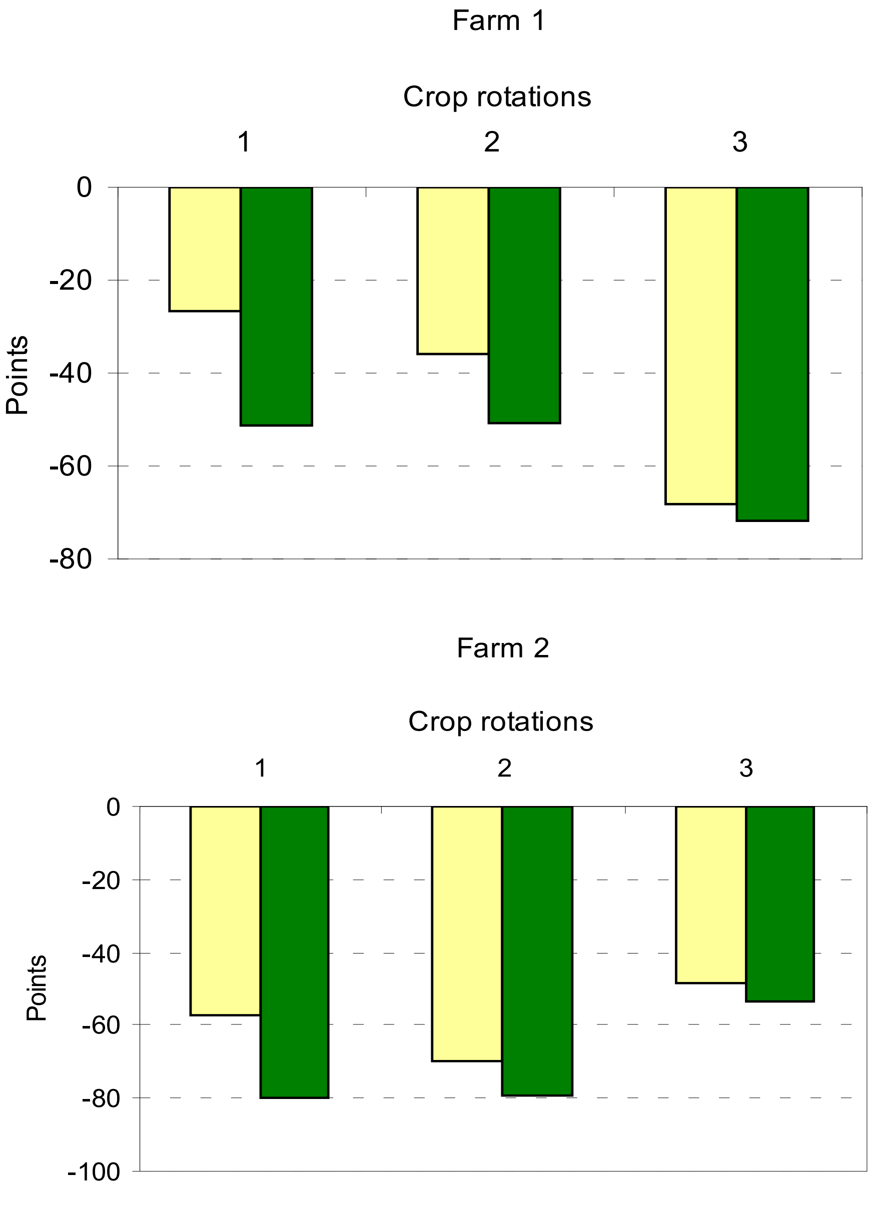
Source: own study

Figure 3. Differences in values of the multi-criterial index of pesticide impact on the environment due to resowing

CONCLUSIONS

On-going global climate changes will cause more frequent and severe extreme weather events. Adaptation to new conditions will be necessary in order to prevent adverse economic and production impacts in agriculture. For this purpose, description and determination of the consequences of occurring extremes will be necessary. Average values will not be sufficient in this case.

Frost killing of winter crops, which occurred during the winter 2011/2012 in a majority of the Polish area, caused the necessity of resowings in spring leading to necessary changes in chemical plant protection program.



Source: own study

Figure 4. Comparison of the multi-criterial index values of pesticide impact on the environment according to crop rotations and occurrence of resowing in farms

In the studied example of two farms, the quantity of p.p.p. used as a result of the spring resowing increased from 51.9 to 153.7%, and the cost of used pesticides in general rose by an average of 28.5%.

As a result of increase in the quantity and in the change of the types of applied p.p.p., threat to the environment also increased. The values of pesticide impact indices used in the studies increased from 16.8 to 39.8% for Farms.

The factor that influenced the quantity of pesticides used and economical as well as environmental effects of resowings was crop rotation.

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