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Dependence of potato yield on weed infestation

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Abstract. Results of the research were based on a field experiment carried out in 2007–2009 at the Experimental Plant of the IHAR-PIB in Jadwisin, on podzolic soil with a granulometric composition of loamy sand. The experiment was established by means of a random sub-block method in a dependent split-plot pattern, in triplicate. The first order factor were the potato cultivars: 'Irga' and 'Fianna', the second order factor were the methods of weeds regulation: 1) control − without chemical protection; 2) extensive mechanical treatments (every 2 weeks) from planting to closing the rows; 3) Sencor 70 WG – 1 kg ha^{-1} before potato emergence; 4) Sencor 70 WG – 1 kg ha^{-1} + Titus 25 WG – 40 g ha^{-1} + Trend 90 EC – 0.1% before potato emergence; 5) Sencor 70 WG – 0.5 kg ha^{-1} after potato emergence; 6) Sencor 70 WG – 0.3 kg ha^{-1} + Titus 25 WG – 30 g ha^{-1} + Trend 90 EC – 0.1% after potato emergence; 7) Sencor 70 WG – 0.3 kg ha^{-1} + Fusilade Forte 150 EC – 2 dm^3 ha^{-1} after potato emergence; 8) Sencor 70 WG – 0.3 kg ha^{-1} + Apyros 75 WG 26.5 g ha^{-1} + Atpolan 80 SC – 1 dm^3 ha^{-1} after potato emergence. The number, floristic compositions, fresh weight and dry matter of weeds were determined. A high, yield-protective effect of herbicides was obtained as a result of limited competition of weeds. Mechanical care contributed to the increase in the total potato yield by 36.2%, and the marketable yield by 45.7%, as compared to the control object.

Key words: potato, cultivars, weeds infestation, yield.

INTRODUCTION

Potato tuber yields are shaped by agrotechnical treatments, cultivars and environmental conditions (Mišovic et al., 1997; Đalovic et al., 2008; Gugała & Zarzecka, 2013; Hassannejad & Porheidar, 2013; Caldiz et al., 2016). One of the most important factors limiting the yield is the occurrence of weeds in cropland communities (Hashim et al., 2003 and Arora et al., 2009). In the potato cultivation, weeds are particularly harmful at the beginning of the growing season (so-called primary weed infestation) and at the end of this period (secondary weed infestation) (Hashim et al., 2003; Hassannejad & Porheidar, 2013). Research performed by Jones et al. (2007) showed that primary weed infestation reduced the yield by 54% and before potato harvest by 16%. Weeds are characterized by the highest potential for lowering the yields − by 34%, while pests by 18% and diseases by 16%, on average (Fernandes-Quintanilla et al., 2008; Merga &

Dechassa 2019). Yielding of potato, as a result of the presence of weeds in the analysis carried out by Mondani et al. (2011) decreased by 54.8%, while in the studies of Sharshar et al. (2015) − by 61.4–74%. In domestic studies, depending on the state and degree of weed infestation, the yield losses of potato tubers were estimated at 10–50% (Azadbakht et al., 2017; Walkowiak et al., 2017; Gugała et al., 2018) and up to 70% (Zarzecka et al., 1999; Zarzecka 2004). Therefore, the use of chemical protection has become an indispensable and permanent element in technologies of growing agricultural plants. Almost all agrotechnical operations carried out on a potato plantation serve, among others, to reduce weed infestation. The sum of losses caused by weeds usually exceeds damage caused by diseases and pests. Sometimes, with little aggravation of diseases or pests, weed control can be given up. In the case of weeds, this situation is extremely rare. Thus, limiting the number and weight of weeds is now considered the main plant protection procedure, and herbicides are the basic group of pesticides. The skillful use of herbicides makes it possible to eliminate the competitive impact of weeds on arable crops from the beginning of potato vegetation, as well as to limit the subsequent emergence of weeds (secondary weed infestation). Therefore, the aim of this work was to determine whether and to what extent different ways of protecting plantations against weeds can limit the negative relationships between the general and marketable yield and the degree of weed infestation.

MATERIAL AND METHODS

Results of the research were based on a field experiment carried out in 2007–2009 at the Plant Breeding and Acclimatization Institute − National Research Institute in Jadwisin (52°28′44″ N, 21°2′38″ E) on podzolic soil with a granulometric composition of loamy sand of weak rye complex with acidic to slightly acidic reaction (pH 4.7–5.5) (WRB, 2014). The experiment was established by means of a random sub-block method in a dependent split-plot pattern, in triplicate. The first order factor were the potato cultivars: 'Irga' and 'Fianna', the second order factor were the methods of weeds regulation: 1) control − without chemical protection; 2) extensive mechanical treatments (every 2 weeks) from planting to closing the rows; 3) Sencor 70 WG – 1 kg ha^{-1} before potato emergence; 4) Sencor 70 WG – 1 kg ha^{-1} + Titus 25 WG – 40 g ha^{-1} + Trend 90 EC – 0.1% before potato emergence; 5) Sencor 70 WG − 0.5 kg ha^{-1} after potato emergence; 6) Sencor 70 WG − 0.3 kg ha^{-1} + Titus 25 WG – 30 g ha^{-1} + Trend 90 EC − 0.1% after potato emergence; 7) Sencor 70 WG − 0.3 kg ha^{-1} + Fusilade Forte 150 EC – 2 dm ha^{-1} after potato emergence; 8) Sencor 70 WG − 0.3 kg ha^{-1} + Apyros 75 WG 26.5 g ha^{-1} + Atpolan 80 SC – 1 dm ha^{-1} after potato emergence. Metribuzin (4-amine-6-tert-buthyl-3-(methylation)-as-triazine-5(4H)-one) was used in a form of Sencor 70 WG, sulfosulfurone (1-(4,6-dimethoxypyrimidin-2-yl)-3-(2-ethylsulfonylimidazol(1,2-a) pyridin-3-ylsulfonyl) – as Apyros 75 WG, rimsulfurone (1-(4,6-dimethoxypyrimidin-2-yl)-3-(3-ethylsulfonylpyridin-2-yl) sulfonylurea) – in a form of Titus 25 WG herbicide, fluazyfop ((R)-2-(4-((5-(trifluormethyl)-2-pyridinyl)-oxy) phenoxy) propionic acid – as Fusilade Forte 150 EC preparation. Organic fertilization in the study consisted of straw plowed after harvesting in the amount of 4–5 t ha^{-1} with the addition of nitrogen (1 kg of N per 100 kg of plowed straw) and white mustard post-crop in the amount of 15–16 t ha^{-1} of fresh weight, plowed in autumn. Every year, in autumn, mineral phosphorus-potassium fertilization was applied in the amount of 39.3 kg P ha^{-1} and 116.2 kg K ha^{-1}, which were plowed with pre-season plowing. Nitrogen fertilizers were used in spring in the amount of 100 kg N ha^{-1} by mixing them with the soil using a cultivating unit (cultivator + string roller). Potato tubers were planted manually at the end of April, with a spacing of 75×33 cm. The propagating material was in the C/A class. Herbicide spraying was done manually using a backpack sprayer. Protection of the potato against diseases and pests was applied in accordance with the IOR-PIB recommendations. Following preparations were used to protect against alternariosis and late blight: Tattoo C 750 SC at a dose of 2.5 dm^3 ha^{-1}, Altima 500 SC − 0.4 dm^3 ha^{-1}, Python Consento 450 SC − 2.0 dm ha^{-1}. In order to reduce potato beetle, following insecticides were used: Actara 25 WG at a dose of 0.4 kg ha^{-1}, Calypso 480 SC − 0.75 dm^3 ha^{-1} and Mospilan 20 SP in an amount of 0.05 kg ha^{-1}). In the field experiment were used insulations belts accordance with the principles of good agricultural practice, and the plot area given in the research methodology concerned only to the harvesting area. Plot area, assuming experiment, was 31.0 m^2, while for harvesting – 25 m^2.

In order to compare the effectiveness of the examined methods of pre-harvest tuber treatment, weed infestation was assessed using a quantitative and qualitative method, Weed Infestation Analysis, Tuber Yield and Its Components.

Analysis of fresh weight of weeds in experimental plots just before tuber harvest was performed using the quantitative and weight method when plants entered the stage 97 based on the BBCH scale (Roztropowicz, 1999; Bleinholder et al., 2001). The frame was tossed three times diagonally across the ridges and weeds within the frame were collected (Adamczewski & Matuszewski 2011). The number, floristic compositions, fresh and dry matter of weeds were determined on three randomly selected areas of each plot, marked with a frame (1.0 m^2). The dominant weed species in the experiment were: *Echinochloa crus-galli, Chenopodium album, Stellaria media, Lycopsis arvensis, Viola arvensis*. Each year prior to harvest, tubers of ten plants selected at random from each plot were dug to determine the following: to determine the number and weight of tubers < 35, 35−45, 45−55, 55−65 and > 65 mm in diameter. Potato tubers were harvested at physiological maturity (phase BBCH 97) (Roztropowicz, 1999; Bleinholder et al., 2001) at the end of September. During the harvest, representative samples of tubers were collected from each plot to assess the potato yielding. Total tuber yield consisted of the weight of tubers harvested from the whole plot area and the weight of previously taken samples, both converted to t ha$^{−1}$. Marketable yield included tubers with the diameter of over 35 mm without external and internal defects (Regulation of the Minister of Agriculture, 2003).

Results of weed infestation assessment concerning the total number of weeds, number of monocotyledonous and dicotyledonous weeds, fresh and air-dry weed matter, as well as total and marketable yield were subjected to descriptive statistics, Pearson's analysis of simple correlation and multiple regression analysis. The basic assumption of the linear regression model was that for each observation of the independent variable there is a relationship with the value of the dependent variable and that the dependent variable has a normal distribution with a constant expected value and variance. The following assumptions were made: the explanatory variables are non-random, their values are fixed real numbers; explanatory variables are not collinear, i.e. there is no exact linear relationship between them; the random component has a normal distribution and is independent for any two different observations (i.e. no autocorrelation). The expected value of the probability distribution of the random component is zero. It was assumed that the variance of the random component is constant for all observations, because the random disorder is not a function of the explanatory variables of the model (exogenity of independent variables). These dependencies were considered within the scope of standard deviation of independent variables from the arithmetic mean. Parameters of the function were determined by the least-squares method and the significance verification by the t-Student's test. Assessment of the significance of differences between compared average values was made using multiple Tukey intervals (Raudonius, 2017).

Before starting the field experiment, soil samples were taken for physicochemical analyzes in each study year. Soil acidity determined in a 1 mL solution of KCl dm^{-1} ranged from acidic (4.7 pH) to slightly acidic (5.4 pH). The content of organic weight in the arable layer was low and ranged from 0.68 to 0.73% (WRB 2014). Soil's phosphorus abundance ranged from very low (2009) to very high (2007) (1.7–10.4 mg of P 100 g^{-1} of soil). Soil compostability in absorbable forms of potassium was also characterized by considerable variability in the years of research and ranged from low to high (6.1−18.4 mg K 100 g^{-1}gleby). The average abundance of available magnesium was found in the soil collected for analysis in 2009 third year of research (3.6 mg Mg 100 g^{-1}), and very high – in 2007 the first year (12.1 mg Mg 100 g^{-1}) (Table 1).

Table 1. Physicochemical properties of soil in Jadwisin, in 2007–2009

Year	The content of assimilable forms (mg.100 g^{-1} d.m. soil)			pH (1M KCl)	Content of the organic substance (%)
	P	K	Mg		
2007	10.4	18.4	12.1	4.7	0.73
2008	4.3	13.9	9.3	5.4	0.68
2009	1.7	6.1	3.6	5.0	0.70
Mean	5.5	12.8	8.3	5.0	0.70

Source: own research based on the designations at the Chemo-Agricultural Station in Wesoła.

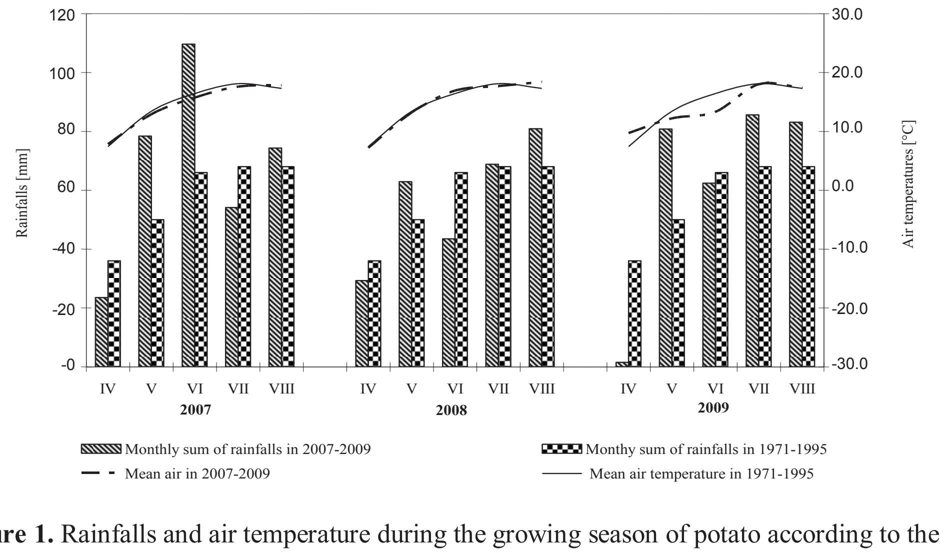

Figure 1. Rainfalls and air temperature during the growing season of potato according to the weather station IHAR-PIB in Jadwisin (2007–2009), against the average of the multiannual.

Conditions during the growing season in 2007–2009 were characterized by diversified air and rainfall temperatures (Fig. 1). The year 2007 can be described as quite dry, year 2008 as dry, and 2009 − with the most favorable humidity and thermal conditions for potato development (Skowera et al., 2016).

RESULTS AND DISCUSSION

Relations between the total and marketable yield vs. degree of weed infestation were considered in the scope of standard deviation from the arithmetic mean (Table 2 and 3).

Table 2. Statistical characteristics of dependent and independent variables

Weed control*	Arithmetical means	Standard deviations	Variability coefficient V (%)
Total yield of tubers (t ha^{-1})			
1	27.4	10.2	37.3
2	30.8	9.3	30.2
3	32.5	11.7	36.4
4	32.0	9.7	30.4
5	28.2	7.9	28.2
6	30.5	7.8	25.6
7	34.6	13.0	37.6
8	35.1	12.8	36.5
Marketable yield of tubers t ha^{-1}			
1	24.4	11.1	45.4
2	29.0	12.8	44.1
3	32.0	11.7	36.6
4	30.1	9.9	32.9
5	26.7	8.1	30.3
6	28.7	7.7	26.8
7	31.6	13.9	44.0
8	32.0	13.8	43.1
Total numbers of weeds per 1 m^2			
1	46.0	43.0	92.9
2	43.0	44.0	103.3
3	19.2	17.6	91.6
4	10.8	13.2	122.2
5	11.4	7.3	64.0
6	13.2	6.8	51.5
7	58.0	52.0	89.5
8	36.0	31.0	85.2

1. Control − without chemical protection;
2. Extensive mechanical treatments (every 2 weeks) from planting to closing the rows;
3. Sencor 70 WG – 1 kg ha^{-1} before potato emergence;
4. Sencor 70 WG – 1 kg ha^{-1} + Titus 25 WG - 40g ha^{-1} + Trend 90 EC − 0.1% before potato emergence;
5. Sencor 70 WG – 0.5 kg ha^{-1} after potato emergence;
6. Sencor 70 WG – 0.3 kg ha^{-1} + Titus 25 WG – 30 g ha^{-1} + Trend 90 EC − 0.1% after potato emergence;
7. Sencor 70 WG – 0.3 kg ha^{-1} + Fusilade Forte 150 EC – 2 dm ha^{-1} after potato emergence;
8. Sencor 70 WG – 0.3 kg ha^{-1} + Apyros 75 WG 26.5 g ha^{-1} + Atpolan 80 SC – 1 dm ha^{-1} after potato emergence.

Among the assessed variable characteristics, the total yield of tubers was characterized by the highest stability (V = 32.8%), while the number of dicotyledonous weeds − by the highest variability (V = 112.5%) (Table 2 and 3). Arithmetic mean as well as standard deviation influenced the value of this rating indicator. Stability of the total yield was the highest after application of the mixture of Sencor (active substance metribuzin) + Fusilade Forte (active substance fluazyfop-propionic acid) herbicides

(V = 37.6%), and the lowest after the post-emergence application of Sencor (active substance metribuzin) + Titus (active substance rimsulfurone) + Trend, as wetter (25.6%). Variability coefficient for marketable yield was at the level of 26.8–50.4%. Meanwhile, variability of dicotyledonous weeds was the highest after the use of Sencor + Titus + Trend (V = 184.4%), and the lowest due to Sencor herbicide applied after the emergence of the crop (V = 81.2%). The coefficient of variability in the statistical analysis carried out in the case of fresh weight of weeds was 62.1–153.8%, while dry matter − 31.3–97.1%. The highest stability of fresh weed weight was obtained after application of Sencor herbicide before the emergence of potato (V = 62.1%), and the lowest, after application of the mixture of preparations Sencor + Fusilade Forte (V = 172.4%). Stability of weed dry matter was the highest when weed control was carried out mechanically (V = 31.3%), and the lowest after application of Sencor + Titus + Trend herbicide before emergence of the crop (V = 85.6%).

Our research indicates a close relationship between tuber yield and the degree of weed infestation (Table 4).

Pearson's simple correlation analysis showed a significant, negative relationship between total, commercial and seed potatoes yield, and fresh and air-dry weed matter (Table 4). Zarzecka (2004) also proved that Pearson's simple correlation coefficients show a high negative correlation between potato yield and the number and dry weight of weeds determined at the beginning and end of crop vegetation. In addition, Zarzecka (2004) showed that the relationship between the number and weight of weeds and crop features is straightforward, which was not confirmed by the research.

Table 3. Statistical characteristics of dependent and independent variables

Weed control*	Arithmetical means	Standard deviations	Variability coefficient V (%)
Number of monocotyledonous weeds per 1 m^2			
1	28.0	31.0	111.1
2	19.0	30.0	162.2
3	9.0	6.9	76.6
4	6.6	6.8	103.0
5	8.1	4.3	83.9
6	8.0	4.3	75.0
7	34.0	31.0	90.4
8	22.0	25.0	114.2
Number of dicotyledonous weeds per 1 m^2			
1	18.0	22.0	119.6
2	24.0	22.0	90.9
3	10.1	13.0	126.7
4	4.5	8.0	184.4
5	3.2	3.0	81.2
6	5.2	6.0	113.4
7	5.1	24.0	100.8
8	3.1	12.0	82.8
Fresh weight of weeds g· m^{-2}			
1	576.9	143.0	153.8
2	321.6	100.0	120.5
3	231.6	144.0	62.1
4	111.3	82.0	73.5
5	260.5	189.0	72.6
6	227.5	142.0	62.6
7	142.5	200.0	172.4
8	161.1	100.0	107.5
Dry matter of weeds g m^{-2}			
1	236.7	33.0	97.1
2	142.7	10.0	31.3
3	76.6	44.0	56.7
4	55.8	48.0	85.6
5	90.1	70.0	77.2
6	94.5	60.2	63.7
7	63.1	42.5	62.4
8	62.8	53.6	85.3

[a]the explanations as in Table 2.

Both the total number and number of mono- and dicotyledonous weeds had smaller impact on the total yield and marketable yield of tubers than on the fresh and air-dry weight of weeds (Table 5−8). Similar results were obtained by Różyło & Pałys (2008) and Mondani et al. (2011). The decrease in the total and marketable yield under the influence of fresh and air-dry weed weight took the parabolic character in the experiment, 2° and 3°. These dependencies were used to calculate the maximum weight of weeds, which does not negatively affect the yield. Zarzecka (2004) showed a greater negative effect of weed infestation on crop characteristics before tuber harvesting than before shorting of potato rows.

Table 4. Coefficients of Pearson's simple correlation between crop weeds and yield in potato tubers

Independent variables	Dependent variables		
	y_1	y_2	y_3
x_1	- 0.183	- 0.194	- 0.120
x_2	- 0.055	- 0.063	0.034
x_3	- 0.429**	- 0.437**	- 0.416**
x_4	- 0.378*	- 0.391*	- 0.385*

Source: Own research; ** significant at the level of $p_{0.01}$; * significant at the level of $p_{0.05}$; y_1 − total yield of tubers; y_2 − commercial yield of tubers; y_3 − yield of seed potatoes; x_1 − number of weeds per 1 m^2 before closing of rows; x_2 − number of weeds per 1 m^2 before harvest of tubers; x_3 − fresh weed weight before harvesting (g m^{-2}); x_4 − dry matter of weeds before harvesting (g m^{-2}).

Considering the relationship between total and marketable yield vs. fresh weed weight (Table 6 and 8), in the scope of standard deviation from the arithmetic mean, the parabolic relationship was the most reliable in the case of mechanical-chemical treatment using the mixture of Sencor (active substance metribuzin) + Titus (active substance rimsulfurone) + Trend, as wetter applied before potato emergence, for which the coefficient of determination was over 50%. Fresh weight of weeds calculated from regression equations, the level of which the yield does not reach amounted to 6.3 g in the case of total yield and 10.6 g m^{-2} in the case of marketable yield of tubers. In the studies of Sawicka et al. (2006) admissible threshold value of fresh weight of weeds, which did not significantly affect the yield, was at the level of 802 g for total yield and 840 g m^{-2} for commercial yield in the organic farming system, while for integrated cultivation: 279 and 246 g m^{-2}, respectively. Gugała et al. (2018), Mystkowska et al. (2018) and Zarzecka et al. (2020) also they found that integration of mechanical and chemical practices as well as biostimulant application increases weed control efficiency and positively affects potato yield performance.

Depending on the commercial yield from air-dry and fresh weight of weeds, a significant linear relationship was found when using Sencor 70 WG (1 kg ha^{-1}) before emergence and Sencor 70 WG (1 kg ha^{-1}) + Titus 25 WG (40 g ha^{-1}) + Trend 90 EC (0.1%) after potato emergence. The coefficient of determination of these dependencies reached the level of over 50%, which confirms the adopted method (Kranz, 1988). Różyło & Pałys (2008) showed a significant negative relationship between weed infestation rates (number and weight of weeds) and the yield of potato tubers. Also, Zarzecka et al. (2020) they found that herbicides and herbicide + biostimulant mixtures applied in potato cultivation contributed to an increase in marketable tuber yields, ranging 27.5–61.0% compared with mechanical weed control, due to removal of competition with weeds and improved utilization of crop plant yield-formation potential. The total yield of potato tubers on heavy soil was also significantly negatively correlated with the number of monocot weeds. On the light soil, however, these relations occurred only before the rows were shorted.

Table 5. Relationships between total yield of tubers and total numbers of weeds, number of mono- and dicotyledonous weeds

Weed control [a]	Regression equations	Significance level	Coefficient of determination (%)
	The total numbers of weeds		
1	$y = 0.001x^4 – 0.108x^3 + 3.701x^2 - 49.161x + 239,001$	0.026	56.3
2	$y = 9E\text{-}0.6x^6 - 0.001^5 + 0.181x^4 - 8.516x^3 + 217.080x^2 - 2846.300x + 15007.000$	0.008	29.5
3	$y = 5E\text{-}06x^5 - 0.001x^4 + 0.004x^3 + 0.536x^2 - 14.557x - 104.010$	0.007	29.1
4	$y = 4E\text{-}05x^5 - 0.006x^4 + 0.339x^3 - 9.354x^2 + 121.650x - 582.540$	0.006	16.3
5	$y = -0.022x^2 + 0.983x + 2.405$	0.128*	56.0
6	$y = 0.001x^5 - 0.038x^4 + 1.901x^3 - 55.547x^2 + 790.260x - 4363.900$	0.001	36.5
7	$y = 3E\text{-}0.5x^4 - 0.0111x^3 + 0.8291x^2 - 22.038x + 202.76$	0.026	35.4
8	$y = 0.033x^3 - 0.3097x^2 + 9.3665x - 84.62$	0.013	0.5
	The number of monocotyledonous weeds		
1	$y = -1E\text{-}0.5x^6 + 0.002x^5 - 0.116x^4 + 3.431x^3 - 53.353x^2 + 413.790x - 1252.600$	0.218*	48.3
2	$y = 2E\text{-}05x^6 - 0.003x^5 + 0.292x^4 - 13.234x^3 + 327.590x^2 - 4195.800x + 21721.000$	0.010	27.7
3	$y = 0.001x^4 - 0.019x^3 + 0.0889x^2 - 15.256x + 84.168$	0.046	24.0
4	$y = 3E\text{-}05x^5 - 0.005x^4 + 0.272x^3 - 7.377x^2 + 93.455x - 437.230$	0.008	28.9
5	$y = - 0.2172x + 9.404$	0.419**	41.9
6	$y = - 0.001x^5 - 0.017x^4 + 1.017x^3 - 29.281x^2 + 410.180x - 22.344$	0.004	34.8
7	$y = 0.004x^4 - 0.053x^3 + 2.511x^2 - 50.922x + 374.580$	0.000	24.4
8	$y = 0.001x^4 - 0.094x^3 + 4.433x^2 - 90.850x + 681.230$	0.054	21.1
	The number of dicotyledonous weeds		
1	$y = -1E\text{-}0.5x^6 + 0.002x^5 - 0.1159x^4 + 3.4314x^3 - 53.353x^2 + 413.79x - 1252.6$	0.218*	48.3
2	$y = 2E\text{-}05x^6 - 0.0033x^5 + 0.2921x^4 - 13.234x^3 + 327.59x^2 - 4195.8x + 21721$	0.010	27.7
3	$y = 0.00001x^4 - 0.0194x^3 + 0.0886x^2 - 15.256x + 84.168$	0.046	24.0
4	$y = 3E\text{-}05x^5 - 0.0047x^4 + 0.272x^3 - 7.3766x^2 + 93.455x - 437.23$	0.008	28.9
5	$y = - 0.2172x + 9.4044$	0.419**	41.9
6	$y = - 0.0001x^5 - 0.0172x^4 + 1.0171x^3 - 29.281x^2 + 410.18x - 22.34.4$	0.004	34.8
7	$y = 0.0004x^4 - 0.0527x^3 + 2.5105x^2 - 50.922x + 374.58$	0.000	24.4
8	$y = 0.0007x^4 - 0.0938x^3 + 4.4331x^2 - 90.85x + 681.23$	0.054	21.1

[a]the explanations as in Table 2; *significant at the level of $p_{0.05}$; **significant at the level of $p_{0.01}$.

Table 6. Relationships between total yield of tubers and fresh weight and air-dry matter of weeds

Weed control [a]	Regression equations	Significance level	Coefficient of determination (%)
	The fresh weight of weeds		
1	$y = 0.002x^5 - 0.022x^4 + 11.010x^3 - 258.320x^2 + 2841.900x – 10964.000$	0.042	23.8
2	$y = 0.001x^6 – 0.037x^5 + 3.332x^4 - 138.140x^3 + 3343,000x^2 - 42002,000x + 214040,000$	0.002	24.7
3	$y = 0.0001x^4 + 0.0188x^3 - 0.1213x^2 + 1571.000x + 206.050$	0.463**	61.1
4	$y = - 6.339x + 314.620$	0.570**	76.9
5	$y = -0.046x^3 + 3.924x^2 - 117.200x + 1472.500$	0.189*	50.5
6	$y = - 9. 0456x^3 + 3.924x^2 - 117.200x + 1472.500$	0.283**	58.3
7	$y = 0.001x^4 - 0.053x^3 + 2.511x^2 - 50.922x + 374.580$	0.001	31.8
8	$y = 1.2141x^2 - 84.49x + 1438.3$	0.046	29.9
	The dry matter of weeds		
1	$y = 0.001x^5 - 0.117x^4 + 5.749x^3 - 134.360x^{2+} 1478.800x - 5830.200$	0.000	30.3
2	$y = 7E-0.9x^6 - 0.138x^5 + 1.154x^4 - 50.228x^3 + 1203.800x^2 – 15045.000x + 76737.000$	0.019	11.3
3	$y = 0.001x^4 - 0.079x^3 + 3.601x^{2-} 70.286x + 599.160$	0.506**	60.2
4	$y = 0.007x^3 - 0.654x^{2+} 14.475x + 24.480$	0.595**	64.3
5	$y = 0.001x^4 - 0.111x^3 + 6.781x^2 - 164.890x + 1485.700$	0.099	20.3
6	$y = 0.063x^3 - 5.929x^{2+} 174.260x - 1487.400$	0.352**	58.3
7	$y = -0.003x^5 + 0.426x^4 - 25.047x^3 + 718.810x^2 - 100420x + 54650.000$	0.001	33.2
8	$y = 0.012x^4 - 1.337x^3 + 56.831x^2 - 1045.700x + 7080.600$	0.042	25.9

[a]the explanations as in Table 2; *significant at the level of $p_{0.05}$; ** significant at the level of $p_{0.01}$.

Table 7. Relationships between marketable of tubers and total numbers of weeds, number of mono- and dicotyledonous weeds

Weed control [a]	Regression equations	Significance level	Coefficient of determination (%)
	The total numbers of weeds		
1	$y = 0.007x^3 -0.537x^2+13.636x-57.426$	0.027	51.7
2	$y = - 0.001x^5 + 0.031x^4-1.766x^3+48.346x^2-634.150x+3200.100$	0.012	14.8
3	$y = 3E-0.5x^5+0.005x^4-0.326x^3+9.2884x^2-119.11x+543.880$	0.007	27.9
4	$y = -8E-0.7x^6$+0.001x5-0.018x4+0.826x3-19.010x2+213.180x-895.410	0.002	18.9
5	$y = 3E-0.5x^5-0.003x^4-0.147x^3-3.0519x^2+27.089x-57.236$	0.147*	58.1
6	$y = 0.001x^5 - 0.038x^4+2.162x^3-60.481x^2+824.480x-4370.500$	0.001	41.0
7	$y = 0.007x^5 +0.614x^2-16.542x+152.420$	0.016	41.3
8	$y = - 0.001x^4-0.034x^3-1.495x^2-28.24x -187.580$	0.009	0.1

Table 7 (continued)

	The number of monocotyledonous weeds		
1	$y = 4E\text{-}0.5x^5 - 0.004x^4 + 0.198x^3 - 4.053x^2 + 37.887x - 109.800$	0.002	17.2
2	$y = 0.001x + 7.671$	0.070	32.2
3	$y = -0.002x^4 - 0.021x^3 + 0.854x^2 - 13.516x + 77.233$	0.046	32.8
4	$y = -0.232x + 13.588$	0.114*	51.4
5	$y = 0.001x^4 - 0.079x^3 + 3.445x^2 - 63.029x - 417.910$	0.030	28.8
6	$y = 0.001x^5 - 0.025x^4 + 1.427x^3 - 40.003x^2 + 547.050x - 2911.00$	0.000	18.9
7	$y = 0.061x + 4.720$	0.005	39.8
8	$y = 0.001x^3 - 0.066x^2 + 1.743x - 9.7063$	0.012	1.9
	The number of dicotyledonous weeds		
1	$y = -9E\text{-}0.5x^5 + 0.0116x^4 - 0.54394x^3 + 11.396x^2 - 103.06x + 327.03$	0.021	47.0
2	$y = 0.1242x + 9.837$	0.179*	53.9
3	$y = 0.0002x^4 - 0.02144x^3 + 0.8935x^2 - 13.91x + 68.708$	0.054	20.7
4	$y = 4E\text{-}0.5x^5 - 0.0063x^4 + 0.3451x^3 - 8.7894x^2 + 103.67x - 445.96$	0.015	31.7
5	$y = -0.2013x + 8.651$	0.373**	67.2
6	$y = -1.004x^3 + 0.3316x^2 - 8.538x + 73.791$	0.000	22.4
7	$y = 0.0005x^4 - 0.0067x^3 + 3.0172x^2 - 58.139x + 408.28$	0.002	17.8
8	$y = 0.0012x^3 + 0.103x^2 - 2.751x + 25.095$	0.066	7.2

[a]the explanations as in Table 2; *significant at the level of $p_{0.05}$; ** significant at the level of $p_{0.01}$.

In the case of potato weed control: Sencor 70 WG – 0.3 kg ha^{-1} + Titus 25 WG – 30 g ha^{-1} + Trend 90 EC – 0.1% - after potato emergence, a curvilinear relationship was found, 3rd degree between the fresh and the dry matter of weeds and the commercial yield of tubers (Table 8). The credibility of this equation is confirmed by quite high determination coefficients (Kranz, 1988).

Weed infestation studies carried out by Deveikyte & Seibutis (2006) showed a higher yield of sugar beet after herbicide mixtures than phenmedipham + desmedipham + ethofumesate. The authors also proved that reducing the dose of phenmedipham + desmedipham + ethofumesate and triflusulfuron, chloridazon, metamitron, chloridazon + quimerac caused an increase in dry matter of weeds by 25% but the beet yield did not decrease significantly.

Doses of tested herbicides in corn cultivation in the Auškalnienė & Auškalnis (2006) studies differentiated the weed infestation of this plant. Rimsulfuron-methyl and nicosulfuron-methyl were effective against *Echinochloa crus - galli* a primisulfuron-methyl had no effect on this weed species. Nicosulfuron – methyl and primisulfuron-methyl were effective against *Chenopodium album*, however, rimisulfuron methyl did not destroy that weed as effectively.

The dry matter of weeds proved to be the most useful indicator for determining the weight and total yield losses. Drop in the yield under the influence of dry matter of weeds growth, in the scope of standard deviation from the arithmetic mean, a most often took on the character of curvilinear, second, or third degree. These dependencies were used to calculate the tolerated weed weight. This does not cause a yield decrease. In the case of total yield, for mechanical and chemical care with the use of Sencor herbicide, it was 6 g, when applying the treatment with the use of Sencor (active substance metribuzin) +

Titus (active substance rimsulfurone) + Trend, as wetter − 72 g and in the case of marketable yield, these values were respectively: 2 g and 3 g m^{-2}. The coefficient of determination for these dependencies postulated by (Kranz, 1988) achieved 50% level, which makes it possible to consider the accepted method as reliable.

Table 8. Relationships between marketable of tubers of fresh weight and dry matter of weeds

Weed control [a]	Regression equations	Significance level	Coefficient of determination (%)
	The fresh weight of weeds		
1	$y = -0.0012x^5 + 0.1469x^4+6.6463x^3-131.81x^2+13.463x-4016.400$	0.029	25.9
2	$y = 0.0017x^5-0.257x^4-14.997x^3+419.600x^2-5601.00x+2870.800$	0.001	19.7
3	$y = -6.210x + 298.270$	0.344**	66.4
4	$y = -10.68x + 545.610$	0.467**	70.7
5	$y = -9.854x + 510.380$	0.189*	60.9
6	$y = 0.132x^3-11.794x^2+325.250x-2510.800$	0.290**	65.3
7	$y = -0.008x^4+1.071x^3-50.112x^2+1019.800x-7425.5$	0.000	6.7
8	$y = -3.919x+277.310$	0.064	42.9
	The dry matter of weeds		
1	$y = 0.001x^5 + 0.074x^4+3.310x^3-69.130x^2-666.050x-2078.500$	0.001	31.9
2	$y = 0.001x^4-0.003x^3-0.737x^2+30.058x-163.220$	0.022	16.9
3	$y = -2.739x + 164.500$	0.345**	54.5
4	$y = -3.879x + 172.620$	0.449**	64.9
5	$y = 0.001x^5-0.083x^4+4.563x^3-121.220x^2+1541.800x-7385.100$	0.118*	50.2
6	$y = 0.068x^3-6.152x^2+172.360x-1388.000$	0.371**	59.6
7	$y = -0.303x^2 + 17.172x-166.740$	0.007	11.2
8	$y = 0.025x^3-2.161x^2+67.357x-507.14$	0.024	37.0

[a]the explanations as in Table 2; *significant at the level of $p_{0.05}$; **significant at the level of $p_{0.01}$.

The increase in the total number of weeds, ranging from 10 to 58 plants m^{-2}, lowered the total and marketable yield of tubers in the experiment. The decrease in yield took a parabolic character (Tables 5 and 7). The empirical model allowed explaining 36.5% of the real total yield variability − in the case of care using Sencor + Titus + Trend and 35.4% due to Sencor + Fusilade Forte herbicides as well as 41.0% and 41.3%, respectively for the variability of marketable yield of tubers. Poddar et al., (2017) proved that all mechanical and mechanical-chemical treatments result in significantly lower efficiency than manual weed control.

In research of Zarzecka et al. (1999) an increase in weed infestation about one plant per 1 m^{-2} resulted in a decrease in the total yield by 0.23 t and marketable yield fraction of tubers by 0.28 t ha^{-1}; the increase in weed infestation by one ton of their dry matter per 1 ha decreased the yields by 2.6 and 3.2 t ha^{-1}, respectively.

The polynomial regression analysis showed a significant parabolic dependence of tuber yield on the number of monocotyledonous weeds (Tables 5 and 7). Polynomial regression model explained 36.7% of the actual total yield variation for weed control using pre-emergence Sencor and only 14% when applying the Sencor + Titus + Trend preparations mixture, whereas for the marketable yield – 32.8% and 18.9% of variability, respectively.

The increase in weed infestation with dicotyledonous weeds, ranging from 2 to 24 plants m^{-2} contributed to a linear reduction in the total yield at the care with the use of Sencor herbicide after the emergence of the crop by 2.1 t , while the mixture of Sencor + Titus + Trend – 0.22 t ha^{-1}. In the case of marketable yield, this reduction was recorded only due to the application of Sencor herbicide after potato emergence, which amounted to 2.0 t ha^{-1} (Table 5 and 7). The coefficients of determination for the discussed equations were not high. This means that also other parameters, not included in the equation, may have contributed to the fall in the total and marketable yield. In addition, it should be considered that segetal vegetation is not a direct cause of this phenomenon. It makes, especially during the high rainfall in May-June period are favorable conditions for the development of *Phytophthora infestans*, as well as other fungal diseases that limit the assimilation of plants and thus prevent achieving the maximum yield of moderately early and early potato cultivars. Merga & Dechassa (2019) found significant interaction of cultivars with the use of herbicides.

CONCLUSIONS

1. The use of herbicides in the reduction of weed infestation, especially mixtures of preparations, enabled a larger spectrum of chemical agent action and resulted in a greater efficiency of their destruction than mechanical regulation of weed infestation.

2. Mechanical care was less effective in combating the infestation than using mechanical and chemical methods of protection against weeds.

3. The dry matter of weeds proved to be the most useful indicator for determining the total and marketable yield losses. The decrease in yield under the influence of the weed dry matter has taken on a curved, second- or third-degree character.

4. The tolerated, dry matter of weeds that does not cause any yield decrease was determined. In the case of total yield, for mechanical and chemical care with the use of Sencor herbicide, it was 6 g, while for the care with preparations: Sencor + Titus + Trend – 72 g m^{-2}.

5. A high yield-protective effect of herbicides was obtained as a result of limited competition of weeds. Mechanical treatment contributed to the increase in the total potato yield by 36.2%, and the marketable yield by 45.7%, as compared to the control object. Methods of mechanical and chemical care increased the total yield by 24.7–50% and the marketable yield by 43.7–60.8%, in relation to the control object. The greatest yield-protective effect, of both total and marketable yield, was obtained with the pre-emergence use of Sencor.

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