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ORIGINAL ARTICLE

Desiccant activity of nonanoic acid on potato foliage in Poland

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Abstract

During potato desiccation the above-ground parts can be destroyed by mechanical, mechanical-chemical, or chemical methods. In the current study, the mechanical-chemical method was used and instead of chemical compounds natural nonanoic acid (pelargonic acid) was used. Nonanoic acid is a natural active ingredient that can be extracted from vegetable oil (rapeseed oil). It is a short chain fatty acid and a natural product, that fits well with the principles of the Green Revolution, which has introduced restrictions worldwide on the use of chemical plant protection products and promotes natural ones. For comparison carfentrazone-ethyl and glufosinate-ammonium were used. Studies were carried out in Poland during 2012–2014 with the potato variety Ikar, which is known to be among the varieties difficult to desicccate in Poland. The results show that potato leaves were efficiently destroyed by both nonanoic acid and chemicals (carfentrazone-ethyl and glufosinate-ammonium). The level of destruction varied from 94.5% to 99%. The level of stalk drying caused by nonanoic acid was high and it was similar to that of chemical desiccants. None of the studied desiccants significantly affected yield, vascular necrosis or quantity of starch in tubers.

Keywords: haulm destruction, natural desiccant, nonanoic acid, potato

Introduction

Poland is one of the largest potato (*Solanum tuberosum* L.) producers in the world, after China, India, the Russian Federation, Ukraine, the United States and Germany. Although its growing area has decreased in recent years, potato is still one of the most common crops grown in Poland (Faostat 2012; PCSO 2012).

One of the most important stages in the production of potatoes is preparation for harvest. This is important especially for potato crops since there is lush growth of the aerial parts and intensive fertilization. Tubers in such crops reach maturity very late and are more susceptible to mechanical damage (bruises) (Erlichowski 2005). Desiccation before the harvest of potatoes improves the appearance of tubers, enhances periderm development and improves storability (Renner 1991). The foliage can be destroyed by mechanical, mechanical-chemical, or chemical methods. Frequently mechanical-chemical methods are used, in which chemical treatment is applied after the destruction of the foliage by a stem crusher (grinding approx. 20 cm of the plant height). This method is more effective and more reliable than each of them used separately, especially in potato crops with vigorous growth and extensive canopy (Erlichowski 2005). In such potato crops chemical methods alone are less effective, because it is difficult to obtain complete spray coverage of dense potato and weed canopies. Exact wetting of plants is of major importance, because the contact agents which are often used to desiccate potatoes, work locally and do not move throughout the plant once it enters tissues (Praczyk and Skrzypczak 2004; Woźnica 2008). The uniformity of spray coverage with contact desiccants influences efficacy. Such methods are used to desiccate due to their localized effect. They do not accumulate in the tubers and therefore they do not influence the quality or decrease the ability to sprout. The chemical method used to desiccate can change potato yield and its quality, influencing both unfavorably (Renner 1991). In our study, the mechanical-chemical method was used and instead of chemical compounds natural nonanoic acid (pelargonic acid) was used – a natural compound to destroy potatoes' top leaves. Nonanoic acid contains a natural active ingredient that can be extracted from vegetable oil (rapeseed oil). The active ingredient is prepared by a physical process and not by any chemical method. Nonanoic acid also does not contain any synthetic adjuvants. The nonanoic acid used in this study was manufactured by JADE Avenue Ariane France. The formulation used in this study (VVH 86086) was registered in Poland as Beloukha 680 EC on 05 April 2016 (ANSES 2016). For comparison carfentrazone-ethyl (manufactured by FMC Chemical Sprl., Brussels, Belgium) and glufosinate-ammonium (manufactured by Bayer CropScience AG, Germany) were used. According to the principles of integrated pest management, farmers are required to use non-chemical methods on the crops initially, and only as a last option are allowed to use chemical methods (Directive 2009/128/EC). Concerns over the potential impact of pesticides on human health and the environment have led to the introduction of new pesticide registration procedures, such as the Food Quality Protection Act in the United States. These new regulations have reduced the number of synthetic pesticides available in agriculture (Dayan *et al.* 2009). Nonanoic acid, a short chain fatty acid (Coleman and Penner 2006), is a natural product, which can be used instead of a chemical.

Materials and Methods

Our studies were carried out at the Agricultural Experimental Station of the Institute of Plant Protection–National Research Institute in Winna Góra (Poland) during 2012–2014 with the potato variety Ikar, which is known to be among the varieties difficult to desiccate in Poland. Planted during the second part of April, sowing density was 3.0 t · ha^{-1}. During the growth period standard herbicide, fungicide, and insecticide protection were used. The following mineral fertilization was used: pre-sowing – 18 kg N, 72 kg P, 79 kg K; straight N at two rates: first rate – 92 kg · ha^{-1}, second rate – 80 kg · ha^{-1}. Organic fertilization was not used. The previous crop in 2012 and 2013 was winter wheat and in 2014, it was spring wheat.

The study was carried out in random blocks in four replications. The area of field plots was around 33.0 m^2 (width – 3.0 m, length – 11.0 m).

The study used a mechanical-chemical method for desiccation. Twenty-four hours before desiccant application, 20 cm of the above-ground parts of the plants were destroyed with a potato haulm topper Gremme KS 75-4. In the study two doses of nonanoic acid were applied: 8,160 g active ingredient (a.i.) · ha^{-1} and 10,880 g a.i. · ha^{-1}; a comparative substance carfentrazone-ethyl was applied in dose 60 g a.i. · ha^{-1} and glufosinate-ammonium in dose 375 g a.i. · ha^{-1}. In the study two controls were done. The control without mechanical cutting and desiccant application was to show natural plant ageing. The control served to assess yield and its parameters, such as vascular necroses and starch in tubers. Nonanoic acid was applied when plants started to age – the lower leaves started to yellow and potato berries started to change color – 91 in BBCH-scale. The date of application depended on the maturity of the skin, but it was always in the first part of August 3, 2012; August 5, 2013; and August 4, 2014. The period from germination of potatoes to desiccant application was approx. 70 days. Weather conditions during application and for a short period afterwards were positive for desiccation. They did not differ significantly between the years of study (Table 1). The desiccant was applied with a compressed air knapsack sprayer equipped with 5 nozzles XR TeeJet 110 02 VP. The length between the beam and the top of plant was 50 cm. The spraying fluid had a pressure of 0.3 MPa at 250 l · ha^{-1}. The desiccation efficiency was visually evaluated 1, 3, 7, 14, and 21 days after treatment, and the condition of potato foliage and stalks was compared for each desiccant treated and untreated plots. Efficacy of desiccation was shown as a percent scale, where 100% was total damage of leaves and stems and 0% was the lack of a desiccant effect. Re-growth efficiency was visually evaluated 14–21 days after application and is defined as the percentage of stems on which visible symptoms of initial vegetation is noted (100% refers to the amount, color, and quantity of re-growths, which are the same as in the control with mechanical cutting; 0% indicated lack of re-growth). Potato yield was specified for each plot. Potatoes were harvested with an "Anna Z 644" combine from the entire surface of each plot (4 rows). Total yield of potatoes was divided into three fractions (>5.5 mm; 3.5–5.5 mm; <3.5 cm). Yield division into fractions was conducted directly after harvest by using potato grader T365. Results are shown in t · ha^{-1}. Vascular necroses was determined for samples from each plot – each sample contained 50 tubers. From each plot, 25 randomly chosen tubers were collected across the three size categories and analyzed for vascular necrosis. Symptoms are presented as a percent scale (100% meant that there were visible symptoms in all 25 tubers of the sample, 0% meant the lack of vascular necrosis symptoms). The quantity of starch in tubers was evaluated for a collective sample

Table 1. Weather conditions 7 days after application of nonanoic acid

Date	Daily mean temperature [°C]	Precipitation [mm]
3 Aug. 2012*	20.3	–
4 Aug. 2012	22.0	–
5 Aug. 2012	25.0	4.5
6 Aug. 2012	25.0	8.2
7 Aug. 2012	21.3	0.5
8 Aug. 2012	19.3	0.3
9 Aug. 2012	18.0	–
10 Aug. 2012	16.7	6.0
Average	21.0	Total 19.5
5 Aug. 2013*	21.0	–
6 Aug. 2013	24.7	–
7 Aug. 2013	24.5	0.9
8 Aug. 2013	24.5	16.7
9 Aug. 2013	24.7	0.8
10 Aug. 2013	20.7	–
11 Aug. 2013	20.7	–
12 Aug. 2013	19.3	0.2
Average	22.7	Total 18.6
4 Aug. 2014*	21.3	–
5 Aug. 2014	21.5	–
6 Aug. 2014	24.3	1.9
7 Aug. 2014	24.0	8.5
8 Aug. 2014	23.0	5.5
9 Aug. 2014	21.0	–
10 Aug. 2014	22.0	–
11 Aug. 2014	20.0	1.8
Average	22.2	Total 17.7

*date and weather conditions on day of application of nonanoic acid

(10 kg), collected from each plot (without fraction division) directly after harvest. The quantity of starch in tubers was evaluated by a wet method, with hydrostatic scales TP-15/1, for percent evaluation content of starch in tubers. This method consisted of weighing them in the air, then in water. Based on these results tuber density and dry matter content were determined. Through the dependence between starch content and density of potato tubers, using Archimedes' principle, the starch content of the studied tubers was determined. It is the difference between dry matter and non-starch ingredients.

Statistical analysis

Three years of results from field experiments were statistically analyzed. Data was subjected to the analysis of variance test (ANOVA) as a completely randomized design by using Statistica computer program v. 10. Means were compared using Tukey's test at a 0.05 level of significance.

Results

Nonanoic acid showed high efficiency of desiccation of both foliage and stalks of potatoes of the Ikar variety, which is known to be among the difficult varieties to desiccate (authors' unpublished observations). Results are shown as an average of a 3 year study. The analysis of variance showed that the year was not a significant factor.

The desiccation of leaves

The results of the 3 years of research show that potato leaves were efficiently destroyed by both nonanoic acid and the chemical desiccants carfentrazone and glufosinate (Fig. 1). The level of destruction varied from 94.5% to 99%. Mechanical destruction of the aboveground parts of the potato, caused the leaves to dry out. It was around 81.3% effective in leaf desiccation over this same time period, and was significantly less than the desiccant treatments. This percentage was statistically lower compared to mechanical cutting where compounds supporting drying were applied later.

Based on the results it can be noted that nonanoic acid is fast-acting in comparison with control conditions on potato leaves. During the last assessment of leaf destruction a significant impact of nonanoic acid, independent of dose application and comparative preparations for leaf drying, was noted in comparison with control both with and without mechanical cutting.

Desiccation of stalks

The level of stalk drying caused by nonanoic acid was high, and comparable to chemical desiccants. After application of both nonanoic acid and chemicals, the level of desiccation exceeded 90%, 14 and 21 days after treatment. The poorest effect was obtained when a substance interrupting the vegetation was not used. The use of mechanical cutting caused 70% of stalk desiccation. In potato plants without mechanical cutting and desiccant application, the natural ageing level was 57.5%. Statistical analysis of results showed significant differences between controls, and those objects on which, after mechanical cutting, products for drying plants were used (Fig. 2).

On the first day after the application of nonanoic acid the greatest inhibition of vegetation was found. It

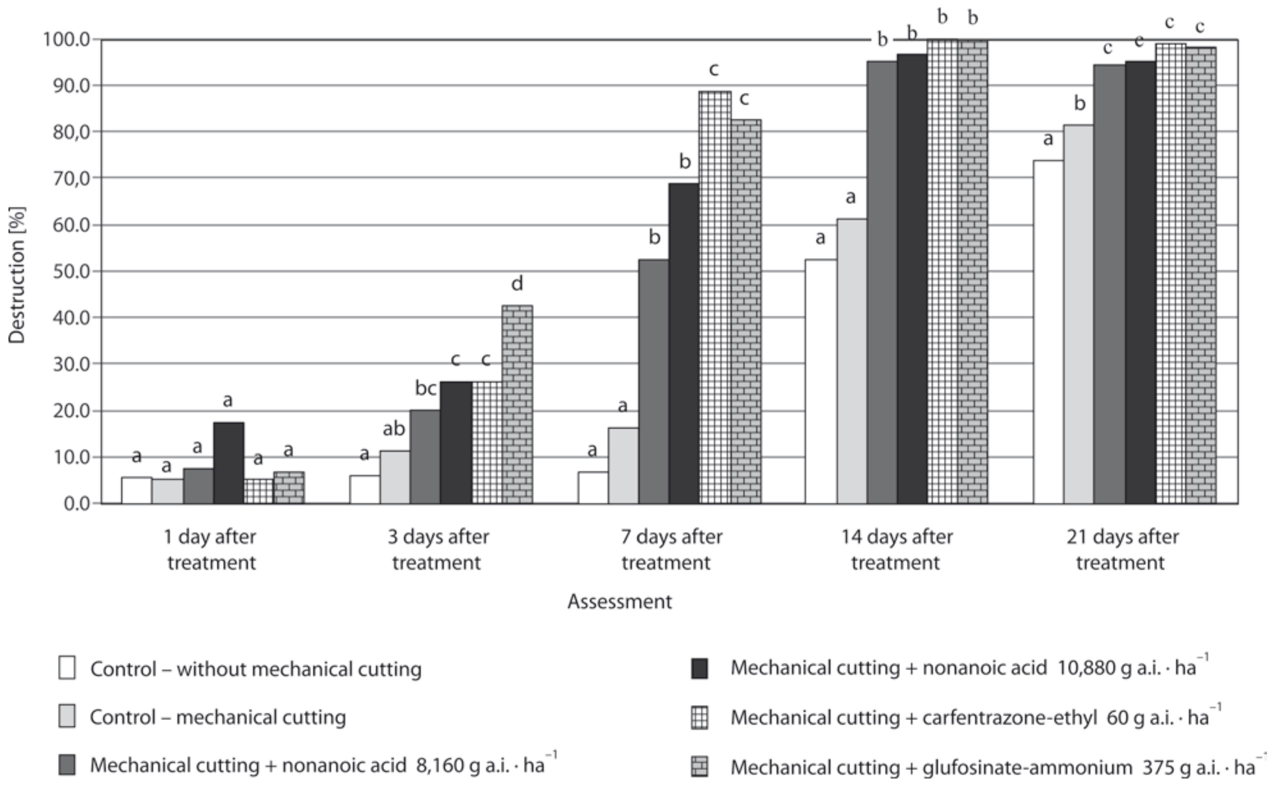

Fig. 1. Effect of mechanical and chemical methods of leaf desiccation of variety Ikar grown in Winna Góra (Poland). Values are means of 4 replications averaged over 3 years (2012–2014). Means followed by a letter are not significantly different at $p \leq 0.05$ Tukey's test

was reflected both in turgor reduction by aboveground parts of potatoes and the occurrence of chlorotic spots. The initial symptoms of stalks drying after mechanical destruction of leaves without desiccant application were seen only 14 days after the treatment. The level was just 28.8%. Symptoms of natural plant (stalks) ageing were also found 14 days after the beginning of study. The level of natural plant ageing was similar and did not statistically differ from control objects, where plants were mechanically destroyed. The last assessment of stalk destruction showed high efficacy after applying nonanoic acid.

Regrowth

Regrowth after mechanical cutting and desiccants was poor. It ranged from 0.5 to 2.8%. Mechanical destruction of leaves without desiccant agents helped increase the resumption of vegetation by 4.3% (Table 2).

Nonanoic acid to a lesser extent inhibited the start of the growing season. This indicates that the compound does not penetrate the tubers and is quickly biodegradable, allowing growth to start relatively quickly. However, no statistical differences were found between the use of nonanoic acid and carfentrazone-ethyl or glufosinate-ammonium. All compounds used did not fully inhibit regrowth, which is consistent with its mechanism of action.

Effect on yield

Analysis of potato yield showed no statistical differences between conditions (Table 3). The highest yield was found in the treatment with both mechanical cutting and nonanoic acid at dose 8160.

Assessment of the impact of desiccants on the occurrence of vascular necrosis of tubers showed that nonanoic acid did not stimulate their damage, which is connected with its mechanical action. Evaluation of potato tuber starch content did not show a negative influence of desiccation. Starch content in potatoes was high (21.7–22.1%). The differences between plots were not statistically significant (Table 3).

Discussion

Nonanoic acid does not belong to any ecotoxicological category. It is natural and it does not negatively affect people, aquatic and soil environments and air (Coleman and Penner 2008). Nonanoic acid is a contact, broad-spectrum commercial herbicide for control of annual weeds, mosses (*Bryum argenteum*) and liverwort (*Marcbantia polymorpha*) (Fausey 2003; Lederer *et al.* 2004; Shaner 2014). It is a contact (stinging) compound and therefore it does not move throughout the

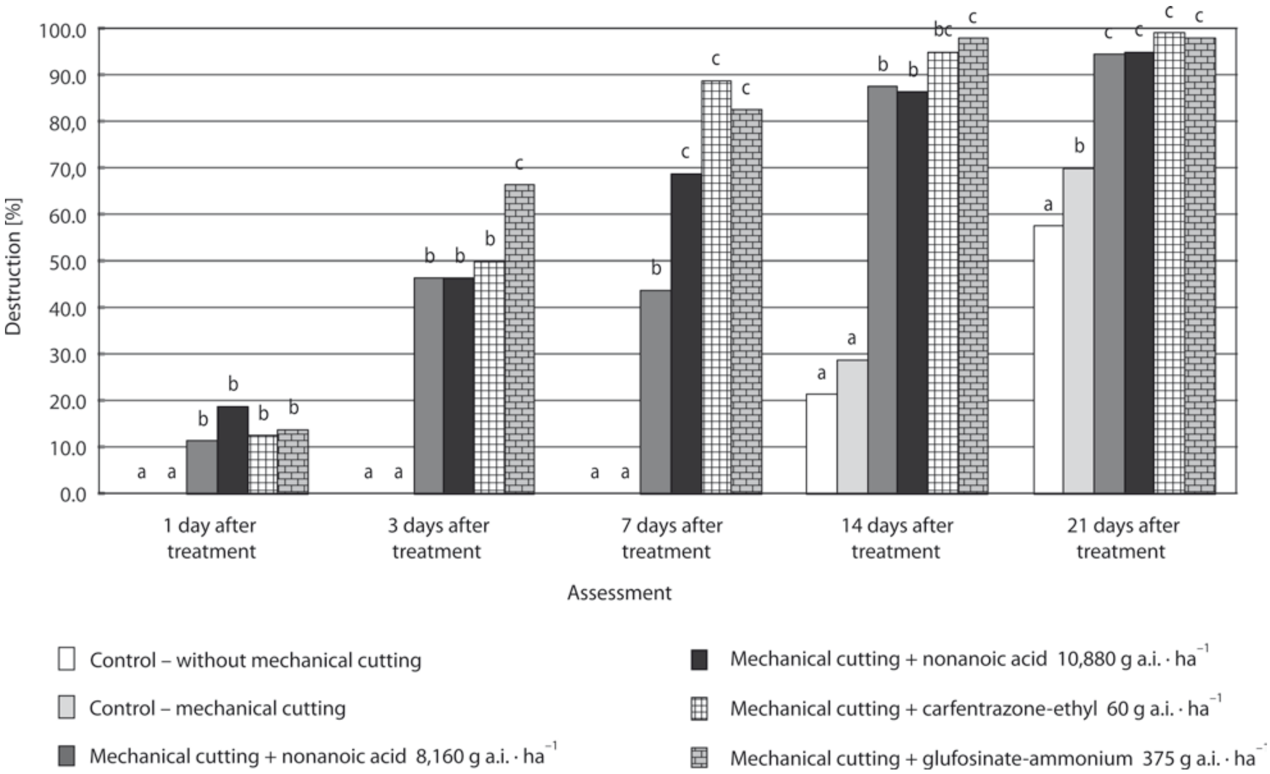

Fig. 2. Effect of mechanical and chemical methods on stalk desiccation of variety Ikar grown in Winna Góra (Poland). Values are means of 4 replications averaged over 3 years (2012–2014). Means followed by the letter are not significantly different at $p \leq 0.05$ Tukey's test

plant once it enters tissues and it does not negatively affect the growth of tubers (Wróbel 2007; Woźnica 2008). As shown by Praczyk and Skrzypczak (2004) and Woźnica (2008), compounds which act locally (stinging) show negligible translocation in plant tissues. Short chain fatty acids, which include the tested nonanoic acid, rapidly penetrate plant tissues destroying the permeability of cell membranes, resulting in the inhibition of photosynthesis and other physiological processes connected with the functioning of membranes. Studies on the activity of short chain fatty acids carried out by Coleman and Penner (2006) showed that these compounds are characterized by quick action and high efficiency. Our study confirms that effects of nonanoic acid used after mechanical treatment can already be seen 24 h after application. Erlichowski's research (2004) showed that after the use of chemical desiccants the desiccation can last from 14 to 21 days. Our study was carried out with a mechanical-chemical method, which is the most effective and more reliable than other available methods: mechanical or chemical (Erlichowski 2005). Furthermore, this method ensures fast drying of leaves (Wróbel 2005). With this method under favorable conditions, the amount of the active substance used can be significantly reduced. As shown by Larsson (1992) and Erlichowski (2005), it can even be reduced to 50% when the treatment is performed on a sunny day and on a variety with less lush growth. When using desiccants on a variety with lush growth the dose should not be reduced, because the resulting effect can be disappointing. In this study, the use of a natural desiccant – nonanoic acid – produced similar efficacy of leaf and stem destruction, which did not differ statistically from currently used chemical desiccants. Specifying the percentage of regrowth in this research it must be said that with a natural compound (nonanoic acid) the percentage of regrowth was the largest. However, it did not differ statistically from the chemical agents. A large amount of regrowth is not desirable because, according to Turska (1997) and Kürzinger (1999), it significantly contributes to increasing the infestation of potatoes by viruses as a result of their transportation into the tuber.

An important effect of the use of desiccants is their impact on yield and quality. In this study the largest total potato yield, though not statistically significant, was found on plots where mechanical cutting and nonanoic acid were used. As shown by Wróbel (2005) and Ivany and Sanderson (2001), early destruction of leaves reduces crop yield in natural ways by shortening the vegetation period, which was confirmed in our study. The reaction of potatoes to early destruction of leaves depends on the variety and the day of application of chemical desiccant (Wróbel 2005). Agents used

Table 2. Assessment of regrowth of variety Ikar grown in Poland (%). Values are means of 4 replications averaged over 3 years (2012–2014)

Treatment	Dose [a.i. · ha^{-1}]	Assessment	
		14 days after treatment	21 days after treatment
Control – mechanical cutting	–	0.3 a	4.3 b
Mechanical cutting + nonanoic acid	8,160	0.3 a	2.8 ab
Mechanical cutting + nonanoic acid	10,880	0.0 a	2.5 ab
Mechanical cutting + carfentrazone-ethyl	60	0.5 a	1.0 ab
Mechanical cutting + glufosinate-ammonium	375	0.0 a	0.5 a

Means followed by a letter are not significantly different at $p \leq 0.05$ Tukey's test

Table 3. Assessment of potato yield, vascular necrosis, and starch content of the tubers. Values are means of 4 replications averaged over 3 years (2012–2014)

Treatment	Dose [a.i. · ha^{-1}]	Yield [t · ha^{-1}]				Vascular necrosis [%]	Starch [%]
		total	>5.5 cm	3.5–5.5 cm	<3.5 cm		
Control – without mechanical cutting	–	44.71 a	34.51 a	6.85 a	3.36 a	0.0 a	22.1 a
Control – mechanical cutting	–	44.40 a	35.97 a	5.88 a	2.55 a	0.0 a	22.0 a
Mechanical cutting + nonanoic acid	8,160	47.00 a	34.48 a	8.39 a	4.13 a	0.0 a	21.7 a
Mechanical cutting + nonanoic acid	10,880	46.61 a	35.89 a	7.67 a	3.06 a	0.0 a	21.7 a
Mechanical cutting + carfentrazone-ethyl	60	44.52 a	35.32 a	6.30 a	2.91 a	0.0 a	21.7 a
Mechanical cutting + glufosinate-ammonium	375	46.11 a	32.55 a	8.79 a	4.77 a	0.0 a	22.0 a

Means followed by a letter are not significantly different at $p \leq 0.05$ Tukey's test

for chemical destruction of leaves should not negatively influence the quality of tubers. In the conducted research there was no effect of nonanoic acid or of comparative active substances on the occurrence of vascular necrosis of tubers. No sign of necrosis is connected with the mechanism of action of the used compounds. Wróbel (2007) and Worthington (1985) found many negative impacts of applying a rapidly moving active substance – glyphosate – to desiccate potato. They depend on the absence or the unnatural growth and development of sprouts. Potato yield response to glyphosate herbicide has been a subject of renewed research interest in recent years in response to widespread adoption of glyphosate-resistant agronomic crops near potato production (Olszyk *et al.* 2010; Felix *et al.* 2011; Hutchinson *et al.* 2014; Colquhon *et al.* 2017). An important aspect of potato production is the starch content in tubers. After nonanoic acid and comparative desiccation application, there was no negative influence of desiccation on starch content in tubers. The same was written by Wróbel (2005), who did not show a decrease of starch content in tubers after the application of different methods of destroying aboveground parts of potatoes.

Conclusions

Nonanoic acid has a positive effect on foliage destruction of potato crops. The tested compound destroyed potato leaves by more than 94.5%. The level of drying of stalks after using nonanoic acid was high and it did not statistically differ from the usage of carfentrazone-ethyl and glufosinate-ammonium. Application of nonanoic acid in higher doses (10,880 g a.i. · ha^{-1}) is baseless, because it did not affect significantly the drying of potato plants and did not reduce significantly the quantity of regrowth. For effective desiccation a dose of 8,160 g a.i. · ha^{-1} is enough. After application of nonanoic acid there were no significant differences in yield of potato tubers, symptoms of tuber vascular necrosis or starch content.

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