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THE TUBER CONTENT OF HARMFUL SUBSTANCES IN POTATO MANURED WITH UNDERSOWN CATCH CROPS

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ABSTRACT

Potato tubers are capable of accumulating both nutrients and substances which are harmful to human health, in particular nitrates and glycoalkaloids. Bearing this in mind, field research was conducted between 2006 and 2009 to determine the effect of undersown catch crop biomass on nitrates (V) and glycoalkaloids in potato tubers in the integrated and organic production systems. Two factors were examined: factor 1 – manuring with undersown catch crops (control treatment – no undersown catch crop, farmyard manure, serradella, westerwolds ryegrass, serradella – mulch, westerwolds ryegrass – mulch), factor 2 – production system (integrated and organic). Total tuber yield and marketable yield were determined, and average samples of potato tubers were collected during harvest to determine nitrates and glycoalkaloids.

The lowest concentration of harmful substances was found in the tubers of potato manured with serradella which had been either ploughed under in autumn or left on the soil surface for spring incorporation. Tubers of potato grown in the integrated production system had less nitrates and glycoalkaloids than organic tubers. The highest potato tuber yields were harvested in serradella mulch-manured plots.

Key words: catch crop, glycoalkaloid content, mulch, nitrate (V) content, production system, yield.

INTRODUCTION

Potato is an important staple food in many European countries and in the world (Horvat et al., 2014; Wegener et al., 2015; Parmar et al., 2016). The chemical composition of potato tubers is genetically controlled but also affected by environmental factors (climatic, meteorological and soil conditions) as well as agrotechnological factors, including fertilization (Płaza and Ceglarek, 2009; Zarzecka and Gugała, 2010; Bártová et al., 2013; Ahmed, 2015; Pobereżny et al., 2015). Potato tubers are capable of accumulating not only nutrients but also substances which are harmful to human health, in particular nitrates and glycoalkaloids. Nitrates are natural components of plant products. Nitrates (V) alone are not toxic, but they are likely to be converted by the intestinal microflora to nitrates (III) which may take part in the formation of cancerous nitrosamines (Bottex et al., 2008; Janowiak et al., 2009). According to Jamaati-e-Somarin et al. (2009), Shahbazi et al. (2009) and Pobereżny et al. (2015), nitrate concentration increases in potato tubers as a result of mineral fertilization, nitrogen nutrition in particular.

Glycoalkaloids (TGA) are natural toxins occurring in potato tubers and they include α-chaconine (about 60%) and α-solanine (about 40%). TGA amount varies. Research by Mondy and Mush (1990) as well as Płaza and Ceglarek (2009) demonstrated that potatoes manured with the biomass of undersown catch crops contain less glycoalkaloids. Sawicka (2003), Hamouz et al. (2005) and Wierzbicka (2011) reported that the production system significantly affected the potato tuber content of harmful substances. However, there is insufficient information in literature on the topic so the need arises to conduct this type of research. The present work is an attempt to fill the gap, and its aim was to determine the effect of the biomass of undersown catch crops, which were either autumn-incorporated or left on the soil surface for spring incorporation, on nitrate (V) and glycoalkaloid contents in potato tubers in the integrated and organic production system.

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MATERIAL AND METHODS

The experiment was carried out in 2006-2009 at the Experimental Station of the Siedlce University of Natural Sciences and Humanities, which is located in central-eastern Poland (52°03′39″ N, 22°33′80″ E). According to the international system of FAO classification, the soil was classified as Luvisol (World Reference…, 2014). The soil reaction was neutral (pHKCl = 6.6), and humus content was at a level of 1.41%. Available phosphorus, potassium and magnesium contents in 100 g soil were, respectively, 11.88, 13.94 and 5.56 mg.

The experiment was a two-factor split-block arrangement with three replicates. The studied factors included: A – manuring with undersown catch crop: control treatment – no manuring with undersown catch crop, farmyard manure (30 t ha^{-1}), serradella (*Ornithopus sativus* Brot.) – green manure, westerwolds ryegrass (*Lolium westerwoldicum*) – green manure, serradella – mulch, westerwolds ryegrass – mulch; B – production system: integrated and organic. The respective biomass yields of serradella and westerwolds ryegrass were 22.5 and 34.9 $t \cdot ha^{-1}$, on average.

Serradella and westerwolds ryegrass were undersown in spring triticale grown for grain in early April. The respective seeding rates for serradella and westerwolds ryegrass were 40 and 20 $kg \cdot ha^{-1}$. Parts of the undersown catch crops were incorporated in autumn for green manuring purposes (at the same time as farmyard manure) and the rest overwintered in the field as mulch. Table potato cv. 'Zeus' was grown in the first year after manuring with undersown catch crops.

In the integrated potato production system, mineral fertilizers were applied in early spring at the following per 1 ha rates: 90 kg N, 36.9 kg P and 99.6 kg K. The mineral fertilization rates were adjusted to soil availability and potato crop demand. In plots which had been ploughed in autumn, mineral fertilizers were mixed with the soil using a cultivator with a harrow attached to it whereas in mulched plots a disc harrow was followed by a cultivator. In the organic production system, farmyard manure was used instead of mineral fertilization and it was applied at the rate of 30 t ha^{-1} before cultivation of spring triticale undersown with catch crops. Potatoes were planted in late April and harvested in mid-September. Weeds in potatoes grown in the integrated production system were controlled both mechanically and chemically. Potatoes were hilled and harrowed every seven days until emergence and sprayed with Afalon 50 WP + Reglone Turbo 200 SL (1 kg + 1 dm^3 ha^{-1}) just before emergence. Colorado potato beetle was controlled using Fastac (0.1 dm^3 ha^{-1}), and potato blight using Ridomil MZ 72 WP (2 dm^3 ha^{-1}). Weeds in organic potatoes were mechanically controlled. Hilling followed by harrowing were performed every seven days from planting to canopy closure. Colorado potato beetle was controlled by means of Novodor SC (2.5 dm^3 ha^{-1}), and potato blight using Miedzian 50 WP (4 dm^3 ha^{-1}).

During potato harvest, total yield and marketable yield (only healthy tubers with the diameter greater than 40 cm) were determined in every plot. Next, samples of tubers were collected in every plot to determine nitrates (V) by means of a nitrate ion-selective electrode and a chlorine-silver reference electrode, and glycoalkaloids using the Bergers method.

Each characteristic studied was subjected to variance analysis according to the model for split-plot design. When sources of variation were significant, mean separation was obtained by Tukey's test at the significance level of $p \leq 0.05$. All the calculations were performed in STATISTICA®, version 12.0 and MS Excel.

The weather conditions in the study years differed considerably (Table 1). In 2007 precipitation was the lowest but temperature was the highest, and a slight drought was recorded in August. The highest precipitation sum was recorded in 2008 when the mean temperature was by 0.4°C higher than the long-term average temperature. In 2008, when precipitation was the highest, a slight drought was recorded in April only whereas in 2009 a severe drought occurred in April, July and September. The precipitation sum in 2009 was lower than in 2008, but it was higher than the long-term sum.

Table 1. Weather conditions in the growing season of potato according to the Zawady Meteorological Station

Years	Month						Mean
	April	May	June	July	August	September	
Mean air temperature, °C							
2007	8.6	14.6	18.2	18.9	18.9	13.1	15.4
2008	9.1	12.7	17.4	18.4	18.5	12.2	14.7
2009	10.3	12.9	15.7	19.4	17.7	14.6	15.1
Long-term (15 yr) mean	8.2	14.2	17.6	19.7	19.1	12.9	15.3
Rainfall sum, mm							
2007	21.2	59.1	59.0	70.2	31.1	67.6	308.2
2008	28.1	85.6	49.0	69.8	75.4	63.4	371.2
2009	8.1	68.9	145.2	26.4	80.9	24.9	354.4
Long-term (15 yr) mean	37.4	47.1	48.1	65.5	43.5	47.3	288.9

RESULTS AND DISCUSSION

Nitrate (V) content determined in the fresh matter of potato tubers was significantly affected by weather conditions, experimental factors and their interaction. In 2007 and 2009, nitrate (V) content in potato tubers was significantly lower than in 2008 (Table 2). Studies by Lachman et al. (2005) and Parmar et al. (2016) demonstrated that stress during the potato growing season, that is periodic water shortage and high temperature, or precipitation excess and low temperature, contributed to an increase in nitrate (V) content in tubers.

In plots manured with either autumn- or spring-incorporated westerwolds ryegrass, nitrate (V) concentration was at a level which was similar to farmyard manure-treated plots, which agrees with findings reported by Płaza and Ceglarek (2009). The above-mentioned relationship can be explained by the fact that the biomass of white clover, phacelia and serradella contains more nitrogen but little fibre, which contributed to a more rapid decomposition of the biomass. As a result, nutrients, including nitrogen, are steadily made available for uptake by potato plants, and all the mineral nitrogen can be converted into protein nitrogen. According to Ahmed et al. (2015), an application of farmyard manure, whose chemical composition can be controlled, may increase, e.g., the concentration of nitrogen and other components in the plant. In turn, Boligłowa and Gleń (2003), Lechman et al. (2005) Kołodziejczyk et al. (2007) as well as Smith (2007) demonstrated that nitrate (V) content in the tubers of potato manured with white mustard was similar to the level recorded in potato fertilised with farmyard manure. In the present study, there was found an interaction between meteorological conditions and manuring with the biomass of undersown catch crops. The interaction indicates that, in all the study years, the concentration of nitrates (V) was the lowest when potato had been manured with serradella, either autumn-incorporated or left as mulch on the soil surface for spring incorporation, and the highest in control potato tubers grown with mineral fertilization only.

Nitrate (V) content in potato tubers was significantly affected by the production system (Table 3). Potatoes grown in the integrated production system had a significantly lower nitrate (V) concentration compared with organic potatoes. It agrees with results reported by Sawicka (2003) but disagrees with findings of Bártová et al. (2013) who observed a significant increase in nitrate (V) content in tubers harvested in conventionally versus organically cultivated plots. Also Janowiak et al. (2009) reported a significant effect of production system on nitrate (V) content. There is more and more debate concerning the issue of nitrate (V) content in organic potato tubers (Hamouz et al., 2005). It has turned out that the amount of nitrates (V) in the tubers of potato grown

organically can be very high (Sawicka, 2003; Smith, 2007) due to many factors coming into play. On heavy soils, legumes are used extensively in crop rotation to balance out nitrogen in the whole rotation. Potato is the plant which, in a crop rotation, immediately follows farmyard manure or compost application. In such cases, the rate of organic nitrogen may be too high for the potato crop to convert it to protein nitrogen. As a result, the nitrogen remains in tubers as nitrates (V). In the present study, there was found an interaction between manuring with the biomass of undersown catch crops and production system. The interaction indicates that the lowest nitrate (V) concentration occurred in the tubers of potato manured with serradella, whether autumn- or spring-incorporated, in both the production systems. The concentration was the highest in control potato tubers grown in both the production systems.

Table 2. Nitrate (V) content (mg kg^{-1} f. m.) in potato tubers as affected by manuring with undersown catch crops in the study years (2007-2009)

Undersown catch crop	2007	2008	2009	Means
Control	146.9 d*	148.7 d	147.3 d	147.6 c
Farmyard manure	115.9 c	117.7 c	116.3 c	116.6 b
Serradella	91.9 ab	93.7 ab	92.4 ab	92.7 a
Westerwolds ryegrass	109.1 c	111.1 c	110.1 c	110.1 b
Serradella – mulch	87.9 a	89.7 a	88.4 a	88.7 a
Westerwolds ryegrass – mulch	104.1 bc	105.9 bc	104.5 bc	104.8 b
Means	109.3 A*	111.1 B	109.8 A	110.1
ANOVA	P-value		$LSD_{0.05}$	
Years	<0.001		1.1	
Undersown catch crop	<0.001		11.8	
Interaction	0.003		15.6	

*Values in columns followed by the same small letter and values in rows followed by the same capital letter do not differ significantly at p<0.05.

Table 3. Nitrate (V) content (mg kg^{-1} f. m.) in potato tubers as affected by manuring with undersown catch crop and production system (mean across 2007-2009)

Undersown catch crop	Production system	
	integrated	organic
Control	147.3 d*	147.9 e
Farmyard manure	109.1 c	124.2 d
Serradella	92.2 ab	93.1 ab
Westerwolds ryegrass	108.9 c	111.2 c
Serradella – mulch	87.9 a	89.4 a
Westerwolds rygerass – mulch	104.2 bc	105.4 bc
Means	108.3 A*	111.9 B
ANOVA	*P*-value	$LSD_{0.05}$
Production system	<0.001	0.9
Interaction	<0.001	12.6

*Values in columns followed by the same small letter and values in rows followed by the same capital letter do not differ significantly at p<0.05.

According to many authors (Bártová et al., 2013; Koh et al., 2013,; Hamouz et al., 2014; Zarzecka et al., 2015), the content of glycoalkaloids depends primarily on the cultivar and weather conditions prevailing during the growing season. In the present study, there was found a significant effect of weather conditions during the growing season, experimental factors and their interaction on glycoalkaloid content in potato tubers. It was the highest in 2008 when precipitation during the whole growing season was the greatest (Table 4). Glycoalkaloid content in tubers increases due to the effect of the following stressors occurring when potatoes grow: prolonged cold, rain, overcast weather, heat,

drought or water excess and intense sunlight (Percival and Dixon, 1996; Gregory, 2008). Diviš (2008) demonstrated that tubers harvested in a growing season characterized by high temperature and insufficient water supply had the highest glycoalkaloid level. In the current study, glycoalkaloid concentration was significantly lower in 2007 and 2009, both years characterised by favourable precipitation and temperature distribution.

Manuring with the biomass of undersown catch crops contributed to a decline in the potato tuber content of glycoalkaloids. Also Mondy and Munsh (1990) as well as Płaza and Ceglarek (2009) reported that potatoes manured with catch crop biomass contained less glycoalkaloids. In the present study, a significant decline in glycoalkaloid content was observed in plots manured with undersown catch crops compared with control treatment. Also Mondy and Munsh (1990) and Smith (2007) pointed out that mineral fertilization increased glycoalkaloid content in potato tubers. In the present study, glycoalkaloid level was the lowest in the tubers of potato manured with serradella, whether autumn- or spring-incorporated, and spring-incorporated westerwolds ryegrass mulch. It agrees with findings reported by Płaza and Ceglarek (2009). Moreover, an interaction between weather conditions during the growing season and undersown catch crop manures was found, which indicates that glycoalkaloid content was the highest in control potatoes in all the study years, and the lowest in potatoes manured with autumn or spring-incorporated serradella in 2007, and serradella mulch in 2009.

Table 4. Glycoalkaloid content (mg kg^{-1} f. m.) in potato tubers as affected by manuring with undersown catch crops in the study years (2007-2009)

Undersown catch crop	2007	2008	2009	Means
Control	74.5 d*	75.8 d	74.8 e	75.0 e
Farmyard manure	62.1 c	63.5 c	62.4 d	62.7 d
Serradella	55.2 a	56.6 a	56.0 b	55.9 b
Westerwolds ryegrass	61.8 c	63.1 bc	62.1 d	62.3 d
Serradella – mulch	53.6 a	55.0 a	53.9 a	54.2 a
Westerwolds ryegrass – mulch	60.1 b	61.5 b	60.4 c	60.7 c
Means	61.2 A*	62.6 C	61.6 B	61.8
ANOVA	P-value		$LSD_{0.05}$	
Years	<0.001		0.5	
Undersown catch crop	<0.001		1.5	
Interaction	<0.001		1.7	

*Values in columns followed by the same small letter and values in rows followed by the same capital letter do not differ significantly at $p<0.05$.

Less glycoalkaloids were found in the tubers of potato grown in the integrated versus organic production system. It agrees with results reported by Sawicka (2003) and Hellenäs et al. (1995). The above relationship may be explained by the fact that tuber yields of organic potato are lower and organic tubers are smaller compared with the integrated or conventional production system. It has been confirmed that small potato tubers (less than 50 g) contain more glycoalkaloids than large tubers (Zarzyńska and Wroniak, 2008). Koh et al. (2013) conducted a 10-year experiment and found that glycoalkaloids were significantly higher in organic tomato fruits compared with conventionally grown tomato. However, study of Abreu et al. (2007) presented decreasing concentration of total glycoalkaloids in tubers of organic potato tubers. In the present study, an interaction of the experimental factors was found. It indicates that glycoalkaloid content was the lowest in the tubers of potato manured with serradella left as mulch on the soil surface for spring incorporation, and the highest in control potato tubers grown organically.

Marketable yield of potato tubers was significantly affected by manuring with undersown catch crop, production system and their interaction (Table 6). Potato tuber yields

were significantly higher in serradella mulch-manured plots. According to Mauromicale et al. (2003), considerable nitrogen losses may occur during decomposition of legumes, and, depending on temperature, moisture and decomposition time, they may be as high as 50%. To prevent this, legumes can be left as mulch on the soil surface until spring, which slows down the process of mineralization and reduces nutrient losses, nitrogen loss in particular. In the present study, tuber yields of potato manured with autumn-incorporated serradella differed insignificantly from yields of farmyard manure-fertilized potato. Only when manured with autumn- or spring-incorporated westerwolds ryegrass, did potato tubers grow significantly smaller compared with farmyard manure-fertilized tubers. However, the sooner yields were higher than yields of control potato which had not been manured with undersown catch crops. An increase in yield following incorporation of grasses was reported by Spiertz et al. (1996) and Rudella et al. (2002), but the yields were significantly lower compared with farmyard manure-fertilised potato due to the fact that a large amount of biomass, which was low in macro-elements, had been incorporated into the soil (Mauromicale et al., 2003). Additionally, grasses are characterized by a broad C:N ratio. When this is the case, less nitrogen is mineralized and the nitrogen is used predominantly by soil microorganisms.

Table 5. Glycoalkaloid content (mg kg^{-1} f. m.) in potato tubers as affected by manuring with undersown catch crop and production system (means across 2007-2009)

Undersown catch crop	Production system	
	integrated	organic
Control	73.2 e*	76.8 e
Farmyard manure	62.1 d	63.2 d
Serradella	55.1 b	56.7 b
Westerwolds ryegrass	61.7 d	62.9 d
Serradella – mulch	53.1 a	55.2 a
Westerwolds ryegrass – mulch	60.2 c	61.1 c
Means	60.9 A*	62.7 B
ANOVA	P-value	$LSD_{0.05}$
Production system	<0.001	0.4
Interaction	<0.001	1.5

*Values in columns followed by the same small letter and values in rows followed by the same capital letter do not differ significantly at p<0.05.

Table 6. Marketable potato tuber yield (t ha^{-1}) as affected by manuring with undersown catch crop and production system (means across 2007-2009)

Undersown catch crop	Production system		Means
	integrated	organic	
Control	22.6 a*	17.8 a	20.2 a
Farmyard manure	41.2 d	29.1 d	35.2 d
Serradella	40.8 d	28.8 d	34.8 d
Westerwolds ryegrass	30.6 c	21.7 c	26.2 c
Serradella – mulch	44.1 e	30.9 e	37.5 e
Westerwolds ryegrass – mulch	29.0 b	20.1 b	24.6 b
Means	34.7 B*	24.7 A	29.7
ANOVA	*P*-value	$LSD_{0.05}$	
Undersown catch crop	<0.001	1.0	
Production system	<0.001	0.8	
Interaction	<0.001	1.4	

*Values in columns followed by the same small letter and values in rows followed by the same capital letter do not differ significantly at p<0.05.

In the present study, potato tuber yield was affected by production system as well. Significantly higher tuber yields were harvested in the integrated versus organic production system. It agrees with results obtained by Sawicka (2003), Hamouz et al. (2005) as well as Zarzyńska and Wroniak (2008). In the study reported here, an interaction between the experimental factors was found. The interaction means that the highest potato tuber yields were harvested in serradella mulch-manured plots in the integrated production system and the lowest yields in control treatment without undersown catch crop manuring in the organic production system.

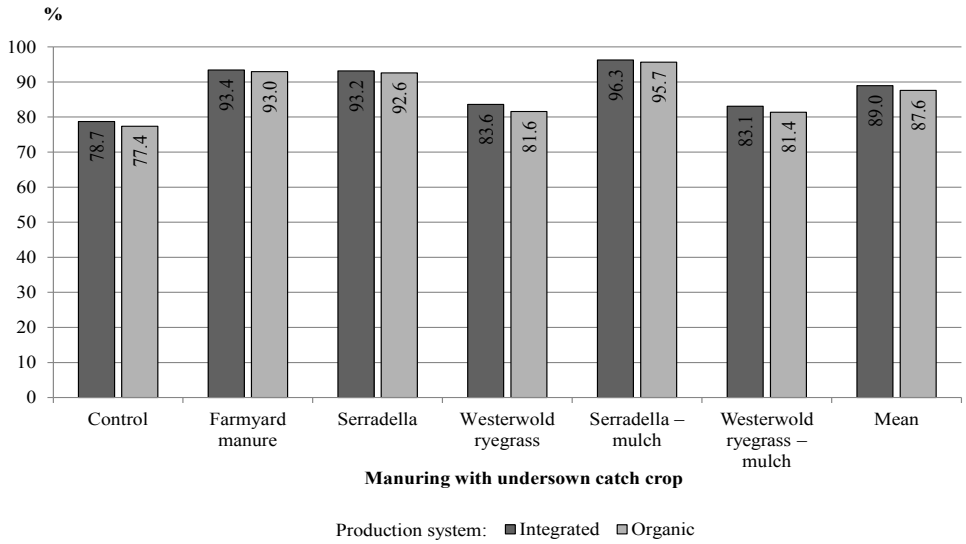

Figure 1. Share (%) of marketable yield in the total potato yield (means across 2007-2009)

The highest share of marketable yield in the total yield in the integrated and organic production system, amounting to, respectively, to 96.3 and 95.7%, was obtained after manuring with serradella mulch (Figure 1). What is more, marketable yield constituted over 90% of the total yield for potatoes following farmyard manure and serradella. The lowest share of marketable tubers in the total yield was found for control potatoes cultivated without organic manuring.

CONCLUSIONS

Thermal conditions and precipitation significantly affected nitrate (V) content and glycoalkaloid content in potato tubers. The highest concentrations were recorded in 2007 and 2009 when both precipitation distribution and temperature distribution were favourable.

The lowest nitrate (V) content was obtained in the tubers of potato manured with autumn- or spring-incorporated serradella in both the production systems. Glycoalkaloids were the lowest in the tubers of serradella mulch-manured potato in the integrated production system.

The highest potato tuber yields were harvested in plots manured with serradella mulch in the integrated production system. Autumn-incorporated serradella fully replaces farmyard manure when applied prior to potato cultivation in the integrated production system.

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