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YIELD AND QUALITY OF POTATO TUBERS FERTILIZED WITH UNDERSOWN CROPS IN AN INTEGRATED AND ORGANIC PRODUCTION SYSTEM

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Abstract. The yield and chemical composition of potato tubers is significantly diversified by fertilization with undersown crops and by the production system. The study presents research results from the years 2007-2010 whose aim is comparison of the yield and quality of potato tubers fertilized with undersown crops in an integrated and organic production system. Two factors were studied in the experiment: I – fertilization with an undersown crop: control (without fertilization with an undersown crop), manure, undersown crop – the biomassis ploughed in autumn (serradella, annual ryegrass), undersown crop – biomass left until spring in the form of mulch (serradella, annual ryegrass), II – production system: integrated and organic. Undersown crops were incorporated into spring triticale cultivated for grain. In the first year after applying undersown crops, edible potatoes were cultivated. While harvesting potato tubers, total and marketable yields were determined. In the collected tuber samples, the content of the following was determined: starch, vitamin C and true protein. Significantly, the highest yields of potato tubers were obtained from the plot fertilized with serradella in the form of mulch. Higher yields of potato tubers were obtained in an integrated than in an organic production system. Vitamin C content in potato tubers was significantly diversified by fertilization with an undersown crop, by the production system and their interaction. Significantly, the highest content of true protein was observed in potato tubers fertilized with serradella both ploughed in autumn, and left until spring in the form of mulch. Production system diversified the yield and chemical composition of potato tubers. The highest starch content was characteristic of potato tubers fertilized with annual ryegrass left until spring in the form of mulch, the highest vitamin C content was found in potato tubers fertilized with undersown crops left until spring in the form of mulch, and the highest true protein content in potato tubers fertilized with serradella both ploughed in autumn and left until spring in the form of mulch. Fertilization with serradella, both ploughed in autumn and left until spring in the form of mulch, fully substitutes manure in an integrated production system of potato.

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Key words: chemical composition of tubers, cultivation system, marketable yield, mulch, total yield, undersown crop

INTRODUCTION

Potato intended for direct consumption should be distinguished by high marketable yield of the best quality traits. The basic natural fertilizer used in potato cultivation is manure. The decreasing manure production caused by decrease in the livestock population as well as development of an integrated and organic potato production induce searching for alternative solutions. The beneficial effect of organic fertilization can be seen here. In this situation, green fertilizers take on great significance [Spiertz *et al.* 1996, Reust *et al.* 1999, Boligłowa and Gleń 2003, Dzienia *et al.* 2004, Płaza and Ceglarek 2009]. Introducing intercrops into cultivation means not only production of a biomass, but they are also a sort of sorbent preventing nutrients leaching out into deeper soil layers and groundwater, which has a significant meaning in protecting agricultural environment [Spiertz *et al.* 1996, Boliglowa and Gleń 2003, Hagman *et al.* 2008]. Among the intercrops, the cheapest source of organic substance are undersown crops [Sadowski 1992, Płaza and Ceglarek 2009]. Their beneficial effect can be seen here on the yield and chemical composition of potato tubers. Consumers expect from potato producers, especially of organic potato, a higher health and nutritive value, however, there are still few studies comparing quality of potato tubers cultivated in various production systems. Thus, there occurs a need to carry out this kind of research.

It was assumed that application of undersown crops both in an integrated and organic production system may substitute manure in potato fertilization without deteriorating quality traits of the tubers. The aim of the conducted research was comparison of the yield and quality of potato tubers fertilized with undersown crops in an integrated and organic production system.

MATERIAL AND METHODS

The field experiment was carried out in the years 2007-2010 at the Experimental Station in Zawady ($50^o20'$ N; $22^o30'$ E) property of Siedlce University of Natural Sciences and Humanities. The research was conducted on lessive soil developed from heavy loamy sand, of an average content of available phosphorus, potassium and magnesium. The experiment was set up in a split-block design, in three replications. Two factors were studied: I – fertilization with an undersown crop (6 levels of the factor): control (without fertilization with an undersown crop), manure (30 $t \cdot ha^{-1}$), undersown crop – biomass ploughed in autumn (serradella 21.7 $t \cdot ha^{-1}$, annual ryegrass 35.8 $t \cdot ha^{-1}$), undersown crop – biomass left until spring in the form of mulch (serradella 21.9 $t \cdot ha^{-1}$, annual ryegrass 35.7 $t \cdot ha^{-1}$); II –production system: integrated and organic.

Undersown crops were incorporated into spring triticale cultivated for grain. In autumn, fresh matter yield of undersown crops was determined on each plot, along with their root weight from the 30 cm soil layer. Directly after fertilization with undersown crops, potatoes cv. Zeus were cultivated. In an integrated production system of potato, mineral fertilizers were applied in early spring, whose rate when calculated per 1 ha was: 90 kg N, 39.6 kg P and 99.6 kg K. Doses of mineral fertilization were adapted to

soil fertility and quantity of the predicted yield. On plots with pre-winter ploughing, mineral fertilizers were mixed with soil with the use of a cultivator with a harrow. Whereas, disc harrow and cultivator were used on plots with mulch. In an organic production system of potato, instead of mineral fertilization, manure was used at a rate of 30 t·ha^{-1}under spring triticale cultivated with undersown crops. Potatoes were planted in late April, and they were collected in mid September. In an integrated production system, mechanical and chemical treatment was applied on potato plantation. Until emergence, every 7 days, they were mounded and harrowed, and just before emergence sprayed with a herbicidal mixture, Afalon 50 WP + Reglone Turbo 200 SL (1 kg + 1 dm^3·ha^{-1}). Colorado potato beetle was controlled with Fastac preparation (0.1 dm^3·ha^{-1}), while phytophthora fungus with a fungicide, Ridomil MZ 72WP (2 dm^3·ha^{-1}). On the other hand, in an organic production system, weeds were controlled mechanically. From planting up to row closeness, every 7 days they were mounded and harrowed. Colorado potato beetle was controlled with Novodor SC preparation (2.5 dm^3·ha^{-1}), while phytophthora fungus with fungicide Miedzian 50 WP (4 kg·ha^{-1}).

During potato harvest, total and marketable yield were determined on each plot, taking healthy tubers of a diameter over 40 mm as the marketable yield. Next, from each plot, samples were taken in order to determine content of the following: starch with Reimman's method [Roztropowicz *et al.* 1999], vitamin C with Pijanowski's method [Rutkowska 1981] and true protein with Kjeldahl's method after precipitation with trichloroacetic acid [Krełowska-Kułas 1993]. Each of the studied traits was subjected to the analysis of variance. In case of significant sources of variation, a detailed comparison of the means was carried out with Tukey's test. For statistical calculations, program with our own algorithms was used, written in Exel 7.0.

The experimental years were characterized by a significant variation in weather conditions (Table 1).

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

Tabela 1. Warunki pogodowe w okresie wegetacji ziemniaka wg Stacji Meteorologicznej w Zawadach

Year Rok	Month – Miesiąc						Mean Średnia
	April kwiecień	May maj	June czerwiec	July lipiec	August sierpień	September wrzesień	
Mean air temperature – Średnia temperatura powietrza, °C							
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
2010	8.9	14.0	17.4	21.6	19.8	11.8	15.6
1990-2005	8.2	14.2	17.6	19.7	19.1	12.9	15.3
Rainfall total – Suma opadów, mm							
2008	28.2	85.6	49.0	69.8	75.4	63.4	371.4
2009	8.1	68.9	145.2	26.4	80.9	24.9	354.4
2010	10.7	93.2	62.6	77.0	106.3	109.9	459.7
1990-2005	37.4	47.1	48.1	65.5	43.5	47.3	288.9

Conditions in the growing season diversified quantity and quality of the yield of potato tubers cultivated directly after fertilization with undersown crops. The highest

rainfall total was observed in 2010. In that year, the average temperature was higher by 0.3°C than the mean one in the long-term period. Such weather conditions favorably affected quantity of the potato yield, and unfavorably its quality. In the years 2008 and 2009, rainfall total was lower than in 2010, but higher than the long-term total. These years were less favorable for the potato yield, though better for accumulating nutrients in tubers.

RESULTS AND DISCUSSION

The total and marketable yield of potato tubers was significantly diversified by fertilization with an undersown crop, by the production system and their interaction (Tables 2, 3). Significantly, the highest yields of potato tubers (total yield of 39.3 $Mg \cdot ha^{-1}$ and marketable yield of 37.1 $Mg \cdot ha^{-1}$) were obtained from the plot fertilized with serradella in the form of mulch. As it is stated by Nowak [1982] and Mauromicale *et al.* [2003], during decomposition of fabaceae plants there may occur high nitrogen losses, depending on temperature, moisture and decomposition time, nitrogen losses may even reach 50%. In order to prevent this, an organic substance rich in carbon, e.g. grasses should be added to the decomposing fabaceae mass in order to increase the ratio C:N or leave them until spring in the form of mulch, which slows down the process of mineralization and reduces losses of nutrients, especially nitrogen. In our research, the yield of potato tubers fertilized with serradella ploughed in autumn did not differ significantly from the yields obtained with manure. Only after fertilization with annual ryegrass, irrespective of the form of its application, potato tuber yields were significantly lower than the ones observed on manure. However, also in this case, tuber yields were higher than the ones obtained on the control, without fertilization with an undersown crop. Increase in the tuber yield after ploughing grasses, was also found by Sadowski [1992], Spiertz *et al.* [1996], Duer and Jończyk [1998] as well as Reust *et al.* [1999], however these yields were significantly lower than with manure. This results from the fact of incorporating a large amount of biomass of a low macroelements content into the soil [Sadowski 1992, Duer and Jończyk 1998]. Furthermore, the grasses are characterized by a wide C:N ratio. In this case lower amount of nitrogen is mineralized, and it is used mainly by microorganisms in the soil. In the conducted research, the second factor which significantly modified yields of potato tubers was the production system. Higher tuber yields were obtained in an integrated than in an organic production system. It is analogous with the research results of Sawicka *et al.* [2007], Hagman *et al.* [2008] as well as Zarzyńska and Wroniak [2008]. In the conducted experiment, an interaction was indicated between the studied factors, from which it follows that the highest yields of potato tubers were obtained on the plot fertilized with serradella both ploughed in autumn and left until spring in the form of mulch as well as with manure in an integrated production system. The lowest yields of potato tubers were obtained from the control plot without fertilization with an undersown crop in an organic production system.

Table 2. The total yield of potato tubers (means from the years 2008-2010), Mg·ha^{-1}
Tabela 2. Plon ogólny bulw ziemniaka (średnie z lat 2008-2010), Mg·ha^{-1}

Fertilization with an undersown crop Nawożenie wsiewką międzyplonową	Production system – System produkcji		Mean Średnia
	integrated integrowany	organic ekologiczny	
Control – Obiekt kontrolny	28.4	23.6	26.0
Manure – Obornik	44.2	31.4	37.8
Serradella – Seradela	43.7	31.0	37.4
Annual ryegrass – Życica westerwoldzka	34.5	26.3	30.4
Serradella-mulch – Seradela – mulcz	45.8	32.7	39.3
Annual ryegrass-mulch – Życica westerwoldzka – mulcz	33.6	25.4	29.5
Mean – Średnia	38.4	28.4	–
$LSD_{0.05}$ – $NIR_{0,05}$			
fertilization with an undersown crop – nawożenie wsiewką międzyplonową			1.4
production system – system produkcji			1.2
interaction – interakcja			2.1

Table 3. Marketable yield of potato tubers (means from the years 2008-2010), Mg·ha^{-1}
Tabela 3. Plon handlowy bulw ziemniaka (średnie z lat 2008-2010), Mg·ha^{-1}

Fertilization with an undersown crop Nawożenie wsiewką międzyplonową	Production system – System produkcji		Mean Średnia
	integrated integrowany	organic ekologiczny	
Control – Obiekt kontrolny	22.9	17.7	20.3
Manure – Obornik	41.3	29.8	35.6
Serradella – Seradela	40.9	29.4	35.2
Annual ryegrass – Życica westerwoldzka	30.2	21.5	25.9
Serradella-mulch – Seradela – mulcz	42.8	31.3	37.1
Annual ryegrass-mulch – Życica westerwoldzka – mulcz	29.3	20.6	25.0
Mean – Średnia	34.6	25.1	–
$LSD_{0.05}$ – $NIR_{0,05}$			
fertilization with an undersown crop – nawożenie wsiewką międzyplonową			1.2
production system – system produkcji			0.9
interaction – interakcja			1.9

Statistical analysis indicated a significant effect of the studied experimental factors and their interaction on the starch content in potato tubers (Table 4). The highest starch content was observed in potato tubers fertilized with annual ryegrass in the form of mulch (146 g·kg^{-1} f.m.). The studies of Boligłowa and Gleń [2003], Makaraviciute [2003] and Rudell *et al.* [2005] indicated that application of intercrops in the form of mulch favorably affects chemical composition of potato tubers, including the starch content. In our research on other plots fertilized with undersown crops, except serradella ploughed in autumn, starch content in potato tubers oscillated on a similar level as in potatoes fertilized with manure. This is analogous with the research results of Sadowski [1992], Jansen *et al.* [2001], Hamouz *et al.* [2005] and Kołodziejczyk *et al.* [2007]. In the mentioned experiment, the system of production also significantly diversified starch concentration in potato tubers. A significantly higher starch content was characteristic of potatoes cultivated in an integrated than in an organic production system. This is analogous with research results of Reust *et al.* [1999], Sawicka and Kuś [2002], Rudell *et al.* [2005] and Smith [2007]. However, studies of Zarzyńska and Wroniak [2008]

indicate a higher starch content in potatoes cultivated in an organic system on heavy soil, lower in an integrated system on light soil, and the lowest in an organic system on light soil. In the mentioned experiment, an interaction between the studied factors was indicated from which it follows that the highest starch content was characteristic of potato tubers fertilized with annual ryegrass in the form of mulch, with serradella in the form of mulch and with manure in an integrated production system, and the lowest of potato tubers collected from the control plot in an organic production system.

Table 4. Starch content in potato tubers (means from the years 2008-2010), $g \cdot kg^{-1}$ f.m
Tabela 4. Zawartość skrobi w bulwach ziemniaka (średnie z lat 2008-2010), $g \cdot kg^{-1}$ ś.m.

Fertilization with an undersown crop Nawożenie wsiewką międzyplonową	Production system – System produkcji		Mean Średnia
	integrated integrowany	organic ekologiczny	
Control – Obiekt kontrolny	132	129	131
Manure – Obornik	144	140	142
Serradella – Seradela	138	134	136
Annual ryegrass – Życica westerwoldzka	142	141	142
Serradella-mulch – Seradela – mulcz	143	139	141
Annual ryegrass-mulch – Życica westerwoldzka – mulcz	147	144	146
Mean–Średnia	141	138	–
$LSD_{0.05}$ – $NIR_{0,05}$			
fertilization with an undersown crop – nawożenie wsiewką międzyplonową			3
production system – system produkcji			2
interaction – interakcja			4

Vitamin C content in potato tubers was significantly diversified by fertilization with an undersown crop, by the system of production and their interaction (Table 5). The highest vitamin C concentration was characteristic of potatoes fertilized with serradella both ploughed in autumn and left until spring in the form of mulch and with annual ryegrass in the form of mulch. On the plot fertilized with annual ryegrass ploughed in autumn, vitamin C content in potato tubers did not differ significantly from the one observed in potato tubers fertilized with manure. Only in potato tubers cultivated on the control plot it was significantly lower. Also, research results of Weber and Putz [1999], Leszczyński [2000], Sawicka and Kuś [2002], Hamouz *et al.* [2005, 2007] as well as Płaza and Ceglarek [2009] indicate a positive correlation between organic fertilization and vitamin C content in potato tubers. In our research, also the production system significantly diversified vitamin C content in potato tubers. A significantly higher vitamin C concentration analogically as in the studies of Warman and Havard [1998] and Sawicka and Kuś [2002] was observed in potato tubers cultivated in an integrated production system. A different approach is presented by Zarzyńska and Wroniak [2008] who state that potatoes cultivated in an organic system contained more vitamin C. However, these differences were statistically insignificant. In our studies, an interaction was indicated, from which it follows that the highest vitamin C concentration was observed in potatoes fertilized with serradella ploughed in autumn in an integrated production system, and the lowest in potato tubers cultivated on the control plot in an organic production system.

Table 5. Vitamin C content in potato tubers (means from the years 2008-2010), g·kg^{-1}f.m
Tabela 5. Zawartość witaminy C w bulwach ziemniaka (średnie z lat 2008-2010), g·kg^{-1}ś.m.

Fertilization with an undersown crop Nawożenie wsiewką międzyplonową	Production system – System produkcji		Mean Średnia
	integrated integrowany	integrated integrowany	
Control – Obiekt kontrolny	167.4	163.2	165.3
Manure – Obornik	180.6	177.5	179.1
Serradella – Seradela	198.8	186.7	192.8
Annual ryegrass – Życica westerwoldzka	179.2	176.6	177.9
Serradella-mulch – Seradela – mulcz	194.7	192.4	193.6
Annual ryegrass-mulch – Życica westerwoldzka – mulcz	183.3	183.8	183.6
Mean – Średnia	184.0	180.0	–
$LSD_{0.05}$ – $NIR_{0,05}$			
fertilization with an undersown crop – nawożenie wsiewką międzyplonową			2.7
production system – system produkcji			1.5
interaction – interakcja			3.4

Statistical analysis indicated a significant effect of fertilization with an undersown crop and interaction between fertilization with an undersown crop and the system of production on the content of true protein in potato tubers (Table 6).

Table 6. The true protein content in potato tubers (means from the years 2008-2010), g·kg^{-1} d.m.
Tabela 6. Zawartość białka właściwego w bulwach ziemniaka (średnie z lat 2008-2010), g·kg^{-1} s.m.

Fertilization with an undersown crop Nawożenie wsiewką międzyplonową	Production system – System produkcji		Mean Średnia
	integrated integrowany	integrated integrowany	
Control – Obiekt kontrolny	41.7	42.9	42.3
Manure – Obornik	51.5	53.1	52.3
Serradella – Seradela	58.7	60.2	59.5
Annual ryegrass – Życica westerwoldzka	45.2	46.6	45.9
Serradella-mulch – Seradela – mulcz	61.2	62.7	62.0
Annual ryegrass-mulch – Życica westerwoldzka – mulcz	47.2	49.0	48.1
Mean – Średnia	50.9	52.4	–
$LSD_{0.05}$ – $NIR_{0,05}$			
fertilization with an undersown crop – nawożenie wsiewką międzyplonową			3.9
production system – system produkcji			ns – ni
interaction – interakcja			4.6

ns – ni – non-significant difference – różnica nieistotna

Significantly the highest content of true protein was observed in potato tubers fertilized with serradella both ploughed in autumn and left until spring in the form of mulch. This results from the fact that nitrogen contained in the biomass of papilionaceous plants, gradually undergoes mineralization, and is evenly made available for the potato plant, which provides its total conversion into protein nitrogen [Wiater 2002]. However, the content of true protein in potato tubers fertilized with annual ryegrass, irrespective of the form of its application, was significantly lower than in potato tubers fertilized with manure. In our research, analogically as in the studies of Reust *et al.* [1999], Smith [2007] and Zarzyńska and Wroniak [2008], the system of

potato production although did not significantly diversify the content of true protein in potato tubers, higher concentration of this nutrient was observed in potato tubers cultivated in an organic production system. However, the studies of Sawicka and Kuś [2002] and Fjelkner-Moding *et al.* [2000] indicate a higher concentration of this nutrient in potato tubers cultivated in an integrated production system. In our research, an interaction was indicated from which it follows that the highest concentration of true protein was observed in potato tubers fertilized with serradella both ploughed in autumn and left until spring in the form of mulch in an integrated and organic production system, and the lowest in potato tubers cultivated on the control plot also in both production systems.

CONCLUSIONS

1. Irrespective of the system of production, the highest yields of potato tubers were obtained from the plot fertilized with serradella used in the form of mulch.
2. The system of production significantly diversified the yields and chemical composition of potato tubers. Higher yields of potato tubers of a higher content of starch and vitamin C were observed in an integrated production system.
3. The highest starch content was characteristic of potato tubers fertilized with annual ryegrass applied in the form of mulch, the highest vitamin C content was found in potato tubers fertilized with undersown crops used in the form of mulch, and the highest content of true protein in potato tubers fertilized with serradella both ploughed in autumn and left until spring in the form of mulch.
4. Fertilization with serradella, both ploughed in autumn and left until spring in the form of mulch, fully substitutes manure in an integrated system of potato production.

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PLON I JAKOŚĆ BULW ZIEMNIAKA NAWOŻONEGO WSIEWKAMI MIĘDZYPLONOWYMI W INTEGROWANYM I EKOLOGICZNYM SYSTEMIE PRODUKCJI

Streszczenie. Plon i skład chemiczny bulw ziemniaka jest istotnie różnicowany przez nawożenie wsiewkami międzyplonowymi i system produkcji. W pracy przedstawiono wyniki badań z lat 2007-2010, mające na celu porównanie plonowania i jakości bulw ziemniaka jadalnego nawożonego wsiewkami międzyplonowymi w integrowanym i ekologicznym systemie produkcji. W doświadczeniu badano dwa czynniki: I – nawożenie wsiewką międzyplonową: obiekt kontrolny (bez nawożenia wsiewką międzyplonową), obornik, wsiewka – biomasa przyorana jesienią (seradela, życica westerwoldzka), wsiewka – biomasa pozostawiona do wiosny w formie mulczu (seradela, życica westerwoldzka); II – system produkcji: integrowany, ekologiczny. Wsiewki międzyplonowe wsiewano w pszenżyto jare uprawiane na ziarno. W pierwszym roku po zastosowaniu wsiewek międzyplonowych uprawiano ziemniaki jadalne. Podczas zbioru bulw ziemniaka określono plon ogólny i handlowy. W pobranych próbach bulw oznaczono zawartość: skrobi, witaminy C i białka właściwego. Istotnie największe plony bulw ziemniaka otrzymano z obiektu nawożonego seradelą w formie mulczu. Większe plony bulw ziemniaka otrzymano w integrowanym niż w ekologicznym systemie produkcji. Zawartość witaminy C w bulwach ziemniaka była istotnie różnicowana przez nawożenie wsiewką międzyplonową, system produkcji i ich współdziałanie. Istotnie najwyższą zawartość białka właściwego odnotowano w bulwach ziemniaka nawożonego seradelą zarówno przyoraną jesienią, jak i pozostawioną do wiosny w formie mulczu. System produkcji różnicował plon i skład chemiczny bulw ziemniaka. Najwyższą zawartością skrobi charakteryzowały się bulwy ziemniaka nawożone życicą westerwoldzką pozostawioną do wiosny w formie mulczu, witaminy C – bulwy ziemniaka nawożone wsiewkami międzyplonowymi pozostawionymi do wiosny w formie mulczu, a białka właściwego – bulwy ziemniaka nawożone seradelą zarówno przyoraną jesienią, jak i pozostawioną do wiosny w formie mulczu. Nawożenie seradelą, zarówno przyoraną jesienią, jak i pozostawioną do wiosny w formie mulczu, w pełni zastępuje obornik w integrowanym systemie produkcji ziemniaka.

Słowa kluczowe: międzyplon, mulcz, plon handlowy, plon ogólny, skład chemiczny bulw, system uprawy

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