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EFFECT OF NUTRIENT SUPPLY FROM DIFFERENT SOURCES ON SOME QUALITY PARAMETERS OF POTATO TUBERS

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Abstract

Application of mineral fertilisers, especially nitrogen ones, increases potato yields. On the other hand, it can depreciate the quality of potato tubers and raise storage loss. With bio-fertilisers like UGmax, farmers can limit the need for mineral fertilisers by activating minerals which occur in soil. Microorganisms contained in UGmax, enriched with the start-nutrition medium, process (compost) residue of the last harvested crop, straw, manure break crops (organic fertilisers), etc. Together with soil minerals, they make humus, a natural environment for soil life as well as a 'store' of nutrients. The aim of the following, 3-year research was to determine changes in the content of vitamin C, nitrogen, phosphorus, potassium and crude protein (nitrogen x 6.25) in cv. Satina potato tubers stored for 6 months indoors at the temperature of 4°C, depending on previous application of soil fertiliser (with/ without UGmax), varied organic matter (without fertiliser, stubble intercrop: pea, straw and farmyard manure (FYM) as well as a half dose of mineral fertilisation as compared with the control. The highest vitamin C content was recorded in potato tubers from the treatments with FYM, full NPK and soil fertiliser. With half the dose of mineral fertilisation, UGmax most effectively increased the vitamin C content in potato tubers in the treatments with FYM and pea. The biggest decrease in the content of that nutrient after 6-month storage appeared in tubers from the plots with FYM, 50% NPK and without UGmax (38.5%). The content of nitrogen, phosphorus, potassium and total protein in tubers significantly depended on the dose of mineral fertilisation, where full NPK increased the content of the analysed nutrients. Moreover, the content of potassium was significantly higher in tubers from the plots with farmyard manure (FYM). The use of the soil fertiliser significantly increased nitrogen and total protein in tubers. After 6-month storage in chambers at + 4°C, the nitrogen, phosphorus and potassium content decreased slightly, on average by 4.9%, 12.4%, 13.1%, respectively.

Key words: vitamin C, nitrogen, phosphorus and potassium, total protein, bio-fertiliser, storage.

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INTRODUCTION

Organic food has been enjoying a growing consumer interest, which *inter alia* necessitates performance of an objective evaluation of potato tuber quality in terms of their chemical composition. For the last ten years, the number of organic farms in Poland has risen by several-fold (TRUBA at al. 2012). The European Union countries promote organic farming, hence an answer is searched for to the question whether organic potato tubers or those derived from reduced mineral fertilisation plantations where farmyard manure (FYM), green manure as well as plant growth enhancers are applied, achieve a better nutritive value than those grown in other farming systems. The use of microbiological bio-agents (also referred to as 'fertilisers') enhances tuber yielding and chemical composition (TRAWCZYŃSKI, BOGDANOWICZ 2007). The soil fertiliser UGmax is a microbiological preparation composed of yeasts, lactic acid bacteria, photosynthetic bacteria, *Azotobacter*, *Pseudomonas* and *Actinobacteria*, as well as potassium (3500 mg dm^{-3}), nitrogen (1200 mg dm^{-3}), sulphur (1000 mg dm^{-3}), phosphorus (500 mg dm^{-3}), sodium (200 mg dm^{-3}), magnesium (100 mg dm^{-3}), zinc (20 mg dm^{-3}) and manganese (0.3 mg dm^{-3}) (TRAWCZYŃSKI 2007). The use of UGmax aims at improving physiochemical soil properties. It accelerates the decomposition of post-harvest residue and organic fertilisers, activates nutrients from minerals or insoluble compounds and improves water relations (DŁUGOSZ et al. 2010). Thus, crops can use elements from mineral fertilisers more efficiently, which in turn allows farmers to lower mineral fertilisation doses, consequently limiting the emission of harmful substances to surface waters. The positive effect on potato tuber yield volumes is also well known (ZARZECKA et al. 2011).

The nutritive value of potato tubers is determined by such nutrients which, having been digested and absorbed into blood, are used by the body as a source of energy, building material or a factor controlling life processes (*Law* ... 2009). Examples are vitamin C and proteins. In organic farming, farmyard manure (FYM) and green manure are the source of nitrogen, phosphorus, potassium and trace elements. Plants take up nitrogen up to the share of 50% over a period of 45 days after emergence. Thus, delayed mineralization of FYM and green manure to available nitrogen forms during the plant growth can be a problem, causing adverse effects on the quality and storage life of tubers (WHEATLEY et al. 2000). The aim of the present research was to verify whether a farming system with limited mineral fertilisation and the use of organic fertilisers as well as soil fertiliser can affect the content of vitamin C, nitrogen, phosphorus, potassium and crude protein content in cv. Satina potato tubers.

MATERIAL AND METHODS

Tubers of the table cultivar Satina N (mid-early potato cultivar) were obtained from experimental plots set up on soil class IV b in a three-factor split-plot design at Mochełek Experimental Station of the University of Technology and Life Sciences in Bydgoszcz. After harvest, they were stored for 6 months in chambers at the temperature of + 4°C and relative air humidity of 95%. For the experiment factors, see Table 1.

Table 1

Research factors

First factor (A): type of organic matter	
Control	without organic fertilisers
Intercrop - pea	at a dose of 40 kg ha^{-1} on experimental plots in autumn after post-harvest treatments and before pre-winter plough
Straw	at a dose of 4 t ha^{-1} on experimental plots in autumn after post-harvest treatments and before pre-winter plough
Farmyard manure - FYM	at a dose of 25 t ha^{-1} in autumn
Second factor (B): mineral fertilisation	
100% dose of NPK fertilisation	applied in spring prior to potato planting, at doses adjusted to the soil richness (low phosphors very low potassium) and nutritive requirements of the plant: 100 kg N ha^{-1}, 100 kg P_2O_5 ha^{-1}, 150 kg K_2O ha^{-1}
50% of NPK fertilisation	
Third factor (C): the application of the bio- fertiliser UGmax	
With bio-fertiliser	The bio-fertiliser was applied in the experiments at three doses: in autumn prior to pre-winter plough on organic matter at the dose of 0.6 l ha^{-1}, in spring prior to tuber planting during land tillage at the amount of 0.3 l ha^{-1}, as foliar fertilisation at the potato plant height of 15-20 cm at the dose of 0.3 l ha^{-1}.
Without bio-fertiliser	

The vitamin C content was assayed with the Tillmans method, by titration of an adequately prepared sample with the titrant of 2.6-dichlorophenoloindophenol, in line with standard PN-90/A-75101/11; the content of total protein was calculated from the content of nitrogen multiplied by 6.25, assayed with the Kjeldahl method on a BüchiLabortechnik B-324 apparatus, after mineralization in concentrated sulphuric acid (VI). The potassium content was determined in the dry weight in potato tubers after mineralization and using atomic absorption spectrophotometry. Phosphorus was assayed by the photometric method. The significance of differences between the results was tested at $\alpha = 0.05$; the data were submitted to analysis of variance with the help of Statistica 8.0.

The course of the weather during the growing season was described with the precipitation sum and coefficient K (Table 2), calculated from the formula $K = 10$ (P/T), which includes the sum of precipitations in (mm) during the analysed time (P) and the sum of mean daily temperatures in (°C) in the same time period (T). Optimal values fall within the range from 1.0 to 2.0. Values of $K > 2.0$ stand for a wet plant growing period with water excess. The meteorological data were collated from records of the Weather Station at

Table 2

Weather conditions during the plant growing season at Mochełek Experiment Station

Years	Rainfall						Sum
	month						
	Apr	May	June	July	Aug	Sept	
2009	0.4	12.4	53.4	118.0	17.6	34.4	236.1
2010	33.8	92.6	18.1	107.4	150.7	74.7	477.3
2011	13.5	35.4	100.8	132.5	67.7	37.0	386.9
Average	15.9	46.8	57.4	119.3	78.7	48.7	366.8
	Temperature						
2009	9.8	12.3	14.5	18.6	18.2	13.7	87.1
2010	7.8	11.5	16.7	21.6	18.4	12.2	88.2
2011	10.5	13.5	17.7	17.5	17.7	14.3	91.2
Average	9.4	12.4	16.3	19.2	18.1	13.4	88.8
	Hydrotermal coefficient *K*						average
2009	0.01	0.32	1.23	2.05	0.61	0.84	0.84
2010	1.44	2.60	0.36	1.60	2.64	2.04	1.78
2011	0.43	0.85	1.90	2.44	1.23	0.86	1.29
Average	0.63	1.25	1.16	2.03	1.50	1.25	1.30

K: 0-0.5 drought; 0.6-1.0 mild drought; 1.1-2.0 moist, optimal conditions; 2.1- wet

Mochełek. The 2009 season showed drought periods during the early plant growth, much moisture afterwards and a spell of semi-dry weather at the end of the growing season. During the 2010 and 2011 growing seasons, the weather was quite wet, thus being optimal for the potato development and growth.

The chemical composition of soil before the onset of the field experiment was similar in each year; the soil was very poor in available forms of potassium and magnesium and poor in available phosphorus (Table 3). Besides, the soil pH implicated slight acidification with trace elements of organic carbon and total nitrogen.

Table 3

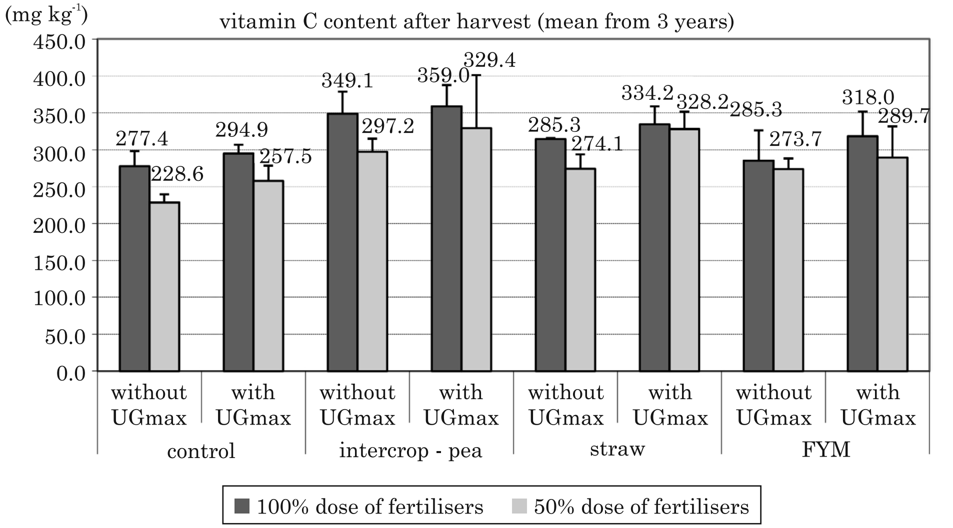
Chemical properties of the soil (mean from years 2009-2011)

Specification	Richness
pH H_2O 6.5 pH KCl 6.0	slightly acid soil
Organic matter 6.95 g kg^{-1}	
Total nitrogen 0.7 g kg^{-1}	
Content of available nutrients (mg kg^{-1}) P - 26.0 K - 45.0 Mg - 16.0	 poor very poor very poor

RESULTS AND DISCUSSION

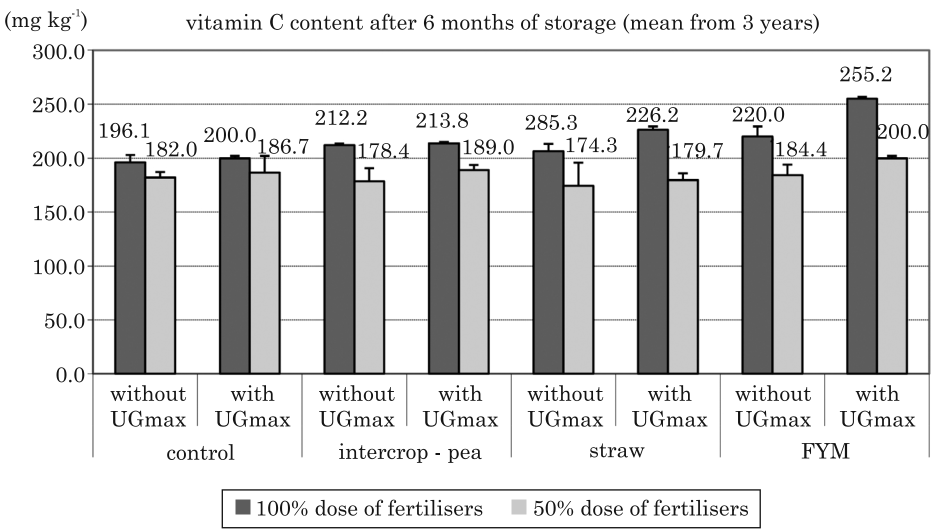
The human body cannot synthesize vitamin C, which must be supplied with a diet. By eating about 300 g potato tubers per day, the body can be supplied with up to 50% of daily vitamin C requirement (Wichrowska, Pobereżny 2008). Vitamin C is an essential health-enhancing exogenous nutrient for humans, and potatoes are one of the staple foodstuffs supplying this nutrient. Vitamin C plays an essential role in cells maintaining an adequate redox potential, by scavenging reactive forms of oxygen and neutralizing nitrogen produced by the cellular metabolism (Sies et al. 1992). Vitamin C also affects the production of collagen, which accelerates wound healing, increases resistance to infections and, as an antioxidant, offers protection from carcinogenic changes. Its content in potato tubers ranges from 100 to 300 mg kg^{-1} and is mostly cultivar-specific, although considerably depending on the climate conditions during vegetation (Rogozińska 2000, Wichrowska, Pobereżny 2008). With our research results confirmed by the statistical analysis, it was proven that all the experimental factors significantly differentiated the content of vitamin C in potato tubers after harvest (Figure 1). The highest content of that nutrient was reported in potato tubers from the treatments with FYM, a full dose of mineral fertilisation and the bio-fertiliser (359.0 mg kg^{-1}). The vitamin C accumulation was enhanced by an application of UGmax into soil (an average increase by 11% compared with tubers collected from the treatments with no bio-fertiliser) and full NPK. With half the mineral fertilisation dose, UGmax increased the content of vitamin C in potato tubers most effectively in the treatments with the application of FYM and pea (Figure 1).

Similar relationships between fertilisation with FYM and catch crop versus an increasing content of vitamin C in tubers (compared with treatments without organic fertilisation) were reported by Boligłowa and Gleń (2003). Inoculation of soil with microorganisms enhances its fertility, the yielding of plants and the chemical composition of tubers (Sulewska et al. 2005, Trawczyński, Bogdanowicz 2007). After storage, the content of vitamin C in potato tubers derived from the experiment decreased by 33.3%, on average for all the treatments, compared with the content immediately after harvest (Figure 2). The biggest decrease in the nutrient analysed after 6-month storage was recorded in tubers from the plots with the application of FYM, 50% NPK and without UGmax (38.5%). All the research factors applied in the experiment significantly differentiated the level of vitamin C in potato tubers. There were also significant interactions between the application of organic matter as well as mineral fertilisation. Similarly to the findings immediately after harvest, most vitamin C was contained in potato tubers from the treatment with FYM, full mineral fertilisation and soil fertiliser, where the content of the nutrient equalled 255.2 mg kg^{-1} of fresh weight of tubers. The storage period duration as well as temperature and moisture in



LSD $p \geq 0.05$ (Tukey test): A (organic matter) = 60.7
B (mineral fertilisers)= 2.2
C (used UGmax)= 14.9
B/A = n.s. A/B = n.s. C/A = n.s. A/C = n.s. C/B = n.s. B/C = n.s.
n.s. – non significant

Fig. 1. Vitamin C content in potato tubers after harvest depending on research factors (mg kg^{-1} fresh weight) the 2009-2011 average



LSD (Tukey test) $p \geq 0.05$ A (organic matter) = 10.3
B (mineral fertilisers) = 5.8 C (used UGmax) = 7.9
B/A = 11.6 A/B = 12.7 C/A = n.s.
A/C = n.s. C/B = n.s. B/C = n.s.
n.s. – non significant

Fig. 2. Vitamin C content in potato tubers after 6 months of storage depending on research factors (mg kg^{-1} fresh weight) average from the 2009/2010-2011/2012 storage seasons

the storage room can change the content of nutrients, including vitamin C, nitrogen, protein (Gąsiorowska 2000, Wichrowska et al. 2009).

During storage, both forms of vitamin C (ascorbic acid and dehydroascorbic acid) undergo irreversible oxidation to biologically inactive products (2,3- dioxol-L-gluconic acid). The process intensifies during tuber sprouting, hence optimal temperature to minimise vitamin C losses ranges from +4 to +6°C. The content of vitamin C after seven-month storage could decrease by as much as 60-80%.

The results have shown that the content of the macroelements under study was modified by the experimental factors. Nitrogen is an important macroelement in an assessment of the chemical composition of potato tubers. Its amount is mostly determined by organic and mineral fertilisers (Wierzbicka, Trawczyński 2011). In the tuber samples they investigated, the nitrogen content varied dependng on effective microorganisms, cultivars and weather conditions. The highest content of nitrogen in tubers was recorded for very early cultivar Miłek (13.2 g kg^{-1}), and the lowest one for late cultivar Ursus (11.0 g kg^{-1}). The application of effective microorganisms increased the content of nitrogen in tubers by an average of 1.2 g kg^{-1}. Trawczyński and Bogdanowicz (2007) revealed the effect of soil microorganisms contained in soil fertiliser on the content of nitrogen, phosphorus and potassium. As reported by many authors (Gianquinto, Bona 2000, Płaza 2004, Różyło, Pałys 2006, Piikki et al. 2007), each form of fertilisation significantly increased the nitrogen content in tubers. In tubers produced by potatoes fertilised with FYM and NPK, the nitrogen content was 16.5 g kg^{-1}; control tubers (only mineral NPK) had 15.4 gN kg^{-1} (Płaza 2004).

In this study, the nitrogen concentration ranged from 15.86 to 18.30g kg^{-1} dry weight after harvest (Table 4), falling to 15.1 to 17.1 g kg^{-1} of dry weight after 6 months of storage (Table 5). A full dose of mineral fertilisation and applied bio-fertiliser significantly increased the nitrogen content in potato tubers after harvest. The interaction between organic matter and mineral fertilisation was also significant, with a positive effect in tubers from the treatment with pea as intercrop; full mineral fertilisation dose and bio-fertiliser. The effect of organic matter and bio-fertiliser on the nitrogen content in potato tubers during storage was not significant. After 6-month storage in chambers at the temperature of +4°C, the nitrogen content decreased slightly, by an average of 4.9% for treatments. The storage capacity and the system of storage used are very much associated with the carbohydrate metabolism and the substances affecting it as well as the nitrogen metabolism (Mohamed E.O. Elsayed, 2008).

The content of phosphorus in tubers determines the technological value of potato. According to Wierzbicka and Trawczyński (2011), its amount depends on the cultivar and weather conditions. The content of phosphorus in the experiments in which standard fertilisation was applied (Płaza 2004, Zarzecka, Gugała 2010) ranged from 2.5 to 2.9 g kg^{-1} and it was two-fold higher than in those investigated by Wierzbicka and Trawczyński (2011) in organic tubers. Zarzecka and Gugała (2010) also found that more phosphorus

Table 4

Nitrogen, phosphorus and potassium content in potato tubers after harvest depending on research factors (g kg^{-1} dry weight), 2009-2011 average

Factors			Mineral fertilisation (B)						Average		
			100% dose			50% dose					
Organic matter (A)	bio- fertiliser (C)		N	P	K	N	P	K	N	P	K
Control	without soil fertilisers	average from years	17.30	3.26	26.86	16.61	2.26	21.55	16.94	2.76	24.21
		SD	1.14	0.04	0,25	1.14	0.06	0.37	1.14	0.05	0.31
	with soil fertilisers	average from years	17.74	3.36	27.84	16.70	2.31	22.49	17.23	2.83	25.16
		SD	0.50	0.01	1.07	0.14	0.01	0.52	0.32	0.01	0.80
Average			17.52	3.31	27.35	16.66	2.28	22.02	17.09	2.81	25.16
Intercrop-pea	without soil fertilisers	average from years	17.81	3.32	27.59	15.86	2.31	22.39	16.83	2.82	24.99
		SD	0.29	0.02	0.16	0.78	0.01	0.49	0.53	0.02	0.3
	with soil fertilisers	average from years	18.30	3.40	28.29	16.45	2.38	22.97	17.38	2.89	24.99
		SD	0.29	0.02	0.34	0.50	0.01	0.13	0.38	0.01	0.23
average			18.05	3.36	28.41	16.14	2.35	23.02	17.10	2.85	25.71
Straw	without soil fertilisers	average from years	18.14	3.33	27.59	16.54	2.31	23.50	17.34	2.82	25.59
		SD	1.06	0.01	0.25	0.78	0.01	0.49	0.91	0.01	0.37
	with soil fertilisers	average from years	18.00	3.39	28.39	17.34	2.35	24.79	17.68	2.87	26.59
		SD	0.85	0.04	0.34	0.78	0.04	0.23	0.82	0.04	0.29
average			18.08	3.36	28.51	16.94	2.33	24.87	17.52	2.85	26.69
FYM	without soil fertilisers	average from years	16.75	3.48	28.77	16.05	2.44	25.39	16.40	2.96	27.08
		SD	0.35	0.01	0.20	0.21	0.01	0.23	0.29	0.01	0.21
	with soil fertilisers	average from years	16.66	3.59	28.96	16.66	2.50	26.78	16.66	3.04	27.87
		SD	0.21	0.02	0.10	0.26	0.04	0.15	0.24	0.03	0.12
average			16.70	3.53	28.86	16.36	2.47	26.83	16.53	3.00	27.91
Average	without soil fertilisers	average from years	17.50	3.35	27.70	16.26	2.33	23.21	16.88	2.84	25.45
	with soil fertilisers	average from years	17.68	3.44	28.41	16.78	2.40	24.29	17.23	2.92	26.35
Average			17.58	3.51	28.05	16.52	2.46	23.75	17.05	2.98	25.90
LSD (Tukey test) $p \geq 0.05$								A	n.s.	n.s.	1.183
								B	0.256	0.994	0.994
								C	0.304	n.s.	n.s.
								B/A	0.496	n.s.	n.s.
								A/B	2.832	n.s.	n.s.
								C/A	n.s.	n.s.	n.s.
								A/C	n.s.	n.s.	n.s.
								C/B	n.s.	n.s.	n.s.
								B/C	n.s.	n.s.	n.s.

n.s. – not significant
SD – standard deviation

Table 5

Nitrogen, phosphorus and potassium content in potato tubers after 6 months of storage depending on research factors (g kg^{-1} dry weight), average from 2009/2010-2011/2012 storage seasons

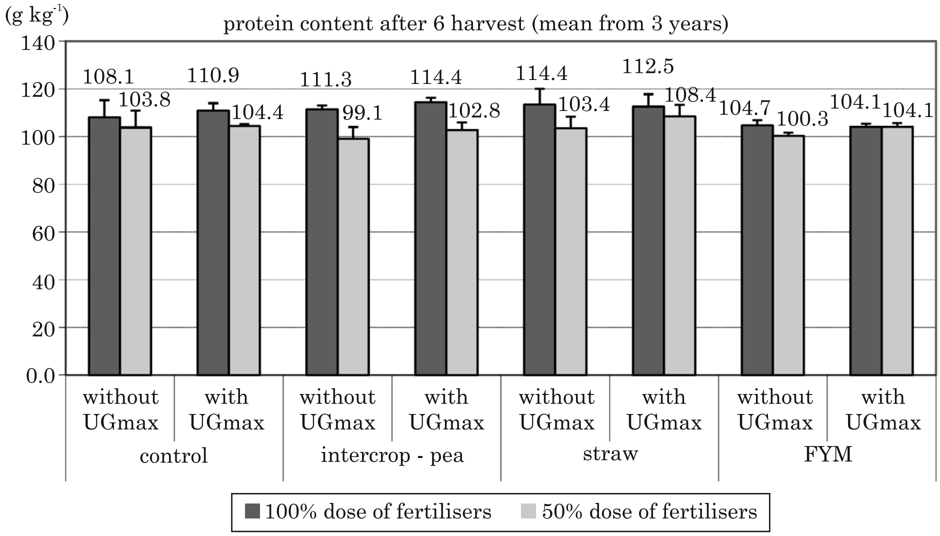
Research factors			Mineral fertilisation (B)						Average		
			100% dose			50% dose					
Organic matter (A)	bio- fertiliser (C)		N	P	K	N	P	K	N	P	K
Control	without soil fertili- sers	average from years	16.26	2.97	20.65	15.10	1.93	20.23	15.68	2.45	20.44
		SD	0.35	0.02	0.21	1.14	0.01	0.44	0.74	0.02	0.33
	with soil fertili- sers	average from years	16.94	3.00	21.25	15.81	1.98	20.63	16.37	2.49	20.94
		SD	0.21	0.02	0.33	0.29	0.01	0.43	0.24	0.02	0.38
average			16.61	2.99	20.95	15.46	1.96	20.43	16.03	2.47	20.69
Intercrop- pea	without soil fertili- sers	average from years	15.55	3.08	21.98	15.86	2.02	21.66	15.70	2.55	21.82
		SD	0.64	0.01	0.16	1.63	0.01	0.23	1.14	0.01	0.19
	with soil fertili- sers	average from years	17.06	3.09	22.73	16.26	2.04	22.16	16.66	2.56	22.44
		SD	0.21	0.01	0.32	0.21	0.01	0.38	0.21	0.01	0.35
Average			16.30	3.09	22.35	16.05	2.03	21.91	16.18	2.56	22.13
Straw	without soil ferti- lisers	average from years	15.90	3.10	22.74	15.30	2.07	22.58	15.60	2.58	22.66
		SD	1.28	0.01	0.23	0.29	0.01	0.41	0,78	0.01	0.32
	with soil fertili- sers	average from years	17.10	3.13	23.44	15.90	2.07	23.38	16.50	2.60	23.41
		SD	0.43	0.01	0.21	0.14	0.01	0.41	0,29	0.01	0.31
Average			16.50	3.12	23.09	15.60	2.07	22.98	16.05	2.59	23.03
FYM	without soil fertili- sers	average from years	17.34	3.28	24.46	15.86	2.26	23.97	16.61	2.77	24.22
		SD	0.21	0.01	0.44	0.21	0.01	0.11	0.21	0.01	0.28
	with soil fertili- zers	average from years	17.06	3.37	24.65	16.00	2.34	23.49	16.53	2.86	24.07
		SD	0.06	0.01	0.33	0.70	0.02	0.35	0.38	0.02	0.34
average			17.20	3.32	24.56	15.92	2.30	23.73	16.56	2.81	24.14
Average	without soil ferti- lizers	average from years	16.26	3.11	22.46	15.52	2.07	22.11	15.89	2.59	22.28
	with soil fertili- sers	average from years	17.04	3.15	23.01	15.98	2.11	22.41	16.51	2.63	22.71
Average			16.66	3.13	22.74	15.76	2.09	22.26	16.21	2.61	22.50
LSD (Tukey test) $p \geq 0.05$ n.s. – not significant								A	n.s.	n.s.	n.s.
								B	0.896	0.994	n.s.
								C	n.s.	n.s.	n.s.
								B/A	n.s.	n.s.	n.s.
								A/B	n.s.	n.s.	n.s.
								C/A	n.s.	n.s.	n.s.
								A/C	n.s.	n.s.	n.s.
								C/B	n.s.	n.s.	n.s.
								B/C	n.s.	n.s.	n.s.

was contained in potato tubers in simplified cultivation as compared with the traditional one, and the herbicides used for cultivation decreased the content of phosphorus. Other authors [Różyło and Pałys 2006] observed neither the effect of fertilisation nor the type of soil on the content of phosphorus, although in all the objects the phosphorus content was high: from 4.4 to 4.6 g kg^{-1}. In the tubers analysed in our experiment, the mean content of phosphorus for the objects was 3.51 g kg^{-1} of dry weight (Table 4).

The tubers from plants fertilised with full NPK contained significantly more phosphorus (by 30%) than those harvested from the plots with half a dose of mineral fertilisation. A similar tendency was observed, i.e. a higher concentration of phosphorus, after 6 months of storage in tubers from the plots of full mineral fertilisation (Table 5). Manure (FYM) introduced into soil significantly increased the content of potassium in tubers after harvest (Table 3). The concentrations of phosphorus decreased during storage (Table 5) depending on the content after harvest.

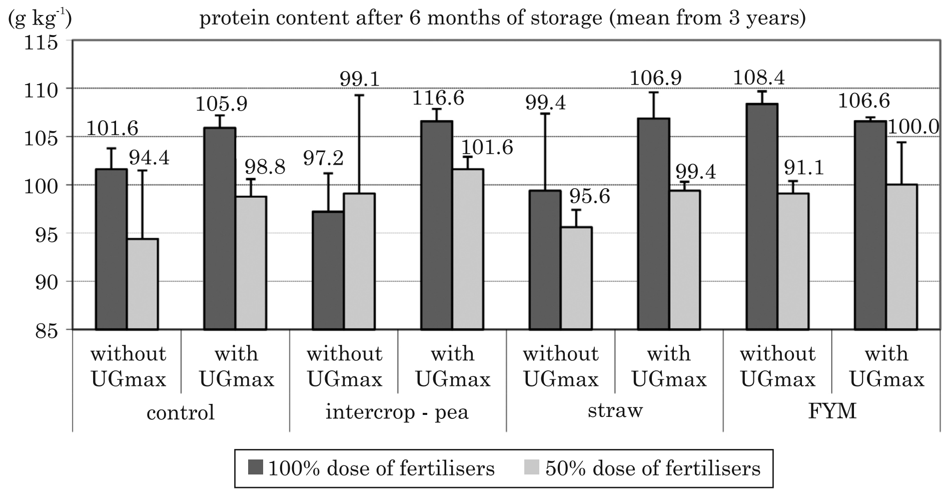
Of all the macroelements, potato tubers contained most potassium. The content of potassium in the dry weight of tubers was 25.9 g kg^{-1} on average and varied as a result of the type of organic and mineral fertilisation applied. The content of potassium in organic tubers investigated by Wierzbicka and Trawczyński (2011) was similar to the level of the potassium content in the fertilisation experiments, being on average 16.3 g kg^{-1} (Zarzecka, Gąsiorowska 2000, Płaza 2004, Prośba-Białczyk, Tajner-Czopek 2006). A higher level of potassium (17.5 g kg^{-1}) was recorded in tubers when mineral NPK fertilisation was applied than without it (15.5 g kg^{-1}) (Prośba-Białczyk, Tajner-Czopek 2006). In the studies which involved organic and mineral fertilisation (Płaza 2004), the mean content of potassium in tubers collected from an object with farmyard manure was 15.6 g kg^{-1} and in tubers from a variant with mineral fertilisation (without FYM) it declined to 14.1 g kg^{-1}. In other research (Różyło, Pałys 2006), the level of potassium was much higher than in the organic tubers investigated by Wierzbicka and Trawczyński (2011). The application of varied mineral-and-organic fertilisation by those authors resulted in a significant increase in the content of potassium (22.2 g kg^{-1}) compared to organic fertilisation (21.6 g kg^{-1}) or to the variant without fertilisation (21.1 g kg^{-1}). In the present research, the significantly highest amount of potassium was recorded in tubers from the plots fertilised with FYM as well as a complete dose of mineral fertilisation (27.91 g kg^{-1}).

Nitrogen compounds occur in tubers at the amount of about 2% converted into protein (N x 6.25), i.e. as the so-called total protein, with the share of pure protein between 35 and 65%. The daily protein requirements for an adult is 1 gram per kilogram of the body weight, e.g. with the body weight of 70 kg one should consume 70 g of protein daily (including 35 g of animal and 35 g of plant protein). Potato protein is a valuable nutrient, although its content in potato is small. The protein quality is determined by essential amino acids it contains; the body cannot synthesize them independently, which is why they must be supplied with food. Out of the eight amino acids people must ingest, seven are found in potato protein: leucine, lysine, isoleucine, phenylalanine, threonine, methionine and valine (Woda-Leśniewska 1993, Zgórska 2002, Ahmed et al. 2010). The content of protein considerably depends on the climate conditions during the vegetation period. Dry years enhance the increase in the total protein content in tubers (Roztropowicz 1989). The protein accumulation in tubers is also affected by genetic traits (Woda-Leśniewska 1993) and agrotechnical conditions (Szynal, Sykut 1992, Boligłowa, Dzienia 1999, Rivero 2003, Tekalign, Hammes 2005, Brzozowska 2008, Wichrowska et al. 2009). Based on the results given in Figure 3, the content of total protein in tubers ranged from 99.1 to 114.4 g kg^{-1} of dry weight and significantly depended on mineral fertilisation, where full NPK increased the content of the compound. The application of bio-fertiliser increased the content of total protein in tubers. According to Różyło and Pałys (2009), potato tubers from organic + mineral objects contained significantly more total proteins than tubers from the remaining objects. After 6-month storage in chambers at the temperature +4°C, the content of total protein decreased slightly, on average for treatments by 2.3% (Figure 4). According to Wichrowska et al. (2009) and Wichrowska (2013), total protein losses in the tubers stored at +4°C are lower than in chambers at the temperature of +8°C: by 1% after 3 months and by 2.9% after 6 months.



LSD (Tukey test) $p \geq 0.05$ A (organic matter) = n.s. B (mineral fertilisers) =1.6 C (UGmax) =1.9 B/A = 3.1 A/B = 17.7 C/A = n.s. A/C = n.s. C/B = n.s. B/C = n.s.

Fig. 3. Protein content in potato tubers after harvest depending on research factors (mg kg^{-1}dry weight) 2009-2011 average



LSD (Tukey test) $p \geq 0.05$ A (organic matter) = n.s. B (mineral fertilisers) = 5.6 C (UGmax) = n.s. B/A = n.s. A/B = n.s. C/A = n.s. A/C = n.s. C/B = n.s. B/C = n.s.

Fig. 4. Protein content in potato tubers after 6 months of storage depending on research factors (mg kg^{-1} dry weight), average from 2009/2010-2011/2012 storage seasons

CONCLUSIONS

1. A significant effect of the organic matter applied on the content of vitamin C and potassium in potato tubers was demonstrated.

2. Potato tubers from the plots fertilised with a complete dose of mineral fertilisers contained significantly more macroelements than tubers collected from the plots with half the dose of mineral fertilisers.

3. The microorganisms introduced into soil together with the bio-fertiliser caused a significant increase in the content of vitamin C, nitrogen as well as protein in tubers; they also increased the content of phosphorus and potassium in tubers. Beraing this in mind, it is justified to apply bio-agents in potato growing because they can transform the unavailable forms of nutrients into available ones owing to the microorganisms which they contain.

4. The content of nitrogen and protein in tubers significantly depended on the interaction of organic matter as well as a dose of mineral fertilisation introduced to soil. The highest levels of nutrients were found in tubers from the plots fertilised with pea grown as an intercrop, and from the plots with full NPK fertilisation.

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