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ORIGINAL PAPER

EFFECT OF MANURING WITH UNDERSOWN CATCH CROPS AND PRODUCTION SYSTEM ON THE POTATO TUBER CONTENT OF MACROELEMENTS*

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Abstract

Catch crop cultivation is facilitated by the systems of integrated and organic farming, which enable the best exploitation of natural factors affecting the yielding and chemical composition of potato tubers. The objective of this study has been to determine the effect of manuring with undersown catch crops and of a production system on the potato tuber content of macroelements. A field experiment was carried out in central-eastern Poland (52°03′N, 22°33′E), in 2009-2012. The aim was to examine the following two factors: I – manuring with undersown catch crops: control, (no manuring with undersown catch crop), farmyard manure, Persian clover, westerwolds ryegrass, Persian clover – mulch, westerwolds ryegrass – mulch; II – production system: integrated and organic. Total nitrogen, phosphorus, potassium, calcium and magnesium content was determined in the dry matter of potato tubers. The highest nitrogen content was found in tubers of potato manured with Persian clover applied as mulch. Phosphorus, potassium, calcium and magnesium were the highest only in tubers of potato manured with Persian clover incorporated into soil in the autumn. Potato tubers cultivated in the integrated production system contained more macroelements compared with organically grown potato. Potato manured with Persian clover mulch was supplied with the highest amount of nitrogen. Moreover, tubers of potato manured with Persian clover applied in the autumn contained the highest amounts of phosphorus, potassium, calcium and magnesium.

Keywords: minerals, potato, green manure, organic mulch, catch crops, production system.

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INTRODUCTION

Catch crop cultivation is facilitated by the system of integrated farming, which enables the best exploitation of natural factors affecting the yielding and chemical composition of potato tubers. It is also a conventional element of crop rotation in organic agriculture (Płaza 2004, Różyło, Pałys 2006). Persian clover and westerwolds ryegrass stand out among species recommended for cultivation owing to their high biomass production (Redulla et al. 2005). Catch crops provide potato with nutrients in various available forms. The mineralisation process of these manures gradually releases nutrients to the soil solution, where they become readily available for use by plants. These elements are both building blocks of plants and participants in their physiological functions (Leszczyński 2002). The potato tuber content of macroelements is affected by agrotechnological factors, including fertilisation. Findings reported by Leszczyński (2002) and Majchrowska-Safaryan (2015) have demonstrated an increase in the potato tuber content of microelements following organic and mineral fertilisation. Potato tubers accumulate nitrogen, potassium and phosphorus more readily than magnesium and calcium. Research by Płaza (2004) revealed that phosphorus, calcium and magnesium concentrations in tubers of potato manured with undersown catch crops and undersown catch crops + straw were at a similar level compared with tubers of potato following farmyard manure. However, the potassium content in tubers of potato manured with bird's foot trefoil + straw was higher compared with tubers of potato following farmyard manure application. In Poland, there is no research on the effect of green manures in different production systems on the potato tuber content of macroelements. Thus, the need arises to conduct this type of research. The objective of this study has been to determine the effect of manuring with undersown catch crops and of a production system on the table potato tuber content of macroelements.

MATERIAL AND METHODS

Field research was conducted in 2009-2012, at the Zawady Experimental Station owned by the Siedlce University of Natural Sciences and Humanities (52°03′N, 22°33′E). The research was carried out in the soil taxonomically classified as follows: order – Luvisols, type – Luvisols, subtype – Albic Luvisols. The soil represents the very good rye complex of agricultural soil suitability, quality class IVa. It had neutral pH and a moderate content of available phosphorus, potassium and magnesium (Table 1). Its humus content was 1.39% (Tiurin method – Ostrowska et al. 1991).

The experiment was set up in a split-block arrangement with three replicates. The following two factors were examined: I – manuring with under-

Table 1

Chemical properties of soil plough layer before the experiment in 2009-2011

Years	Available form content (mg kg^{-1})			pH in KCL	Humus content (%)
	P	K	Mg		
2009	5.14	11.15	5.49	6.4	1.36
2010	5.32	12.23	5.66	6.7	1.40
2011	5.23	11.30	5.55	6.6	1.41

sown catch crops: control (no manuring with undersown catch crop), farmyard manure (30 t ha^{-1}), Persian clover (seed sowing dose: 18 kg ha^{-1}), westerwolds ryegrass (seed sowing dose: 20 kg ha^{-1}), Persian clover – mulch (seed sowing dose: 18 kg ha^{-1}), westerwolds ryegrass – mulch (seed sowing dose: 20 kg ha^{-1}); II – production system: integrated and organic.

In autumn, aerial parts and post-harvest residues, including roots in the topmost, 0-30 cm soil layer, were sampled from 1 m^2 on each plot in order to determine fresh matter yield. Samples of undersown catch crop post-harvest residues were collected with a borehole method (Batalin 1962). The respective average yields across the study years for Persian clover and westerwolds ryegrass were: 28.3 and 36.4 t ha^{-1} in the integrated production system, and 23.7 and 28.1 t ha^{-1} in the organic production system.

The undersown catch crops were seeded into spring triticale, which was cultivated for grain and followed by table potato. In the integrated production system, mineral fertilisers were applied over the whole experimental area at the following doses: 90 kg N as 34% ammonium nitrate, 36.9 kg P as 46% triple superphosphate and 99.6 kg K as 60% potassium chloride per 1 ha in early spring. The doses were adjusted to the soil availability and anticipated yield levels. In autumn ploughed plots, mineral fertilisers were mixed with soil with a cultivator coupled with a harrow. In mulched plots, a disc harrow was followed by a cultivator. In the organic production system, mineral fertilisation was replaced with farmyard manure spread over the whole experimental area at a dose of 30 t ha^{-1} before spring triticale was cultivated with undersown catch crops. The application of 30 t ha^{-1} farmyard manure resulted in the following nutrient amounts introduced into the soil per 1 ha: 160.8 kg N, 47.9 kg P, 133.4 kg K, 62.8 kg Ca and 39.4 kg Mg. Potatoes were planted in late April and harvested in mid-September. Table potato cv Zeus, which is a medium late variety, was cultivated. In the integrated production system, weeds in potato fields were controlled mechanically and chemically. Potatoes were hilled and harrowed every seven days prior to emergence. Just before potatoes emerged, a mixture of Afalon 50 WP and Reglone Turbo 200 SL (1 kg + 1 dm^3 ha^{-1}) was applied. The Colorado potato beetle was controlled by two applications of Fastac (0.1 dm^3 ha^{-1}), and potato blight was controlled by two applications of Ridomil MZ 72 WP (2 dm^3 ha^{-1}). In organic potato fields, mechanical weed control was used. The Colorado

potato beetle was controlled by two applications of Novodor SC (2.5 dm^3 ha^{-1}), and potato blight was controlled by two applications of Miedzian 50 WP (4 kg ha^{-1}). For a series of 3 experiments, strips of organically managed fields (204 m^2 for each replicate) were excluded from conventional cultivation in 2008-2010. Throughout these years, oat-based crop rotation was used with no chemical plant protection applied. During potato harvest, tuber samples were collected to determine the macroelement content. The content of the following minerals was determined in the dry matter of potatoes: nitrogen – with the Kjeldahl method (Krełowska-Kułas 1993), phosphorus – the vanadium -molybdenum method (Kalembasa et al. 1989), potassium and calcium – with the flame photometry method (Kalembasa et al. 1989) and magnesium – with atomic absorption spectrometry (Kalembasa et al. 1989).

The data concerning all the characteristics examined was subjected to variance analysis for the split-block design. Separation of means for significant sources of variation was obtained with the Tukey test. Statistical calculations were performed using algorithms written by the authors in Excel 7.7.

RESULTS AND DISCUSSION

The nitrogen content in potato tubers was significantly affected by the experimental factors and their interaction (Table 2). Manuring with undersown catch crop biomass and farmyard manure significantly increased the nitrogen content in potato tubers compared with control. Undersown catch crops applied as manures contributed to a significant increase in the nitrogen content in potato tubers compared with autumn-incorporated undersown

Table 2

Nitrogen content in potato tubers, means from 2010-2012 (g kg^{-1} d.m.)

Manuring with undersown catch crop	Production system		Means
	integrated	organic	
Control	13.69	13.18	13.44
Farmyard manure	14.89	14.40	14.65
Persian clover	16.60	15.50	16.05
Westerwolds ryegrass	14.27	13.71	13.99
Persian clover – mulch	17.73	16.00	16.87
Westerwolds ryegrass – mulch	15.12	14.70	14.91
Means	15.38	14.58	-
$LSD_{0.05}$			
Manuring with undersown catch crops			0.283
Production system			0.172
Interaction			0.424

catch crops. A possible explanation for this is that the process of organic matter mineralisation is inhibited when undersown catch crops are left on the soil surface until spring, and nitrogen is gradually released for uptake by potato plants. There is no nitrogen loss, unlike autumn-incorporated undersown catch crops, in particular leguminous plants. Research by Gianquinto, Bona (2000) Płaza (2004), Różyło, Pałys (2006), Pikka et al. (2007), Wierzbicka, Trawczyński (2011) and Wierzbicka (2012) indicated that each form of fertilisation significantly increased the nitrogen content in potato tubers. In the present study, the highest nitrogen concentration was recorded in tubers of potato manured with either autumn- or spring-incorporated Persian clover undersown catch crop. Ceglarek, Płaza (2000) and Płaza (2004) demonstrated that the nitrogen content was the highest in potato tubers following the ploughing in of undersown legumes, which was due to the fact that leguminous plants are an abundant nitrogen source for potato. In the study discussed here, the nitrogen content in tubers of potato manured with westerwolds ryegrass left as mulch on the soil surface until spring differed insignificantly from potato following farmyard manure. It was significantly lower in potato following westerwolds ryegrass compared with crops following farmyard manure. However, in this case, the nitrogen concentration in potato tubers was significantly higher compared with control potatoes cultivated without undersown catch crop manuring. This finding agrees with the results reported by Majchrowska-Safaryan (2015), who demonstrated that in the control unit, which was either non-fertilised or fertilised with mineral fertiliser only, the nitrogen content of potato tubers was the lowest. A production system significantly affected the nitrogen content in potato tubers. A higher nitrogen concentration was recorded in the integrated rather than organic production system. Also Sawicka, Barbaś (2007), Hargreaves et al. (2008) and Sawicka et al. (2016) reported a higher nitrogen content in tubers of potato cultivated in the integrated production system, where organic and mineral fertilisation was applied compared with the organic system, where only organic fertilisation was used. Compared with natural or organic manures, nitrogen supplied with mineral fertilisers is more readily available for potato crop uptake. In the present experiment, an interaction of the experimental factors was found. The lowest nitrogen content was determined in tubers of control potato in the organic system in which potato took up nitrogen supplied with farmyard manure applied before the cultivation of spring triticale undersown with undersown catch crops. An application of mineral fertilisation in the control treatment of the integrated production system significantly increased the mineral nitrogen content in potato tubers. A combined application of mineral fertilisation, farmyard manure and undersown catch crops in the integrated production system significantly increased the mineral nitrogen content of potato tubers compared with their organic counterparts cultivated without mineral fertilisation. The highest nitrogen content was determined in tubers of potato manured with undersown Persian clover mulch in the integrated production system. Also, potato tubers following autumn-incorpo-

rated Persian clover contained significantly more nitrogen than potatoes following farmyard manure.

Statistical analysis demonstrated a significant effect of the experimental factors and their interaction on the potato tuber content of phosphorus (Table 3). Manuring with undersown catch crops and farmyard manure pro-

Table 3

Phosphorus content in potato tubers, means from 2010-2012 (g kg^{-1} d.m.)

Manuring with undersown catch crop	Production system		Means
	integrated	organic	
Control	2.583	2.194	2.389
Farmyard manure	3.157	2.556	2.857
Persian clover	3.564	2.883	3.224
Westerwolds ryegrass	2.872	2.351	2.612
Persian clover – mulch	3.256	2.695	2.976
Westerwolds ryegrass – mulch	2.734	2.262	2.498
Means	3.028	2.490	-
$LSD_{0.05}$			
Manuring with undersown catch crop			0.072
Production system			0.058
Interaction			0.085

moted a higher phosphorus content in potato tubers compared with control potato. The phosphorus content in tubers of potato manured with autumn-incorporated undersown catch crops was significantly higher compared with potato following farmyard manure. However, undersown catch crops applied as mulch contributed to a significant decline in the potato tuber content of phosphorus compared with potato following farmyard manure. It follows from the fact that the decomposition of organic matter left as mulch on the soil surface until spring is less rapid, hence less phosphorus is available for uptake by plants. Nevertheless, the phosphorus content in tubers of potato manured with Persian clover, which was either left as mulch on the soil surface or incorporated in autumn, was higher compared with potato following farmyard manure. This can be explained by the fact that leguminous plants used to manure potato crops have got high phosphorus content, which results in more phosphorus being made available for the potato plants. This finding agrees with reports by Płaza, Ceglarek (2000), Płaza (2004) and Kołodziejczyk, Szmigiel (2005), who have demonstrated that an application of catch crops or vermicompost increases the phosphorus content in potato tubers. In the study discussed here, only tubers of potato following westerwolds ryegrass contained significantly less phosphorus than tubers of potato following farmyard manure. However, the phosphorus concentration in these tubers was still higher than in control ones, which can be explained by the fact that grasses contain low amounts of phosphorus, and therefore when

the grasses are used as manures the availability of this element for crops is lower. According to Wierzbicka, Trawczyński (2011) and Majchrowska-Safaryan (2015), every type of organic manuring increases the phosphorus content in potato tubers. Also research by Płaza (2004) and Wang et al. (2008) demonstrated that an application of standard fertilisation promoted the accumulation of phosphorus in potato tubers. Blecharczyk et al. (2008) and Majchrowska-Safaryan (2015) showed that farmyard manure and spent mushroom substrate increased the phosphorus content in potato tubers. In the present study, a production system had a significant influence on the phosphorus content in potato tubers. Similarly to reports by Hajšlová et al. (2005), Sawicka, Barbaś (2007), Food et al. (2011) and Wierzbica (2012), the potato tuber content of phosphorus was higher in the integrated production system, which can be explained by the fact that potato plants in this system can use phosphorus supplied in both mineral and organic form while organic potatoes have only organic phosphorus at their disposal. Organic matter decomposes over a longer period of time and so less phosphorus is available for uptake by plants. In the study reported here, an interaction was confirmed between the experimental factors. The lowest phosphorus content was determined in organic control potato tubers. In this case, potato plants made use of phosphorus supplied with farmyard manure applied prior to the cultivation of the crop which preceded potato. Even in the control unit, an application of mineral fertilisation prior to potato cultivation in the integrated production system significantly increased the phosphorus content in potato tubers. The potato tuber content of phosphorus was significantly higher in all the plots fertilised with undersown catch crops, farmyard manure and mineral fertiliser in the integrated production system compared with plots where potato was organically cultivated and followed farmyard manure and green manures. The highest phosphorus content was recorded in tubers of potato manured with Persian clover, regardless of the mode of its application, in the integrated production system. Persian clover green manure decomposes more rapidly than farmyard manure and, as a result, more phosphorus is available for potato crops. Lower phosphorus content was determined in tubers of potato manured with westerwolds ryegrass, regardless of its mode of application, compared with farmyard manure.

The potassium content in potato tubers was significantly affected by the experimental factors and their interaction (Table 4). Manuring with undersown catch crops significantly increased the potassium content in potato tubers compared with tubers of potato cultivated in the control unit. The potassium content in tubers of potato manured with autumn-incorporated undersown catch crops was significantly higher than in tubers of potato following undersown catch crops applied as mulch. The organic matter of undersown catch crops left as mulch on the soil surface for spring incorporation underwent mineralisation, and less potassium was available for potato crops. The highest potassium concentration was determined in tubers of potato manured with autumn-incorporated Persian clover. Also in the study

Table 4

Potassium content in potato tubers, means from 2010-2012 (g kg^{-1} d.m.)

Manuring with undersown catch crop	Production system		Means
	integrated	organic	
Control	15.36	13.97	14.67
Farmyard manure	16.74	15.68	16.21
Persian clover	17.19	15.94	16.57
Westerwolds ryegrass	16.38	15.30	15.84
Persian clover – mulch	16.64	15.44	16.04
Westerwolds ryegrass – mulch	15.95	15.01	15.48
Means	16.38	15.22	-
$LSD_{0.05}$			
Manuring with undersown catch crop			0.323
Production system			0.241
Interaction			0.485

by Płaza (2004), the highest potassium content was recorded in tubers of potato manured with leguminous undersown crops. Similarly, Kołodziejczyk, Szmigiel (2005) found the highest potassium content in catch crop- and vermicompost-manured potato tubers. In this study, the potassium content in tubers of potato manured with Persian clover mulch differed insignificantly from the potassium concentration recorded in tubers of potato following farmyard manure. The potassium content was significantly lower in tubers of potato following westerwolds ryegrass, regardless of its mode of application, than in tubers of potato following farmyard manure. However, the potassium content was still significantly higher than the control concentration. Płaza (2004), Prośba-Białczyk, Tajner-Czopek (2006), Blecharczyk et al. (2008), Klikocka (2009) and Majchrowska-Safaryan (2015) reported higher potassium content in tubers of potato crops following both organic and mineral fertilisation compared with the control where only mineral fertilisation was applied. In the experiment reported here, a production system had a significant effect on potassium content in potato tubers. The concentration of this element was significantly higher in potato tubers in the integrated production system, which agrees with reports by Sawicka, Barbaś (2007) and Hargreaves et al. (2008). Also in the study by Różyło, Pałys 2006), the tuber content of potassium in the integrated production system was much higher than in organic tubers. A possible explanation is that in the aforementioned production system, both organic manuring and mineral fertilisers are applied in the integratedc system, and the potassium supplied with the latter fertilisation is more readily available for potato plant uptake from the soil compared with the organic production system. Natural and organic manure decomposition takes longer and so the potassium availability is lower. In the present study, an interaction was found. The lowest potassium content was

determined in tubers of control potatoes in the organic production system, where the crop preceding potato followed farmyard manure. An application of mineral fertilisation in the control unit contributed to an increase in the tuber content of potassium in the integrated production system. Moreover, in this system, the potassium content in tubers of potato manured with undersown catch crops, excluding westerwolds ryegrass applied as mulch, differed insignificantly from the concentration of this element in tubers of potato following farmyard manure. A similar relationship was observed in the organic production system, but the potassium content in individual fertilisation units was significantly lower compared with the integrated production system. By contrast, Wierzbicka, Trawczyński (2011) reported a higher potassium content in tubers of potato crop following mineral fertilisers only.

Statistical analysis demonstrated a significant effect of the experimental factors and their interaction on the calcium content in potato tubers (Table 5). Manuring with undersown catch crops increased the calcium content in potato tubers compared with control. The calcium content in tubers of potato manured with autumn-incorporated undersown catch crops was significantly higher compared with the one in tubers of potato following undersown catch crops applied as mulch. The highest calcium content was determined in tubers of potato manured with autumn-incorporated Persian clover. Also Płaza (2004) found that an application of leguminous undersown crops beneficially influenced calcium content in potato tubers. In a study by Kołodziejczyk, Szmigiel (2005) calcium content in potato tubers was the highest when catch crop had been applied. It can be explained by the fact that leguminous plants contain more calcium compared with grasses. In the present study, calcium content in tubers of potato manured with Persian clover mulch differed insignificantly from the calcium concentration in potato tubers following far-

Table 5

Calcium content in potato tubers, means from 2010-2012 (g kg^{-1} d.m.)

Manuring with undersown catch crop	Production system		Means
	integrated	organic	
Control	0.683	0.491	0.587
Farmyard manure	1.167	1.053	1.110
Persian clover	1.354	1.067	1.211
Westerwolds ryegrass	1.025	0.724	0.875
Persian clover – mulch	1.166	0.862	1.014
Westerwolds ryegrass – mulch	0.782	0.586	0.684
Means	1.196	0.797	-
$LSD_{0.05}$			
Manuring with undersown catch crop			0.097
Production system			0.076
Interaction			0.109

myard manure. The calcium content in potato tubers was significantly lower only for potato manured with westerwolds ryegrass, regardless of its mode of application, compared with tubers of potato following farmyard manure. By contrast, Różyło, Pałys (2006) found no significant effect of fertilisation on potassium content in potato tubers. In the study reported here, production system had a significant effect on calcium content in potato tubers. Its concentration was higher in potato tubers in the integrated rather than organic production system. A similar relationship was reported by Sawicka, Barbaś (2007), whereas Wierzbicka, Trawczyński (2011) and Sayed et al. (2015) found a lower calcium content in organic tubers. In the present study, an interaction was found. The lowest calcium content was determined in control tubers in the organic production system where the crop preceding potato followed farmyard manure application. More calcium was taken up by the preceding crop than by potato. In the integrated production system, the calcium content in control potato tubers was significantly higher, but lower compared with tubers of potato crop following farmyard manure or manured with undersown catch crops. The highest calcium content was recorded in tubers of potato manured with autumn-incorporated Persian clover. The calcium concentration in tubers of potato manured with Persian clover mulch differed insignificantly from the calcium content determined in tubers of potato following farmyard manure. The calcium content was significantly lower in tubers of potato following the above manures in the organic production system. It was due to the fact that undersown crops cultivated in the organic production system produced less biomass, which translated into a lower calcium quantity supplied for uptake by plants.

The magnesium content in potato tubers was significantly influenced by manuring with undersown catch crops, production system and interaction of these two factors (Table 6). Manuring with undersown catch crops and farmyard manure increased the magnesium content in potato tubers compared with control tubers. Undersown catch crops incorporated in autumn supplied potato crops with more magnesium than undersown catch crops left on the soil surface as mulch for spring incorporation, as the latter inhibited the process of organic matter decomposition and potato plants had less magnesium available for uptake. The highest magnesium concentration was found in tubers of potato manured with autumn-incorporated Persian clover, which agrees with results reported by Płaza (2004) and Kołodziejczyk, Szmigiel (2005). In the present study, the magnesium concentration in tubers of potato manured with Persian clover mulch differed insignificantly from its content in tubers of potato following farmyard manure. An application of mulch consisting of leguminous plants, which are rich in magnesium, inhibits the process of organic matter mineralisation and reduces the availability of this element for plants. The magnesium content in potato tubers was significantly lower in plots manured with westerwolds ryegrass, regardless of the mode of its application, than the concentration determined in tubers of potato following farmyard manure. However, the magnesium concentration was

Table 6

Magnesium content in potato tubers, means from 2010-2012 (g kg^{-1} d.m.)

Manuring with undersown catch crop	Production system		Means
	integrated	organic	
Control	0.592	0.277	0.435
Farmyard manure	0.886	0.483	0.685
Persian clover	1.137	0.762	0.950
Westerwolds ryegrass	0.784	0.486	0.635
Persian clover – mulch	0.903	0.675	0.789
Westerwolds ryegrass – mulch	0.698	0.374	0.536
Means	0.833	0.510	-
$LSD_{0.05}$			
Manuring with undersown catch crop			0.106
Production system			0.089
Interaction			0.124

still significantly higher compared with control tubers. In contrast, Wierzbicka, Trawczyński (2011) and Sayed et al. (2015) reported similar magnesium content in tubers of potato crops following various forms of fertilisation. In the study discussed here, a production system significantly affected the magnesium content in potato tubers, which was higher in organic tubers. Also Różyło, Pałys (2006), Wierzbica, Trawczyński (2011) and Sawicka et al. (2016) found a significantly lower magnesium content in organic tubers. In an organic production system, catch crops produce less biomass and supply potato crops with less magnesium. In the present study, an interaction of the experimental factors was found. The magnesium content was the lowest in control tubers in the organic production system, where the crop preceding potato followed farmyard manure. The highest magnesium content in the integrated production system was recorded in tubers of potato manured with autumn-incorporated Persian clover. The magnesium concentration in tubers of potato manured with the remaining undersown catch crops, excluding westerwolds ryegrass applied as mulch, differed insignificantly from the magnesium content in tubers of potato following farmyard manure. In contrast, in the organic production system the magnesium content in potato tubers was significantly lower for all the fertilisation treatments. This can be explained by the fact that in the integrated production system catch crops produce more biomass and consequently supply potato crops with more magnesium compared with the organic system.

CONCLUSIONS

1. The highest nitrogen content was recorded in tubers of potato manured with Persian clover applied as mulch. The concentration of macroelements in tubers of potato manured with autumn-incorporated Persian clover was at a level similar to the one in tubers of potato following farmyard manure, both in the integrated and organic production system.

2. Potato tubers in the integrated production system contained more macroelements compared with organic tubers.

3. Manuring of potato with Persian clover mulch contributed to the highest concentration of nitrogen, and manuring with autumn-incorporated Persian clover resulted in the highest concentration of phosphorus, potassium, calcium and magnesium.

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