Journal of Elementology ISSN 1644-2296

Klikocka H., Kobiałka A., Juszczak D., Głowacka A. 2015. *The influence of sulphur on phosphorus and potassium content in potato tubers (Solanum tuberosum L.)*. J. Elem., 20(3): 621-629. DOI: 10.5601/jelem.2014.19.2.661

THE INFLUENCE OF SULPHUR ON PHOSPHORUS AND POTASSIUM CONTENT IN POTATO TUBERS (*SOLANUM TUBEROSUM* L.)

Hanna Klikocka, Anna Kobiałka, Dariusz Juszczak, Aleksandra Głowacka

Faculty of Agrobioengineering
University of Life Sciences in Lublin

Abstract

The objective of the study was to investigate the impact of sulphur application on the content (g kg^{-1}) and uptake (kg ha^{-1}) of phosphorus and potassium with the yield of potato tubers. In 2004-2006, a field experiment on potato was conducted, in which S was applied in different forms (elemental and K_2SO_4) and doses (0, 25 and 50 kg ha^{-1}).

The content and uptake of P and K in the dry mass of potato tubers was significantly increased by sulphur. The application of sulphur increased the P content and uptake irrespective of the S dose, but elemental S proved more effective. The K content was the highest when sulphate was applied at 50 kg S ha^{-1}. The K uptake by tubers was significantly increased by both of the applied doses versus the control plots. The tuber yield depended substantially on the rate of S fertilizer.

Sulphur applied as sulphate increased the content of SO_4-S in the soil. The application of elemental S in a dose of 50 kg ha^{-1} decreased the soil pH. The soil content of total C was dependent on each dose and form of the applied sulphur. The content of SO_4-S and total C in the soil positively correlated with the P content and uptake by potato tubers. A negative correlation was found between the pH value and content and uptake of P by potato tubers. No correlation was found between K and soil parameters, but a positive correlation was found between the P and K uptake by tubers and between the P and K uptake versus tuber yield.

Keywords: phosphorus, potassium, fertilization, potato.

prof. dr hab. Hanna Klikocka, Faculty of Agrobioengineering, University of Life Sciences, 20-950 Lublin, Akademicka 13, Poland, e-mail: hanna.klikocka@up.lublin.pl

INTRODUCTION

The clean air laws have drastically restrained SO_2 emissions in Europe, including Poland, up to the point when macroscopic sulphur deficiency became a widespread nutrient disorder in agricultural production (Haneklaus et al. 2003, Siebielec et al. 2012). Sulphur application has been found to increase yields of potato tubers, improve tuber quality and strengthen resistance to *Streptomyces scabies* and *Rhizoctonia solani* (Klikocka et al. 2005, Klikocka 2010). According to Wang et al. (2008), potato is not a highly sulphur demanding crop, with the S concentrations ranging from 1.2 to 2.8 g kg^{-1} in the dry matter of tuber and haulm, but considerable amounts of S can be removed from the soil over years when potato yields are high. In S-deficient soil, application of S fertilizer can significantly increase the tuber yield and starch content of potato, while contributing to a decrease in the tuber N concentration owing to increased dry matter production (Kołodziejczyk 2014). Furthermore, Eppendorfer and Eggum (1994) found that S deficiency significantly influenced the amino acid composition of potatoes; the concentration of the S-containing amino acids methionine and cysteine decreased by 30% and 60%, respectively, in S-deficient soil.

Potatoes (*Solanum tuberosum* L.) are the fourth most important food crop in the world, providing more food than the combined world output of fish and meat. Potato tubers contain 1-1.2% mineral compounds, of which the most basic ones are potassium, magnesium, calcium and phosphorus (Gugała, Zarzecka 2011, Klikocka,Głowacka 2013). Potassium and phosphorus perform important building functions, they are also an integral part of enzymes and play an important role as regulators of metabolic processes (Rivero al. 2003). Research by Wichrowska et al. (2009) has indicated that a portion of about 300 g of potatoes provides the human body with 48.6% of the recommended daily dietary intake of potassium and 25.1% of the recommended intake of phosphorus.

However, little information is available on the influence of S supply on the phosphorus and potassium content in potato tubers. Thus, an attempt was made to determine the effect of the form (sulphate or elemental) and dose (0, 25, 50 kg ha^{-1}) of soil-applied sulphur on the content and uptake of P and K in the dry mass of potato tubers.

MATERIAL AND METHODS

In 2004-2006, field experiments on potatoes were conducted at Malice (N 50°42′; E 23°15′), south-eastern Poland. They were set up in a split plot design with four replications, on Cambisols (WRB 2007) consisting of light silty sand. The soil pH was 5.2. The average soil content (g kg^{-1} of soil) of total C was 7.4 and total N was 0.7. The soil content (mg kg^{-1} of soil) of P was 41.7, K – 76.8, Mg – 30.8 and S-SO_4 – 10.1 (analytical methods for soil parameters are in Table 1).

Table 1

Analytical methods for plant tissue materials and for soil

Parameter	Method
Plant tissue materials	
Dry matter	by the oven method (at 105°C)
P	determined by the photometric method
K	extraction with 2 N HCl, determined by atomic absorption spectrophotometry (AAS)
Soil	
pH	potentiometrically in 0.01 M $CaCl_2$ suspension using a Methrohm 605 pH-meter
C-total	combustion by LECO EC-12®, model 752-100
N-total	determined by the Kjeldahl's method
P	determined by the photometric method
K	determined by AAS
Mg	determined by AAS
SO_4-S	extracted by 0.025 M KCl and determined by ion-chromatograph

The area of the plots was 30 m^2 for planting and observation, and 19.5 m^2 (3.0 m× 6.5 m) for harvesting. A medium-early, edible potato variety called Iriga was planted.

The following S treatments were tested: 0, 25 and 50 kg ha^{-1}as K_2SO_4 and as elemental S. After harvesting of spring triticale, 3 t ha^{-1} straw from that cereal (as organic fertilizer) and 46 kg N ha^{-1} (urea $CO(NH_2)_2$, for stabilization of the C:N ratio) were applied, and the soil was ploughed (20 cm, second or third decade of August). Spring field work was carried out in the third decade of March, using shallow ploughing (15 cm). Each year, mineral fertilizers were applied pre-planting (kg ha^{-1}): 100 N (as ammonium nitrate); 40 P (as mineral superphosphate – triple granular); and 140 K (as potassium chloride in control plots and in plots with elemental S, and as potassium chloride balanced with potassium sulphate in plots with sulphate sulphur – 116 kg of K as K_2SO_4 + 24 kg of K as KCl). Potato planting was carried out in the second decade of April. The inter-row space was 67.5 cm with 44,000 tubers planted per ha. The distance between plants in a row was 30 cm.

Chemical application of fungicides and herbicides for control of pests and potato diseases was carried out as recommended by the Institute of Plant Protection (IOR-Poland).

Precipitation (April-September) was similar to the long-term average during the potato growing seasons in 2005-2006. The long-term average (1971-2005) was 329.8 mm, while in 2005 and 2006 it was 315.2 and

329.8 mm. In 2004, precipitation was higher than the long-term average (less than 54.3 mm). The sum of mean monthly temperatures (April-September) during the analysed period was higher than the sum of mean monthly temperatures in the long-term: 2901°C in 2004, 2949°C in 2005, and 3142°C in 2006, while in the long-term it was 2687°C.

Potato dry matter was determined by the oven method (at 105°C). The P content in the dry mass of tubers was determined by the photometric method, and K by atomic absorption spectrophotometry (Table 1).

Statistical analysis of data was carried out using Manova in Excel 7.0 and Statistica (StatSoft Polska'97). The differences between means were determined using the Tukey's test at a significance level of $P = 0.05$.

RESULTS AND DISCUSSION

The analysis of variance showed that the differences in the content and uptake of phosphorus and potassium with the yield of potato tubers were statistically significant. The experimental factors had different effects on the analysed characteristics (Table 2).

The content and uptake of P with the yield of tubers depended significantly on the dose of S and form of S fertilizer as well as their interaction, and on the year of the study. Doses of 25 and 50 kg ha^{-1}, irrespective of the form of S fertilizer, significantly increased the P content and P uptake with yield in comparison to the control, but the difference between the two doses of S was not significant. The effect of both forms of S fertilizer was favourable in comparison to the control. As regards the dose × form interaction, the highest P content in the dry mass of tubers was observed after an application of elemental S, irrespective of the dose, and after a double dose of sulphate. The uptake of P with the yield of tubers was increased by the S application, irrespective of the dose and form of S fertilizer.

In 2004 and 2006, the content of P in the dry mass of tubers was higher than in 2005. The uptake of P with the yield of tubers was higher in 2006 and 2004 than in 2005 (Table 2).

The K content in the dry mass of potato tubers was higher after the dose of 50 kg S ha^{-1} in the form of sulphate than in the control, the dose of 25 kg ha^{-1} and the application of elemental form. However, taking into account the interaction between the S form and dose, the highest K content was noted in the combinations with 50 kg S ha^{-1}, both sulphate and elemental sulphur. The lowest uptake of K by tubers was observed in the control and in the plots with 25 kg of elemental form ha^{-1}. The years of the study did not modify the K content in the dry mass of tubers, but the K uptake with the yield of tubers was dependent on the growing season. The highest K uptake was in 2005 and 2006, whereas the highest content of K in tubers was noted in

Table 2

The influence of S application on the content (g kg^{-1}) and uptake (kg ha^{-1}) of P and K in potato tubers and yield of tubers (t ha^{-1}), as well as the soil characteristics

S dose (kg ha^{-1})	S form	Phosphorus		Potassium		Tuber yield (t ha^{-1})	pH (0.01 M $CaCl_2$)	Content C-total (g kg^{-1})	Content SO_4-S (mg kg^{-1})
		A*	B**	A	B				
content in dry mass of potato tubers							content in soil		
0 – control		2.95	17.10	20.19	117.4	25.56	5.25-5.33	7.97	24.78
25	SO_4-S	3.11	19.54	21.88	137.5	28.06	5.18-5.40	7.88	28.73
25	S^0	3.29	19.06	20.17	116.6	26.17	5.19-5.32	9.69	25.83
50	SO_4-S	3.22	18.69	22.97	132.6	27.02	5.20-5.42	9.01	33.07
50	S^0	3.39	20.20	22.42	132.4	27.44	5.08-5.21	9.33	26.26
0 – control		2.95	17.10	20.19	117.4	25.56	5.25-5.33	7.97	24.78
25	mean	3.20	19.30	21.03	127.0	27.12	5.21-5.31	8.79	27.28
50		3.30	19.35	22.69	132.5	27.23	5.15-5.32	9.17	29.66
0 – control		2.95	17.10	20.19	117.4	25.56	5.25-5.33	7.97	24.78
SO_4-S	mean	3.17	19.11	22.42	135.1	27.54	5.24-5.32	8.45	30.90
S^0		3.34	19.54	21.30	124.5	26.81	5.15-5.23	9.51	26.05
	2004	2.87	16.01	21.84	121.8	25.03	5.26-5.33	7.61	23.50
Years	2005	3.72	22.34	21.25	127.6	27.07	5.26-5.38	9.12	35.44
	2006	2.98	18.29	21.49	132.4	28.46	5.23-5.35	9.61	24.26
F-distribution	R	11.88	9.80	3.99	4.62	5.20	-	24.78	2.43
	F	10.63	7.81	3.77	5.16	6.55	-	67.21	5.58
	R × F	4.73	4.12	3.72	3.93	3.11	-	18.55	3.47
	Y	57.69	57.06	0.33	1.99	15.67	-	50.85	23.49
p-value	R	0.0001	0.0006	0.0303	0.0188	0.0123	-	0.0001	0.1070
	F	0.0004	0.0021	0.0359	0.0126	0.0048	-	0.0001	0.0116
	R × F	0.0028	0.0064	0.0107	0.0081	0.0242	-	0.0001	0.0149
	Y	0.0001	0.0001	0.7181	0.1479	0.0001	-	0.0001	0.0001
LSD *P* = 0.05	R	0.17	1.19	1.75	8.30	1.13	-	0.28	n.s.
	F	0.17	1.19	1.75	8.30	1.13	-	0.28	3.34
	R × F	0.22	1.56	1.90	10.05	1.60	-	0.54	5.07
	Y	0.17	1.19	n.s.	8.30	1.13	-	0.28	3.34

*A – content in d.m. of tubers (g kg^{-1}), **B – uptake with the yield of tubers (kg ha^{-1})
Variable: R – dose (df_1 = 2, df_2 = 27), F – form (df_1 = 2, df_2 = 27), RF – dose x form (df_1 = 4, df_2 = 45), Y – years (df_1 = 2, df_2 = 45): where df_1 – variable degree of freedom, df_2 – error degree of freedom, F – distribution in analysis of variance, *p*-value of F variance ratio, LSD – least significant difference, n.s. – not significant

2004, although the final K uptake was the lowest. It was so because the 2004tuber yield was the lowest (Table 2). Płaza (2004) found out that a warm year with high precipitation in August and low precipitation in September was the best for the content of macronutrients (N, P, K, Mg, Ca) in potato tubers. Less rain in August and more rain in September proved less beneficial, and a growing season with a shortage of precipitation in August and excess precipitation in September had a negative effect. Such weather conditions are not conducive to the concentration of macronutrients in potato tubers. In the present study, the precipitation in August in 2004, 2005 and 2006 was 71.9, 52.7 and 144.8 mm, respectively, and in September – 36.3, 15.8 and 0.8 mm. The data show that in the case of lower rainfall in August and September the tubers contained more P, while higher rainfall in August and September was conducive to a higher potassium content. Wadas et al. (2008) also confirmed that the weather conditions affect the phosphorus content in potato tubers.

Eppendorfer and Eggum (1994) as well as Singh et al. (1995) or El -Fayoumy and El-Gamal (1998) state that S application increased the tuber total-N, P, K, Na, Ca, Mg, Zn Mn, Cu and Fe content.

In general, S application had a positive effect on the tuber yield. The application of 25 kg ^{1} elemental S per ha^{-} was an exception, failing to cause a significant increase in tuber yield. However, a significant effect on the increaseing tuber yield was attributed to each dose and form of sulphur fertilization in relation to the control object (without sulphur) – Table 2. As reported by Klikocka et al. (2005), elemental sulphur must undergo a number of biochemical and microbiological processes in the soil before it becomes available to plants, so a dose of 25 kg ha^{-1} in the elemental form is not as effective as sulphate, which is directly available to plants.

Positive impact of sulphur fertilization (in the form of potassium sulphate, ammonium sulphate, single superphosphate, gypsum and elemental sulphur) on potato yields has been reported by numerous authors, e.g. El -Fayoumy and El-Gamal (1998) and Carew et al. (2009). Wang et al. (2008) state that application of S fertilizer to S-deficient soil can significantly increase the tuber yield and starch content of potato, while decreasing the tuber N concentration owing to an increased dry matter production. Kumar et al. (2007) reported that the tuber dry matter percentage was higher after application of K in the form of potassium sulphate and nitrate than potassium chloride.

Table 2 presents the soil pH and soil content of total carbon and SO_4-S after the potato harvest. Generally, S application significantly increased the soil SO_4-S content. The soil content of SO_4-S depended more on the form of S than on the applied dose, and was the highest after the application of elemental S at 50 kg ha^{-1}.

Elemental S noticeably reduced the soil pH. The S application in the form of sulphate generally increased the content of SO_4-S in the soil, while fertilization with elemental S at a dose of 50 kg ha^{-1} decreased soil acidity. Irrespective of the form of S, the dose of 50 kg ha^{-1} was more favourable to the total C content in soil. Wang et al. (2006) found significant correlation between the soil organic carbon and organic sulphur. Sulphate applied with mineral fertilizers has been found to be more prone to leaching, and S sequestration depends on both the fertilizer type and S applicationdose (Scherer et al. 2012).

The content of SO_4-S in the soil positively correlated with the content and uptake of P by the yield of tubers (Table 3). The content of total C in the soil positively correlated with content and uptake of P with the yield of tubers. A negative correlation was found between pH and the content or uptake of P with the yield. No correlation was found between K and soil parameters. The total C in soil was positively correlated with the tuber yield, while the soil pH was negatively correlated with the tuber yield. A negative correlation was also found between the soil pH and total C content in the soil. A positive correlation was noted between the P and K uptake by tubers. Another positive correlation was noted between the P and K uptake and yield of tubers (Figure 1). There was also a positive correlation between the P content and P uptake as well as between the K content and K uptake (Table 3).

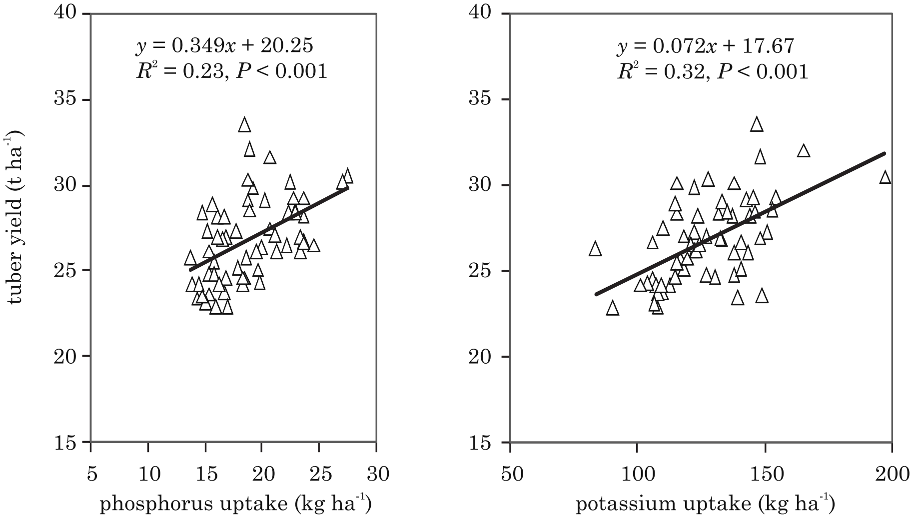

Fig. 1. Relationship between tuber yield of potato and uptake of P and K (n = 60, P = 0.05)

As reported by Jaggi et al. (2005) and Scherereet al. (2012), S deficiency in soils in several parts of the world has encouraged farmers to use S fertilizers to enhance the production and quality of crops. Among S-containing fertilizers, elemental S (S^o) is becoming increasingly popular for use on field crops. The use of S^o helps to reduce leaching and run-off losses, leaving prolonged residual effects on the S nutrition of the succeeding crop. The biochemical oxidation of S^o produces H_2SO_4, which decreases soil pH and solubilizes $CaCO_3$ in alkaline calcareous soils, making soil conditions more favourable for plant growth, including better availability of plant nutrients, especially P (Jaggi et al. 2005, Saffa et al. 2013). This effect was confirmed in the present study. Therefore, supplementation of mineral fertilization under potatoes with sulphur, particularly its elemental form, should be advised.

Based on the present study, an optimal dose of 50 kg ha^{-1} of elemental sulphur under potato may be recommended. This will introduce an additio-

Table 3

Significant correlation coefficients between elements in plants, soil properties and yield of potato tubers (mean from 2004-2006)

Specification (n = 60)	Total C in soil	Yield of tubers	Elements in tubers			
			P		K	
			content	uptake	content	uptake
pH of soil	-0.33*	-0.28	-0.25	-0.25	-	-
Total C in soil	-	0.34	0.25	0.28	-	-
SO_4-S in soil	-	-	0.47	0.50	-	-
Yield of tubers	-	-	-	0.48	-	0.56
P content	-	-	-	0.90	-	-
P uptake	-	-	-	-	-	0.31
K content	-	-	-	-	-	0.83

* significant coefficients (P = 0.05)

nal 39.9 mg SO_4-S kg^{-1} of soil (assuming that the average depth of the topsoil is 25 cm and soil density is 1.5 M g m^{-3}). At present, 90% of soil profiles in Poland contain less than 16.5 mg SO_4-S kg^{-1}, hence they are classified as low-sulphur, and this entails a possible risk of possibility of sulphur deficit in these soils (Siebielec et al. 2012). The soil on which the experiment was conducted contained 10.1 mg SO_4-S kg^{-1}, which was a very low content.

CONCLUSIONS

The application of S increased P content and uptake irrespective of the S dose or form of fertilizer. The K content was the highest when sulphate was applied at a dose of 50 kg S ha^{-1}. The K uptake by the yield of tubers was significantly increased by both application doses and both forms of S fertilizer.

The tuber yield depended substantially on the form and application dose of S fertilizer. Positive correlation was found between the P and K uptake by the yield of tubers and between the P and K uptake and tubers yield.

The content of SO_4-S and total C in soil were positively correlated with the content and uptake of P by the yield of tubers. A negative correlation was found between the soil pH value and the content and uptake of P by the yield of tubers. No correlation was found between K and soil parameters.

REFERENCES

Carew R., Khakbazan M., Mohr R. 2009. *Cultivar developments, fertilizer inputs, environmental conditions, and yield determination for potatoes in manitoba.* Am. J. Potato Res., 86: 442-455.

El-Fayoumy M.E., El-Gamal A.M. 1998. *Effects of sulphur application rates on nutrients avail-*

ability, uptake and potato quality and yield in calcaerous soil. Egypt. J. Soil Sci., 38(1-4): 271-286.

EPPENDORFER W.H., EGGUM B.O. 1994. *Sulphur deficiency of potatoes as reflected in chemical composition and in some measures of nutritive value.* Norweg. J. Agric. Sci., Suppl., 15: 127-134.

GUGAŁA M., ZARZECKA K. 2011. *Effect of insecticides on phosphorus and potassium content in tubers of three potato cultivars.* J. Elem., 16(1): 43-50.

HANEKLAUS S., BLOEM E., SCHNUG E. 2003. *The global sulphur cycle and its links to plant environment.* In: *Sulphur in plants.* Y.P. ABROL and A. AHMAD, eds. Kluwer Acad. Publ. Dordrecht, 1-28.

JAGGI R.C., AULAKH M.S., SHARMA R. 2005. *Impacts of elemental S applied under various temperature and moisture regimes on pH and available P in acidic, neutral and alkaline soils.* Biol. Fert. Soils, 41: 52-58.

KLIKOCKA H., HANEKLAUS S., BLOEM E., SCHNUG E. 2005. *Influence of sulfur fertilization on infection of potato tubers with Rhizoctonia solani and Streptomyces scabies.* J. Plant Nutr., 28(05): 1-14.

KLIKOCKA H. 2010. *The importance of sulfur in the biosphere and fertilizing plants.* Przem. Chem., 89(7): 903-908.

KLIKOCKA H., GŁOWACKA A. 2013. *Does the sulphur fertilization modify magnesium and calcium content in potato tubers (Solanum tuberosum* L.*)* Acta Sci. Pol., Hort. Cul. 12(5): 41-53.

KOŁODZIEJCZYK M. 2014. *Effectiveness of nitrogen fertilization and application of microbial preparations in potato cultivation.* Turk. J. Agric. For., 38: 299-310.

KUMAR P., PANDEV S.K., SINGH B.P., SINGH S.V., KUMAR D. 2007. *Influence of the source and time of potassium application on potato growth, yield, economics and crisp quality.* Potato Res., 50: 1-13.

PŁAZA A. 2004. *The chemical composition of potato in different organic fertilization regimes.* Ann. UMCS, Sect. E, 59(3): 1327-1334. (in Polish)

RIVERO R.C., SUAREZ P.S., RODRIGUEZ E.M., MARTIN J.D., ROMARA C.D. 2003. *Mineral concentrations in cultivars of potatoes.* Food Chem., 83: 247-253.

SAFAA M.M., KHALED S.M., HANAN S.S. 2013. *Effect of elemental sulphur on solubility of soil nutrients and soil heavy metals and their uptake by maize plants.* J. Am. Sci., 9(12): 19-24.

SCHERER H.W., FŐRSTER S., WELP G. 2012. *Sulfur fractions in particle-size separates as influenced by long-term application of mineral and organic fertilizers.* Plant Soil Environ., 58(5): 242-248.

SIEBIELEC G., SMERCZAK B., KLIMKOWICZ-PAWLAS A., MALISZEWSKA-KORDYBACH B., TERELAK H., KOZA P., ŁYSIAK M., GAŁAZKA R., PECIO M., SUSZEK B., MITURSKI T., HRYŃCZUK B. 2012. *Chemistry of arable soils in Poland in 2010-2012.* IOŚ, Warszawa, Bibl. Monit. Środ. (in Polish)

SINGH J.P., MARWAHA R.S., SRIVASTAVA O.P. 1995. *Processing and nutritive qualities of potato tubers as affected by fertilizer nutrients and sulphur application.* J. Ind. Potato Assoc., 22(1-2): 32–37.

WADAS W., JABŁOŃSKA-CEGLAREK R., KUROWSKA A. 2008. *Effect of using covers in early crop potato culture on the content of phosphorus and magnesium in tubers.* J. Elem., 13(2): 275-280.

WANG J., SOLOMON D., LEHMANN J., ZHANG X., AMELUNG W. 2006. *Soil organic sulphur forms and dynamic in the Great Plants of North America as influenced by long-term cultivation.* Geoderma 133: 160-172.

WANG ZHAO-HUI, LI SHENG-XIU, MALHI S. 2008. *Effects of fertilization and other agronomic measures on nutritional quality of crops.* J. Sc. Food Agric., 88: 7-23.

WICHROWSKA D., WOJDYŁA T., ROGOZIŃSKA I. 2009. *Concentrations of some macroelements in potato tubers stored at 4°C and 8°C.* J.Elem., 14(2): 373-382.