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ANTONI ROGÓŻ*, MONIKA TABAK

University of Agriculture in Kraków, Department of Agricultural and Environmental Chemistry
Al. Mickiewicza 21, 31-120 Kraków, Poland

Contents of selected macroelements in soils, potatoes and fodder beets at variable soil reaction

Abstract: The aim of the research was to determine the concentration of selected macroelements in soil and in root crops (potatoes and fodder beets) at a variable soil reaction. The changes in pH values in the studied soils influenced the content of these elements in soluble forms determined in 0.1 mol HCl·dm^{-3}. A statistical analysis showed a positive relationship between the soil pH value and the calcium and magnesium contents in a form close to the total form, as well as the content of soluble forms of phosphorus, calcium, and magnesium. The content of the studied macroelements, i.e. phosphorus, calcium, magnesium in the cultivated fodder beets and potatoes depended on abundance and form in which the studied elements occurred in soil, and also on specie and analyzed part of the plant. Along with the increase in pH values of the an increase in the phosphorus content and reduction of the magnesium content in the roots and above-ground parts of the beets were found. The calcium content in the roots increased along with an increase in pH of the soils, whereas direction of changes in the content of this element in the petioles and laminae of the beets was not unambiguous. A slight decrease in the content of the studied elements in the potato tubers (along with the increase in pH of the soils) was found.

Keywords: phosphorus, calcium, magnesium, soil pH, root crops

INTRODUCTION

Natural physical, chemical, and biological processes occurring in soil cause an increase in concentration of protons which disturb the ionic balance in soil solution. These changes influence the disturbances in mineral feeding which decide on the growth and development of plants (Filipek 2001).

The quality of agricultural products may be assessed by organoleptic and chemical methods which define chemical composition of plants. The content of nutrients may undergo considerable modifications under the influence of various factors such as moisture, insolation, soil reaction, organic and mineral fertilization, as well as cultivation technology (Jurkowska et al. 1992, Gąsior 1997, Elsheikh et al. 2009, Cai et al. 2015).

The aim of the research was to determine the content of selected macroelements in soils and in selected root crops at a variable soil reaction. In addition, the aim of the research was to determine the plant fodder value based on the ratios between the studied elements.

MATERIALS AND METHODS

The research material was collected in mid-September from arable lands of the Kraków district. 43 soil samples were collected from a depth between 0 and 25 cm. Each of the analyzed soil samples was a mean from individual samples (approximately 1 kg of soil). Basic physical and chemical properties were determined in the collected soil material by methods used in agricultural chemistry (Gorlach 2007). The research also involved determination of the total content of three macroelements (phosphorus, potassium and magnesium) as well as the content of these elements in a soluble form.

The content of macroelements in forms close to the total content was determined after prior mineralization at a temperature of 450°C, then etching in mixture of perchloric acid $HClO_4$ and nitric acid HNO_3; after evaporation of these acids, the formed salts (e.g. $KClO_4$, $Ca(ClO_4)_2$) were dissolved in hydrochloric acid HCl (Ostrowska et al. 1991). According to Ostrowska et al. (1991), total decomposition of mineral parts of soil is very difficult. Leaching of elements is carried out using acids or

* Dr. Eng. A. Rogóz, rrrogoz@cyf-kr.edu.pl

their mixtures with variable etching strengths. Hot leaching with the use of mixtures of perchloric and nitric acids allows to extract elements with a content similar to the total content (e.g. approximately 80% of most elements is transferred from light soils to the solution). Content of individual macro- and microelements in soil, as well as form in which they occur in soil, vary depending on the following: parent rock, soil-forming processes, pH value, organic matter content, interaction between individual cations, and anthropogenic factors. Determination of total content of elements in soil, as well as content of soluble forms, in connection with the knowledge of soil physicochemical properties (influencing, for example, the force of chemical sorption of phosphorus), allows to predict direction of changes in contents of individual elements in soils, and can be helpful in explaining content of these elements in plants.

The content of the studied elements in a soluble form was determined in 0.1 mol HCl·dm^{-3} (Gorlach 2007). The purpose of fertilization is to meet plant nutritional needs taking into account current soil richness in available forms of nutrients. In the present research, extraction of available forms of phosphorus, calcium and magnesium from soil was conducted with 0.1 mol·dm^{-3} HCl acid. The use of such an extractant resulted from the intention to use one extraction agent to determine the content of available forms of various macroelements and microelements in soil (results presented in this paper are a part of wider research works). Mineral acids are one kind of chemical reagents used for element extraction. Szumska (Wilk) and Gworek (2009) stated that when using mineral or organic acids as extraction solutions, partially soluble fractions bound to carbonates as well as bound to metal oxides and organic matter are extracted. 0.1 mol·dm^{-3} HCl used in the present research extracted phosphorus present in a soil solution ($H_2PO_4^-$ and HPO_4^{2-}). It also extracted phosphorus specifically sorbed on hydrated aluminum and iron oxides as well as on the surface of clay minerals. Calcium lactate acidified to pH 3.55 (used in Egner-Riehm method) extracts from soil mainly phosphorus forms bound to calcium and partially to iron. As highlighted by Tujaka et al. (2011), the Egner-Riehm method not always gives precise information on soil richness in phosphorus, so other methods of phosphorus extraction are sought. In the cited work, the usefulness of Hedley method to determine the content of available phosphorus in soil was assessed. This method allows to extract five phosphorus fractions. However, this method is labor-consuming and useless for routine analyses, it also does not enable evaluation of available phosphorus content in soil.

The plant material (potato tubers and fodder beets) was collected from the locations of soil sample collection. Each of the analyzed root plant samples was a mean from 12 individual samples (approximately 1 kg of fresh matter). After removing soil from the potato tubers and beet roots, the collected plant material was washed (the beets were divided into roots and above-ground parts, i.e. the petiole and the lamina) and dried at a temperature of 80şC. The plant material was then crushed and subjected to dry mineralization. The obtained ashes were digested in HNO_3 diluted with water at 1:2 ratio, obtaining solutions in which phosphorus, calcium, and magnesium contents were determined. Concentration of the studied elements in the soil and in the plant material was determined on JY 238 Ultrace apparatus using Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES). The obtained results concerning the phosphorus, calcium, and magnesium contents, as well as physicochemical properties of the soils were used for statistical calculations.

RESULTS AND DISCUSSION

Results on some physical and chemical properties of the studied soils were provided in a previous work (Rogóż and Grudnik 2004). The studied soils were highly diversified in terms of: the pH value measured in 1 mol KCl·dm^{-3} (4.13–7.31), the organic carbon content (0.55–3.38 g·kg^{-1}), the content of floatable particles (9–65%) and of colloidal clay (4–27%), and also the content of the studied elements in the soil in a form close to the total form as well as in soluble forms.

Size of obtained yield and chemical composition of plants (so also the plant fodder value) depend on the following: species, developmental stage and part of the plant, soil reaction, soil texture, degree of soil moistening, content of nutrients in available forms, quantitative relations between individual cations and anions, content of organic matter, organic-mineral fertilization, type of soil microflora, content of toxic metals, and many other (Czuba 1998, Krzywy et al. 2003, Rogóż 2003, Rogozińska et al. 2004, Kołodziejczyk and Szmigiel 2005, Hernández et al. 2013).

Changes in pH values have varied influences on assimilability of individual nutrients (Rogóż 2003). Reaction of the studied soils varied considerably. Results of measurements of pH values in 1 mol KCl·dm^{-3} varied between 4.13 and 7.31. Assuming a five-degree scale of acidification (very acid soils with a pH value measured in 1 mol KCl·dm^{-3} amounting to 4.5; acid soils with a pH within the range of 4.6–5.5; slightly acid soils with a pH of 5.6–6.5; neutral soils with a pH of 6.6–7.2; and alkaline soils with a pH from 7.3) (Gorlach 2007), the collected soil samples were divided into three groups, i.e.:

– 10 samples were very acid and acid soils, the pH value measured in 1 mol $KCl{\cdot}dm^{-3} \leq 5.5$;
– 19 samples were slightly acid soils, pH in 1 mol $KCl{\cdot}dm^{-3}$ within the range from 5.6 to 6.5;
– 14 samples were neutral and alkaline soils, the pH value in 1 mol $KCl{\cdot}dm^{-3} \geq 6.6$.

The phosphorus, calcium, and magnesium contents in forms close to the total content in the studied soils, as well as contents of their soluble forms determined in 0.1 mol $HCl{\cdot}dm^{-3}$ solution were varied. The changes in pH values of the studied soils (being an effect of both natural physico-chemical, chemical, and biological processes which occurred in the soils and farmer's activities) influenced the content of phosphorus, calcium, and magnesium in soluble forms determined in 0.1 mol $HCl{\cdot}dm^{-3}$ solution. The amount of extracted phosphorus in a soluble form determined in 0.1 mol $HCl{\cdot}dm^{-3}$ solution from slightly acid and neutral soils was approximately 2.5 and 3-times higher, the amount of extracted calcium was 2 and 4-times higher, and the amount of extracted magnesium was 2 and 2.5-times higher with respect to soils with pH ≤ 5.5 (Table 1).

A statistical analysis of the obtained results showed that physico-chemical properties of the studied soils had varied influences on the phosphorus, calcium, and magnesium contents, as well as on the contents of their soluble forms determined in 0.1 mol $HCl{\cdot}dm^{-3}$. A significant positive relationship between the organic carbon content and the total phosphorus content was found, as well as a significant positive relationship between the content of floatable particles and colloidal clay and the magnesium content in a form close to the total content (Table 2). As stated by Brogowski et al. (2010), magnesium content in granulometric fractions of soils increases along with a decrease in fraction diameter.

TABLE 1. Mean total contents as well as mean contents of soluble forms of phosphorus, calcium and magnesium in soils ($g{\cdot}kg^{-1}$) depending on soil pH value

Parameter	Total content			Content of soluble forms		
	P	Ca	Mg	P	Ca	Mg
pH 1 mol $KCl{\cdot}dm^{-3}$ ≤ 5.5						
Arithmetic mean	0.465	1.830	1.453	0.077	1.664	0.140
Geometric mean	**0.465**	**1.777**	**1.430**	**0.055**	**1.384**	**0.117**
Variability coefficient (V%)	28.99	23.68	20.52	103.1	38.95	36.37
Minimum	0.294	1.151	1.222	0.011	0.112	0.013
Maximum	0.768	2.428	2.286	0.298	2.60	0.189
pH 1 mol $KCl{\cdot}dm^{-3}$ 5.6–6.5						
Arithmetic mean	0.499	2.958	1.530	0.157	2.805	0.288
Geometric mean	**0.480**	**2.733**	**1.413**	**0.134**	**2.679**	**0.231**
Variability coefficient (V%)	32.17	44.30	37.34	58.36	32.62	80.63
Minimum	0.314	1.702	0.395	0.037	1.86	0.071
Maximum	0.872	5.821	2.46	0.376	4.69	1.01
pH 1 mol $KCl{\cdot}dm^{-3}$ ≥6.6						
Arithmetic mean	0.507	8.755	1.772	0.169	6.578	0.326
Geometric mean	**0.493**	**7.492**	**1.732**	**0.152**	**5.935**	**0.304**
Variability coefficient (V%)	22.01	53.29	22.43	43.20	44.42	36.57
Minimum	0.333	3.56	1.124	0.053	2.97	0.145
Maximum	0.724	14.28	2.536	0.268	10.20	0.485

TABLE 2. Simple correlation coefficients (r) between phosphorus, calcium, and magnesium contents in soils and selected soil properties

	Total content			Content of soluble forms		
	P	Ca	Mg	P	Ca	Mg
pH_{KCl}	ns	0.663***	0.254	0.417**	0.721***	0.601***
Organic C content	0.610***	ns	ns	ns	ns	ns
Fraction < 0.02 mm	ns	ns	0.503**	ns	ns	ns
Fraction < 0.002 mm	ns	ns	0.599**	ns	ns	ns

significant at: *p = 0.05, **p = 0.01, ***p = 0.001; n = 43; ns – not significant.

The present research results have shown that soil reaction decided (slightly) on the content of macroelements in the potato tubers. Contents of calcium and magnesium in the potato tubers decreased slightly along with the increase in pH values, whereas the increase in pH values had variable impact on the phosphorus content. The contents of the Ca, Mg, and P in the potato tubers coming from soils with pH_{KCl} ≥ 6.6 were 12–15% lower than the contents in the potato tubers coming from soils with $pH_{KCl} \leq 5.5$ (Table 3). A statistical analysis showed a significant positive relationship between the phosphorus content in a soluble form determined in 0.1 mol $HCl \cdot dm^{-3}$ and the content of this element in the potato tubers, where r = 0.346 (p = 0.05).

Kotowska and Maciejewska (2001), as well as Kołodziejczyk and Szmigiel (2005) showed that applied doses of NPK and $CaCO_3$ fertilizers caused a slight increase in phosphorus and potassium contents in potato tubers, whereas they did not cause considerable changes in the calcium content.

The content of phosphorus, calcium, magnesium in the fodder beets depended on the soil reaction and the analyzed parts of the plant. The increase in soil pH values was accompanied by an increase in the phosphorus and calcium contents in the beet roots, and by an increase in the phosphorus content in the above-ground parts of the plants. The phosphorus content in the beet roots coming from slightly acid and neutral soils was 49 and 60% higher, and the calcium content 3 and 41% higher than the contents of these elements in the beet roots coming from soils with $pH_{KCl} \leq 5.5$. The content of magnesium in the roots was getting lower along with the increase in pH values, and more visibly in the above-ground parts of the beets (Table 4). Regardless of the changes in the pH values, higher contents of the studied elements were found in the above-ground parts than in the beet roots. If we assume the phosphorus, calcium and magnesium contents in the roots to be 1, then the phosphorus content in the petiole was 1.6-times, and in the lamina 2-times higher, the calcium content was 5 and 8-times higher, whereas in the case of magnesium it was 2.4 and 3.4-times higher, respectively.

A statistical analysis showed a significant positive relationship between the soil pH value and the phosphorus content in the beet roots, where r = 0.341 (p = 0.05), and also a positive relationship between the content of phosphorus and calcium in the soils (total content and content of soluble form) and the content of these elements in the beet roots (Table 5).

Plant fodder value is assessed not only based on the absolute content of nutrients present in it, but also according to their mutual quantitative relations. The optimal Ca:P weight ratio in fodders for ruminants should be between 0.5 and 2.0, while the optimal Ca:Mg weight ratio should be between 2 and 3 (Filipek 1999). According to Antonkiewicz (2007 following Underwood 1971), the optimal Ca:P mass ratio (calculated based on optimal contents in the plants intended for fodder) should be 1,7–2,6. The optimal value of the ionic ratio K:(Ca+Mg) is 1,6–2,2 (Antonkiewicz 2007 following Czuba and Mazur).

TABLE 3. Mean phosphorus, calcium, and magnesium contents in potato tubers ($g \cdot kg^{-1}$ d.m.) as well as weight ratios between Ca:P and Ca:Mg depending on soil pH value

Parameter	P	Ca	Mg	Ca:P	Ca:Mg
pH 1 mol $KCl \cdot dm^{-3} \leq 5.5$					
Arithmetic mean	0.300	0.069	0.101	0.23	0.70
Geometric mean	**0.297**	**0.066**	**0.101**	**0.22**	**0.66**
Variability coefficient (V%)	15.95	29.72	12.37	31.2	37.39
Minimum	0.230	0.040	0.080	0.15	0.33
Maximum	0.380	0.090	0.120	0.33	1.12
pH 1 mol $KCl \cdot dm^{-3}$ 5.6–6.5					
Arithmetic mean	0.312	0.060	0.098	0.20	0.62
Geometric mean	**0.307**	**0.057**	**0.097**	**0.19**	**0.59**
Variability coefficient (V%)	18.11	30.64	13.81	33.2	29.28
Minimum	0.210	0.020	0.080	0.06	0.20
Maximum	0.410	0.090	0.120	0.28	0.89
pH 1 mol $KCl \cdot dm^{-3} \geq 6.6$					
Arithmetic mean	0.266	0.059	0.090	0.23	0.66
Geometric mean	**0.261**	**0.056**	**0.089**	**0.22**	**0.63**
Variability coefficient (V%)	21.40	28.45	17.45	39.85	29.22
Minimum	0.200	0.030	0.070	0.13	0.37
Maximum	0.370	0.080	0.120	0.36	0.89

TABLE 4. Mean phosphorus, calcium, and magnesium contents in fodder beets ($g \cdot kg^{-1}$ d.m.) depending on soil pH value

Parameter	Roots			Petiole			Lamina		
	P	Ca	Mg	P	Ca	Mg	P	Ca	Mg
pH 1 mol KCl·dm^{-3} ≤ 5.5									
Arithmetic mean	0.136	0.154	0.121	0.231	0.880	0.290	0.317	1.425	0.426
Geometric mean	**0.124**	**0.149**	**0.117**	**0.227**	**0.842**	**0.284**	**0.309**	**1.398**	**0.418**
Variability coefficient (V%)	57.20	26.73	28.62	19.84	31.42	21.98	26.82	20.52	20.30
Minimum	0.08	0.11	0.07	0.15	0.54	0.21	0.25	1.05	0.31
Maximum	0.36	0.22	0.19	0.3	1.38	0.39	0.50	1.92	0.58
pH 1 mol KCl·dm^{-3} 5.6–6.5									
Arithmetic mean	0.190	0.160	0.121	0.304	0.844	0.276	0.357	1.378	0.424
Geometric mean	**0.185**	**0.154**	**0.114**	**0.297**	**0.812**	**0.272**	**0.349**	**1.332**	**0.414**
Variability coefficient (V%)	23.63	31.66	38.99	19.91	27.67	18.29	22.90	27.04	21.03
Minimum	0.12	0.09	0.06	0.18	0.46	0.19	0.27	0.87	0.26
Maximum	0.26	0.32	0.27	0.4	1.33	0.36	0.56	1.94	0.54
pH 1 mol KCl·dm^{-3} ≥ 6.6									
Arithmetic mean	0.210	0.239	0.106	0.312	0.882	0.236	0.375	1.476	0.308
Geometric mean	**0.199**	**0.210**	**0.100**	**0.298**	**0.829**	**0.228**	**0.357**	**1.375**	**0.287**
Variability coefficient (V%)	35.06	55.83	31.82	33.19	33.73	26.43	30.97	36.38	29.65
Minimum	0.13	0.11	0.06	0.21	0.43	0.15	0.19	0.55	0.08
Maximum	0.37	0.54	0.15	0.49	1.26	0.31	0.55	2.45	0.41

TABLE 5. Simple correlation coefficients (r) between phosphorus, calcium, and magnesium contents in roots of fodder beets and selected soil properties

	P	Ca	Mg
pH_{KCl}	0.352*	ns	ns
Total phosphorus content	0.382*	ns	ns
Soluble phosphorus content	0.618***	ns	ns
Total calcium content	ns	0.512***	ns
Soluble calcium content	ns	0.473**	ns

significant at: *p = 0.05, **p = 0.01, ***p = 0.001; n = 43; ns – not significant.

Value of the calculated Ca:P parameter in the potato tubers varied between 0.057 and 0.363 (geometric mean 0.204), whereas the Ca:Mg ratio value was between 0.200 and 1.125 (geometric mean 0.619). The changes in reaction of the studied soils (pH values) had a multi-sided impact on the Ca:P and Ca:Mg relations in the potato tubers. Similar results were obtained by Krzywy et al. (2003), which stated that ionic ratio of Ca to P in potato tubers varied from 0.23 to 0.36, whereas in yellow lupine seeds the ratio was between 0.37 and 0.39. The authors of the mentioned paper highlight that the applied mineral fertilizers, regardless of form, did not have a significant influence on the shaping of the Ca:P ratio values.

Value of the calculated Ca:P parameter in the beet roots varied between 0.538 and 1.900 (geometric mean 1.050), whereas the Ca:Mg ratio value was between 0.444 and 4.167 (geometric mean 2.091). The changes in soil reaction influenced the relations between Ca:P and Ca:Mg in the roots and above-ground parts of the beets (Table 6).

When evaluating the fodder value based on values of the Ca:P and Ca:Mg ratios, it needs to be stated that the potato tubers and the beet roots generally did not meet the feeding standards (particularly the more rigorous ones, cited by Antonkiewicz (2007 following Underwood 1971)). In the above-ground parts of the beets, values of the Ca:P and Ca:Mg ratios were generally optimal or higher than the ones provided above as optimal ones.

CONCLUSIONS

1. The studied soil samples were diversified in terms of the pH value measured in 1 mol·KCldm^{-3} (between 4.13 and 7.31), the organic carbon content (between 0.55 and 3.38 $g \cdot kg^{-1}$), texture, and also the content of P, Ca and Mg in a form close to the total form as well as in soluble forms. The total phosphorus content in soils varied between 0.294 and 0.872 $g \cdot kg^{-1}$, the total calcium content varied between 1.15 and 14.28 $g \cdot kg^{-1}$, and the total magnesium content varied between 0.395 and 2.536 $g \cdot kg^{-1}$. The contents of soluble forms were as follows: 0.11–0.379 g P; 0.11–10.20 g Ca and 0.013–1.01 g Mg per 1 kg of soil.
2. The contents of the studied elements in a soluble form, determined in 0.1 mol HCl·dm^{-3}, were varied depending on soil pH values and the type

TABLE 6. Weight ratios between Ca:P and Ca:Mg in fodder beets depending on soil pH value

Parameter	Roots	Petiole	Lamina	Roots	Petiole	Lamina
	Ca:P			Ca:Mg		
pH 1 mol KCl·dm^{-3} ≤ 5.5						
Arithmetic mean	1.29	4.12	4.81	1.30	3.10	3.48
Geometric mean	**1.21**	**3.71**	**4.53**	**1.28**	**2.96**	**3.34**
Variability coefficient (V%)	35.50	49.65	32.30	20.16	32.21	30.66
Minimum	0.61	2.25	2.08	1.00	1.81	2.13
Maximum	1.90	7.4	6.65	1.75	4.84	5.23
pH 1 mol KCl·dm^{-3} 5.6–6.5						
Arithmetic mean	0.86	2.93	4.04	1.45	3.24	3.42
Geometric mean	**0.84**	**2.82**	**3.87**	**1.37**	**3.08**	**3.29**
Variability coefficient (V%)	24.71	27.10	29.94	29.47	32.23	28.55
Minimum	0.54	1.48	1.89	0.44	1.84	1.91
Maximum	1.52	3.90	7.11	2.25	5.32	4.98
pH 1 mol KCl·dm^{-3} ≥ 6.6						
Arithmetic mean	1.11	2.93	4.36	2.31	3.86	5.81
Geometric mean	**1.05**	**2.78**	**3.85**	**2.09**	**3.63**	**4.78**
Variability coefficient (V%)	32.64	33.76	52.11	45.16	34.49	77.63
Minimum	0.65	1.52	1.41	1.076	1.81	1.71
Maximum	1.63	4.68	9.37	4.17	6.16	17.5

of determined cation. The content of soluble forms of phosphorus, calcium, and magnesium in soils was strongly positively correlated with the soil pH values.

3. The changes in soil reaction did not have a considerable effect on the content of P, Ca and Mg in the potato tubers. The increase in soil pH was accompanied by an increase in the phosphorus and calcium contents as well as a decrease in the magnesium content in the roots of fodder beets. A similar relation, in a greater or lesser degree, applied to the above-ground parts of the beets, especially with respect to phosphorus.
4. The phosphorus content in the roots of beets was significantly positively correlated with the soil pH, the content of phosphorus in the form close to the total as well as phosphorus in the soluble form. The calcium content in the roots of beets was significantly positively correlated with the calcium content in the form close to the total as well as in the soluble form. A significant positive correlation between the phosphorus content in the potato tubers and in the soluble form in soil was found.

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Zawartość wybranych makroelementów w glebach oraz w ziemniakach i burakach pastewnych przy zmiennym odczynie gleby

Streszczenie: Celem przeprowadzonych badań było określenie koncentracji wybranych makroelementów w glebie i w roślinach okopowych (ziemniakach i burakach pastewnych) przy zmiennym odczynie gleby. Zmiany wartości pH w badanych glebach decydowały o zawartości tych pierwiastków w formach rozpuszczalnych oznaczanych w HCl o stężeniu 0,1 mol·dm^{-3}. Analiza statystyczna wykazała dodatnią zależność pomiędzy wartością pH gleb a zawartością wapnia i magnezu w formie zbliżonej do ogólnej oraz zawartością rozpuszczalnych form fosforu, wapnia i magnezu. Zawartość badanych makroelementów, tj. fosforu, wapnia, magnezu w uprawianych burakach pastewnych oraz ziemniakach zależała od zasobności i form, w jakiej badane pierwiastki występują w glebie, a także od gatunku oraz analizowanej części rośliny. Wraz ze wzrostem wartości pH gleb stwierdzano zwiększenie zawartości fosforu i zmniejszenie zawartości magnezu w korzeniach i częściach nadziemnych buraków. Zawartość wapnia w korzeniach uległa zwiększeniu wraz ze wzrostem wartości pH gleb, natomiast kierunek zmian zawartości tego pierwiastka w ogonkach i blaszkach liściowych buraków nie był jednoznaczny. W bulwach ziemniaków stwierdzono nieznaczne obniżenie się zawartości badanych pierwiastków wraz ze wzrostem wartości pH gleb.

Słowa kluczowe: fosfor, wapń, magnez, pH gleby, rośliny okopowe