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Estimation of the macro- and micronutrient status of raspberries grown in the Lublin region

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ABSTRACT

Environmental monitoring was conducted in the Lublin region in 2009-2012 aimed at the assessment of the supply of several macro- and micronutrients in raspberries plants. The plantations studied were located in eight main regions for the growing of raspberries (Bełżyce, Chodel, Godziszów, Kraśnik, Lublin, Międzyrzec Podlaski, Opole Lubelskie and Urzędów). The contents of nitrogen (N), potassium (K), phosphorus (P), magnesium (Mg), calcium (Ca), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu) and boron (B) were determined in raspberry leaves. Furthermore, the impact of select soil properties on the content of essential elements in the leaves was assessed. The results obtained revealed the suitable N, P, K, Mg, B, Zn and Cu supplies in the plants. However, the mean content of Mn greatly exceeded the optimal level recommended for this species. Also, the content of Fe in some regions was above the optimal value. The calculated correlation coefficients between soil properties and the content of the elements in raspberry leaves suggest that these variables were interdependent in only a few cases.

Key words: essential elements, leaves, *Rubus idaeus* L., soil analysis

INTRODUCTION

Due to favourable weather conditions, topography, and optimal soil properties, the Lublin region has become one of the major regions of growing raspberries in Poland. In 2011, 84% of harvested raspberries in Poland originated from the Lublin Province, where plantations of the fruit are located in the southwestern part of the region in the Puławy, Opole Lubelskie, Kraśnik, Janów, Lublin and Biłgoraj Counties (Danek and Król 2008).

Soil properties are important environmental factors that determine the quality and the content of mineral nutrient status in plants. Only fertile soil

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with a regulated pH value and an optimal nutrient supply ensures adequate yields of plants with desirable quality parameters (Buskiene and Uselis 2008). Previous studies confirm that the proper assessment of the nutrient status in terms of both macro- and micronutrients is essential to obtain the expected yield (Kowalenko 2005). One of the widely used tests of the mineral nutrient status in raspberries is the determination of the level of macro- and microelements in leaves. In addition to genetic traits, the concentration of elements in leaves largely depends on the content of minerals in the soil and agrotechnical methods of cultivation (Chaplin and Martin 1980, Prive and Sullivan 1994, Hargreaves et al. 2008, Koumanov et al. 2009). Moreover, the concentration of nutrients in leaf tissues may change during the vegetation period (John et al. 1976). The most important yield-promoting mineral nutrients for raspberry production include nitrogen (N) and potassium (K). N determines vegetative growth, whereas K increases the cold-hardiness and drought resistance of plants. The mean content of both elements is usually at a similar level and may be even eight-fold higher that the content of phosphorus (P) (Kowalenko 2005, Buskiene and Uselis 2008). Among the essential micronutrients, raspberries are sensitive to deficiencies of boron (B), which should be applied at 0.1 kg ha^{-1}, particularly in light soils characterized by a low content of B (Wójcik 2005). Buskiene and Uselis (2008) suggest the necessity of properly balanced fertilisation due to ion antagonism. The investigations conducted by Horuz et al. (2013) have demonstrated that the content of mineral components in raspberry leaves is significantly determined by ion interactions. The researchers have found that excessive N fertilisation leads to P and K deficiency, and an excess of calcium (Ca) results in magnesium (Mg) deficiency. Additionally, they have reported a risk of B deficiency in the leaves in the case of high N+P/K and Ca/B ratios.

The aim of this study was to assess macro- and micronutrient supplies in raspberries grown in the Lublin region and to evaluate the impact of selected soil properties on the content of these elements measured in the leaves.

MATERIAL AND METHODS

In 2009-2012, the leaves of raspberry (*Rubus idaeus* L.) 'Polana' were sampled from 80 plantations located in the Lublin region, and analyses of macro- and micronutrients were performed. The plantations belonged to eight groups of raspberry growing regions – Bełżyce, Chodel, Godziszów, Kraśnik, Lublin, Międzyrzec Podlaski, Opole Lubelskie and Urzędów (Fig. 1). Chemical analyses

Figure 1. Location of the raspberry growing regions and the numbers of plantations studied

Table 1. Chemical soil properties in the respective raspberry growing regions

Region	pH in KCl	P	K	Mg	B	Cu	Zn	Mn	Fe
					(mg kg^{-1})				
Bełżyce	4.14	59.0	166.0	46.0	0.68	1.30	4.42	177.9	1022
Chodel	5.11	14.1	59.0	15.1	1.10	4.56	15.01	159.7	832
Godziszów	5.25	75.2	92.4	68.3	1.26	3.37	14.22	264.9	1408
Kraśnik	5.50	138.2	81.8	24.2	1.56	2.07	5.58	155.3	747
Lublin	5.02	6.6	18.4	8.1	0.66	2.50	8.62	179.9	946
Międzyrzec Podlaski	5.66	31.1	36.9	30.6	0.80	2.93	11.52	323.2	1116
Opole Lubelskie	6.25	9.9	13.4	6.4	0.92	5.83	6.86	140.7	657
Urzędów	5.34	51.7	136.1	42.5	1.53	4.11	12.25	175.8	1039

were performed using leaves sampled exclusively from fully fruiting plantations. During the first harvesting period, leaf blades only without petioles were collected from the plots. The representative sample (a minimum of 200 fully developed leaves without petioles) was collected on sunny days in July and August from at least 100 plants (two leaves from the fruiting shoot). Thereafter, the leaves were immediately transported to the accredited laboratory of the Regional Chemical-Agricultural Station in Lublin, where the chemical analyses were performed. Any soil or foreign material was dusted off the sample, but the leaves were not washed, as this would have removed soluble nutrients. The collected leaves were oven-dried at 60^{o}C. The dried samples were stored in paper bags before the analysis. The following parameters were determined in the plant material: dry weight (DW); the total N (by the classic Kjeldahl method) using the B-324 Distillation Unit (Büchi Labortechnik AG, Flawil, Switzerland); the P content through vanadium-molybdate colorimetry using an SQ-118 photometer (Merck, Darmstadt, Germany); the K and Ca contents with flame photometry (Sherwood, Flame Photometer 410, Sherwood Scientific Ltd. Cambridge, UK); the contents of Mg, copper (Cu), zinc (Zn), manganese (Mn) and iron (Fe) with the atomic absorption spectrophotometry (AAS) technique (Perkin-ELMER AAS 1100B, Überlingen, Germany), and the B content with the curcumin method (IUNG 1972). Additionally, soil samples were taken from the 0-20 cm layer from all raspberry plantations. The final soil samples were composed of at least 20 initial samples collected from 20 or more random sample sites in each field. The following determinations were performed (Directory 2007): pH in 1 mol KCl dm^{-3}; the content of available P and K with the Egner-Riehm method (extracted with 0.2 mol L^{-1} calcium lactate) using a flame photometer (Sherwood Flame Photometer 410, Sherwood Scientific Ltd. Cambridge, UK) and a SQ-118 photometer (Merck, Darmstadt, Germany), respectively; available Mg (extracted with 0.0125 mol L^{-1} $CaCl_2$) with the Schachtschabel method using AAS (AAS Model IN, Carl Zeiss, Jena, Germany); Fe, Mn, Cu and Zn with the AAS method (Perkin-ELMER AAS 1100B, Überlingen, Germany); and B with the curcumin method using spectrophotometry (Spekol 11, Carl Zeiss, Jena, Germany).

The mean content of macronutrients (N, P, K, Ca and Mg) and micronutrients (B, Cu, Zn, Fe and Mn) was calculated on the DW basis for the individual plantation regions. The percentages of N, P and K in the total NPK content as well as the percentages of K, Ca and Mg in the total KCaMg content were determined for the plant leaves. The relationships between the variables were assessed based on correlation coefficients and multiple regression equations. The selection of factors was forward stepwise, and the factors were included in the model once an F-value of 3 was exceeded. All data were analysed using Statistica software (Stat Soft, Inc 2004, Statistica ver. 6).

RESULTS AND DISCUSSION

Properties of soil samples

The properties of the soil sampled from the test plantations are presented in Table 1. These results indicate that the pH of the soil varied from 4.14 (Bełżyce) to 6.25 (Opole Lubelskie). According to the recommendations (Methodology 2010), the optimum soil pH should be in the range of 6.2-6.7. Since the soil pH may be too low for plants, it is recommended that soil liming should be performed, with the exception of plantations localised in the Opole Lubelskie region. Also, the concentrations of the studied macro- and micronutrients in the soil

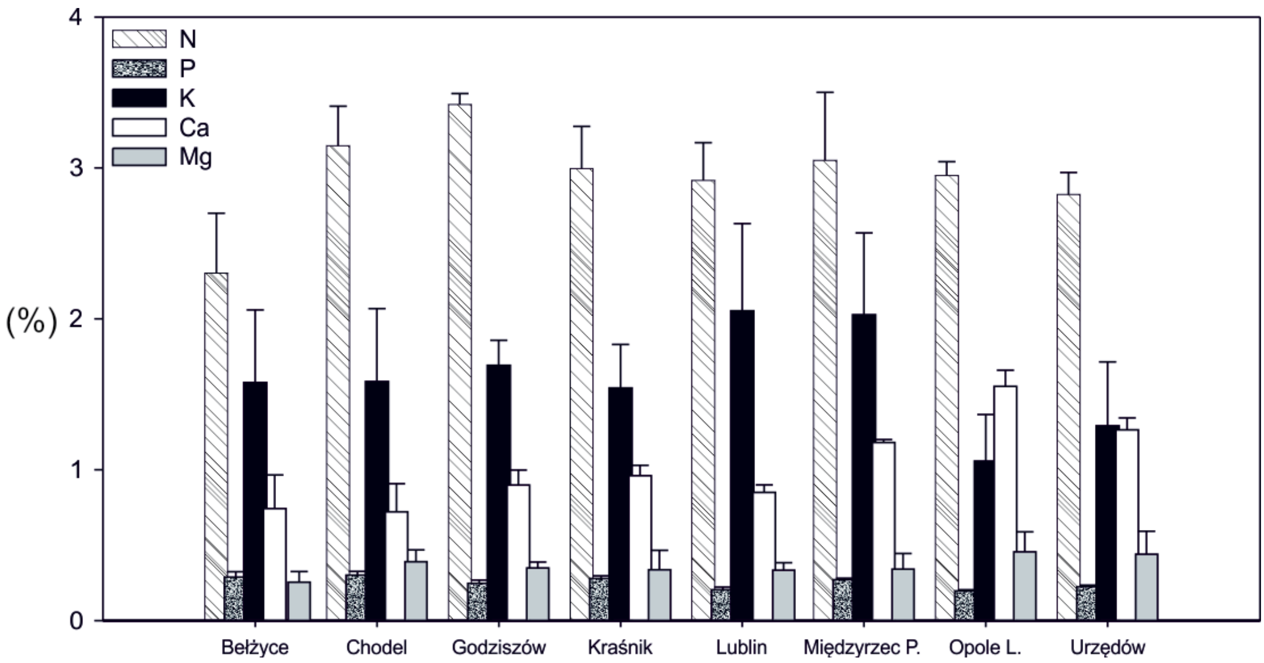

Figure 2. The contents of N, P, K, Ca and Mg in the raspberry leaves from different growing regions. The bars and whisker plots give the mean and 95% confidence limits (95% confidence interval), respectively

samples varied in a wide range between the growing regions. For example, the soils of the Lublin region generally contained low concentrations of P, K, Mg and B, whereas the soils of the Urzędów region were relatively rich in the analysed nutrients. This phenomenon is probably due to the different natural abundance of the elements in the individual regions and/or agrotechnical methods of cultivation, including soil fertilisation.

Contents of nutrients in raspberry leaves in relation to soil properties

Nitrogen

The mean N content in the raspberry leaves ranged from 2.30% in the Bełżyce region to 3.42% in the Godziszów region (Fig. 2). These values were within the critical range of values for raspberry leaves, i.e. 2-3.5% (Kessel 2003, Methodology 2010). In turn, the mean value for all the plantations (2.89%) was slightly higher than the optimal content (2.75%) recommended for this species (Horuz et al. 2013). The differences observed between the regions of cultivation and the content of N as well as other macronutrients were probably related to weather conditions. Besides this factor, previous studies indicated that N accumulation in raspberry was dependent on N fertilisation (Reickenberg and Pritts 1996), sampling time (John et al. 1976) and environmental and soil conditions (Prive and Sullivan 1994). Kowalenko (1994) showed that

Table 2. The percentage of N, P and K in the total NPK content and percentage of K, Ca and Mg in the total KCaMg content in the raspberry leaves

Region	% N	% P	% K	% K	% Ca	% Mg
	in the total NPK content			in the total KCaMg content		
Total	63.9	5.5	30.7	48.7	37.9	13.4
Bełżyce	55.1	7.1	37.9	60.8	29.3	9.8
Chodel	62.4	6.1	31.5	59.5	26.0	14.5
Godziszów	63.9	4.6	31.6	57.7	30.3	11.9
Kraśnik	61.0	6.2	32.7	54.1	34.0	11.8
Lublin	56.7	3.9	39.4	62.7	26.6	10.6
Międzyrzec Podlaski	56.9	5.4	37.7	56.4	34.1	9.4
Opole Lubelskie	70.3	4.7	25.0	34.6	50.5	15.0
Urzędów	64.9	5.6	29.4	43.0	42.3	14.7

Table 3. Correlations between the content of macro- and micronutrients in the raspberry leaves and soil properties (correlation coefficients)

Variables		Content of macronutrients in leaves					Content of micronutrients in leaves				
		N	P	K	Ca	Mg	Fe	Cu	Zn	Mn	B
Content of macronutrients in leaves	N		0.21 p=.026	0.26 p=.005		0.28 p=.003					
	P	0.21 p=.026		0.59 p=.000		-0.28 p=.002					-0.40 p=.000
	K	0.26 p=.005	0.59 p=.000			-0.29 p=.002					-0.24 p=.002
	Ca					0.28 p=.002					0.30 p=.009
	Mg	0.28 p=.003	-0.28 p=.002	-0.29 p=.002	0.28 p=.002						0.36 p=.002
Content of micronutrients in leaves*	Fe			0.61 p=.019							
	Zn						0.50 p=.000				0.31 p=.008
	Mn										0.51 p=.000
	B		-0.40 p=.031	-0.24 p=.002	-0.30 p=.009	-0.36 p=.002			0.31 p=.008	0.51 p=.000	
Soil properties**	K					-0.36 p=.012	0.42 p=.010				
	Mg							0.48 p=.003			
	Cu				-0.49 p=.001						
	Zn										0.57 p=.000
	Mn							0.44 p=.009			

*No correlation was found between the Cu content in the leaves and the content of macro-and micronutrients in the leaves
**No correlation was found between pH and the content of P, Fe and B in the soil and the content of macro- and micronutrients in the leaves

the range of N uptake over a four-year study was from 85 to 122 kg ha^{-1}. In a study by Rumasz-Rudnicka et al. (2009), the effects of drip irrigation and N fertilisation on the chemical composition of raspberry fruit and leaves were investigated. They reported that after fertilisation with 120 kg N ha^{-1} the content of this element in leaves was slightly lower (2.58%) than that reported in our research; it was optimal in comparison with critical values in raspberry integrated management (Methodology 2010). The percentage of N in the total N+P+K content in the leaves was on average 63.9% (Tab. 2) and was similar to the value reported by Horuz et al. (2013). The N content was significantly correlated with P, K and Mg in the leaves (Tab. 3, Fig. 4). In turn, the multiple regression equation calculated after a selection of the best subset of independent variables shows that the variables (content of B and Mn in the soil and Mg, P and Zn in the leaves) determined 60% of the N content in raspberry leaves. However, the combinations of the mentioned variables had a different influence on the N content. The concentration of B in the soil as well as Zn, P and Mg in the leaves positively influenced the N accumulation. In turn, taking into account other factors, an increase in the Mn content in the soil by 1 mg kg^{-1} decreased the N content by 0.003% (Tab. 4).

Phosphorus

The P content in the raspberry leaves varied between the growing regions and ranged between 0.19% (Opole Lubelskie) and 0.30% (Chodel) (Fig. 2). The mean P content was 0.24%, which was within the range of optimal values reported in the literature (Kessel 2003, Methodology 2010). The content of P in the leaves was significantly positively correlated with the content of N and K and negatively correlated with the content of Mg and B (Tab. 3). Taking into account the interactions among all the variables analysed and based on the multiple regression equation, it was found that the

Table 4. Results of forward stepwise multiple regression analysis of the macro- and micronutrient content in the raspberry leaves as dependent variables

Content of elements in the leaves	R	R^2 100 (%)	Significance level	Multiple regression equation
N (%)	0.773	59.7	0.003	$Y=1.65+0.582_{B(mg\ kg^{-1}\ soil)}+2.32_{Mg(\%)}+0.002_{P(\%)}+0.046_{Zn(mg\ kg^{-1})}-0.003_{Mn(mg\ kg^{-1}\ soil)}$
P (%)	0.686	47.0	0.001	$Y=0.260-0.0006_{B(mg\ kg^{-1}\ soil)}+0.0021_{Zn(mg\ kg^{-1})}-0.00005_{Mn(mg\ kg^{-1}\ soil)}$
K (%)	0.653	42.6	0.015	$Y=1.10-0.624_{Ca(\%)}+0.271_{N(\%)}+0.0016_{Mn(mg\ kg^{-1}\ soil)}-0.00034_{Mn(mg\ kg^{-1})}-0.0015_{K(mg\ kg^{-1}\ soil)}$
Ca (%)	0.659	43.4	0.002	$Y=1.14+0.855_{Mg(\%)}-0.220_{K(\%)}-0.034_{Cu(mg\ kg^{-1}\ soil)}$
Mg (%)	0.669	44.8	0.001	$Y=0.081+0.150_{Ca(\%)}-0.061_{N(\%)}-0.00041_{K(mg\ kg^{-1}\ soil)}$
B (mg kg^{-1})	0.825	68.0	0.000	$Y=66.62+1.36_{Zn(mg\ kg^{-1}\ soil)}-233.5_{P(\%)}+159.1_{Mg(\%)}+0.433_{Cu(mg\ kg^{-1})}-0.669_{pH\ in\ KCl}$
Cu (mg kg^{-1})	0.732	53.6	0.000	$Y=-21.36+0.550_{Mg(mg\ kg^{-1}\ soil)}+0.121_{Mn(mg\ kg^{-1}\ soil)}$
Zn (mg kg^{-1})	0.676	45.7	0.000	$Y=5.84+0.012_{Fe(mg\ kg^{-1}\ soil)}+4.16_{N(\%)}+0.0057_{Mn(mg\ kg^{-1})}$
Mn (mg kg^{-1})	0.585	34.3	0.011	$Y=866.5+17.40_{Zn(mg\ kg^{-1})}-3300.3_{P(\%)}+0.91_{P(mg\ kg^{-1}\ soil)}$
Fe (mg kg^{-1})	0.572	32.8	0.005	$Y=152.35+586.88_{P(\%)}-45.40_{N(\%)}$

effect of the variables reached 47% (Tab. 4). The results obtained indicate a high N/P ratio of 12.2. An N/P ratio exceeding the value of 9 may reveal temporary P deficiency caused by excessive N fertilisation (Horuz et al. 2013). The adverse effect of N fertilisation on the P accumulation in leaves was also reported by Rumasz-Rudnicka et al. (2009). Güsewell (2004) indicated that N/P ratios can vary widely (1-100); however, generally N/P ratios <10 and >20 correspond with P and N intake restriction.

Potassium

The K content in the raspberry leaves ranged from 1.06% (Opole Lubelskie) to 2.05% (Lublin) (Fig. 2). The values obtained imply a low content of this element in two regions (Opole Lubelskie and Urzędów) (Methodology 2010). On the other hand, some authors suggest that a 1-2% content of K in raspberry leaves is optimal (Kessel 2003). These results are quite surprising, given the high K level in the soils of the Urzędów region and much lower levels of this element in the soils of the Lublin region (Tab. 1). However, when plant tissue levels are compared to the corresponding soil nutrient contents, no correlation is often found (Roper 1995). The N/K ratio (2.2) and the high percentage of K in the total N+P+K content (30.7%; Tab. 2) indicate a proper level of K in the raspberries. The values obtained imply a well-balanced N/K fertilisation, which minimizes the possibility of K deficiency (Horuz et al. 2013). The content of K in the leaves was significantly correlated with the content of N, P and Mg as well as Fe and B (Tab. 3). The multiple regression equation indicates the well-known ion antagonism between K and Ca. For all the variables assessed, increasing Ca content by 1% reduced the K content by 0.62%. On the other hand, taking into account other factors, an increase in the K content of 1% reduced the content of Ca by 0.22% (Tab. 4).

Calcium

The mean Ca content in the raspberry leaves ranged from 0.72% (Chodel) to 1.55% (Opole Lubelskie) (Fig. 2). Although the results obtained are within the optimal range of the Ca content in raspberries (Kessel 2003), the mean percentage Ca concentration in the total K+Ca+Mg content (Tab. 2) may indicate a periodical deficiency of this element. Horuz et al. (2013) has demonstrated that the percentage Ca concentration below the reference value of 42.7% in the total K+Ca+Mg content may imply a poor supply of this element in raspberries. The calculated model of multiple regression accounted for the 43.4% content of Ca in the raspberry leaves (Tab. 4).

Magnesium

Depending on the region of cultivation, the mean content of Mg in the raspberries ranged from 0.26% (Bełżyce) to 0.45% (Opole Lubelskie) (Fig. 2). The level of this element in raspberry leaves was optimal, being within the critical value range provided in

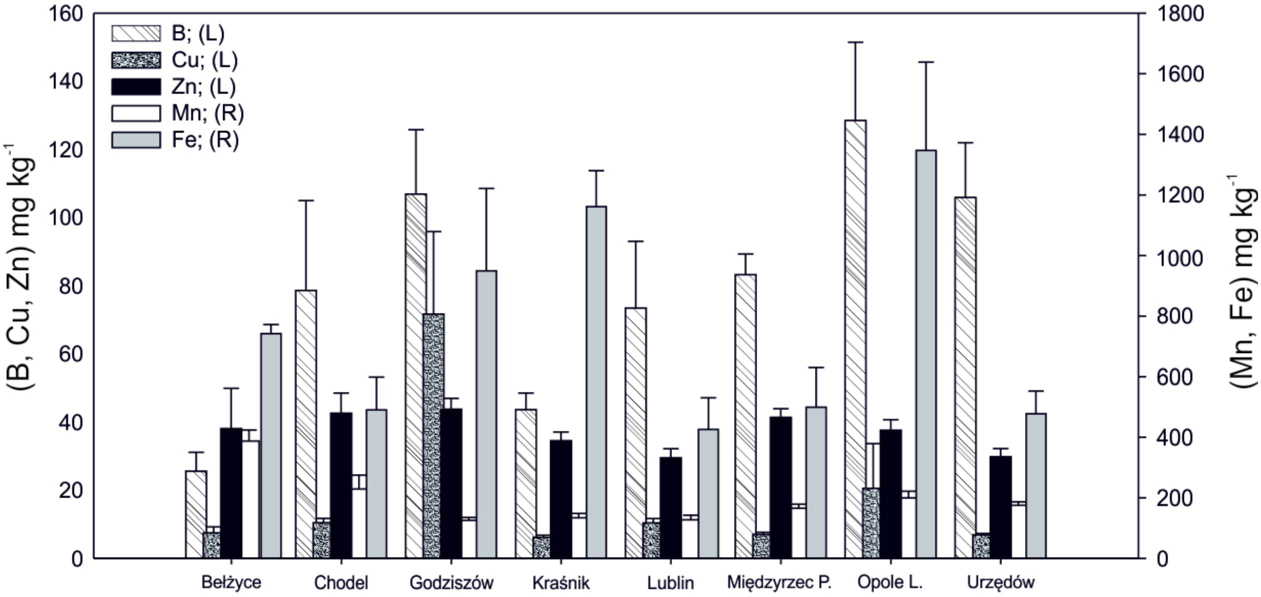

Figure 3. The contents of B, Cu, Zn (L – left axis), Mn and Fe (R – right axis) in the raspberry leaves from different growing regions. The bars and whisker plots give the mean and 95% confidence limits (95% confidence interval), respectively

the literature, i.e. 0.25-0.5% (Kessel 2003) and 0.30 -0.45% (Methodology 2010). Both the concentration of Mg and its high proportion in the total K+Ca+Mg content (Tab. 2) indicate a sufficient supply of this macronutrient in the raspberries. The calculated correlation coefficients reveal that the Mg level in the plants was negatively correlated with the content of K in the soil and leaves (Tab. 3, Fig. 5), which confirms the well-known antagonistic interaction between these two cations (Kabu and Toop 1970).

In the nutrient uptake processes, K, Mg and Ca are strongly antagonistic. Generally, increased K, Ca or Mg levels result in a lower uptake of the remaining two cations, regardless of the crop grown. Ca and Mg uptake by plants is also affected by the antagonistic effect of NH_4 (Horuz et al. 2013 and references therein). Kowalenko (1994) suggested that despite differences observed in the total macronutrient concentration among different studies, the relative proportion and magnitude of the elements generally remain similar.

Manganese

The raspberry leaves were characterized by a very high content of Mn; the mean concentration of this element was 702 mg kg^{-1} (Fig. 3), which was 2.5 -fold higher than the maximum critical value for this species (Kessel 2003). One of the indicators of Mn toxicity in plants is the Fe/Mn ratio, which in our study was 0.39. Horuz et al. (2013) indicate that symptoms of Mn toxicity in raspberry leaves may appear at a Fe/Mn ratio below 1.0. In a fertilisation experiment, Warman (2009) reported that long-term mineral fertilisation (NPK) might lead to the accumulation of Mn in leaves at a rate exceeding 250 mg kg^{-1}. Furthermore, Karaklajić-Stajić et al. (2012) suggest that Mn may be accumulated in leaves of raspberries growing on clay soils with water-air imbalance and a low pH. The results of our study also demonstrated the low pH of the soil samples, which may be one of the causes of the high Mn content in the leaves. Orhan et al. (2006) suggested that excessive concentrations of Mn and Fe in raspberry leaves may be also explained by the activity of rhizosphere bacteria, which produce organic acids and acidify soil solutions, thereby increasing the availability of Fe and Mn for plants.

Iron

The mean Fe concentration in the plants was 191 mg kg^{-1} (Fig. 3). Although the mean value was in the optimal range of 50-200 mg kg^{-1} (Kessel 2003), the values reported from some regions suggest an excess of this element in plants (Bełżyce – 387, Chodel – 258, Urzędów – 221). The Fe concentration was found to be positively correlated with the Zn content in the leaves and the K content in the soil (Tab. 3).

Boron

The B concentration in the raspberry leaves ranged from 25.5 (Bełżyce) to 128.5 mg kg^{-1} (Opole Lubelskie) (Fig. 3) and these values were similar

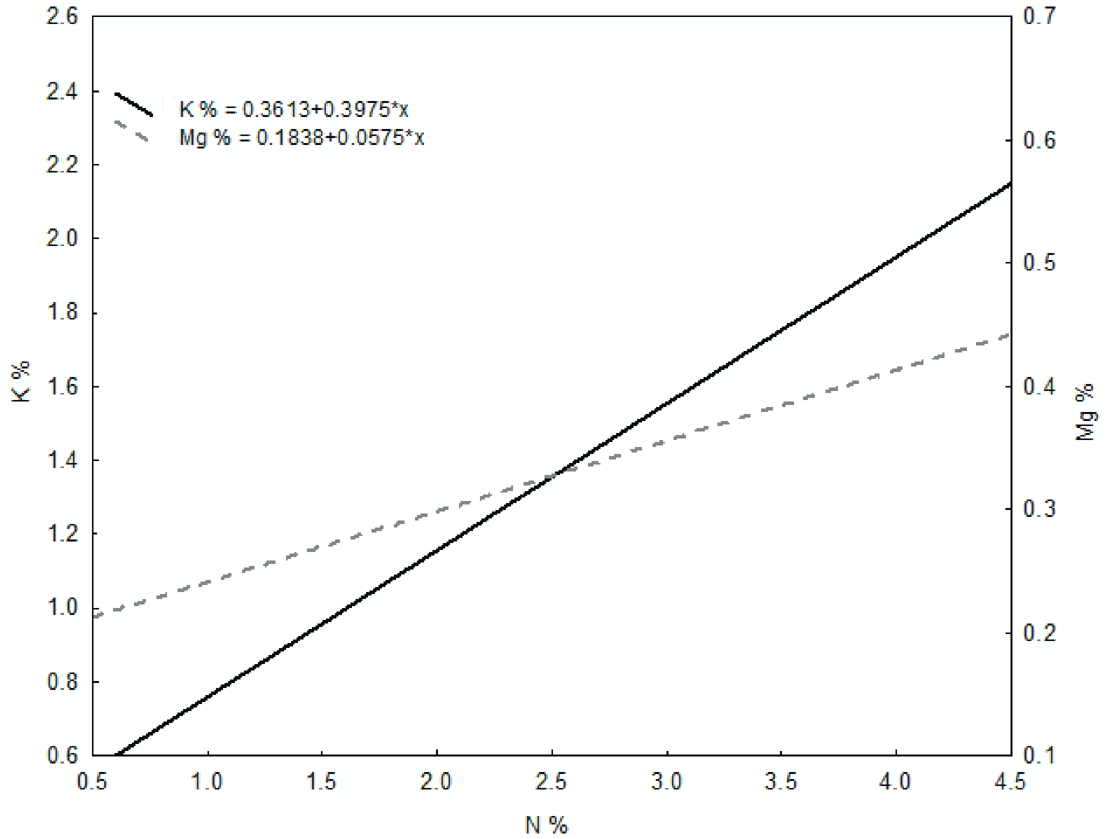

Figure 4. The content of N in the raspberry leaves in correlation with the K (left axis) and Mg (right axis) content in the leaves

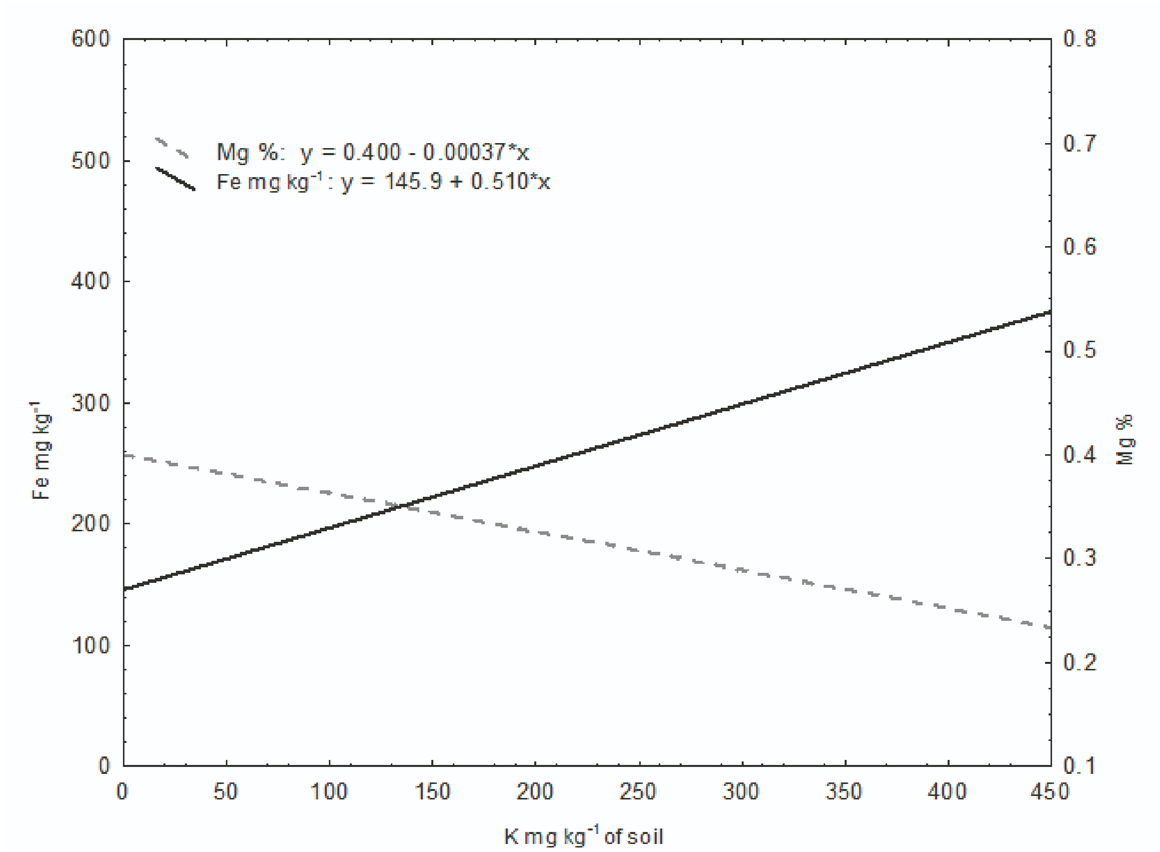

Figure 5. The content of Fe and Mg in the raspberry leaves in correlation with the K concentration in the soil

to those reported by Wójcik (2005) for raspberries receiving foliar or soil applied B. The results obtained indicate that in the raspberry there was no risk of deficiency of this element, as its critical value ranges from 20 to 60 mg B kg^{-1} (Kessel 2003). The data reveal that the B concentration is correlated with the content of most macroelements (P, K, Ca and Mg) and some microelements (Zn and Mn) in leaves and with the Zn content in the soil (Tab. 3). The multiple regression equation calculated with the selection of the best subset of independent variables shows that the selected variables determined 68% of the B content in raspberry leaves (Tab. 4).

Zinc

The mean Zn concentration in the raspberry leaves was 40.3 mg kg^{-1} (Fig. 3), which was higher than the minimal content (15 mg Zn kg^{-1}) recommended for this species (Kessel 2003) and indicated no risk of deficiency of this micronutrient in the plants. Furthermore, the calculated Fe/Zn ratio of 5, which is below the critical value (30) (Horuz et al. 2013), reveals a sufficient Zn supply in the raspberries grown in the studied regions. The results obtained indicate that, taking into account others factors, the content of N and Mn in the leaves and the content of Fe in the soil were positively correlated with Zn level in the leaves. The selected variables using the forward stepwise regression method determined 45.7% of the Zn content in raspberry leaves (Tab. 4).

Copper

The mean Cu concentration of 15.3 mg kg^{-1} was within the optimal range of values for this element in raspberry leaves (2-20 mg kg^{-1}) (Kessel 2003). Although the results obtained indicate that the plants received an optimal Cu supply, substantial discrepancies in the content of this element were reported between the plantation region ranging from 6.2 (Kraśnik) to 71.7 (Godziszów) (Fig. 3).

Based on the results obtained, we can conclude that the optimal supply of raspberries in macro- and micronutrients is a resultant of several factors, including some soil properties and interactions between the content of individual nutrients in leaves. We have shown that in many cases the ion antagonism/synergism has a great impact on the level of essential ions. However, the mechanistic explanation of nutrient uptake by raspberries requires further laboratory experiments in controlled growth conditions.

CONCLUSIONS

1. The raspberries grown in the Lublin region contained an optimal level of N, K, P and Mg and of some micronutrients (B, Zn and Cu).
2. The concentration of Mn in raspberry leaves is very high and greatly exceeds the maximum critical value for this species. Also, the concentration of Fe in some regions indicates an excess of this element in the plants.
3. The levels of macro- and micronutrients in the leaves generally do not correlate with their concentration in the soil.

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