Journal of Elementology ISSN 1644-2296

Komosa A., Roszyk J., Mieloch M. 2017. *Content of nutrients in soils of highbush blueberry (Vaccinium corymbosum* L.*) plantations in Poland in a long-term study*. J. Elem., 22(4): 1193-1207.
DOI: 10.5601/jelem.2016.21.4.1329

ORIGINAL PAPER

CONTENT OF NUTRIENTS IN SOILS OF HIGHBUSH BLUEBERRY (*VACCINIUM CORYMBOSUM* L.) PLANTATIONS IN POLAND IN A LONG-TERM STUDY*

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Abstract

The cultivation of highbush blueberry (*Vaccinium corymbosum* L.) in Poland has gained an increasing interest in the last years. Optimal fertilization of soils under highbush blueberry plantations is essential for obtaining the proper growth and yield of plants. A 12-year study (2004 - 2015) was conducted on plantations across Poland. In total, 2543 soil samples collected from the upper layer of soils (0 - 20 cm) in 220 plantations were tested. It was found that 77% of highbush blueberry plantations had a low average content of available soil nitrogen ($N\text{-}NH_4 + N\text{-}NO_3$), 68% – phosphorus, 60% – sulfur, 45% – potassium, 35 – magnesium, 7% – calcium, 38% – manganese, 27% – zinc, 23% – chloride, 21% – copper and 3% – iron. Some of the soils were rich in available boron, which is unfavourable for the plants. Approximately 90% of the plantations had a low soil content of this micronutrient. A large share of soils with the high content of available calcium (52%) meant that approximately 48% of the plantations had high soil pH_{H_2O} (above 5.00), which is unsuitable for highbush blueberry. Around 6% of the plantations had excessively low pH_{H_2O}, but 46% presented soil reaction withing the optimal range. No serious problems due to undesirable valeus of the electrical conductivity (EC) of soils were detected. An average of 93% of the plantations had EC within an acceptable range, whereas just 7% demonstrated a high level of soil EC. The research results seem to suggest that there are good opportunities to increase the yield of highbush blueberry in terms of its quantity and quality aspects by optimizing the abundance of soils in macro- and micronutrients and maintaining the required pH_{H_2O} of soils.

Keywords: macronutrients, micronutrients, soil analysis, guideline values, plant nutrition.

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* A study financed in the program of "Service work of a scientific research no 1/2004(U)-1/2016(U)" Poznań University of Life Sciences.

INTRODUCTION

The cultivation of highbush blueberry (*Vaccinium corymbosum* L.) in Poland had gained a rapidly increasing interest in the last 10 years. The total highbush blueberry cultivation area in 2015 was approximately 6,500 hectares (IERIGŻ-PIB 2016), which gives Poland the first place in Europe. The climatic conditions in Poland favour the cultivation of highbush blueberry, despite unfavourable spring frosts which can result in the freezing of flower buds or summer hailstorms causing some damage of fruits (Smolarz, Pliszka 2006).

Initially, the Polish plantators mainly grew such cultivars as Bluecrop, Earliblue, Darrow and Jersey, but in the subsequent years they introduced more varieties, like Duke, Spartan, Patriot, Toro, Nelson and lately Chandler, Brigitta Blue, Draper, Liberty, Aurora and Chanticleer, although the cultivar Bluecrop remains the most popular one (Smolarz, Pluta 2014).

Highbush blueberry requires acid soils or substrates pH_{H_2O} 4.00 - 5.00 or pH_{KCl} 3.70 –4.70, and specific content of macro- and micronutrients in the root environment (Komosa 2012, 2014). These plants could be grown in soils rich in organic substrates, e.g. high peat, sawdust and bark of coniferous and deciduous trees or mixtures of these substrates (Strik 2014, Strik, Buller 2014). Soils suitable for the cultivation of highbush blueberry are clay and sandy-clay ones, which are classified as brown soils (covering 56% of Poland's area) and lessive soils (5%), which belong to valuation classes IIIa, IIIb and Iva, as well as light, sandy, podzolic soils (25%), assigned to valuation classes IVb and even V and VI. Wach (2008) demonstrated that the highest yield on slightly loamy and sandy soil was produced by the cultivars Northland and Bluecrop, lower yield was harvested from the cultivars Ivanhoe and Blueray, and the lowest one was obtained from cv. Darrow and Spartan. Komosa (2014) reported that plantations could be established on most of arable soils, but especially on sandy soils, which should then be equipped in fertigation systems with two dripping lines running along rows of blueberry shrubs and supplying nutrient solution. The above author showed the response of shrubs to excessive amounts of macronutrients, mainly potassium, magnesium and sulfur, or micronutrients, such as manganese and copper, applied with the broadcast and fertigation methods.

Assessment of the nutrient content in soils under highbush blueberry plantations could be achieved relative to the guideline values developed by Komosa (2007, 2012). Recently, nutrient solutions for fertigation of highbush blueberry grown in mineral soils (Glonek, Komosa 2013*abc*) and in containers filled with a mixture of high peat and perlite 1:1 (v/v) have been designed (Voogt et al. 2014). In order to ensure an optimal growth and yield of highbush blueberry, two techniques of plant nutrition are needed, namely broadcast fertilization and fertigation. Ehret et al. (2014) and Vargas and Bryla (2015) showed that fertigation with ammonium sulfate and urea was more efficient in optimizing the yield and nitrogen nutrition status of cv. Bluecrop highbush blueberry than spreading granular fertilizer, and that the yield was 17% higher from plants treated with ammonium sulfate than with urea. Vargas et al. (2015) reported that highbush blueberry yield was better when the plants were drip fertigated than when microsplinkers were used. The latter method reduced the berry yield and quality, due to salt stains appearing on berries and a much lower nitrogen efficiency. A contemporary approach to the nutrient requirements, leaf tissue standards, fertigation with nitrogen as well as other macro- and micronutrients has been presented by Bryla and Strik (2015).

The main purpose of this research was to evaluate the macro- and micronutrient content, pH_{H_2O} and EC of soils under Polish highbush blueberry plantations over the last 12 years. These data could support making decisions about mineral fertilization of soils in highbush blueberry plantations and help to optimize nutrition of this plant in the future.

MATERIAL AND METHODS

In 2004 - 2015, research was conducted on highbush blueberry plantations located across Poland. In total, 220 plantations on which highbush blueberry were grown in mineral soils were examined. The distribution of the above plantations in particular provinces of Poland is shown in Figure 1. In total, 2,543 soil samples were collected from these plantations. In the consecutive years of the research, the following number of soil samples was tested: 46 in 2004, 72 in 2005, 107 in 2006, 98 in 2007, 184 in 2008, 139 in 2009, 229 in 2010, 226 in 2011, 305 in 2012, 263 in 2013, 364 in 2014 and 510 samples in 2015. The highest number of plantations was tested in the provinces: *mazowickie* (62) and *wielkopolskie* (55), followed by the provinces *łódzkie* (23), *zachodniopomorskie* (16), *podkarpackie* (13) and *lubelskie* (10) – Figure 1.

In all the plantations, plants were nourished through the application of mineral fertilizers. Soil analyses were made every year to determine quantities of macro- and micronutrients, pH_{H2O} and EC. These determinations were performed in autumn in years of yielding, whereas in years preceding bluberry yielding they were conducted in early spring. By the year 2009, the following cultivars had been mainly grown on these plantations: Bluecrop, Earliblue, Duke, Sunrise, Spartan, Toro, Bluegold, Bluejay, Ivanhoe, Draper, Chandler, Patriot, Sierra, Liberty, Dixi, Nelson, Darrow, Jersey, Brigitta, Lateblue and Aurora, afterwards other cultivars were additionally planted: Bluetta, Berkley, Bonus, Chanticleer, Herbert, Coville, Elizabeth, Meader and Elliott. About 10% of the tested plantations were newly established (no more than 3 years old), about 10% were at the beginning of yielding (4-5 years old) and the others were in the full fruiting stage (over 6 years old).

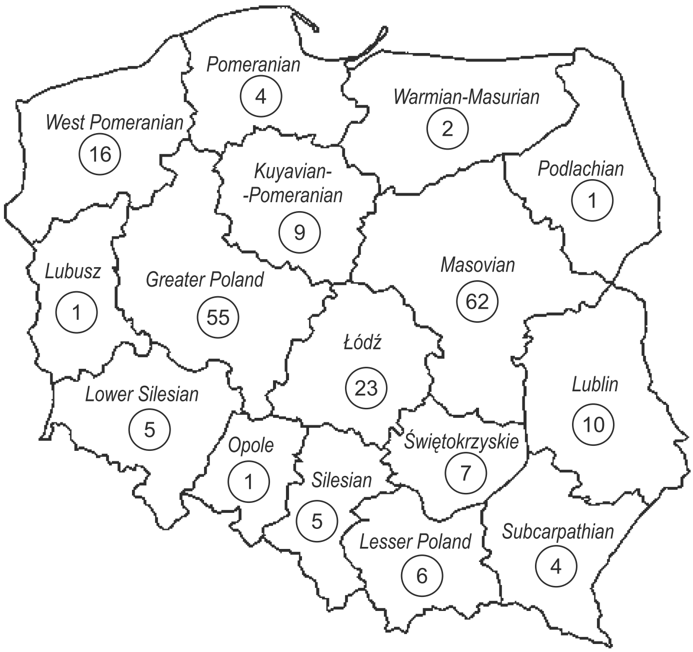

Fig. 1. Number of highbush plantations studied in different voivodships of Poland

From the plantations without fertigation system, soil samples were taken randomly along the rows of shrubs, 20 - 30 cm to the left and right from the axis of the row, to the depth of 0 - 20 cm, using a soil sampler (an Egner's stick). One mixed sample was collected from 0.5 - 1.0 ha of a plantation consisting of 15 - 20 individual samples. They were taken from October 15 to November 30 before the year of yielding or from 1 to 31 of March in the year of yielding. Samples from plantations with fertigation systems were collected in a similar way, except being taken about 30 cm from drippers in the fertigation pipes.

Soil samples were dried at 20 - 25°C and passed through a 1 mm mesh sieve. Extractions of $N\text{-}NH_4$, $N\text{-}NO_3$, P, K, Ca, Mg, $S\text{-}SO_4$, Na, Cl, and B were carried out in 0.03 M CH_3COOH in a soil: extraction solution proportion of 1:10 w/w (20 g of soil d.m. with 200 cm^3 of 0.03 M CH_3COOH). This is SPURWAY'S modified method. After extraction the following methods were used: $N\text{-}NH_4$ and $N\text{-}NO_3$ by microdistillation according to BREMNER in the modification by STARCK, P – colorimetric method with ammonium vanado-molybdate, K, Ca, Mg – by atomic spectrometry absorption (ASA), $S\text{-}SO_4$ – nephelometric with $BaCl_2$, Cl – nephelometric with $AgNO_{3,}$ B – colorimetric method with curcumin (NOWOSIELSKI 1974, KOMOSA, STAFECKA 2002).

The micronutrients, i.e. Fe, Mn, Zn and Cu, were extracted with LINDSAY solution. The soil: extraction solution proportion was 1:4 w/w (50 g of soil d.m. and 200 cm^3 of Lindsay's solution). After extraction, Fe, Mn, Zn and Cu were determined by the ASA method. The soil pH_{H2O} was tested with the potentiometric method (soil: distilled water 1:2, w/w), and EC was determined in the same soil solution with the conductometric method (NOWOSIELSKI 1974, KOMOSA, STAFECKA 2002).

Results of the nutrient content, pH_{H_2O} and EC of soil were analyzed individually for a given parameter using one-way variance analysis and the Duncan's multiple-range test at α 0.05.

RESULTS AND DISCUSSION

The nutrient content, reaction (pH_{H2O}) and electrical conductivity (EC) of soils in highbush blueberry plantations were evaluated in relation to the guideline values (KOMOSA 2007, 2012) presented in Table 1. These data ensure

Table 1

Guideline values of nutrients and sodium in mineral soils and organic substrates on highbush blueberry plantations analyzed by universal methods (for mineral soils modified by KOMOSA 2007, 2012)

Nutrients	Mineral soils (mg kg^{-1} d.m.)	Organic substrates (mg dm^{-3} f.m.)
Macronutrients		
$N-NH_4 + N-NO_3$	25 – 50	75 – 150
P	30 – 60	50 – 100
K	50 – 80	100 – 150
Ca	100 – 300	50 – 400
Mg	30 – 60	50 – 100
$S-SO_4$	10 – 30	20 – 60
Micronutrients		
Fe	75 – 150	50 – 150
Mn	20 – 50	20 – 50
Zn	5 – 25	5 – 20
Cu	1 – 4	1 – 5
B	0.5 – 1.5	0.5 – 1.5
Mo	0.1 – 1.4	0.1 – 1.4
Cl	15 – 50	15 – 50
Na*	< 50	< 50
Other parameters		
pH_{H_2O}	4.00 – 5.00	4.00 – 5.00
EC (mS cm^{-1})	< 0.35	< 0.60

* Na – is not a nutrient

that satisfactory yields of highbush blueberry can be achieved, in terms of both quantity and quality (Glonek, Komosa 2013*abc*) and are considered to be optimal, while any values below are thought to be a low content and above are referred to as a high one (Table 2, 3). Table 1 contains guideline values of nutrients for mineral soils and organic substrates, but this research comprised only plantations established on mineral soils.

Table 2

The percentage of soil samples collected from the topsoil (0-20 cm) of highbush blueberry plantations indicating low, optimal and high available macronutrient content (determined with universal methods), pH_{H_2O} and EC in 2004-2015

Macro-nutrients and other parameters	Soil content level	Years				Mean 2004 - 2015 (n = 2543)
		2004 - 2006 (n* = 225)	2007 - 2009 (n = 421)	2010 - 2012 (n = 760)	2013 - 2015 (n = 1137)	
		% rounded to whole numbers				
N	low	73*a***	86*a*	72*a*	78*a*	77
	optimal	24*a*	10*a*	18*a*	16*a*	17
	high	3*a*	4*a*	10*b*	6*ab*	6
P	low	79*a*	68*a*	62*a*	64*a*	68
	optimal	18*a*	29*a*	32*a*	30*a*	27
	high	3*a*	3*a*	6*a*	6*a*	5
K	low	55*b*	45*ab*	42*ab*	39*a*	45
	optimal	30*a*	30*a*	32*a*	34*a*	31
	high	15*a*	26*ab*	27*b*	27*b*	24
Ca	low	5*a*	9*a*	7*a*	7*a*	7
	optimal	39*a*	40*a*	42*a*	42*a*	41
	high	56*a*	50*a*	51*a*	51*a*	52
Mg	low	37*a*	39*a*	31*a*	34*a*	35
	optimal	38*a*	32*a*	38*a*	39*a*	37
	high	25*a*	29*a*	31*a*	26*a*	28
S	low	51*a*	67*b*	60*ab*	63*ab*	60
	optimal	27*b*	12*a*	20*ab*	13*a*	18
	high	22*a*	21*a*	20*a*	24*a*	22
pH_{H_2O}	low	3*a*	8*a*	6*a*	9*a*	6
	optimal	43*a*	41*a*	46*a*	54*a*	46
	high	54*b*	51*ab*	49*ab*	38*a*	48
EC	acceptable	95*a*	95*a*	92*a*	90*a*	93
($mS\ cm^{-1}$)	high	5*a*	5*a*	8*a*	10*a*	7

** values marked with the same letter within a given soil content level or parameter (pH_{H_2O}, EC) did not differ significantly; * n –number of soil samples

Table 3
The percentage of soil samples collected from the topsoil (0-20 cm) of highbush blueberry plantations indicating low, optimal and high available micronutrient content (determined with the universal methods) in 2004-2015

Micro-nutrients	Soil content level	Years				Mean 2004 - 2015 (n = 2543)
		2004-2006 (n* = 225)	2007-2009 (n = 421)	2010-2012 (n = 760)	2013-2015 (n = 1137)	
		% rounded to whole values				
Fe	low	0*a***	2*a*	3*a*	5*a*	3
	optimal	64*a*	75*ab*	85*b*	90*b*	78
	high	36*b*	23*a*	13*a*	5*a*	19
Mn	low	53*b*	35*a*	31*a*	31*a*	38
	optimal	34*a*	51*b*	52*b*	47*b*	46
	high	13*a*	14*a*	17*a*	22*a*	16
Zn	low	13*a*	31*b*	31*b*	31*b*	27
	optimal	69*a*	60*a*	64*a*	63*a*	64
	high	18*b*	9*ab*	5*a*	5*a*	9
Cu	low	40*b*	12*a*	15*a*	17*a*	21
	optimal	57*a*	71*b*	71*b*	74*b*	68
	high	3*a*	17*c*	14*bc*	9*ab*	11
B	low	84*a*	89*ab*	95*b*	93*ab*	90
	optimal	16*b*	11*ab*	5*a*	7*ab*	10
	high	0*a*	0*a*	0*a*	0*a*	0
Cl	low	21*a*	26*a*	21*a*	26*a*	23
	optimal	79*a*	74*a*	79*a*	74*a*	77
	high	0*a*	0*a*	0*a*	0*a*	0

** values marked with the same letter within a given soil content level did not differ significantly
* n – number of soil samples.

Nitrogen

The results showed that during the 12-years study (2004-2015) 77% of plantations on average (Table 2) had a low content of available nitrogen ($N-NH_4$+$N-NO_3$) in soil (below 25 mg ($N-NH_4$ + $N-NO_3$) kg^{-1} of soil d.m. (Table 1). This result confirms that mineral (available) nitrogen ($N-NH_4$+$N-NO_3$) is not accumulated in soil, especially in light, sandy one. The main reasons of are: a large uptake of nitrogen by plants, nitrogen leaching to deeper layers of soil, and autumn and early spring dates of soil analyses (Hanson, Retmales 1992, Bryla, Machado 2011). The low content of mineral nitrogen ($N-NH_4$+$N-NO_3$) in the soils persisted in all the years of the experiment, despite using the required doses of nitrogen in the spring and early summer fertilization. An optimal content of available nitrogen ($N-NH_4$+$N-NO_3$) in soils was found in 17% while a high occurred in 6% of the plantations, on average

(Table 2). A high level of nitrogen at the end of a growing season is not desirable as it reduced the hardiness of blueberry shrubs. Vargas and Bryla (2015) applied three doses of nitrogen in fertigation and granular form of ammonium sulfate and urea, which were increased each year as the highbush blueberry cv. Bluecrop plants matured – 63 to 93, 133 to 187 and 200 to 280 kg N ha^{-1}. The total yield averaged 32 to 63 t ha^{-1} in each treatment over the first 5 years of fruit production and was the highest when the plants were fertigated with ammonium sulfate or urea at doses of at least 63 to 93 kg N ha^{-1} per year. The cited study showed that highbush blueberry belonged to plants with high demand for nitrogen and tolerant to significant amounts of nitrogen applied by spreading or the fertigation method.

Ehret at al. (2014) pointed out that the soil's ammonium and nitrate concentrations increased with a dose of nitrogen, but only amounts of nitrate differed between the two application methods – broadcast and fertigation. Soil nitrate was higher with fertigation than with granular fertilizers, particularly at the end of the season and when greater doses of nitrogen were applied. Fertigation produced more shoot growth and greater yields with less nitrogen than did broadcast applications of fertilizer.

Phosphorus

The soil abudance of phosphorus was similar to that of nitrogen. On average, 68% of the plantations showed low levels of available phosphorus (Table 2), below 30 mg P kg^{-1} of soil d.m. (Table 1). Only 27% plantations had an optimal level of this element (30 - 60 mg P), while 5% revealed a high level on average (above 60 mg P kg^{-1} of soil d.m.) – Tables 1, 2. There was a decreasing tendency for the low content of available phosphorus, declining from 79% in 2004 to 64% in 2015, while the optimal level tended to increase from 18 to 30% over the twelve years analyzed, but these changes were not statistically proven (Table 2). The high percentage of plantations with a low content of available phosphorus could be due to the retrogradation phosphorus in acid soils (Hisinger 2001, Urrutia et al. 2013), which are required for the cultivation of highbush blueberry (Williamson et al. 2006, Komosa 2007).

Potassium

The soil potassium content was much better for highbush bluberries than the concentrations of nitrogen and phosphorus. On average, 45% plantations had a low content of available potassium (below 50 mg K kg^{-1} of soil d.m.) but 31% plantations showed optimal potassium concentrations (50 - 80 mg K) while 24% had a high content of this element (above 80 mg K kg^{-1} of soil d.m.) – Tables 1, 2. The percentage of plantations with a low content of potassium decreased significantly, while the percentage of ones with a high content of potassium increased during the 12-year study (Table 2). Higher abundance of potassium in soils under highbush blueberry plantations is connected with the exchange sorption of this cation by mineral and organic soil colloids. This process inhibits potassium leaching to deeper layers of soil (Sawhney 1972, Alfaro et al. 2004).

Calcium and pH_{H_2O}

In contrast to nitrogen, phosphorus and potassium, the percentage of soils with a low content of calcium was small. It was found that only 7% of the plantations (on average) demonstrated a low content of available calcium (below 100 mg Ca kg^{-1} of soil d.m.) but 41% plantations had an optimal content (100 - 300 mg Ca kg^{-1} of soil d.m.) – Tables 1, 2. On the other hand, there is an undesirably high percentage (52%) of calcium-rich soils (above 300 mg Ca kg^{-1} of soil d.m.). This explains why 48% of the plantations showed excessively high pH_{H2O}, above 5.0, which is unsuitable for highbush blueberry growth. The research demonstrated that the percentage of plantations with high pH_{H_2O} of soil decreased significantly, from 54 to 38%, during the twelve years of our investigations (Table 2).

The main reason for the high calcium content in soils under the highbush blueberry plantations was that they were set up on soils rich in native calcium (Komosa 2007). Plantators try to decrease soil pH by applying fertilizers that acidify soils, such as ammonium sulfate, potassium sulfate, elementary sulfur, or by using fertigation with nutrient solution acidified to pH 5.00 - 5.50 through an application of nitric acid or/and phosphoric acid (Sonneveld, Voogt 2009, Glonek, Komosa 2013*abc*, Voogt et al. 2014).

Magnesium

The percentage of soils with the low, optimum and high content of magnesium was similar to potassium. Average 35% plantations had the low content of available magnesium (below 30 mg Mg kg^{-1} of soil d.m.), 37% plantations showed optimal content (30 - 60 mg Mg kg^{-1} of soil d.m.) and 28% plantations pointed the high content of this nutrient (Tables 1, 2). The percentage of soils with the low, optimum and high contents of magnesium did not differ significantly at the study period. A large share of soils with the optimum and high contents of available magnesium could be connected with the reach content of native soil magnesium and high pH_{H_2O} (Andruszczak, Szczegodzińska 1991, Tkaczyk et al 2016).

Sulfur

As in the case of nitrogen and phosphorus abundance, average 60% of plantations had the low content of available sulfur (below 10 mg $S\text{-}SO_4$ kg^{-1} of soil d.m.). Average 18% plantations showed the optimal content (10 - 30 mg $S\text{-}SO_4$ kg^{-1} of soil d.m.) but 22% plantations had the high content of this nutrient (above 30 mg $S\text{-}SO_4$ kg^{-1} of soil d.m.) – Tables 1, 2.The high percentage of plantations with the low content of sulfur is the result of easy leaching of available sulfur ($S\text{-}SO_4$) to the deeper layers of soil, mainly on light and sandy soils. Szwonek (2007) pointed out that about 90% of orchard soils maintained in the cultivation of apple trees in Poland had the low content of available sulfur (S-SO_4).

The main sources of this nutrient in soils are sulfur contained in organic matter and sulfur applied by growers in mineral fertilizers such as ammonium sulfate, potassium sulfate, magnesium sulfate and elementary sulfur. The major disadvantage is the high percentage of plantations (average 22%) with the high content of sulfur in soils. It is the effect of application high rates of elementary sulfur sometime in combination with ammonium sulfate or/and potassium sulfate fertilizers to decrease soil pH_{H_2O} to the range 4.0 - 5.0 (Komosa 2007). In the present study was found that differences in the percentage of soils with the low and optimal available sulfur contents were changed significantly but the percentage of plantations with the high content was similar in different years of study.

Electrical conductivity (EC)

There was no problem with the excessive electrical conductivity (EC) of soils on blueberry plantations. Only average 7% plantations had the high soil EC (above 0.35 mS cm^{-1}) – Tables 1, 2. This situation was caused usually by excessive fertilization of nitrogen, potassium and sulfur in such fertilizers as ammonium sulfate, potassium sulfate and elementary sulfur. A large application of these fertilizers was linked to the need of decreasing pH_{H_2O} in soils. Average 93% plantations had the acceptable EC (below 0.35 mS cm^{-1}). On these plantations were conducted controlled fertilization based on the annual soil analyses which prevented the application of high fertilizer rates and causing the excessive soil EC.

Summary of macronutrient soil contents

The study carried out in 2004 - 2015 showed that average 77% plantations had the low content of available nitrogen in soil, 68% – phosphorus, 60% – sulfur, 45% – potassium, 35% – magnesium and 7% – calcium. There was also very unfavorable abundance of soils in available calcium content. Average 52% plantations had the high content of this macronutrient, which cased that 48% plantations showed the high pH_{H_2O} above 5.00 which is inappropriate to the cultivation of highbush blueberry. Besides that a significant threat for obtaining the high yield of plants was excess of magnesium soil content (28% plantations), potassium (24%) and sulfur (22%). The results showed that are considerable practical opportunities to further increase the yield of highbush blueberry by optimization abundance of soils in macronutrients and maintaining of the required pH_{H_2O} of soils.

Iron

In relation to the acid reaction of soils on the highbush plantations there was no problem with insufficient contents of iron in soils. Only average 3% of soils shown the low content of available iron (below 75 mg Fe kg^{-1} soil d.m.) but 78% plantations showed the optimal content (75 - 150 mg Fe kg^{-1} soil d.m.) and 19% had the high content (above 150 mg Fe kg^{-1} soil d.m.) – Tables 1, 3. Increasing of iron availability with decreasing pH_{H_2O} in acid soils where shown in the works of Lindsay, Schwab (2008) and Rengel (2015). It was found that the percentage of plantations with the optimum content of iron in soil decreased significantly but increased the percentage of plantations with the high percentage of this micronutrient during 12-years of study. It could be the effect of gradual lowering of soil pH_{H_2O} during long-term cultivation of highbush blueberry.

Manganese

In contrast to iron, far more plantations were poor in manganese. An average 38% of the plantations had a low content of manganese in soil (below 20 mg Mn kg^{-1} soil d. m.), but 46% of the plantations showed an optimal content of this element (20 - 50 mg Mn kg^{-1} soil d.m.) and 16% had a high content (above 50 mg Mn kg^{-1} soil d.m.) – Tables 1, 3). Availability of manganese, as well as iron, increased with a decrease of pH_{H_2O} in acid soils (Rengel 2015). The percentage of plantations with a low content of manganese decreased significantly, at an increasing percentage of plantations with the optimal content of this element, which could be seen as a beneficial effect.

Zinc

Zinc soil abundance was much better than that of manganese. An average 27% of the plantations showed a low content of available zinc (below 5 mg Zn kg^{-1} soil d.m.), but it is a very positive finding that 64% plantations had a optimal content (5 - 25 mg Zn kg^{-1} soil d.m.) and only 9% implicated high zinc abundance (above 25 mg Zn kg^{-1} soil d.m.) – Tables 1, 3. In 2007 - 2015, the percentage of plantations with a low content of zinc was significantly higher than in 2004 - 2006, but the percentage of soils with a high content of this micronutrient declined. A large share of soils with an optimal content of zinc (64%) was due to the low pH_{H_2O} of soils on the highbush blueberry plantations. As in the case of iron and manganese, the availability of zinc increases with the lowering of soil pH_{H_2O} (Metwally et al. 1993, Singh et al. 2008, Rengel 2015).

Copper

The abundance of soils in cooper was very close to that in zinc. Most tested plantations were rich in available cooper, i.e. an average 68% of the plantations had an optimal content of this micronutrient (1 - 4 mg Cu kg^{-1} soil d.m.). An average 21% of the plantations showed a low content of copper (below 1.0 mg Cu kg^{-1} soil d. m.) but only 11% had a high content of this element (above 4 mg Cu kg^{-1} soil d.m.) – Tables 1, 3. The percentage of plantations with a low content of copper decreased significantly during the 12-year study, while the percentage of plantations with the copper content within the optimal range increased. The large percentage of the plantations with the optimal content of copper in soil (68%) could be connected to the application of substantial amounts of organic matter (high peat, sawdust, bark) on the highbush plantations and the chelation of copper cations with organic acids, mainly humic and fulvic ones (Klučákováč 2012).

Chlorine

In the cultivation of blueberry, an important role is played by adequate nutrition of chlorine. It is an essential chemical element for the proper course of photosynthesis (Izawa et al. 1969). The study showed that an average 23% of the blueberry plantations had a low content of available chloride in the form of chlorides (below 15 mg Cl kg^{-1} soil d.m.) while 77% of the plantations were characterized by an optimized chlorine content (15 - 50 mg Cl kg^{-1} soil d.m.) – Tables 1, 3. The abundance of chlorides in soils was stable during the years of study. The main source of chloride in blueberry plantations is water containing this micronutrient used for irrigation and fertigation of plants. The fact that blueberry growers use potassium chloride as a fertilizer could explain the low content of chloride (Komosa 2014).

Boron

The lowest soil nutrient abundance was detected for boron. An average 90% of the plantations had a low content of this micronutrient (below 0.5 mg B kg^{-1} soil d. m.) but only 10% plantations showed an optimal content (0.5 - 1.5 mg B kg^{-1} soil d.m.) – Tables 1, 3. Blueberry growers fertilized soils with borax ($Na_2B_4O_7 \cdot 10\ H_2O$, 11.3% B) and boric acid (H_3BO_3, 17% B) by broadcast fertilization and in fertigation. The large share of plantations with a low content of boron could be the effect of its fixation, that is passing from available to unavailable forms (Khan van et al. 2005). This process is very intensive in acid soils, typical for blueberry growing. Another reason is that boron can leach easily to deeper layers of soil especially on acid, sandy soils (Saleem et al. 2011). Yet another explanation might be the method of boron soil determination. In this work, boron was extracted from soils by 0.03 M CH_3COOH (modified Spurway method) and next determined colorimetrically with curcumin. The highest amounts are determined when the ICP-OES (Inductively Coupled Plasma – Optical Emission Spectrometry) method is used (Sah, Brown 1997).

Summary of macronutrient soil contents

This 12-year study pointed out that an average 38% of the plantations had a low content of soil available manganese, 27% – zinc, 23% – chloride, 21% – copper and 3% of the plantations were low in iron. The lowest soil nutrient abundance was found for available boron – an average 90% of the plantations showed a low content of this micronutrient. More studies on boron are needed to clarify this state, including the application of new methods of soil boron determination, especially ICP-OES and ICP-MS. Manganese (16% plantations), copper (11%) and zinc (9%) were the most highbush blueberry yield micronutrients of the ones found in excessive concentrations. The excess of iron shown in 19% plantations is not dangerous because this micronutrient is not toxic to highbush blueberry, as the plant prefers acidic soil reaction. The high content of iron is the result of its natural abundance of acid soils. Improving the abundance of soils in micronutrients could bring significant benefits by increasing quantity and quality of blueberry yield. This can be done by using broadcast and/or fertigation nourishment systems on highbush blueberry plantations.

CONCLUSIONS

1. This 12-year study (2004-2015) showed that an average 77% of highbush blueberry plantations had a low content of available soil nitrogen, 68% – phosphorus, 60% – sulfur, 45% – potassium, 35% – magnesium, 7% – calcium, 38% – manganese, 27% – zinc, 23% – chloride, 21% – copper and 3% – iron.

2. There was an undesirable soil content of available boron, unfavourable for the plants. An average 90% plantations had a low content of this micronutrient. The boron soil content on plantations of highbush blueberry requires further study with using modern methods of soil boron determination – especially ICP-OES and ICP-MS methods.

3. 17% of the plantations had an optimal content of available nitrogen, 27% – phosphorus, 31% – potassium, 41% – calcium, 37% – magnesium, 18% – sulfur, 78% – iron, 46% – manganese, 64% – zinc, 68% – copper, 10% – boron and 77% – chloride.

4. The study showed that 6% of the plantations had a high content of available nitrogen, 5% – phosphorus, 24% – potassium, 52% – calcium, 28% – magnesium, 22% – sulfur, 19% – iron, 16% – manganese, 9% – zinc, 11% – copper. There was not excess of boron and chloride.

5. The large share of soils with the high content of available calcium in soils (52%) under the highbush plantations determined in our study meant that an average 48% plantations revealed a high pH_{H_2O}, above 5.00, which is unsuitable for blueberry. An average 6 % of the plantations had low pH_{H_2O} but 46% showed an optimal soil reaction range. A serious problem of the electrical conductivity (EC) of soils being unfavourable to blueberry plants was shown. An average 93% of the plantations had soil EC within the acceptable range, but only 7% showed high EC.

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