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RENOVATION OF EXTRACTED HIGH BOGS IN LATVIA: MINERAL NUTRITION AND ECOLOGICAL ASPECTS OF AMERICAN CRANBERRY CULTIVATION

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Abstract: Latvia is a country with abundant peat resources and intensive peat production. Therefore restoration of more than 17,000 ha abandoned and excavated high bogs are an important issue. Scientific researches are necessary to choose the best way for renovation of peatlands after peat cutting. Along with sufficient freshwater supply this specific nutrient-poor and acid growing environment provides the possibilities for commercial cultivation of American cranberry (*Vaccinium macrocarpon*) which was successfully started during last 15 years. Today with more than 100 ha of plantings Latvia is fourth major cranberries producing country. In contrast with North America little is known regarding the fertilizing systems of cranberries planted on bare sphagnum peat. Being a native wetland plant, cranberries are nutrients low requiring culture; however, balanced mineral nutrition is vitally essential in producing high and qualitative yield. On the other hand, excessive or inadequate fertilization is potentially detrimental to the environmentally sensitive cranberry growing medium. Investigations were done to find out the actual status and main tendencies in mineral nutrition of American cranberries in Latvia during 2001–2009. Peat samples from 60 different cranberry producing sites established on extracted high bogs were collected over two periods: 2001–2004 and 2005–2009. Additional 20 samples from cutover and natural bogs were analyzed for background level to assess the changes in peat nutrient content during cranberry cultivation. Soil (peat) testing was used to evaluate the cranberry supply with nutrients (N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, Mo, B). Peat analysis revealed serious imbalance in cranberry providing with essential mineral elements. Deficiency of N P, S, Fe, Mn, Zn, Cu, Mo, and B were stated in the majority of samples. Positive tendencies in nutrient status of cranberry peat were found from 2001-2004 to 2005-2009. Mean concentrations increased for P, K, Ca, Mg, Fe, Mn, Cu, B, and become more corresponding to soil standards. Our results revealed significantly higher mean concentrations of P, K, Ca, Mg, S, Fe, and Mn in cultivated cranberry peat to compare with background level, although only P, Ca and Mg contents exceeded maximal levels of these nutrients stated in cutover peatlands. Lack of seriously increased nutrient concentrations in peat samples (only 3% of indices in high levels) indicated that cranberry fertilization practices in Latvia are likely not detrimental to the environment. The present investigation forms the basis for development of on scientific knowledge based cranberry fertilization guidelines in Latvia.
Key Words: Extracted high bogs, Renovation, American cranberries, Mineral nutrition, Peat analysis

1. INTRODUCTION

Latvia is a country with abundant peat resources and intensive peat production. The total area of peat bogs is 6401 km^2 which makes recourses of peat – 1.7 milliard t. (Abolins and Gurtaja, 2006). The area of peatlands covers 10.7 % of the entire territory and raised bogs occupy 41.7% of the whole area covered by peatlands. There are numerous high bogs where peat mining is of a definite industrial importance. Currently extraction volume is 0.5 – 0.6 million tons per annum, but extraction volume has trend to increase. About 9% of Latvia's raised bogs (37 bogs with a total area of 70000 ha) are affected by peat extraction, 20000 ha are nearly exhausted (Snore, 2004; Pakalne and Kalnina, 2005; Minayeva et al., 2009).Therefore recultivation of more than 17,000 ha abandoned and excavated high bogs are an important issue. Scientific researches are necessary to choose the best way for renovation of peatlands after peat cutting. The main tool for preventing rapid decomposition of technogenic peat soils is their revegetation. Reclamation of cutover peatlands by planting with trees or edible berry plants could be considered as a stand-alone measure, or combined with ecological restoration when conditions are favourable (Bellemare et al, 2009). Many berries possess strong potential for cultivation on cutover peatlands after peat extraction, notably, species from the *Ericaceae* and *Rosaceae* families (Noormets et al., 2004; Bussières et al., 2008b; Bellemare et al., 2009). Along with sufficient freshwater supply and appropriate moderate climate conditions this specific nutrient-poor and acid growing environment provides the possibilities for commercial cultivation of American cranberry (*Vaccinium macrocarpon* Ait.), fruit indigenous to North America. American cranberry fruits are valued for their fresh taste, high dietary and health values, as well as their great potential for being processed. A growing body of research suggests that cranberry is a relatively unique fruit which accumulates one of the highest concentrations of phenolic compounds among fruit species with demonstrable human health benefits, including antioxidant activity, microbial anti-adhesion, and anticancer properties (Vinson et al., 2001; Leahy et al., 2002; Howell et al., 2005). The commercial cultivation of American cranberry in Latvia was successfully started during last 15 years. Today with more than 100 ha of plantings Latvia is fourth major cranberries producing country in the world (www.uga.edu/fruit/cranberi.htm). While nutrient status of cranberries in the United States and Canada (the main cranberry production countries) where cranberries are grown in irrigated beds of sandy soil placed on top of high-organic-matter or clay subsoil has been studied in considerable detail (DeMoranville and Deubert, 1986; Eck, 1990; Roper and Combs, 1992) little is known regarding the cultivation and fertilizing systems of cranberries planted on bare sphagnum peat. As growth conditions are widely different direct application of nutrient recommendations from N. American production areas is limited. Reports concerning the mineral composition of cranberry plants grown in acid sphagnum peat as well as plant available nutrient concentrations in this specific substrate are scarce (Osvalde and Karlsons, 2005; Osvalde and Karlsons, 2010). Few studies on cranberry cultivation were conducted on cutover peatlands in Canada, but no commercial plantations exist to this day (Rochefort and Lapointe, 2009). In Estonia, European cranberries (*Oxycoccus palustris*) were planted within a goal of reclamation in a cutover peatland were cranberry plantation helped favour the establishment of plants typically found in peatlands, such as Polytrichum (Noormets 2006). Being a native wetland plant, cranberries are nutrients low requiring culture (Eck, 1990; Caruso and Ramsdell, 1995) however, balanced mineral nutrition is vitally essential in producing high and qualitative yield. On the other hand, excessive or inadequate fertilization is potentially detrimental to the environmentally sensitive cranberry growing medium. Investigations were done to find out the actual status and main tendencies in mineral nutrition of American cranberries in Latvia during 2001–2009, as well as to evaluate the changes in peat nutrient content during cranberry cultivation. Soil (peat) testing was used to evaluate the cranberry supply with nutrients (N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, Mo, B).

2. MATERIAL AND METHODS

Peat samples from 60 different cranberry producing sites in Latvia established on extracted raised bogs were collected over two time periods: from 2001 to 2004 and 2005 to 2009. Additional 20 peat samples from 17 cutover peatlands (all the harvested sites were originally bogs) and 3 natural raised bogs (the area of natural stands of the wild cranberry, *Vaccinium oxycoccos* L.) were collected for background level evaluation.

The soil (peat) samples were taken with a soil probe from cranberry rooting zone to a depth of 15 – 20 cm. For each sample, five to eight sub-samples were obtained and thoroughly mixed to form one sample. The peat samples were air-dried and sieved through 2-mm sieve. To determine the plant available amounts of 12 biogenous elements (N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, Mo, B) the peat samples were extracted with 1 M HCl (soil - extractant volume ratio 1:5) (Rinkis et al., 1987). The levels of Ca, Mg, Fe, Mn, Zn, and Cu were estimated by atomic absorption spectrophotometer (Perkin Elmer 403 and Perkin Elmer AAnalyst 700, acetylene-air flame), those of N, P, Mo, B by colorimetry, S by turbidimetry, and K by flame photometer (Jenwey PFP7, air-propane butane flame). Soil pH was determined in 1 M KCl (soil - extractant volume ratio 1:2,5) potentiometrically by pHmeter Sartorius PB-20 (Rinkis et al., 1987). Peat electrical conductivity (EC) was determined in distilled water extract (peat – distilled water volume ratio 1:5) by conductometer Hanna EC 215. Analytical replication was at least three times. T-test “Two-Sample Assuming Unequal Variances” ($p<0.05$) was used to compare mean element concentrations in intensive cranberry production, cutover peatland and virgin peat, as well as between study periods (MS Excel 2003). Evaluation of mineral nutrition status of American cranberry was done on basis of soil standards developed by Nollendorfs (1998) for Latvia.

3. RESULTS AND DISCUSSION

To characterize the nutrient status of cutover peatlands the levels of 12 biogenous elements as well as pH and EC were estimated in peat samples (Table 1). Our study revealed that cut-over peatlands in Latvia are harsh growing medium for most of cultivated plants. Certain characteristics as low nutrient concentrations and high acidity of substrata do not favour to re-establishing vegetation in harvested bogs in European countries and Canada (Kaunisto and Aro, 1996; Noormets *et al.* 2004; Bussières et al. 2008a). The residual peat in Latvia was characterised by K, S, Fe, Mn, and Mo concentrations similar to, but more variable than, those found in natural high bogs. The pH values of the uppermost 20 cm of cut-over peatlands varied from 2.37 to 3.30 and also were comparable to those in the wild cranberry bogs. Statistically significant differences ($p<0.05$) were found for N, P, Ca, Mg, Zn, Cu, and B levels in cutover peatland and natural raised bog peat samples. Significantly higher mean concentrations of plant available N, P, Ca, Mg and Cu were found in cutover peatlands peat, while the highest Zn and B levels were found in undisturbed bog peat. In general, our results are in good agreement with those of Wind-Mulder et al. (1996) on peat chemistry of post-harvested and neighbouring, undisturbed peatlands across Canada. Also in Latvia, commercial peat harvesting alters chemical conditions and the peat chemistry of newly exposed peat layers is closer to that of fens than to that of natural high bogs. Upper layer of cutover peatlands were formed in earlier developmental stages and therefore can be more minerotrophic and/or more variable in chemical composition than undisturbed raised bog peat (Wind-Mulder et al., 1996; Klavins et al., 2009). In addition, cutover peatlands are also subject to increased oxidation (Waddington and McNeil, 2002), humification and mineralization processes (Price et al., 2005).

Table 1. Nutrient concentrations in peat samples in Latvia, 2001–2009

Element	Concentrations in 1M HCl extraction (mg/L)				
	Wild bog peat		Cutover bog peat		Cranberry bog peat
	Range	Mean ± SE	Range	Mean ± SE	Mean ± SE
N	12 - 20	15.0±1.40a[1]	17 - 40	29.6±2.2b	22.0±1.3c
P	1.1 - 2.7	1.7±0.19a	1.0 - 24	11.9±2.2b	41.3±5.6c
K	4 - 45	24±5.53a	8 - 71	29.5±5.9a	61.8±4.0b
Ca	65 - 295	165±27.35a	50 - 450	258.2±30.7b	597.7±84.6c
Mg	16 - 75	44±7.41a	55 - 120	82.0±5.9b	158.9±18.8c
S	4 - 11	7.89±0.89a	2 - 40	7.1±2.6a	14.1±2.2b
Fe	12 - 70	41±7.27a	10 - 80	43.7±5.6a	66.9±4.7b
Mn	0.3 - 1.9	1,15±0.20a	0.4 - 6.0	1.6±0.4a	3.0±0.8b
Zn	1.2 - 8.0	3,5±0.80a	0.3 - 3.1	1.4±0.2b	1.9±0.1c
Cu	0.1 - 0.3	0,1±0.02a	0.1 - 6.5	1.1±0.6b	2.1±0.4b
Mo	0.02 - 0.04	0,03±0.002a	0 - 0.1	0.03±0.007a	0.03±0.003a
B	0.1 - 0.5	0,32±0.04a	0 - 0.2	0.02±0.015b	0.34±0.03a
$pH/_{KCl}$	2.62 - 4.92	3,06±0.24a	2.37 - 3.30	2.81±0.07a	3.14±0.06ab
EC, mS/cm	0.10 - 0.42	0,25±0.05a	0.13 - 0.80	0.35±0.09a	0.28±0.02a

[1]Means with the same letter in a row were not significantly different (t-Test, P = 0.05), pH differences for cranberry peat: first letter relate to wild bog peat, second to cutover bog peat

To characterize the mineral nutrition status of American cranberry in Latvia, the levels of 12 macro and micronutrients were estimated in peat samples from different cranberry producing plantings established on extracted high bogs. Mean macro- and micronutrient concentrations, concentration range as well as soil standards developed by Nollendorfs (1998) for American cranberries in Latvia are shown in Table 2. The results obtained on macronutrient concentrations showed serious N deficit in almost all of the peat samples (from 12 mg/L to 75 mg/L) and insufficient mean concentrations of S. The mean content of K and Mg could be characterized as sufficient. There were significant year differences in mean P and Ca contents – from deficient 21.4 mg/L and 347.3 mg/L in 2001-2004 to optimal 56.9 mg/L and 793.3 mg/L in 2005-2009, respectively.

The levels of micronutrients in cranberry peat were of particular interest as with the exception of Mn (2005-2009) a serious deficiency of Fe, Cu, Zn, Mo, and B was found. Mean Fe, Cu and B contents increased significantly between the two surveys from 53.3 mg/L, 1.2 mg/L and 0.3 mg/L (2001–2004) to 77.4 mg/L, 2.8 mg/L and 0.4 mg/L (2005–2009), respectively.

Table 2. Nutrient concentrations in peat samples from cranberry producing plantings established on extracted high bogs in Latvia, 2001–2009

Element	Concentrations (mg/L) in 1M HCl extraction				
	2001–2004 (n = 28)		2005–2009 (n = 32)		Optimal levels in 1M HCl extraction
	Range	Mean ± SE	Range	Mean ± SE	
N	12 - 42	21.8±1.4a[1]	12 - 75	22.1±2.1a	70 - 130
P	1 - 135	21.4±6.3a	6 - 185	56.9±7.6b	55 - 110
K	23 - 107	55.2±5.2a	13 - 130	66.9±5.8a	55 - 110
Ca	210 - 775	347.3±26.9a	250 - 4625	793.3±140.7b	450 - 1250
Mg	4.5 - 100	99.5±7.4a	72 - 1075	204.3±30.8b	100 - 250
S	3 - 85	16.6±4.4a	4 - 58	12.1±2,0a	45 - 90
Fe	16 -135	53.3±6.7a	34 - 150	77.4±5.9b	90 - 250
Mn	0.3 – 5.5	1.5±0.2a	0.5 – 44.0	4,2±1,3b	3.0 - 9.0
Zn	0.5 – 3.8	1.9±0.2a	0.2 - 4.4	1,9±0.2a	3.0 - 9.0
Cu	0.1 – 5.0	1.2±0.3a	0.0 - 12.0	2.8±0.6b	5.0 - 11.0
Mo	<0.010 – 0.13	0.03±0.01a	0.01 - 0.06	0.03±0.002a	0.08 - 0.35
B	<0.1 – 0.6	0.3±0.04a	0.1 - 0.9	0.4±0.04b	0.8 – 1.8
$pH/_{KCl}$	2.63 – 3.65	3.01±0.06a	2.58 - 5.08	3.25±0.10a	4.0 - 5.0
EC, mS/cm	0,20 - 0,33	0.26±0.01a	0.12 - 0.53	0.30±0.02a	0.7 - 1.4

[1]Means with the same letter in a row were not significantly different (t-Test, P = 0.05)

However in both cases microelement concentrations were still in the deficit range. Since post-harvest high bog territories are used for American cranberry cultivation in Latvia, low levels of pH and EC for the bulk of the peat samples tested did not correspond to optimum ($pH/_{KCl}$: 4.0 to 5.0; EC: 0.7 to 1.4 mS/cm) for cranberry growth. Percentage of peat samples with low, optimal and excessive amount of nutrients (Table 3) clearly revealed main cranberry mineral nutrition problems in specific acid growing medium. Although concentrations of the macro and microelements demonstrated high variability, soil or peat tests revealed serious imbalance in cranberry providing with nutrients - deficiency of N P, S, Fe, Mn, Zn, Cu, Mo, and B were found in the vast majority (60 – 100%) of samples analysed. Although in the years 2005-2009 the mean levels of P and Mn in cranberry peat were optimal, more than 60 % of samples were in deficient range. Corresponding to low macronutrient levels in the growing medium all of the peat samples pointed out insufficient peat EC. Positive tendencies in macronutrient status of cranberry were found from 2001-2004 to 2005-2009. Indices in optimal range increased for P, K, Ca and Mg, as well as mean element concentrations have become more corresponding to soil standards.

American cranberries grown on more than 100 ha have become an important horticultural commodity in Latvia with high market demand, prices and export possibilities. In order to get the positive benefits from cranberry farming in cutover peatlands in Latvia, it is necessary to produce cranberries profitably and in concert with the environment. As commercial production of cranberries requires annual fertilizer inputs, balanced mineral nutrition is very essential in producing high and qualitative yield. Therefore soil (peat) test is very important in determining the ability of the soil to supply nutrients needed for optimum plant growth. Because cranberry plantings in Latvia are developed in cutover raised bogs and sphagnum peat are particularly nutrient poor environment with low cation holding capacity and high leaching, special attention should be paid to N, P and S nutrition to avoid cranberry yield limitations. Nitrogen is the controlling nutrient in cranberry nutrition and adequate fertilization is necessary to maintain renewal growth, crop production, and flower bud development for next year's crop (Eck, P. 1990; DeMoranville, 1997).

It should be stressed that mineralization process, through which organic N is released as ammonium during summer season in high-organic-matter mineral soils, in sphagnum peat is slow and nitrogen demanding (Nollendorfs, 1983). Although soil testing for N is not considered as reliable indicator for perennial crop N status (Roper, 1992), deficiency of nitrogen were also stated for cranberry leaves in Latvia (Osvalde and Karlsons, 2010).

Intensive research on P for cranberry production has been conducted in North America. These studies suggest that P in cranberry soils with low pH and high in Fe and Al is tightly bound and to a large extent unavailable to plants. Consequently, cranberry plants with low tissue P levels were often found growing on soils with high P test values (Davenport et al, 1997; DeMoranville and Davenport, 1997). A completely different situation was reported for raised bog peat where Fe concentrations were low and P more available for plants as well as more leachable. Consequently, close correlation between soil and plant P supply levels was found for American cranberry in Latvia (Osvalde and Karlsons, 2005; Osvalde and Karlsons, 2010). Sulphur deficiency is not a common problem for cranberries in North America since pre-plant acidification of mineral soils is usually achieved by applying and incorporating elemental sulphur (Eck, 1990; Roper and Combs, 1992) as well as S (as sulphate) is an ingredient of many fertilizers. Converse situation was found in Latvia where the vast majority of cranberry peat samples tested (about 90 %) was insufficient in S (below 20 mg/L). It is not surprising because S as anion is highly leachable from acid sphagnum peat substrata, as well as additional acidification of peat is unreasonable. Very acid growing conditions characteristics of cranberry bogs (mean $pH/_{KCl}$ 3.01 in 2001-2004) and low concentrations of Ca could cause Ca deficiency in plant roots. Therefore the application of gypsum as main source of Ca for new and bearing beds was included in standard nutrient management practices in Latvia. As a result soil test indices in optimal range increased for Ca more than thrice without serious enhance in peat pH (mean $pH/_{KCl}$ 3.26 in 2005-2009).

The status of micronutrients in cranberry peat is a matter of increasing concern. These elements required in small amounts (parts per million) are critical to normal plant growth (Marshner, 1995). Although better status for Fe, Mn, Cu, B and Mo were found in 2005-2009, optimal levels of micronutrients were not achieved in 60 % to 97 % of samples. In spite of micronutrients are very available in acid growing medium, plant analysis surveys of cranberry plantings in Latvia also revealed Fe, Cu, B, Mo deficiencies (Osvalde and Karlsons, 2010). According to recommendations based on first studies on cranberry nutrition in Latvia the use of foliar micronutrient (Cu, Zn, B, Mo) fertilization were started during recent years to correct deficiencies stated in tissue tests.

The goal of cranberry fertilization is to remove limitation to yield and quality by supplying the plants with all nutrients in optimal concentrations. Excessive fertilization is not only unnecessary expensive but also potentially detrimental to the surrounding environment. From this point of view lack of seriously increased nutrient concentrations in peat samples (from 0% to 3% of indices in high levels) indicated that cranberry fertilization practices in Latvia are likely not detrimental to the environment.

Table 3. Distribution of cranberry peat samples in different nutrient supply levels in Latvia during 2001–2009

Element	Percentage of samples (%) in different nutrient supply levels					
	2001–2004 (n = 28)			2005–2009 (n = 32)		
	Low	Optimum	Excessive	Low	Optimum	Excessive
N	100	0	0	97	3	0
P	88	8	4	60	34	6
K	52	48	0	28	69	3
Ca	80	20	0	25	63	12
Mg	48	52	0	6	81	13
S	88	12	0	94	6	0
Fe	84	16	0	60	40	0
Mn	92	8	0	69	28	3
Zn	84	16	0	84	16	0
Cu	96	4	0	78	22	0
Mo	92	8	0	97	3	0
B	100	0	0	78	22	0
$pH/_{KCl}$	100	0	0	88	12	0
EC mS/cm	100	0	0	100	0	0
All indices	86	14	0	68	29	3

As the result of fertilization, significantly higher mean concentrations of P, K, Ca, Mg, S, Fe, and Mn were found in cultivated cranberry peat to compare with background level (Table 1.). However only P, Ca and Mg average contents exceeded maximal levels of these nutrients stated in cutover peatlands. Although American cranberries evolved on low pH soils that are nutrient-poor have adapted specifically to these soil conditions, deficiencies of N are the most frequently encountered problems in growing cranberries also in North America (DeMoranville, C.J. and Deubert, K.H. 1986; Caruso and Ramsdell, 1995). Therefore low levels of N in cranberry peat which are comparable to those in cutover peatlands and natural bogs could seriously limit cranberry yields in Latvia.

4. CONCLUSION

Peat analysis revealed serious imbalance in American cranberry providing with essential mineral elements in Latvia during 2001-2009. Deficiency of N P, S, Fe, Mn, Zn, Cu, Mo, and B were stated in plantings established on extracted raised bogs. In general, our results suggest that only about 20 % of soil tests were in sufficient range. Positive tendencies in nutrient status of cranberry peat were found from 2001-2004 to 2005-2009. Mean concentrations increased for P, K, Ca, Mg, Fe, Mn, Cu, B, and become more corresponding to soil standards. Our results revealed significantly higher mean concentrations of P, K, Ca, Mg, S, Fe, and Mn in cultivated cranberry peat to compare with background level – harvested bogs, although only P, Ca and Mg contents exceeded maximal levels of these nutrients stated in cutover peatlands. Lack of seriously increased nutrient concentrations in peat samples (3% of indices in high levels) indicated that cranberry fertilization practices in Latvia are likely not detrimental to the environment. The present investigation suggests that environmentally wise cranberry fertilization in plantings established on cutover peatlands is a site specific decision and should be based on precise analytical basis to avoid yield limitations and prevent bog contamination.

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