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Effect of fertilization on growth of lingonberry (*Vaccinium vitis-idaea* L.)

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Abstract. Today, most of the global berry crop of *Vaccinium vitis-idaea* L. is obtained from wild berries. In recent years, however, their cultivation has become slightly more widespread, especially as demand has increased. As the commercial production of lingonberries is a completely new fruit-growing sector in Latvia, research on mineral nutrition, development of the crop production system and proper fertilizer management is critically important. The objective of this study was to elucidate the effect of different fertilizer rates on the nutrient status of lingonberry plant tissues and plant growth performance. Field experiments with the lingonberry variety 'Runo Bielawskie' were carried out during the 2019 and 2020 cropping season. Experimental plantations were established on an excavated peat bog in Latvia. Lingonberry plants received 4 different levels of complex and foliar fertilizers. Leaf analyses and soil (peat) testing were used as diagnostics tools to reveal nutrient (N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, Mo, B), soil pH and EC status. In general, plant growth characteristics were significantly affected by different levels of fertilizer. The results showed that the highest fertilizer rates resulted in a larger shrub diameter, the highest total number of rhizomes and shoots of a mother plant.

Key words: plant and soil analysis, nutrient status, excavated peat bog.

INTRODUCTION

Lingonberries (also called - cowberries, mountain cranberries, foxberries or wolfberries) are dwarf shrubs with high frost and drought hardiness and evergreen foliage. The plant is widely distributed in cold climate areas - all northern (Russia, North America, Northern Europe, Greenland) and some alpine regions of Northeast China and the Korean Peninsula (Lee & Finn, 2012) and traditionally is among the most significant wild-harvested berries in many Nordic countries (Turtiainen et al., 2011).

Berries of *Vaccinium* species have recently attracted growing interest around the world due to their high taste values, as well as their potential to be processed into a variety of healthy foods, as well as their decorative value for home gardens and landscaping.

Numerous studies have shown the valuable nutritional properties and beneficial health effects of berry crops from the genus Vaccinium (Ek et al., 2006). Cultivated and wild lingonberry fruits and leaves have been noted as a good source of antioxidants, organic acids, dietary fiber, essential omega-3 fatty acids, plant sterols, mineral elements and vitamin C (Kylli et al., 2011; Klavins et al., 2015; Shamilov et al., 2020).

Regular intake of lingonberries as a food demonstrate various health-promoting effects: reduction of the cardiometabolic risk and glycemic impact of sugars (Nilsson et al., 2017; Furlan et al., 2019) prevention of atherosclerosis (Matziouridou et al., 2016) and lower the risk of cancer (Vilkickyte et al., 2020), obesity and its co-morbidities (Pan et al., 2010; Williamson, 2017). The metabolic effect of the usage of Vaccinium berries in the conditions of high-fat diets has been studied also in animal experiments. Lingonberries and bilberries have shown a positive impact to diminish low-grade inflammation, prevent weight gain, adjust the composition of gut microbiota and enhance insulin sensitivity of rodents in the context of high-fat diets (Heyman et al., 2014; Heyman-Lindén et al., 2016).

Growing demand for healthy food ensures good potentialities for the increasing progress of lingonberries production worldwide and especially in Latvia. Successful lingonberry cultivation in Latvia could be associated with suitable production conditions - vast high bog territories, a vital requirement for recultivation of more than 17,000 ha abandoned and excavated peat bogs, abundant freshwater supply and mild climate (Silamikele et al., 2011; Osvalde et al., 2018). However, most of the global berry crop of lingonberries are still harvested from wild stands. The main disadvantages of obtaining a sufficient wild berry harvest - widely fluctuating and low yields, variable fruit quality, changes of natural resource management and significant drop of the interest of handpicking of wild berries in Northern countries promoted attempts of domestication and commercial cultivation of this crop (Wallenius, 1999; Gustavsson, 2001; Isaeva, 2001; Pouta et al., 2006; Turtiainen, 2011). First studies to enhance the growth of lingonberry have been conducted since the 1960s in Sweden (Fernqvist, 1977), Germany (Dierking & Krüger, 1984), Finland (Lehmushovi, 1977), USA (Stang et al., 1993) and in Latvia (Ripa & Audriņa, 1986). The reports showed that lingonberries growing in cultivated areas can produce more than five times higher yields compared to those growing in the wild (Teär, 1972; Gustavsson, 2001). However, the total production of cultivated lingonberries still is very low compared to that of wild berries (Ballington, 2001; Debnath, 2009; Debnath & Arigundam 2020) and it is not even close to the current production of cranberries (*Vaccinium macrocarpon*). First commercial lingonberry plantations were introduced in the 1980s in Germany but are now becoming increasingly popular also in Sweden, Finland, Austria Switzerland and United States (Gustavsson, 1999; Burt & Penhallegon, 2003; Heidenreich, 2010).

The growth and development of lingonberries, like any plants, is affected by many biotic and abiotic factors, such as temperature, water availability and quality, light, soil properties, plant physiology and genetics (Marschner, 2012).

Lingonberries are generally considered to be low-maintenance plants adapted to acidic and nutrient-poor soils and have reduced nutritional requirements compared to many other fruit plants. However, to realize the full potential of the crop, balanced plant nutrition is vitally important to provide adequate vegetative growth and fruit production.

Considering that lingonberry plants are shallow-rooted, berry production can be significantly reduced even with a moderate nutrient deficiency. On the other hand, excessive or inadequate fertilization is potentially damaging to lingonberry cultivation especially in plantations established in environmentally sensitive areas such as excavated peat bogs, as well as may increase weed infestation. It should be taken into account that weed control is one of the main problems in lingonberry cultivation considering that plants are poor competitors against most weeds (Gustavsson, 1993; Debnath, 2009).

Previous fertilization trials in natural lingonberry populations in Finland have shown till triple gain in berry yield, but if there were competing plants with broad leaves in the natural habitat, there was no benefit (Lehmusovi, 1977).

In general, while lingonberry propagation and selection methods have been studied in considerable detail (Pliszka, 2002; Ripa & Audriņa, 2009), mineral nutrition issues in Latvia and other countries have not been examined sufficiently.

Considering the limited knowledge of lingonberry mineral nutrition and proper fertilizer management, the present study aimed to investigate the effect of different fertilizer rates on the growth and development of this crop.

MATERIALS AND METHODS

Field experiment

The field trial was arranged during the 2019 and 2020 growing seasons on a farm with specialization in the production of American cranberries, located on an excavated peat bog (56°70′N, 23°59′E, the region of Jelgava, Latvia) to investigate the effect of different levels of complex and foliar fertilizers on the nutrient status of lingonberry plant tissues and plant growth performance. Field experiments with the lingonberry variety 'Runo Bielawskie' were established on an experimental plot in 2 rows with 1m spacing in the flat plain field and direct light conditions. One-year-old seedlings, obtained by plant division in the previous year, were planted in May of 2019. The treatment layout was arranged randomly. The experiment included 4 fertilization levels with 55 plants per treatment. After planting of seedlings in May 2019, each treatment, except control, was equally supplied with a low dose (250 kg ha^{-1}) of complex fertilizer Novatec Classic 12-8-16 with micronutrients (COMPO GmbH & Co, Germany). Peat chemical characteristics, determined from composite peat sample of the upper 0–20 cm taken in the beginning of May, before the start of the experiment, are given in Table 1. In general, peat from the experimental field was characterized by low levels of N, P, S, Mo, B and low pH_{KCl} (3.47), as well as high organic matter content (> 95%).

In the following growing period, the lingonberry fertilization scheme was as follows described in Table 1.

Table 1. The design of the lingonberry fertilization scheme

Control (C)	Treatment 1 (T1)	Treatment 2 (T2)	Treatment 3 (T3)
-	1x granulated complex fertilizer with micronutrients Novatec Classic 12-8-16, 300 kg ha^{-1}		
-	-	1x souluble complex fertilizer with micronutrients Basfoliar SP 20–19-19	
-	-	-	3x foliar fertilization with microelements Omex Bio 20

At the beginning of June 2020, each treatment except control was supplied with a dose (300 kg ha^{-1}) of the same complex fertilizer. In the middle of July treatment 2 and treatment 3 were additionally supplied with soluble complex fertilizer Basfoliar SP 20-19-19 with micronutrients (COMPO GmbH & Co, Germany). Lingonberries from the Treatment 3 three times per growing period (June, July, August) were sprayed with foliar fertilizer Omex Bio 20 (Omex Agrifluids Ltd, United Kingdom) containing micronutrients - Fe, Mn, Zn, Cu, Mo, B.

The lingonberry leaves and peat samples were collected for laboratory analysis monthly from May to September for all treatments. The measurements of lingonberry shrub diameter, the records of the total number of rhizomes and shoots of a mother plant were made once at the beginning of November.

Laboratory analysis and measurements

For each plant sample, approximately 50 g plant material was collected by selecting characteristic disease- and pest-free upright tips of lingonberries. Plant samples were stored refrigerated at 1 to 5 °C for no longer than 24 h. Samples were fixed 2 to 3 min at 105 °C, then dried at 60 °C to constant weight and ground. Plant tissue test solution was prepared by dry ashing with HNO_3 vapor and re-dissolving in a 3% HCl solution (Rinkis et al., 1987). The testing solution was used for the determination of N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, Mo and B in all leaf samples. Microwave plasma atomic emission spectrometry (MP-AES; Agilent 4200) was used for the measurement of K, Ca, Mg, Fe, Mn, Zn and Cu (Sreenivasulu et al., 2017). Those of N, P, Mo, B by colorimetry, sulfur by a turbidimetric method. All spectroscopic, colorimetric or photometric determinations were performed in triplicates. Mineral element concentrations in plant tissue for macronutrients were expressed as mass percent (%) and for micronutrients as mg kg^{-1}.

Peat samples were separately taken from the plant root zone at 0–20 cm depth from each treatment plot. Each peat sample (2 L) consisted of thoroughly mixed five subsamples. Peat samples were cooled at 4 °C to stop further nitrification and dried at 35 °C to air-dry condition, then sieved through a 2 mm sieve. To determine nutrient (N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, Mo, B) concentration soil samples were extracted using 1 M HCl (soil-extractant mixture 1:5 v/v). Oxidation of soil extract with conc. HNO_3, H_2O_2 and $HClO_4$ were performed for the determination of P, S, and Mo. All nutrients were analyzed using the same procedures as in the case of plant samples. For peat, the concentrations of all mineral elements were given as mg L^{-1}.

In addition to the contents of mineral elements, two characteristics of the soil were identified, e.i. the soil reaction (pH) and total concentration of soluble salts as electrical conductivity (EC), expressed as mS cm^{-1}. Soil pH was measured by the pH meter Basic Meter PB-20 in 1M KCl extract. Soil electrical conductivity was determined by conductometer Elwro N 5711 in soil extract with distilled water.

All chemical analyses of peat and plant samples were done in the Laboratory of plant mineral nutrition of the Institute of Biology, University of Latvia.

To characterize the peat nutrient status of lingonberry planting before the establishment of the experiment in 2019 and before the vegetative season of 2020, the concentration of plant available 12 essential nutrients, pH_{KCl} and EC levels were determined in peat samples.

Due to the lack of information on the mineral nutritional needs of lingonberry, as guideline values for peat and tissue concentrations were used standards developed for a related crop of the same genus - American cranberry (Nollendorfs, 1998) (Table 2).

Statistical analysis was performed with MS Excel 2016. Standard errors (SE) were calculated to reflect the mean results of chemical analysis. The Student's *t*-test (Two-Sample Assuming unequal Variances) was used for testing the differences between treatments.

Table 2. Nutrient concentrations in 1M HCl extraction (mg L^{-1}) in peat soil for lingonberries (Soil standards developed by Nollendorfs (1998))

Variable	2019 May Treatments C+T1+T2+T3	2020 May C	T1	T2	T3	Sufficiency range for American cranberry in peat soils
N	24 ± 2.02	6 ± 0.25	5 ± 0.12	5 ± 0.12	5 ± 0.05	60–120
P	8 ± 1.33	3 ± 0.21	3 ± 0.09	4 ± 0.15	3 ± 0.12	50–100
K	37 ± 0.33	35 ± 3.9	27 ± 2.4	42 ± 0.06	25 ± 2.3	50–100
Ca	755 ± 26.4	996 ± 79.8	766 ± 42.3	906 ± 56.2	632 ± 29.3	500–1,000
Mg	168 ± 9.27	242 ± 28.2	130 ± 13.2	191 ± 23.9	122 ± 12.3	100–180
S	7.6 ± 1.17	2.5 ± 0.40	3.8 ± 1.29	4.4 ± 1.32	3.2 ± 0.63	40–80
Fe	98 ± 8.33	97 ± 8.35	72 ± 3.60	87 ± 6.69	59 ± 5.63	60–150
Mn	3.4 ± 0.10	6.50 ± 0.86	3.70 ± 0.23	3.95 ± 0.33	2.35 ± 0.12	3–6
Zn	3.96 ± 0.09	4.2 ± 0.45	2.9 ± 0.33	2.8 ± 0.18	2.0 ± 0.23	4–8
Cu	0.80 ± 0.03	0.4 ± 0.04	0.50 ± 0.03	0.60 ± 0.03	0.55 ± 0.04	4–8
Mo	0.02 ± 0.003	0.04 ± 0.005	0.06 ± 0.004	0.04 ± 0.002	0.04 ± 0.002	0.1–0.2
B	0.3 ± 0.05	0.3 ± 0.05	0.2 ± 0.03	0.1 ± 0.02	0.1 ± 0.02	0.6–1.2
pH_{KCl}	3.47 ± 0.15	3.50 ± 0.03	3.45 ± 0.12	3.35 ± 0.10	3.37 ± 0.13	4.5–4.8
EC (mS cm^{-1})	0.20 ± 0.03	0.10 ± 0.04	0.08 ± 0.01	0.12 ± 0.01	0.07 ± 0.01	0.8–1.2

RESULTS AND DISCUSSION

The weather conditions throughout the study were relatively safe for plant growth, however, 27 plants or 12% were lost due to spring frost injuries in 2020. Lost plants were almost evenly distributed along all treatments. While in the first growing season (2019) lingonberry plants produced only a few new shoots, growth in the second year was significantly more vigorous and continued until the end of the experiment. In the second year (2020), most of the plants were flowering, but considering that lingonberries were still young, the berry yield was not measured.

Considering that the experimental field was established in a non-fertilized peat bog, chemical analyses of peat before trial arrangement in spring of 2019 as well as in 2020, confirmed very low levels of N (5–24 mg L^{-1}), P (3–8 mg L^{-1}) and S (2.5–7.6 mg L^{-1}) in the experimental plots, as well as insufficient level or deficiency of K, Cu, B and Mo compared to recommended values developed by Nollendorfs (1998). It is well known that sphagnum peat is a very acidic and nutrient-poor organic material with low cation holding capacity and high element leaching (Osvalde et al., 2018). Overall, chemical analyzes in May 2019 and 2020 revealed that all parts of the field before field trials have similar nutrient levels and differences in peat pH and total soluble salts - EC values were acceptably low, thus soil conditions are suitable for further fertilization experiment, small differences between years are explained by winter/spring leaching and natural soil heterogeneity. Chemical analyzes of peat also showed that the determined pH values (3.35–3.50) corresponded to the recommendations of several authors for lingonberries (Fernqvist, 1977; Ripa & Audriņa, 1986; Gustavsson, 2001).

Peat chemical analysis during the season of 2020 demonstrated that a granular complex fertilizer applied at the beginning of June was sufficient to maintain the appropriate content of potassium in peat up to September for all fertilized treatment plots (Table 3). While in the case of P and S, only additional fertilization in July ensured adequate nutrient concentrations in treatments 2 and 3. Since sulfur is among nutrients that are easily leached from peat soils (Bougon et al., 2011) it is not surprising that S concentrations after optimized levels in July reduced to amounts similar to control in August and September in all treatments.

Table 3. Macronutrient concentrations in 1M HCl extraction (mg L^{-1}) in peat soil for lingonberries

Variable	June			
	C	T1	T2	T3
N	11 ± 0.9a	15 ± 2.2a	17 ± 3.6b	14 ± 2.2a
P	3 ± 0.25a	28 ± 3.48b	31 ± 3.56b	35 ± 2.90b
K	44 ± 2.9a	129 ± 11.6b	103 ± 9.6b	113 ± 6.3b
Ca	1,072 ± 81.3a	1,100 ± 42.3a	1,094 ± 32.9a	986 ± 17.4a
Mg	279 ± 32.6a	260 ± 13.3a	256 ± 21.3a	244 ± 26.0a
S	13 ± 0.69a	23 ± 2.25b	28 ± 1.44b	25 ± 0.95b
Variable	July			
	C	T1	T2	T3
N	5 ± 1.5a	10 ± 2.6b	18 ± 3.6b	33 ± 3.5b
P	5 ± 1.25a	25 ± 2.81b	30 ± 2.66b	85 ± 7.31b
K	44 ± 2.6a	87 ± 10.2b	204 ± 21.6b	288 ± 18.9b
Ca	919 ± 7.6a	1,025 ± 85.9a	1,076 ± 45.3a	1,427 ± 62.0b
Mg	202 ± 11.9a	217 ± 39.6a	276 ± 26.3b	340 ± 19.6b
S	3.2 ± 1.43a	12 ± 1.44b	60 ± 3.69b	88 ± 8.11b
Variable	August			
	C	T1	T2	T3
N	5 ± 1.3a	6 ± 1.6a	6 ± 2.9a	5 ± 2.3a
P	5 ± 1.08a	13 ± 2.01b	49 ± 4.09b	33 ± 2.25b
K	35 ± 2.7a	84 ± 5.6b	152 ± 7.6b	144 ± 9.7b
Ca	1,028 ± 53.5a	1,559 ± 62.9b	1,120 ± 33.2a	959 ± 74.0a
Mg	248 ± 23.7a	313 ± 19.3b	233 ± 13.6a	226 ± 9.6a
S	5 ± 1.08a	4 ± 0.86a	14 ± 1.52b	6 ± 0.56a
Variable	September			
	C	T1	T2	T3
N	5 ± 1.3a	6 ± 2.3a	5 ± 3.1a	5 ± 1.2a
P	5 ± 0.96a	8 ± 2.39a	17 ± 1.11b	15 ± 0.88b
K	48 ± 6.3a	83 ± 5.9b	141 ± 11.3b	109 ± 12.5b
Ca	1,189 ± 96.2a	1,386 ± 13.9b	1,105 ± 44.6a	987 ± 96.3a
Mg	243 ± 23.3a	255 ± 7.9a	242 ± 20.6a	193 ± 20.0a
S	3 ± 0.09a	3 ± 0.20a	4 ± 0.52a	4 ± 0.66a

[*]Means with different letters in rows were significantly different compared to control for each month (*t*-Test; $p < 0.05$).

Results of the field trial demonstrated a significant effect of the applied fertilizer on the concentration of N in the lingonberry soil. However, optimal concentrations of N were achieved only in treatment 3 in July after additional fertilization, but in August it dropped to the control level. Although soil analysis for nitrogen is not considered as a credible method for diagnosting perennial plant N status (Roper,1992), several studies in Latvia on peat substrates with cranberries demonstrate serious deficiency of nitrogen not only in cranberry soil (Osvalde et al., 2011) but also in plant leaves (Karlsons & Osvalde, 2017). It is well known that nitrogen, in agronomic terms, is one of a key element in crop nutrition: corresponding fertilization is important to maintain adequate renewal growth, yield production, and flower bud development for the following season's yield. However, fertilization with higher-than-recommended N rates can lead to excessive vegetative plant growth, which can induce an increasing fruit rot level as well as elevate the risk of environmental contamination as well as a promoted weed growth (Davenport, 1996).

Although the applied complex fertilizer contained micronutrients - Fe, Mn, Zn, Cu, Mo, B, only a small impact or trend on the concentration of these trace elements in peat during the season was observed (data not shown). It should be noted that today in commercial farms located on peat bogs, foliar fertilization is used as a routine means to ensure a sufficient concentration of micronutrients in cranberry and blueberry leaves (Karlsons & Osvalde, 2019).

The chemical composition of leaves

It is well documented that various climatic conditions and environmental factors - relative air and soil humidity, as well as temperature and microbial soil activity, have a significant impact on the physiological processes of plants and the properties of the fertilizer in the soil, and thus play a notable role in the process of uptake of mineral nutrients by the plant roots (Marschner, 2012). Overall, the research results from the field experiment demonstrated a significant influence of the applied granular complex and foliar fertilizer on the content of N, P, Fe, Zn, Mo and B in the lingonberry leaves (Table 4, Table 5). While only a small effect or trend was stated for S and Mg.

Although fertilization did not provide a sufficient concentration (recommended above 60 mg L^{-1}) of N in lingonberry soil, it contributed to an optimal N content in plant leaves in all fertilized treatments from June till September and reached tissue concentration from 0.93 % (treatment 1) to 1.33% (treatment 2), which is recommended as the sufficient level for cranberries (Davenport et al., 1995; Nollendorfs, 1998). Such results support a presumption that crops from the Vaccinium genus exhibit some nitrogen conservation strategies in suboptimal nutritional conditions that may reduce the necessity for N fertilizer (Karlsons & Osvalde, 2017). Besides, low N concentrations in soil could be explained by increased nitrogen aqueous runoff or atmospheric loss (Stackpoole et al., 2008) as well as reduced fertilizer rate used in our trial.

A similar trend was found for phosphorus where concentrations of the nutrient in peat were significantly lower than recommended - 60 mg L^{-1}, but used fertilizer rates ensured optimal tissue P levels (above 0.2 %) for all fertilized treatments from June. Such results are in agreement with research made by DeMoranville & Davenport (1997) on American cranberry, when comparatively low P applications (20 kg ha^{-1}) were sufficient for producing cranberry crop, while higher than necessary P rates were associated with elevated berry rot and reduced yield.

Table 4. Concentration of macronutrients in lingonberry leaves (%)

Variable	June			
	C	T1	T2	T3
N	0.81 ± 0.02a*	1.22 ± 0.02b	1.16 ± 0.03b	1.18 ± 0.03b
P	0.15 ± 0.01a	0.21 ± 0.01b	0.2 ± 0.02b	0.21 ± 0.02b
K	0.61 ± 0.02a	0.6 ± 0.02a	0.59 ± 0.01a	0.65 ± 0.03a
Ca	0.51 ± 0.01a	0.5 ± 0.01a	0.47 ± 0.01a	0.55 ± 0.01a
Mg	0.14 ± 0.01a	0.16 ± 0.01a	0.17 ± 0.02a	0.14 ± 0.02a
S	0.10 ± 0.01a	0.12 ± 0.01a	0.13 ± 0.01a	0.13 ± 0.01a
Variable	July			
	C	T1	T2	T3
N	0.72 ± 0.02a	1.25 ± 0.04b	1.29 ± 0.03b	1.28 ± 0.02b
P	0.11 ± 0.01a	0.21 ± 0.01b	0.21 ± 0.02b	0.21 ± 0.01b
K	0.46 ± 0.02a	0.59 ± 0.03a	0.62 ± 0.02b	0.64 ± 0.02b
Ca	0.48 ± 0.02a	0.45 ± 0.02a	0.41 ± 0.01a	0.42 ± 0.02a
Mg	0.17 ± 0.02a	0.21 ± 0.02a	0.17 ± 0.01a	0.18 ± 0.02a
S	0.09 ± 0.01a	0.14 ± 0.01a	0.15 ± 0.01b	0.17 ± 0.01b
Variable	August			
	C	T1	T2	T3
N	0.87 ± 0.02a	0.93 ± 0.02a	1.00 ± 0.02a	1.03 ± 0.02a
P	0.11 ± 0.01a	0.17 ± 0.01b	0.17 ± 0.01b	0.18 ± 0.01b
K	0.59 ± 0.03a	0.61 ± 0.02a	0.67 ± 0.02b	0.65 ± 0.04b
Ca	0.49 ± 0.02a	0.56 ± 0.04a	0.44 ± 0.02a	0.47 ± 0.02a
Mg	0.14 ± 0.02a	0.19 ± 0.02a	0.16 ± 0.02a	0.17 ± 0.02a
S	0.11 ± 0.01a	0.14 ± 0.02a	0.14 ± 0.01a	0.15 ± 0.01a
Variable	September			
	C	T1	T2	T3
N	0.88 ± 0.02a	1.09 ± 0.03a	1.33 ± 0.04b	1.27 ± 0.02b
P	0.13 ± 0.02a	0.18 ± 0.02b	0.20 ± 0.02b	0.18 ± 0.01b
K	0.47 ± 0.02a	0.44 ± 0.03a	0.50 ± 0.02a	0.46 ± 0.03a
Ca	0.50 ± 0.02a	0.52 ± 0.02a	0.41 ± 0.03a	0.41 ± 0.01a
Mg	0.13 ± 0.01a	0.21 ± 0.02a	0.18 ± 0.02a	0.18 ± 0.02a
S	0.11 ± 0.01a	0.12 ± 0.01a	0.11 ± 0.01a	0.12 ± 0.01a

* Means with different letters in rows were significantly different compared to control for each month (*t*-Test; $p < 0.05$)

Overall, the results of the field experiments demonstrated that complex and foliar fertilizer rates used were sufficient to provide adequate amounts of Mo, B and partly Fe for lingonberry (Table 4). Especially in treatment 3 where foliar fertilizer where applied. It should be mentioned that despite the Fe deficiency in the leaves throughout the season, Fe concentration in soils (60–114 mg L^{-1}) was in an optimal range. Such phenomenon could be explained by numerous biotic and abiotic factors influencing the availability and uptake of nutrients by plant. It highlight the importance of foliar fertilization and underline the potential of complex diagnostics (soil + plant tissue analysis) not only for the correct determination of the nutritional status of plants but also for the choice of most effective fertilizer and its application approach. An additional reason for low tissue Fe content could be the high range of Mn concentrations found in lingonberry leaves (478–1,060 mg kg^{-1}) even in conditions when low Mn content was found in peat (2.35–13.50 mg L^{-1}).

Table 5. Concentration of micronutrients in lingonberry leaves (mg kg^{-1})

Variable	June			
	C	T1	T2	T3
Fe	39 ± 2.5a*	40 ± 1.9a	40 ± 3.9a	42 ± 3.6a
Mn	980 ± 39.0b	520 ± 33.2a	640 ± 29.3a	560 ± 33.6a
Zn	34 ± 1.1a	30 ± 0.6a	32 ± 0.7a	30 ± 0.1a
Cu	4.0 ± 0.1a	4.2 ± 0.06a	3.8 ± 0.05a	3.6 ± 0.03a
Mo	0.4 ± 0.02a	0.4 ± 0.01a	0.4 ± 0.02a	0.4 ± 0.02a
B	14 ± 0.6a	13 ± 0.5a	14 ± 0.4a	15 ± 0.4a
Variable	July			
	C	T1	T2	T3
Fe	31 ± 3.1a	29 ± 2.0a	31 ± 2.6a	41 ± 3.6b
Mn	880 ± 42.3b	480 ± 11.3a	500 ± 23.6a	660 ± 19.9a
Zn	30 ± 0.5a	34 ± 0.5b	34 ± 0.6b	44 ± 0.9b
Cu	3.6 ± 0.05a	3.4 ± 0.05a	2.8 ± 0.03b	3.6 ± 0.03a
Mo	0.4 ± 0.03a	0.4 ± 0.02a	0.5 ± 0.05a	0.7 ± 0.04b
B	15 ± 0.3a	13 ± 0.5a	15 ± 0.5a	16 ± 0.3a
Variable	August			
	C	T1	T2	T3
Fe	32 ± 3.0a	32 ± 1.6a	30 ± 2.4a	59 ± 3.1b
Mn	1,060 ± 13.6b	600 ± 61.3a	500 ± 23.5a	740 ± 33.2a
Zn	22 ± 0.6a	26 ± 0.4a	24 ± 1.2a	26 ± 0.9a
Cu	2.6 ± 0.05a	2.8 ± 0.05 a	2.4 ± 0.02 a	3.2 ± 0.04b
Mo	0.5 ± 0.02a	0.4 ± 0.03a	0.4 ± 0.03a	0.7 ± 0.03b
B	12 ± 0.2a	12 ± 0.3a	11 ± 0.5a	16 ± 0.3b
Variable	September			
	C	T1	T2	T3
Fe	30 ± 1.0a	32 ± 1.9a	33 ± 2.2a	50 ± 3.9b
Mn	1,090 ± 25.5b	614 ± 12.7a	506 ± 22.2a	478 ± 29.6a
Zn	26 ± 0.3a	32 ± 0.6b	36 ± 0.7b	37 ± 0.5b
Cu	2.4 ± 0.02 a	2.6 ± 0.03 a	1.8 ± 0.05b	2.0 ± 0.02 a
Mo	0.4 ± 0.03a	0.3 ± 0.03a	0.3 ± 0.01a	0.4 ± 0.01a
B	16 ± 0.3a	15 ± 0.3a	16 ± 0.3a	20 ± 0.9b

* Means with different letters in rows were significantly different compared to control for each month (*t*-Test; $p < 0.05$).

The relationship between Mn and Fe in plants from acid soils has been sufficiently studied. Our results support the findings of Lockhart & Langille (1962) on Mn/Fe ratios in the leaves of an acidophilic Ericaceous plant - lowbush blueberry, indicating possible interference of Mn with the absorption of Fe at low pH soils.

As well as several studies with highbush blueberries and American cranberries in Latvia demonstrate that excessive high Mn (above 450 mg kg^{-1}) in plant leaves reflects high Mn availability in low-pH soils (Karlsons & Osvalde, 2017; Osvalde et al., 2018). On the other hand, the data of our study showed that additional supplementation with other nutrients significantly reduces undesirably high Mn concentrations in lingonberry leaves, thus acting as antagonists. It should be noted that insufficient iron concentration in growing medium and, consequently, also in plant leaves are fundamental distinction when compared Latvia and North America. In USA bog environments typically have an abundant supply of soluble Fe and other metals that may be even at toxic levels to non-adapted plant species (Siebach et al., 2015).

Due to the high level of organic matter, peat soils have a higher exchangeable fraction of Zn. Therefore, even in soil conditions when Zn was below sufficiency level, deficiency of Zn has not occurred even in Control treatment.

Since, Mo is the only micronutrient with reduced availability in acid soils (Marshner, 2012) it is not surprising that in all treatments, except treatment 3, Mo concentrations found in lingonberry leaves were below recommended - 0.5 mg kg^{-1}. A similar observation was made in the case of B - only foliar fertilization allowed the B concentrations to reach the low end of the current sufficiency range (from 20 to 60 mg kg^{-1}). Thus, our study demonstrated that foliar fertilization can be an effective method that supplements the fertilization through the soil to promote optimal crop growth, especially in circumstances when a particular nutrient is not available for uptake from soil. Besides, as a small quantities of fertilizers are used by spraying directly to the plants, this method could also contribute to environmental protection.

Growth performance

The average height of lingonberry plants and the diameter of shrubs differed significantly between the treatments (Table 6). The tallest, as well as the widest plants, were determined from all fertilization treatments compared to control. Growth performance is essential for the successful cultivation of lingonberry crop, and vital, high-quality plants are relatively tall and well-branched (Gustavsson, 2001).

A higher plant simplifies berry harvesting, while more branches contribute to a better fruit set and, as a result, higher total yield. As an additional benefit, a wide plant shrub shades the surrounding ground and prevents the germination of weeds. In our study, plants from all fertilized treatments were significantly higher, but they did not differ between the treatments. Similar results were found in comparable studies by Lehmushovi (1977) in Finland, where lingonberry growth and yield was significantly improved by the use of fertilizers and various mulching materials. However, high rates of fertilizers do not always increase fruit yields. Comparatively low amounts of fertilizer are required for adequate growth and development of lingonberries (Holloway, 1981). Excessive fertilization can lead to enhanced vegetative growth at the expense of fruit production (Trajkovski, 1987). A positive correlation between lingonberry plant height and fruit yield was found in studies made by Ripa & Audriņa (1986) in Latvia and Gustavsson (2001) in Sweden. Similar to the results obtained by Tear (1972), our research showed that fertilization of lingonberries slightly increased the production of rhizomes (Table 6).

Table 5. Fertilization effect on lingonberry plant height, plant diameter and number of rhizomes

	Shrub height (cm)	Shrub diameter, cm	Count of mother plant rhizomes
Control	11.14 ± 0.45a*	11.13 ± 0.52a	3.02 ± 0.80a
Treatment 1	17.79 ± 0.76b	18.09 ± 0.87b	4.69 ± 0.89a
Treatment 2	15.67 ± 0.69b	16.79 ± 0.97b	4.14 ± 0.95a
Treatment 3	16.31 ± 0.64b	17.54 ± 0.80b	5.17 ± 0.97a

*Means with different letters in a column were significantly different (*t*–test; $p < 0.05$).

CONCLUSION

Our study illustrates that even low rates of fertilizer use stimulate the lingonberry plant growth response and increase the production of rhizomes and eventually can increase crop yield. As an addition to fertilization thought soil foliar fertilization can be used as a very practical and effective method to provide adequate microelement concentrations in lingonberry leaves.

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