VEGETATIVE GROWTH AND NUTRIENT LEVELS OF LINGONBERRIES GROWN IN FOUR ALASKAN SUBSTRATES[1]

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Vegetative growth of lingonberries was observed on plants growing in four unsterilized, native-Alaskan substrates: coarsely-ground Lemeta peat, Fairbanks silt loam soil, a mixture of peat and silt loam soil and washed Chena very fine sandy loam soil. Following three growing seasons, plants in the peat treatment showed the greatest increase in vegetative growth as revealed by the number of new stems produced, stem length and dry weight per plant. Leaf size did not differ among substrate treatments. The leaves on plants grown in the peat substrate remained green throughout the entire experiment. The leaves of plants in all other treatments showed varying degrees of chlorosis followed by reddening and necrosis. Differences in concentration of N, P, K, Mn, Fe, Zn and Al in whole-plant tissue samples were recorded. The results indicate lingonberries should be grown in a peat substrate for maximum growth and dry matter accumulation.

On a observé la croissance végétative de la Lingonne (*Vaccinium vitis-idaes* L.) sur quelques substrats de culture naturels, non stérilisés, de l'Alaska : tourbe Lemeta grossièrement broyée, loam limoneux de Fairbanks, mélange tourbe et loam limoneux, et loam sableux très fin de Chena lavé. Au terme de trois saisons de végétation, les plantes cultivées en tourbe afficaient la plus forte croissance végétative,d'après le nombre de nouvelles tiges produites, la longueur des tiges et le poids sec par plante. La taille des feuilles était la même dans tous les traitements. Les feuilles des plantes cultivées sur tourbe sont restées vertes durant toute l'expérience, alors que dans les autres substrats elles manifestaient divers degrés de chlorose, suivie de rougissement et de nécrose. On a constaté des différences dans les concentrations de N, P, K, Mn, Fe, Zn et Al des tissus de plante entière. La tourbe apparaît donc comme le meilleur substrat de culture pour ce petit fruit.

The lingonberry, *Vaccinium vitis-idaea* L., is a woody, evergreen shrub whose distribution extends from arctic to north-temperate regions in Eurasia and North America. Throughout this range, the lingonberry is most abundant in forest habitats which

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are characterized by leached soils with low base saturation, low lime content and a low level of available nutrients (Ingestad 1973). Vegetative growth and fruit productivity are favored by acid soils (pH 5-6) (Ipatov et al. 1977; Tear 1972) and a substantial decaying organic matter layer (Tear 1972; Stark et al. 1978). Few studies which determine the optimum substrate environment for lingonberries in cultivation have been reported. Experiments in Finland have shown that milled peat (pH 4.4) provides a better substrate than sandy soils (pH 6.4) or a mixture of equal volumes of sand and peat (pH 5.0). Vegetative growth is poorest on sandy soils (Lehmushovi and Sako 1975). A Swedish study has shown that the best substrates for lingonberry cultivation are sandy, acidic (pH 5-6) soils with at least a 2% organic matter content (Fernqvist 1977). Similar studies using substrates from Alaska have not been reported. The purpose of this study was to investigate differences in plant nutrition and development of lingonberries growing on four Alaskan substrates in order to determine the optimum substrate environment for maximum vegetative growth.

MATERIALS AND METHODS

A clone of lingonberry, *Vaccinium vitis-idaea* L. ssp. *minus* (Lodd.) Hult., was divided into plants consisting of a single rhizome, 10–11 cm in length; a single, leafy, vegetative rhizome branch (the main stem), 6–7 cm in length; and an undetermined amount of adventitious roots on the rhizome. Five plants were grown in a $15 \times 15 \times 15$-cm plywood container lined with clear polyethylene that was perforated at the base to allow drainage. Containers were buried in the ground to within 2 cm of the top. Treatments consisted of equal volumes of four unsterilized, native-Alaskan substrates: coarsely-ground Lemeta peat (peat); Fairbanks silt loam soil (soil); a mixture of equal volumes of peat and silt loam soil (soil-peat); and washed Chena very fine sandy loam soil (sand) (Rieger et al. 1963). Irrometers were placed within each substrate, and treatments were irrigated with rain water to maintain substrate moisture levels below 20 centibars. Daily temperatures were recorded at a depth of 7 cm with a Taylor Bi-Therm soil temperature probe.

Samples of each substrate were frozen for chemical analysis which included the following: percent $(NO_3 + NO_2)-N$ by KCl leaching (Black et al. 1965) and colorimetric analysis on a Technicon Autoanalyzer II; Bray-1 phosphate (Black et al. 1965); ppm of K, Ca and Mg by NH_4OAc leaching and Inductively Coupled Plasma-Atomic Emission Spectroscopy (ICP) (Dahlquist and Knoll 1978); ppm of Fe, Cu, Zn and Mn by DTPA-TEA extraction (Lindsay and Norwell 1978) and ICP; Al by KCl extraction and ICP; and organic matter by colorimetric method after wet oxidation with H_2SO_4 and $K_2Cr_2O_7$ (Black et al. 1965).

The experiment was a randomized complete block design with five plants per treatment and four replicates. Plants were maintained within each treatment for one, two or three growing seasons. All experiments were conducted in the field near Fairbanks, Alaska during the 1978, 1979 and 1980 growing seasons.

Plants were harvested during the second week of September. Data collected included the number of leaves per stem and stem length of the main stem, lateral branches and leafy rhizome branches. Counts also included the number of lateral branches, leafy rhizome branches and new rhizomes per plant. Leaf length and width measurements were combined into a length-width ratio to give an estimate of leaf size of the main stem, lateral branches and leafy rhizome branches.

All plant parts within each treatment were divided into four groups: leaves, vertical stems, rhizomes and roots. Each group was washed in deionized, distilled water and dried in a forced-draft oven at 60°C for 24 h after which dry weight measurements were recorded. The groups were recombined for whole-plant tissue analysis. Samples were ground, dry ashed and analyzed for percent N by the Kjeldahl method, and for ppm P, K, Ca, Mg, Al, Fe, Mn, Zn, Cu and B by ICP. All data were analyzed by the analysis of variance.

RESULTS

On plants maintained for one growing season, the number of lateral branches, leafy rhizome branches and new rhizomes averaged less than one per plant regardless of substrate treatment. Plants in each treat-

ment did not differ in stem length, leaf size or dry weight, and the tissue analysis revealed no significant differences among treatments in the concentration of elements in the whole-plant samples.

Differences among substrates in the concentration of elements are listed in Table 1.

Plants maintained for two growing seasons showed significant differences in the number of new rhizomes and leafy rhizome branches per plant (Table 2). In both instances, plants grown in peat produced more than twice the number of stems per plant than plants grown in soil, soil-peat or sand. The leafy rhizome branches and new rhizomes were significantly longer in plants grown in peat than in all other treatments (Table 2). No differences among treatments were observed in the number of leaves per stem of the main stem, leafy rhizome branches, lateral branches, the number and length of lateral branches, leaf size or dry weight.

The leaves on all stems of plants grown in peat remained green throughout the second growing season. Plants grown in soil-peat had green leaves on the main stem and lateral branches, but leaves of the leafy rhizome branches were pale green with reddish margins. New leaf growth on plants grown in sand was uniformly chlorotic with reddish margins. Older leaves on the main stem were a uniform dull red color. Plants grown in soil had bright red leaves at the base of the main stem. Leaves became progressively greener toward the stem apex. All new growth was pale green, tinged with red.

The tissue analyses of plants grown for two seasons revealed significant differences in the concentration of Al and Fe in the whole-plant tissue samples (Table 3). In both instances, plants grown in soil contained the greatest amount of these elements. The concentration of tissue N was higher in plants grown in peat than in all other treatments. There were no differences among treatments in the concentration of all other elements.

Plants grown for three seasons differed significantly in the number of lateral branches, leafy rhizome branches and new rhizomes per plant (Table 2). With all three stem types, plants grown in peat had significantly greater numbers per plant than plants grown in the other three substrates. The number of leaves on the main stem and

Table 1. Characteristics of four Alaskan substrates used for growing lingonberries

Substrate characteristic	Sand	Soil	Soil-peat	Peat
Organic matter (%)	0.3	1.4	5.3	
pH	6.4	6.5	5.4	4.8
Average temperature† (°C)				
June	13.4	13.2	13.2	13.1
July	16.0	15.8	15.9	15.8
Aug.	15.8	15.0	15.2	15.0
$(NO_3 + NO_2) - N$ (ppm)	4.2	101.0	3.4	3.9
Bray-1 phosphate (ppm)	24.1	26.2	21.7	5.9
K (ppm)	96.0	136.4	103.6	32.8
Ca (ppm)	1947.3	4251.5	1421.9	191.5
Mg (ppm)	370.5	808.1	282.5	34.1
Mn (ppm)	16.1	38.1	11.9	3.4
Fe (ppm)	148.1	992.7	315.6	36.3
Al (ppm)	1.4	7.9	1.0	0.5
Zn (ppm)	2.1	27.2	0.9	0.5
Cu (ppm)	4.9	6.3	5.4	0.8

†Temperature data are for the 1980 growing season. Average temperatures for 1978 and 1979 differed by less than 2°C from the 1980 temperatures.

Table 2. Average number of stems and leaves per plant and average stem length of lingonberries grown in peat, soil, soil-peat and sand substrates

Substrate	Average number per plant				Average length (cm)	
	Lateral branches	Leaves per lateral branch	Leafy rhizome branches	New rhizomes	Leafy rhizome branches	New rhizomes
			Two seasons			
Sand	0.06 NS	3.00 NS	0.00 *b*	0.25 *b*		1.68 *b*
Soil	0.06	4.00	0.31 *b*	0.50 *b*	1.49 *b*	1.37 *b*
Soil-peat	0.31	6.67	0.81 *b*	0.38 *b*	1.94 *b*	1.54 *b*
Peat	0.94	4.00	2.25 *a*	1.13 *a*	3.50 *a*	4.06 *a*
			Three seasons			
Sand	0.19 *b*	3.00 *b*	0.06 *b*	0.88 *b*	1.22 *b*	1.38 *b*
Soil	0.38 *b*	2.33 *b*	0.63 *b*	0.31 *b*	2.18 *b*	1.32 *b*
Soil-peat	0.75 *b*	5.66 *ab*	0.94 *b*	1.56 *b*	1.49 *b*	1.65 *b*
Peat	2.06 *a*	8.15 *a*	4.19 *a*	4.13 *a*	3.98 *a*	4.42 *a*

a,b Mean separation by Duncan's new multiple range test, 5% level.
NS = nonsignificant at the 5% level.

leafy rhizome branches did not differ among treatments. The main stem averaged 16.52–19.25 leaves per stem, while leafy rhizome branches averaged 3.17–4.57 leaves per stem. Plants grown in peat had a significantly greater number of leaves on lateral branches than plants grown in soil and sand. The leafy rhizome branches and new rhizomes were significantly longer in plants grown in peat than in all other treatments (Table 2). Similar leaf size measurements were recorded for each stem type under all treatments. The length-width ratio was 1.69–1.76 for leaves on the main stem, 1.62–1.83 for leaves on lateral branches and 1.38–1.62 for leaves on leafy rhizome branches.

Leaves and rhizomes comprised the greatest proportion of plant dry weight (Table 4). The dry weight of vertical stems, leaves and rhizomes was significantly greater in the peat treatment than in the other substrates. Greater amounts of roots occurred in the peat and sand treatments than in soil and soil-peat treatments.

Leaves on plants in the peat substrate remained green throughout the third growing season. All new leaves on plants grown

Table 3. Element concentration in whole-plant tissue samples of lingonberries grown in peat, soil, soil-peat and sand substrate

Substrate	N (%)	P (ppm)	K (ppm)	Al (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)
				Two seasons			
Sand	0.53 *b*	495.59 NS	2135.75NS	292.80 *b*	273.79 *c*	401.61 NS	23.53 NS
Soil	0.59 *b*	638.51	2132.70	650.44 *a*	1928.35 *a*	476.42	25.51
Soil-peat	0.62 *b*	652.70	1779.25	520.90 *ab*	694.93 *b*	437.50	22.81
Peat	0.87 *a*	885.10	2871.20	302.52 *b*	353.13 *c*	642.03	35.45
				Three seasons			
Sand	0.72 *b*	521.89 *b*	1684.60 *b*	338.88 *b*	686.65 *c*	495.02 *b*	34.07 *ab*
Soil	0.92 *a*	693.21 *b*	2111.10 *b*	1078.36 *a*	3039.25 *a*	333.69 *b*	27.22 *b*
Soil-peat	0.67 *b*	728.96 *b*	1979.90 *b*	867.67 *a*	1446.95 *b*	485.61 *b*	31.12 *ab*
Peat	0.96 *a*	1041.30 *a*	3534.45 *a*	307.58 *b*	311.47 *c*	939.81 *a*	41.70 *a*

a,b Mean separation by Duncan's new multiple range test, 5% level.
NS = nonsignificant at the 5% level.

Table 4. Average dry weight of vertical stems, leaves, rhizomes and roots of lingonberries grown in four Alaskan substrates for three growing seasons

	Dry weight (mg)			
Substrate	Vertical stems	Leaves	Rhizomes	Roots
Sand	35.3 *b*	66.3 *b*	119.8 *b*	12.4 *a*
Soil	44.4 *b*	55.9 *b*	119.7 *b*	3.5 *b*
Soil-peat	38.7 *b*	68.7 *b*	121.5 *b*	7.0 *b*
Peat	70.8 *a*	176.1 *a*	161.9 *a*	17.5 *a*

a,b Mean separation by Duncan's new multiple range test, 5% level.

in soil-peat were uniformly chlorotic with reddish margins. Older leaves on the main stem were pale green, becoming increasingly more red as the season progressed. Plants in soil and sand had similar color patterns to plants grown in the same substrates for two seasons. The reddening of the older leaves on the main stem was generally followed by necrosis.

Significant differences were observed in 7 of the 11 elements studied by tissue analysis (Table 3). Plants grown in peat had greater concentrations of tissue P, K and Mn than plants grown in the other three treatments. Tissue N was highest in the peat and soil treatments. Plants grown in soil and soil-peat had significantly greater quantities of tissue Al and Fe amounting to more than double the concentration found in plants grown in peat and sand. The concentration of tissue Zn was highest in peat and soil-peat treatments. The tissue concentrations of Ca, Mg, Cu and B did not differ among treatments. The average range of these elements was: Ca, 4355.30–6330.70 ppm; Mg, 1336.05–1624.35 ppm; Cu, 11.09–30.45 ppm; and B, 66.33–86.21 ppm.

DISCUSSION

Vegetative growth of lingonberries was best in a peat substrate, and growth was poorest in sand and soil. These results are similar to those reported by Lehmushovi and Sako (1975) who found that milled peat was a better substrate than sand or a mixture of sand and peat. These studies differ from the results reported by Fernqvist (1977) who stated that sandy soils were best for lingonberry growth in cultivation. The discrepancy may be explained by differences in chemical and physical properties of the substrates at each experimental location or to plant variability. All three studies reveal the importance of pH and organic matter content as substrate components.

In their native habitat, lingonberries have been found to grow in substrates having a pH range of 2.7–5.5 (Krylova and Trembalya 1978). The optimum range for vegetative growth and productivity is pH 5–6 (Ipatov et al. 1977; Fernqvist 1977). In the present study, both the soil and sand substrates had pH values which were greater than the optimum range, while the peat substrate was slightly lower than optimum (Table 1). The soil-peat substrate in which lingonberries grew poorly was within this range. These results indicate that the optimum pH range may be lower than previously reported, and other substrate components, in addition to pH, probably influence lingonberry growth. Considerable variability also may exist in lingonberries for tolerance to different pH levels. Brown and Draper (1980) reported such variability in blueberries and concluded that through selection, blueberries might be grown in soils with a wider pH range. Comparisons among several populations will be necessary to verify this in lingonberries.

The substrate organic matter content seems to promote vegetative growth in lingonberries. In their native habitat, lingonberries are often found in greatest abundance on top of decaying tree stumps and old ant hills (Tear 1972). In forest communities, most of the roots and rhizomes of lingonberries occur in the organic litter horizon (Ritchie 1955; Persson 1978). Smith (1962) noted that the maximum rooting depth was a function of the depth of the organic matter layer, but Kerekova (1970) found no such relationship. The organic matter content may also influence the quantity of mycorrhizal fungi infecting the roots (Haselwandter 1979). Mycorrhizas have been shown to enhance the efficiency of nitrogen absorption (Stribley and Read 1975) and improve vegetative growth and vigor of several ericaceous plants including lingonberries (Warming 1908; Haselwandter 1979).

Cultivation experiments substantiate the necessity for organic matter in the substrate. The present study and that of Lehmushovi and Sako (1975) show that substrates composed primarily of organic matter increase vegetative growth. Optimum growth on sandy soils in Sweden requires at least a 2% organic matter content (Fernqvist 1977). In the present study, the organic matter content of the sand and soil substrates may have been too low for optimum growth (Table 1). Although the soil-peat substrate had an organic matter content which was higher than the minimum reported by Fernqvist (1977), growth was poor.

Marginal soils having a low organic matter content produce symptoms of Fe chlorosis in blueberries. This nutrient disorder is characterized by interveinal chlorosis of the younger leaves followed by uniform leaf and stem chlorosis and stunted growth (Ballinger 1966). Chlorosis occurred on the youngest leaves of lingonberries grown in sand, soil and soil-peat, but the characteristic interveinal chlorosis pattern was not evident.

The concentration of Fe in tissue samples is not indicative of the amount of available Fe in the plant. Plants showing Fe chlorosis symptoms may often be higher in the total concentration of tissue Fe than healthy plants (Mengel and Kirkby 1979). DeKock et al. (1960) considered that a better measure of the amount of available Fe in tissue samples is the P/Fe ratio. High P/Fe ratios indicate a greater quantity of the unavailable form of Fe and are usually associated with Fe chlorotic tissue (Mengel and Kirkby 1979). The following P/Fe ratios were calculated for the four treatments following three growing seasons: peat, 3.34; soil-peat, 0.50; soil, 0.23; and sand, 0.76. These data, along with the leaf color symptoms, indicate that Fe deficiency is probably not a factor in this study. The differences in tissue Fe concentrations may be related to the quantity of Fe in each substrate since plants having the highest levels of total Fe after two and three growing seasons (Table 3) were associated with the soil and soil-peat substrates which had very high Fe concentrations (Table 1).

Concentrations of tissue Al differ significantly among substrate treatments after two and three growing seasons (Table 3). Like Fe, the Al concentration is probably related to the availability of Al in each substrate and to substrate pH (Table 1). Toxic levels of Al occur on acid soils especially where pH is below 5.5 (Mengel and Kirkby 1979). Since reduced vegetative growth occurred on substrates with a pH of 5.4 and higher, and the symptoms of Al toxicity (dark green leaves, stem purpling, low P concentration) did not occur, toxicity probably was not a factor. Similar Al concentrations to those reported in this study were recorded by Firsova and Pavlova (1975) for stem and leaf tissue of lingonberries growing in their natural habitat.

The predominant color change noted was a progressive chlorosis of all leaves and a reddening of the older leaves on plants in the sand and soil treatments after two growing seasons and to a lesser extent in

the soil-peat treatment after three growing seasons. Leaf chlorosis and reddening have been associated with N deficiency in blueberries (Ballinger 1966) and cranberries (Somogyi et al. 1964; Torio and Eck 1969). Following two growing seasons, lingonberries in the peat treatment had significantly greater tissue concentrations of N than plants in the other three treatments, indicating a possible deficiency of available N in the soil, soil-peat and sand treatments. During the third growing season, the tissue N levels were similar for the soil and peat treatments even though plants growing in soil were chlorotic and red while plants in the peat substrate remained green. This discrepancy may be explained by the form of N in each substrate. Nitrate (NO_3-N) is usually considered to be the major source of inorganic N for plants, but the rate of nitrification in acid soils below pH 5.5 is very low. Consquently, NO_3-N is not considered to be a significant source of N in acid soils (Havill et al. 1974). The use of ammonium (NH_4-N) as the major source of N has been demonstrated in blueberries (Cain 1952; Townsend 1966), cranberries (Greidanus et al. 1972), and lingonberries (Mueller-Stoll 1947; Marthaler 1939; Havill et al. 1974). In contrast, Hammett and Ballinger (1972) showed that blueberries grown in sand culture utilized either NO_3-N or NH_4-N equally well. Greidanus et al. (1972) found that cranberries grown with high levels of NO_3-N showed deficiency symptoms and poor growth with tissue concentrations of 1.34%. In contrast, where NH_4-N was the only source, deficiency symptoms did not occur until tissue concentrations were 0.72–0.91%. A similar situation in lingonberries might explain why deficiency symptoms occurred in the soil treatment but not in the peat treatment, even though the tissue N levels were the same. The soil substrate contained a considerably greater amount of NO_3-N than the peat substrate (Table 1).

Lingonberries grown on either the soil or sand treatments showed chlorotic and red growth, although the manifestation of these symptoms was different for each substrate. Perhaps the plants grown on the sand substrate were deficient in N because of substrate deficiency, while the reddening and chlorosis in the soil treatment was related to the form and not the quantity of N. Since deficiency levels of N and other elements have not been established, and plant color variations in relation to these deficiencies have not been identified in lingonberries, further studies will be necessary in order to clarify these observations.

The higher amounts of Mn and Zn recorded in plants grown in the peat sustrate do not agree with the concentrations of these elements in each substrate (Tables 1 and 3). The higher levels found in the peat-treated plants may be related to a greater solubility of these elements at low substrate pH levels (Mengel and Kirkby 1979).

Two other substrate components, temperature and moisture content, are probably not significant factors in this study. Substrate temperature did not differ by more than 1°C among treatments for each growing season (Table 1), and, due to frequent rainfall, irrometer readings rarely reached the 20-centibar limit. Supplemental hand irrigation was unnecessary during most of the experiment and substrates remained moist, but well-drained.

In conclusion, maximum vegetative growth and optimum plant nutrition occurred in plants grown in a peat substrate. High pH and low organic matter content probably prevented optimum growth in sand, soil, and soil-peat. In addition, leaf chlorosis and reddening revealed nutritional disorders possibly relating to the form and quantity of N as a factor in reducing vegetative growth in soil, soil-peat and sand. These data indicate that agricultural soils, as exemplified by the silt loam soil and sandy alluvial soils, are not appropriate. Incorporation of peat into the agricultural soils improved growth only slightly. Greater quantities of organic mat-

ter may be necessary to allow cultivation of lingonberries on agricultural soils, but this procedure may be uneconomical.

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