agronomy

MDPI

Article

Growing Media pH and Nutrient Concentrations for Fostering the Propagation and Production of Lingonberry (*Vaccinium vitis-idaea* L.)

Mehdi Sharifi [1,*], Samir C. Debnath [2], Monireh Hajiaghaei-Kamrani [3], Bill Rabie [1] and Jillian Forsyth [1]

[1] Summerland Research and Development Centre, Agriculture and Agri-Food Canada (AAFC), 4200 Highway 97, Summerland, BC V0H 1Z0, Canada; bill.rabie@agr.gc.ca (B.R.); jillian.forsyth@agr.gc.ca (J.F.)
[2] St. John's Research and Development Centre, Agriculture and Agri-Food Canada (AAFC), 204 Brookfield Road, St. John's, NL A1E 0B2, Canada; samir.debnath@agr.gc.ca
[3] Department of Agriculture Engineering, Payame Noor University (PNU), Tehran P.O. Box 19395-3697, Iran; kamranimona@yahoo.com
* Correspondence: mehdi.sharifi@agr.gc.ca

Abstract: The lingonberry (*Vaccinium vitis-idaea* L.), recognized for its nutritional value and adaptability to cold climates, faces cultivation challenges, particularly in soil pH and fertility optimization. In a greenhouse study, lingonberry transplants were grown in media with pH levels of 6.5 (3:1:1 PRO-MIX BX/peat moss/perlite) and 5.2 (2:1 peat moss/perlite). Seven months post-exposure to different media pH, various fertility treatments (NPK) were tested, including a control (0–0–0), a balanced 5–5–5 kg ha^{-1} rate, a standard 36–24–48 kg ha^{-1} rate, and both higher (up to 54–36–72 kg ha^{-1}) and lower (down to 9–6–12 kg ha^{-1}) rates, applied every three weeks for fifteen weeks across six replications with a standard micronutrient rate. Results showed that media pH significantly affected plant height and volume, with plants at pH 6.5 growing 27% taller and larger than plants at pH 5.2. Fertility levels influenced plant volume, peaking at a moderate fertility rate (18–12–24 kg ha^{-1}) before declining at higher rates. Interactions between pH and fertility significantly impacted shoot biomass, where higher fertility rates (above 36–24–48 kg ha^{-1}) had a more pronounced negative effect on shoot biomass at pH 6.5 compared to pH 5.2. Root dry biomass was consistently 1.2–2.3 times greater than shoot dry biomass and less influenced by the treatments. Shoot death rates increased sharply at fertility rates above 18–12–24 kg ha^{-1}, peaking at 21–35%. Nitrogen concentration in shoots and roots increased with higher fertilizer rates, peaking at 1.74% in the 45–30–60 kg ha^{-1} treatment. Fertility treatments raised growing media's electrical conductivity (EC, 1:20 ratio), with a maximum of 1.41 dS m^{-1} in the 54–36–72 kg ha^{-1} treatment, though pH remained unchanged. Growing media nitrate levels increased with higher N rates, while ammonium levels were unaffected. Shoot death rates rose significantly with higher nitrate concentrations, particularly above 17.5 mg L^{-1}, but showed no link to ammonium levels. Lingonberries can survive and thrive across a wide range of pH levels. These results indicate that lingonberries are resilient and low maintenance, requiring modest nutrient levels, and excessive fertilization hampers their growth.

Keywords: fertilizer; growing media pH; lingonberry; nitrogen; phosphorous; potassium

check for updates

Citation: Sharifi, M.; Debnath, S.C.; Hajiaghaei-Kamrani, M.; Rabie, B.; Forsyth, J. Growing Media pH and Nutrient Concentrations for Fostering the Propagation and Production of Lingonberry (*Vaccinium vitis-idaea* L.). *Agronomy* **2024**, *14*, 2533. https://doi.org/10.3390/agronomy14112533

Academic Editor: Isaac Duah Boateng

Received: 17 September 2024
Revised: 21 October 2024
Accepted: 24 October 2024
Published: 28 October 2024

Copyright: © His Majesty the King in Right of Canada, as represented by the Minister of Agriculture and Agri-Food, 2024. This material is licensed under the terms of the Canada Open Government Licence, which permits unrestricted use, distribution, and reproduction in any medium, provided you acknowledge the source of the information or link to any attribution statement specified in the license. To view this license, visit https://open.canada.ca/en/open-government-licence-canada

1. Introduction

The lingonberry (*Vaccinium vitis-idaea* L.), a woody, evergreen dwarf shrub from the heath family (Ericaceae), is native to the Canadian Pacific Northwest and northeastern Canada, and Scandinavia; and it features a sparse, shallow root system [1]. While traditionally harvested from native stands, commercial production has increased with the development of cultivars. Rich in antioxidants, vitamins, minerals, and polyphenols, lingonberries are considered "superfruits" [2,3]. Their bright red berries and health benefits have spurred growing demand in North America, leading to cultivation in several Canadian provinces and northern United States [4–6]. Lingonberries reproduce through seeds,

underground rhizomes, softwood stem cuttings, and micropropagation [7,8]. Their growth is influenced by various biotic and abiotic factors, including temperature, water, light, soil properties, and plant genetics [9]. The horticulture industry is working to expand lingonberry acreage to meet rising market demand, but limited information on optimal growing conditions, particularly soil pH and fertility, hinders progress [7]. Enhancing this knowledge could improve propagation success and boost productivity and quality for the growing market.

Lingonberries grow well in soils with good drainage and abundant organic matter. They prefer acidic conditions, with a pH between 4.5 and 5.5 [10]. These conditions are similar to those needed by bilberry or European blueberry (*V. myrtillus*), cranberry (*V. macrocarpon*), mountain laurel (*Kalmia latifolia*), rhododendron (*Rhododendron arboretum*, Ericaceae), and other lingonberry relatives [10]. Soils that are not sufficiently acidic require periodic adjustments to maintain the optimal pH range for lingonberries. Penhallegon [11] reported that lingonberries thrive in soils with 2–6% organic matter in the top 8–15 cm (3–6 inches) and a pH of 4.3–5.5. When soil pH exceeds 6.5, elemental sulfur should be applied before or during planting [10]. Gustavsson [12] found that lingonberries showed good growth in poor, light soils with a pH of 5 to 6, but pH levels above 7 negatively impacted plant growth. Adding peat to the soil enhanced rhizome development, growth, and reproduction in lingonberries [12]. Soil pH has a significant impact on the availability of nutrients to plant roots [9]. Identifying the optimal pH for growing lingonberries and understanding the interactions between soil pH and nutrient availability will enhance the chance of success for propagation and cultivation of this species [7,13].

Research on the nutrient requirements and management practices for lingonberries is scarce, despite their significant role in ecosystem productivity, particularly through ground coverage and biomass accumulation, which contribute to nutrient cycling [13,14]. Studies have shown that the concentrations of essential elements in lingonberry organs, similar to those in bilberry (*V. myrtillus* L.), vary depending on site conditions and, in particular, soil nutrient availability. For instance, research by Karlsons et al. [15] demonstrated that applying 300 kg ha^{-1} granular complex fertilizer (12% N, 8% P and 16% K) markedly increased the content of nitrogen (N), phosphorus (P), iron (Fe), zinc (Zn), and boron (B) in lingonberry leaves, which led to an increase in the height (by 60%) and stem diameter (by 63%) of lingonberry plants, as well as the number of rhizomes (by 52%) compared to controls. In bilberry, uptake of P from the soil is positively correlated with N uptake [9], and high N and P availability in soils increases fruit yield and shoot growth [16].

The general nutrient dynamics in lingonberries reveal that the concentrations of elements in different plant parts (leaves, stems, fruits) naturally vary due to differences in tissue composition and seasonal biochemical processes [17,18]. Like bilberry, lingonberries translocate nutrients from leaves to stems and rhizomes to minimize nutrient loss through leaf litter, subsequently reallocating these nutrients to growing tissues when conditions are favorable [14]. Nutrient bioaccumulation peaks in aboveground shoots during the full vegetative season and fruit ripening [19]. Fertilizers and mulching can enhance lingonberry growth and yield [20], but over-fertilization may lead to excessive vegetative growth at the expense of fruit production [21]. Comparative studies have also indicated that relatively low amounts of fertilizer are sufficient for optimal lingonberry growth [22], with positive correlations observed between plant height and fruit yield in both Latvia and Sweden by Ripa and Audri [15] and Gustavsson [23]. Understanding and optimizing lingonberry nutrient requirements could thus play a crucial role in maximizing yield and improving cultivation practices [15].

The absence of agronomy recommendations for lingonberries has hindered their cultivation and market availability, making them less common than widely cultivated fruits like blueberries and cranberries [24]. Consequently, lingonberries remain one of the least studied fruits in the Ericaceae family [15]. Lingonberries typically thrive in acidic, nutrient-poor soils, but a deeper understanding of optimal soil pH and fertility is needed [25]. Investigating these areas is essential to fully harness the potential of lingonberry cultivation.

We hypothesized that lingonberries grow best in lower pH growing media (5.2) and that moderate N–P–K concentrations (36–24–48 kg ha^{-1}) will optimize their growth their growth. The objective of this study was to identify the optimal soil pH and N–P–K concentrations for enhancing the success of lingonberry propagation and cultivation.

2. Materials and Methods

A greenhouse study was conducted to evaluate the effect of pH and the effect of different fertility treatments on nutrient status and lingonberry growth at the Summerland Research and Development Centre of Agriculture and Agri-Food Canada, Summerland, BC, Canada (latitude 49°33′59″ N, longitude 119°38′12″ W). A total of 108 one-year-old lingonberry plugs were obtained from NATS Nursery Ltd., Langly, B.C., Canada in Spring 2022 and kept at 4 °C until the experiment began in the summer of 2022. The experiment's main treatments, pH and fertility, were arranged in a factorial design within a randomized complete block design (RCBD) with six replications.

On 16 August 2022, 108 lingonberry seedlings were potted in 5-inch containers using two media: a 3:1:1 PRO-MIX BX/peat moss/perlite mixture with a pH of 6.5 and a 2:1 peat moss/perlite mixture with a pH of 5.2. PRO-MIX BX is a general purpose growing medium with Sphagnum peat moss (75–85%), perlite, limestone, vermiculite, wetting agent, and mycorrhizae fungi (*Glomus intraradices*) ingredients. Initial growing media pH was measured in a 1:20 growing media-to-water ratio solution and four replications using glass pH electrod. The N-P-K fertility treatment included a control (0–0–0), a basic rate of 5–5–5 kg ha^{-1}, a standard rate of 36–24–48 kg ha^{-1}, and two increments above (45–30–60 and 54–36–72, kg ha^{-1}) and three increments below the standard rate (9–6–12, 18–12–24, 27–18–36 kg ha^{-1}). On 20 March 2023, plant volume measurements were taken by measuring the width and heigh of the plants, as part of the first observation data for the start of fertility treatments, after plants had been exposed to pH treatments for 216 days (7 months and 4 days). Then on 22 March 2023, all plants (108 seedlings) were trimmed at a height of 5 cm, and the dry and wet weight of the cut material was recorded. Greenhouse temperatures were maintained at an average of 25 °C during the day and 20 °C at night, with a 14 h photoperiod. The average light intensity during the photoperiod was 550 μmol $m^{-2}s^{-1}$. A saucer was placed under each pot. Plants were irrigated twice per week and any leachate returned back to the pot. Weeds were removed from the pots by hand weekly.

Fertility treatments were defined according to Karlsons et al. [15]. This process involved calculating the required amounts of urea, H_3PO_3, and KCl for each treatment based on the specific nutritional needs of the plants (Table 1). Fertigation was scheduled every 3 weeks over a 15-week period. To determine the total amount of fertilizer needed for the entire 15-week duration, the required quantity of each fertilizer for a single pot was calculated. This total was then divided to establish the amount needed for each 3-week interval (Table 1). Additionally, "Micro 500", a product by AgroLiquid (St Johns, MI, USA, https://www.agroliquid.com/products/micronutrients/micro-500/ accessed on 20 October 2024), was applied to all treatments at the start of the experiment according to the product label to ensure that the lingonberry plants received adequate micronutrients throughout the experiment. The concentrations of B, copper (Cu), Fe, Mn, and Zn in "Micro 500" were 0.02%, 0.25%, 0.37%, 1.20%, and 1.8%.

Table 1. Fertilizer (N–P–K) application rates across different treatments. Fertigation was conducted over a 15-week period, with plants being fertigated every 3 weeks. Total period of the experiment was 19 weeks.

Treatment	N	P	K	Urea	H_3PO_3 [1]	KCl	Fertilizer Application Rate (15-Weeks) Urea	H_3PO_3	KCl
		kg ha^{-1}		kg ha^{-1}	L ha^{-1}	kg ha^{-1}	mg pot^{-1}	µL pot^{-1}	mg pot^{-1}
0–0–0 (Control)	0	0	0	0	0	0	0	0	0
5–5–5	5	5	5	11	18.6	8	8.9	14.9	6.7
9–6–12	9	6	12	20	22.3	20	16.0	17.9	16.0
18–12–24	18	12	24	40	44.7	40	32.0	35.7	32.0
27–18–36	27	18	36	60	67.0	60	48.0	53.6	48.0
36–24–48 (Standard)	36	24	48	80	89.3	80	64.0	71.5	64.0
45–30–60	45	30	60	100	112	100	80.0	89.3	80.0
54–36–72	54	36	72	120	134	120	96.0	107	96.0

[1] H_3PO_3 purity was 85%.

On the harvest date of 3 August 2023, plant final volume measurements were conducted, marking the project's conclusion. The date also marked the second observation for the fertility treatments, signifying the conclusion of the plants' 136-day (4 months and 14 days) growth phase. The preharvest plant volume measurement was subtracted from initial plant volume measured at the start of fertility experiment to calculate the growth volume. At harvest, % dead plant tissue, plant height, and above- and belowground fresh and dry biomass were measured. Aboveground and belowground parts were separated. Roots were washed on top of a 1 mm sieve under gently running tap water and dewatered using a salad spinner. The biomass samples were weighed and immediately dried at 60 °C until they were completely dry and reached a constant weight (on average 48 h). Oven-dried samples (216 samples) were weighed and ground with a Retsch mill SM 100 (Retsch GmbH, Haan, Germany) followed by ball milling using a ball miller with horizontal oscillation (BM500, Anton Paar Co. Ltd., Graz, Austria). Tissue C and N concentrations were measured using a LECO 628 (LECO Corporation, St. Joseph, MI, USA). After separating the roots, the pH and electrical conductivity ($EC_{1:20}$) of the growing media were measured using a 1:20 growing media-to-water ratio solution. The higher growing media-to-water ratio was selected for pH and EC measurements due to the growing media's capacity to absorb large volumes of water. Nitrate (NO_3^-) and ammonium (NH_{4+}) were then extracted using 2 M KCl with a 1:5 growing media-to-solution ratio and analyzed colorimetrically with an AutoAnalyzer 3 Segmented Flow Analyzer (Astoria-Pacific Inc., Clackamas, OR, USA).

Data were analyzed using JMP software version 17.0.0 (SAS Institute, Inc., Cary, NC, USA). The normality of the data distribution was tested using the Shapiro–Wilk test. When normality could not be assumed, data were log-transformed. Data were analyzed using a two-way analysis of variance (ANOVA) by considering pH and fertility rates as fixed factors and replications as a random factor. When a treatment's effect on a parameter was significant, differences between treatment means were evaluated using the Least Square Differences (LSD) test at a significant level of $p \leq 0.05$. Only significant differences at $p \leq 0.05$ are reported as decreased or increased in the Section 3.

3. Results

3.1. Plant Parameters

A clear understanding of the effects of soil pH and fertility levels on lingonberry growth is crucial for optimizing cultivation practices. In this study, plant height at harvest ranged from 3.71 to 6.28 cm, showing a significant 36.5% increase at pH 6.5 compared to pH 5.2 (Table 2). The interaction between pH and fertility treatments did not significantly impact plant height, although there was a trend toward greater heights near the standard fertility level (27–18–36 kg ha^{-1}). However, differences between the various fertility treatments were not statistically significant (Table 2). Both pH and fertility treatments

significantly affected plant volume growth during the fertility application period (Table 2). While the interaction between pH and fertility was not significant, plants grown at pH 6.5 had an average volume growth of 501 cm^3—35.4% greater than the 370 cm^3 observed at pH 5.2. Plant volume growth peaked at the fertility level of 18–12–24 kg ha^{-1} but declined at higher fertility levels, with the lowest growth recorded at 45–30–60 kg ha^{-1}. Specifically, the 18–12–24 kg ha^{-1} fertility treatment resulted in a 154% increase in plant volume compared to the 45–30–60 kg ha^{-1} treatment.

Table 2. Lingonberry growth parameters as affected by pH and fertility treatment.

Treatment		Plant Height	Growth Volume	Shoot Fresh Biomass	Shoot Dry Biomass	Root Fresh Biomass	Root Dry Biomass	Root-to-Shoot Ratio	Total Fresh Biomass	Total Dry Biomass	Growing Media $EC_{1:20}$ [1] Post-Harvest
		cm	cm^3	g	g	g	g	g	g	g	dS m^{-1}
pH											
5.2		4.46	370	15.4	7.16	102	11.3	1.73	118	18.5	0.567
6.5		6.09	501	15.3	6.95	97.7	11.5	1.65	114	18.2	0.673
Fertility (kg ha^{-1})											
0–0–0		4.68	425 ab [2]	15.3 ab	6.54	131 a	15.3 a	2.56 a	146 a	21.8	0.318 c
5–5–5		4.79	431 ab	15.01 ab	6.90	95.3 ab	11.1 ab	1.62 ab	110 ab	18.0	0.341 c
9–6–12		6.07	438 ab	15 ab	7.05	92.0 ab	10.7 ab	1.52 b	107 ab	17.7	0.345 c
18–12–24		5.68	622 a	16.7 a	6.99	109 ab	12.2 ab	1.88 ab	128 ab	18.9	0.294 c
27–18–36		6.28	468 ab	17.3 a	7.48	108 ab	12.1 ab	1.65 ab	123 ab	19.1	0.417 c
36–24–48		5.43	479 ab	17.0 a	7.99	111 ab	10.8 ab	1.43 b	129 ab	18.9	0.719 bc
45–30–60		3.71	245 b	11.6 b	6.23	79.8 b	8.79 b	1.38 b	91.5 b	15.0	1.11 ab
54–36–72		5.43	394 ab	14.9 ab	7.21	74.5 b	9.79 ab	1.44 b	97.3 ab	16.9	1.41 a
SEM [3]		0.271	28.2	0.416	0.189	4.06	0.498	0.081	4.17	0.617	0.058
Source of variation	df						*p* Value				
pH	1	0.003	0.011	0.920	0.535	0.713	0.771	0.668	0.757	0.945	0.203
Fertility	7	0.271	0.055	0.007	0.268	0.008	0.085	0.003	0.015	0.285	0.000
pH × Fertility	7	0.798	0.621	0.013	0.026	0.629	0.931	0.818	0.724	0.768	0.155

[1] $EC_{1:20}$, Growing media electrical conductivity was measured using a 1:20 growing media-to-water ratio solution; [2] Values in the same column followed by the same letter does not differ significantly ($p \leq 0.05$) based on the LSD test; [3] SEM, Standard error mean.

The impact of fertility levels and their interaction with pH on lingonberry growth was evident in the shoot biomass measurements. Shoot fresh biomass ranged from 11.6 to 17.3 g pot^{-1}, showing a significant response to fertility levels and the interaction between fertility and pH treatments (Table 2; Figure 1a). However, media pH alone did not have a significant effect on shoot fresh biomass. For plants grown at pH 5.2, shoot fresh biomass peaked at a higher fertility rate (36–24–48 kg ha^{-1}) compared to those grown at pH 6.5, which peaked at 18–12–24 kg ha^{-1}. Similarly, shoot dry biomass was significantly influenced only by the interaction between pH and fertility treatments, with a peak at a higher fertility rate for pH 5.2 than for pH 6.5 (Table 2; Figure 1b). Root fresh biomass was affected solely by fertility treatment, showing no significant influence from pH or its interaction with fertility. It was highest in the control, dropped with the start of fertility treatments, and then gradually increased up to the 36–24–48 kg ha^{-1} rate. The lowest root biomass values were observed at 54–36–72 kg ha^{-1} fertility rate, significantly lower than the control. The root-to-shoot ratio ranged from 1.38 to 2.56 g pot^{-1}, decreasing with increasing fertility levels, with the lowest values recorded at 36–24–48, 45–30–60, and 54–36–72 kg ha^{-1}, all significantly lower than those in the control.

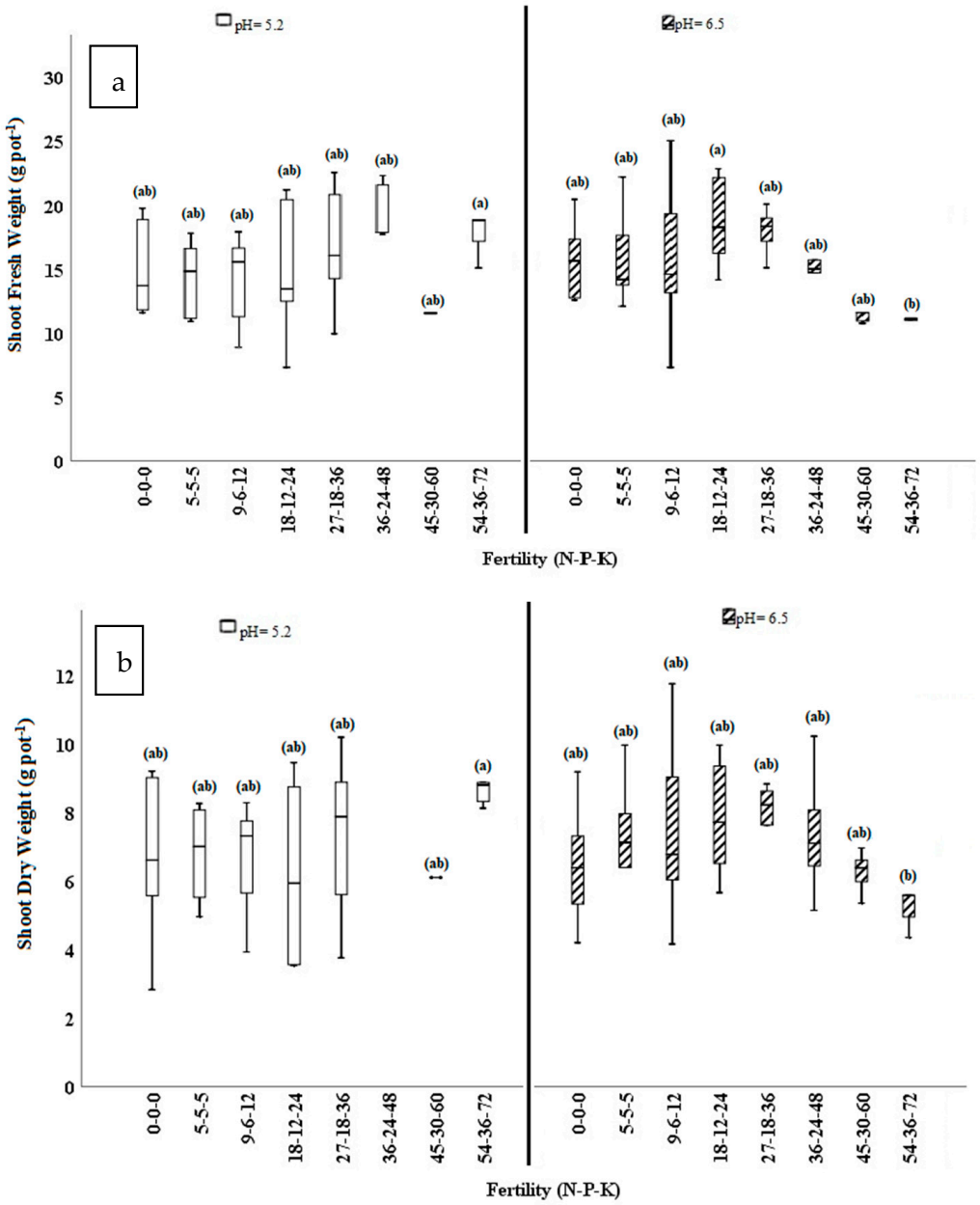


Figure 1. The interaction effect of pH and fertility treatments on lingonberry's shoot fresh weight (**a**) and shoot dry weight (**b**). Boxes in each pH followed by the same letter do not differ significantly ($p \leq 0.05$) based on the LSD test.

Total fresh and dry biomass followed a similar pattern to that of root fresh biomass. Total fresh biomass was influenced solely by the fertility treatment, while total dry biomass was not affected by any treatments or their interactions (Table 2). The total fresh biomass ranged from 91.5 to 146 g pot^{-1}, and total dry biomass ranged from 15.0 to 21.8 g pot^{-1}. The highest total fresh biomass was observed in the control, which then decreased with the introduction of fertility treatments. A gradual increase was noted up to the 36–24–48 kg ha^{-1} treatment. The lowest total fresh biomass values were recorded at 45–30–60 kg ha^{-1}, significantly lower than the control. The N concentration in shoots was affected by both treatments, but not by their interaction. The data showed a clear increasing pattern in shoots' N concentration as the fertilizer rate increased (Table 3). The minimum and maximum values of 1.05% and 1.74% were observed with the 0–0–0 and 45–30–60 kg ha^{-1} treatment, respectively. The fertilizer application rates of 27–18–36, 36–24–48, and 45–30–60 kg ha^{-1}, exhibited a more substantial increase in shoots N concentration, ranging from 25.8% to

65.2% compared to the control treatment. The shoot's carbon concentration showed a narrow range of variation (47.9% to 49.7%) and was influenced solely by the fertility treatment (Table 3). The maximum shoot carbon value was 49.7%, which corresponded to the 6–9–12 kg ha^{-1} treatment. As the fertilizer application rate increased, the carbon concentration of shoots tended to decrease, with the 45–30–60 and 54–36–72 kg ha^{-1} treatments showing the smallest shoot carbon values compared to the fertility rates equal or lower than 9–6–12 kg ha^{-1}.

Table 3. Growing media mineral N (NH_4^+-N and NO_3^--N), and N and carbon in lingonberry shoots and roots.

Treatment		NH_4^+-N	NO_3^--N	Plant Death Tissue	Shoots N	Shoots Carbon	Roots-N	Roots Carbon
		mg N L^{-1}		%		%		
pH								
5.2		1.33	13.7	11.8	1.29	49.2	1.02	41.6
6.5		1.34	13.4	11.6	1.40	49.0	1.06	41.8
Fertility (kg ha^{-1})								
0–0–0		0.91 b [1]	2.00 c	0.00 c	1.05 d	49.7 a	0.862 c	41.4
5–5–5		1.31 ab	1.26 c	0.00 c	1.11 d	49.6 a	0.941 abc	41.6
9–6–12		0.99 ab	2.24 c	7.50 abc	1.17 d	49.7 a	1.03 abc	42.6
18–12–24		1.25 ab	0.86 c	0.00 c	1.26 cd	49.4 ab	0.951 abc	40.0
27–18–36		1.39 ab	5.38 c	3.33 bc	1.32 cd	49.3 ab	1.11 ab	42.2
36–24–48		1.20 ab	21.7 b	12.5 abc	1.47 abc	49.1 ab	1.17 a	41.7
45–30–60		1.44 ab	42.6 a	34.6 ab	1.74 a	48.4 bc	1.18 a	42.1
54–36–72		2.18 a	32.3 ab	35.4 a	1.60 ab	47.9 c	1.09 ab	41.9
SEM [2]		1.103	1.97	2.82	0.032	0.108	0.018	0.285
Source of variation	df				*p* Value			
pH	1	0.955	0.926	0.968	0.023	0.270	0.145	0.721
Fertility	7	0.084	0.000	0.000	0.000	0.000	0.000	0.534
pH × Fertility	7	0.538	0.733	0.594	0.589	0.878	0.943	0.773

[1] Values in the same column followed by the same letter do not differ significantly ($p \leq 0.05$) based on the LSD test. [2] SEM, Standard error mean.

Root-N concentrations were solely influenced by the fertility treatment, showing an increase with higher fertilizer rates (Table 3). The fertility treatments such as 27–18–36, 36–24–48, and 45–30–60 kg ha^{-1} exhibit more substantial increases in root N, ranging from 28.8% to 36.3% compared to the control. Root carbon concentrations were not affected by any treatments or their interaction (Table 3). Root carbon concentrations showed a narrow range of variation across the different pH and fertility treatments (40.0% to 42.6%), similar to shoot carbon.

3.2. Growing Media Parameters

The pH of the growing media at harvest was not significantly affected by any of the treatments. However, the initial pH levels of 5.2 and 6.5 increased slightly to 5.5 and 6.8, respectively, by the time of harvest. In contrast, media $EC_{1:20}$ was influenced solely by fertility treatments (Table 2). Higher fertility levels led to increased $EC_{1:20}$ values, with a marked rise in treatments exceeding 27–18–36 kg ha^{-1}. The highest $EC_{1:20}$ value, 1.41 dS m^{-1}, was recorded in the 54–36–72 kg ha^{-1} treatment. The ammonium (NH_{4+}-N) concentration in the growing media at harvest was not affected by any of the treatments or their interactions (Table 3). The lowest concentration, 0.91 mg N L^{-1}, was measured in the 0–0–0 kg ha^{-1} treatment, while the highest, 2.18 mg N L^{-1}, was observed in the 54–36–72 kg ha^{-1} treatment. Growing media NO_3^--N content was influenced solely by the fertility treatment (Table 3), with concentrations ranging from 0.86 to 42.6 mg N L^{-1}. NO_3^--N levels in the 27–18–36 kg ha^{-1} treatment and lower fertility rates were not significantly

different from the control. However, NO_3^--N concentrations were significantly higher in the 36–24–48 kg ha^{-1} treatment compared to 27–18–36 kg ha^{-1}, but lower than those measured in the 45–30–60 and 54–36–72 kg ha^{-1} treatments.

The probability of shoot death was influenced solely by the fertility treatment, with rates increasing sharply at higher fertility levels. Death rates rose to 52.5% at the 45–30–60 kg ha^{-1} treatment, while the 54–36–72 kg ha^{-1} treatment exhibited a similarly high rate of 46.2% (Table 3). A significant increase in shoot death probability was observed when the growing media NO_3^--N concentrations exceeded 17.5 mg L^{-1} at harvest (Figure 2). In contrast, no relationship was found between post-harvest growing media NH_{4+}-N levels and the probability of shoot death (Figure 3).

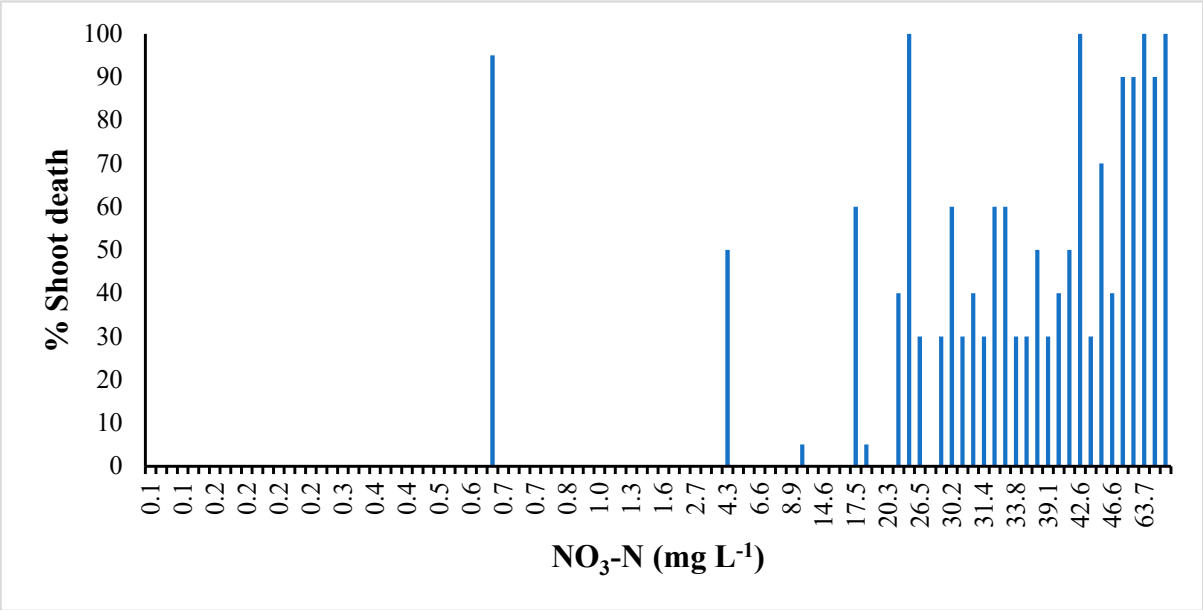


Figure 2. Relationship between residual NO_3-N (mg L^{-1}) concentrations in growing media and percentage plant's death tissues.

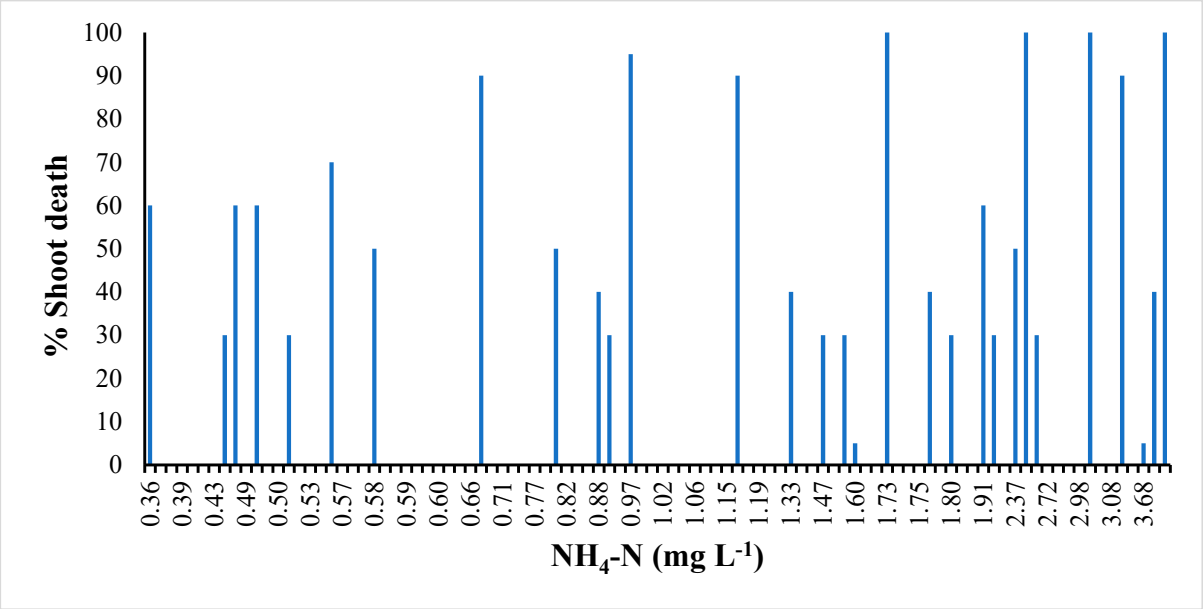


Figure 3. Relationship between residual NH_4-N (mg L^{-1}) concentrations in growing media and percentage shoot death.

4. Discussion

Although previous literature has reported an optimal pH range of 4.5 to 5.5 for lingonberry growth, our findings indicate that lingonberries exhibited increased growth, as measured by plant height and volume, at a pH of 6.5 compared to pH 5.2. This suggests that lingonberries may have a greater ability to adapt and thrive across a wider pH range, as well as higher pH levels, than previously documented. This is further supported by the lack of significant pH effects on other plant growth parameters. The effects of fertility treatments on plant height and volume showed high variability and inconsistency. This variability may be attributed to the plant's ability to grow in low soil fertility and the inherent challenges in accurately measuring height and volume. Lingonberries generate multiple branches, and measuring the height of the tallest branch does not accurately reflect the plant's average height [8]. Similarly, volume measurements do not account for the density of growth. Therefore, these two parameters may not be reliable indicators of lingonberry growth. Chester and McGraw [26] reported that the addition of N increased the rate of lateral meristem release for shoots of all sizes in *V. vitis-idaea* which resulted in shoot population increase. Karlsons et al. [15] found significant differences (60%) in lingonberry plant height and diameter across treatments, with granular complex fertilizer-treated (12% N, 8% K, and 16% K, 300 kg ha^{-1}) plants being taller and wider than controls. Vigorous growth, including taller plants and more branching, is essential for better berry harvesting and higher yields [23]. Shoot fresh and dry biomass responded to fertility treatment; however, this response was affected by growing media pH. The greater shoot biomass in a lower fertility rate for pH 6.5 compared to pH 5.2 is likely associated to the greater availability and cycling of the macronutrient, particularly N, P, and K, in pHs close to neutral [9]. This effect is supported by root-to-shoot ratio results. The root-to-shoot ratio range for lingonberries (1.38–2.56) was greater than the reported root-to-shoot ratio for grasses (1.57), legumes (0.53), and forbs (0.47) [27]. The high root-to-shoot ratio in lingonberries is an adoption strategy for growing in low fertility and unfavorable soil conditions. The reduction in root-to-shoot ratio after fertility treatments above 27–18–36 kg ha^{-1} can be related to negative effect of excess N and the EC of growing media on aboveground biomass. The EC threshold for lingonberries has not been reported; our results show that the lingonberry plant is sensitive to EC [28].

Optimizing fertilization practices is essential for improving lingonberry growth and yield, though careful management is needed to avoid excessive vegetative growth at the expense of fruit production. Lehmushovi [20] in Finland found that fertilizers and mulching positively influenced lingonberry growth and yield, but excessive fertilization favored vegetative growth over fruiting [21,22]. Similarly, Ripa and Audri [15] and Gustavsson [23] identified a positive correlation between plant height and fruit yield. In contrast, Teär [29] observed only modest increases in rhizome production following fertilization. The application of balanced N–P–K fertilizers can enhance fresh biomass and overall yield in lingonberry plants. Chester and McGraw [26] demonstrated that adding nitrogen significantly increased shoot growth rates in lingonberries, with growth rising from 0.96 in the control to 1.14 and 1.19 under 5 and 10 g N m^2 $year^{-1}$, respectively. This nitrogen supplementation also boosted yield by 14% and 24% at these rates. Phosphorus uptake is positively correlated with nitrogen absorption [9], and increased availability of both N and P in the soil has been shown to enhance the yield, shoot growth, and population of both bilberry and lingonberry plants [16,26]. Excessively high N concentrations in soil can significantly harm lingonberry biomass. Lingonberries, which are adapted to low-N, acidic soils, may suffer from reduced growth, poor root development, and overall health decline under high N levels [28]. Fertilization with N levels higher than recommended can lead to excessive vegetative growth of the plant, which can increase the level of fruit rot and also increase the risk of environmental pollution as well as increased weed growth [30]. This imbalance can disrupt nutrient uptake and the critical symbiotic relationships with ericoid mycorrhizal fungi, further reducing biomass [31]. The effects of fertility treatments were primarily observed in aboveground biomass, with root systems remaining largely unaf-

fected by varying fertility rates. Mäkipää [32] reported that Vaccinium species exhibited significant responses to soil N, P, and Ca gradients, but not to other gradients such as K and Mg. Mäkipää [32] demonstrated that increased N concentrations in the humus layer following N addition likely exceed optimal levels for Vaccinium species. This aligns with previous findings that dwarf shrubs, such as Vaccinium, do not show increased abundance after fertilization [33,34]. Given that the Vaccinium plant family typically forms associations with ericoid mycorrhizae rather than arbuscular mycorrhizae like *Glomus intraradices*, it is unlikely that *Glomus intraradices* in PRO-MIX BX would have any effect on lingonberry growth parameters [35].

The total dry biomass measured for lingonberries was within the range typically reported for grasses but lower than that reported for legumes or forbs [27]. Lingonberries generally exhibit a slower growth rate compared to many other plant species, particularly those adapted to more nutrient-rich environments [26,28]. This slow growth is characteristic of plants in the Vaccinium genus, which are adapted to nutrient-poor, acidic soils. Like other Vaccinium species, lingonberries invest more in root development and symbiotic relationships with ericoid mycorrhizal fungi to enhance nutrient uptake, which can limit aboveground growth rates.

For lingonberry plants, which are naturally adapted to acidic soils, the greater shoot-N concentrations observed at pH 6.5 compared to pH 5.2 might indicate that slightly less acidic conditions can still enhance N availability through enhanced interactions of N–microbes–roots. Nitrogen is an essential nutrient actively absorbed by plant roots, primarily through the process of mass flow. As a result, higher N concentrations in the growing medium typically lead to increased N levels in plant tissues, including the shoots and roots of lingonberry plants. Studies confirm this relationship, with N uptake closely correlated with its availability in the soil solution [9,34]. As the response of lingonberry biomass to N rates was modest, the dilution effect did not affected the concentration of N in the plant tissues. In contrast, carbon assimilation in plants is generally unaffected by nutrient treatments. However, if excessive nutrient levels reach toxic concentrations, they can disrupt photosynthesis, potentially leading to a decrease in carbon assimilation [36,37]. This disruption is often observed under conditions of nutrient sever deficiency or toxicity, where metabolic processes, including photosynthesis, are impaired, affecting the overall carbon balance in the plant [9].

Using a 1:20 growing media-to-water ratio for measuring pH, instead of the standard saturated paste or 1:2 ratio, can result in lower pH readings due to the dilution of soluble salts and ions in the growing media, which directly affects the measured pH [38,39]. Although the $EC_{1:20}$ values were lower than the 4 dS m^{-1} threshold for most plants and close to 1.0 dS m^{-1} for salt-sensitive crops [40], the 1:20 extraction ratio likely underestimates the true salinity. When translated to a 1:1 or 1:2 soil-to-water ratio, these EC values could be significantly higher, potentially reaching levels detrimental to lingonberry growth. Consequently, the observed increase in probability of shoot death could be attributed to a combination of N toxicity and elevated EC levels [41].

The concentrations of NH_{4+}-N and $NO_3{}^-$-N in the solution correspond directly to the fertility treatments, with accumulation occurring when N is supplied in excess of lingonberry plant requirements. Excessive N can lead to nutrient imbalances, negatively impacting plant health and growth, as documented in studies highlighting the effects of over-fertilization in horticultural crops [30,42]. *Vaccinium vitis-idaea* and *V. myrtillus* have narrow optimal N ranges and are sensitive to high concentrations. Damage occurred at 200 mg N L^{-1}, and *V. vitis-idaea* showed increased N and salt uptake between 200 and 400 mg N L^{-1}. A safe N range is 50–100 mg N L^{-1}, with an EC of around 0.350–0.700 dS m^{-1} [28]. The result of the current study's fertility rate above 36–24–48 resulted in an EC of above 0.700 dS m^{-1}.

The interaction between N forms and nutrient uptake in ericaceous plants significantly influences plant health and nutrient availability. Cain [43] and Colgrove and Roberts [44] found that the use of $NO_3{}^-$-N in ericaceous plants increased leaf pH, which led to iron

(Fe) inactivation due to the accumulation of cations and a deficiency in organic acids. This observation is consistent with the results of Ingestad [28], where chlorosis developed when high levels of calcium (Ca) or K were combined with NO_3^--N. In contrast, ammonium (NH_{4+}-N) helps lower the pH at the root surface, reducing cation buildup and enhancing iron availability [28,44]. According to Ingestad [29], optimal plant nutrition is achieved when both nitrogen sources are present. However, using either NH_{4+}-N or NO_3^--N alone is not harmful as long as they are maintained at low concentrations.

5. Conclusions

This study highlights the impact of pH and N–P–K fertility treatments on the growth of lingonberry plants, with a particular focus on plant height, volume, biomass, and N uptake. Our findings suggest that lingonberries can adapt to a wider pH range than previously thought, with optimal growth observed at pH 6.5. Fertility treatments, particularly at moderate levels (18–12–24 kg ha^{-1}), significantly influenced plant volume growth and biomass, while higher fertility levels (45–30–60 kg ha^{-1} and above) led to diminished returns in growth, increased root-to-shoot imbalances, and a higher probability of shoot death due to excessive N and salinity levels. Our finding suggest using moderate N–P–K fertility treatments (18–12–24 kg ha^{-1}) to enhance plant growth without overstressing the root system or increasing the risk of nutrient imbalances. Maintaining pH levels between pH 5.5 and 6.5 appears to enhance the availability of key macronutrients, improving overall plant health. Future studies should further investigate the long-term effects of fertility treatments, including micronutrients, on fruit yield in the field; the critical role of mycorrhizal relationships in nutrient uptake; and the potential impacts of varying N sources (ammonium versus nitrate) on growth dynamics. Additionally, more research is needed to determine the threshold for EC and its impact on lingonberry productivity in diverse growing conditions. These insights can inform best practices for lingonberry propagation and cultivation, ensuring sustainable crop management and optimizing yields.

Author Contributions: Conceptualization, M.S.; Methodology, M.S., B.R. and J.F.; Validation, M.S.; Formal analysis, M.S., M.H.-K. and J.F.; Investigation, M.S.; Resources, M.S. and S.C.D.; Data curation, M.S. and M.H.-K.; Writing—original draft, M.S. and M.H.-K.; Writing—review & editing, M.S., S.C.D., M.H.-K., B.R. and J.F.; Visualization, M.S.; Supervision, M.S.; Project administration, M.S. and B.R.; Funding acquisition, M.S. and S.C.D. All authors have read and agreed to the published version of the manuscript.

Funding: This research was conducted as part of a larger project funded by Agriculture and Agri-Food Canada's A-Base funding program (Project ID: J-002637, Innovative techniques for screening, propagation and utilization of wild berry crops for sustainable northern agriculture), with Dr. Samir Debnath serving as the principal investigator. Dr. Mehdi Sharifi led the seed propagation and fertility components of the study.

Data Availability Statement: Data will be made available on request.

Acknowledgments: The authors express their sincere gratitude to Gavin Newall (Coop student), Sarah O'Brien (Coop student) and Jordan Fraser (Technician) for their valuable technical support throughout this study.

Conflicts of Interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Abbreviations

Ammonium, NH_4^+; Analysis Of Variance, ANOVA; Boron, B; Calcium, Ca; Copper, Cu; Electrical Conductivity, EC; Iron, Fe; Least Significant Difference, LSD; Nitrate, NO_3^-; Nitrogen, N; Phosphorus, P; Potassium, K; Randomized Complete Block Design, RCBD; Zinc, Zn.

References

1. Olsen, C. Studies on the hydrogen ion concentration of the soil and its significance to the vegetation, especially to the natural distribution of plants. *CR Lab Carlsberg.* **1921**, *15*, 1–160.
2. Kowalska, K. Lingonberry (*Vaccinium vitis-idaea* L.) fruit as a source of bioactive compounds with health-promoting effects—A review. *Int. J. Mol. Sci.* **2021**, *22*, 5126. [CrossRef] [PubMed]
3. Opal Consulting Inc. Labrador Wild Berry Strategic Development Plan. A Strategy to Expand the Capacity of the Wild Berry Industry in Southern Labrador: Opal Consulting Inc. and P & G Management Services; Sep. 2010. p. 86. Available online: http://nakn.ca/data/4/wildberry_study-zone_4_and_5.pdf (accessed on 22 March 2024).
4. Debnath, S.C. Genetic diversity and erosion in berries. In *Sustainable Development and Biodiversity*; Ahuja, M.R., Jain, S.M., Eds.; Springer International Publishing: Cham, Switzerland, 2016; Volume 8.
5. Dróżdż, P.; Šėžienė, V.; Wójcik, J.; Pyrzyńska, K. Evaluation of bioactive compounds, minerals and antioxidant activity of lingonberry (*Vaccinium vitis-idaea* L.) fruits. *Molecules* **2017**, *23*, 53. [CrossRef] [PubMed]
6. Kowalska, K.; Olejnik, A.; Zielińska-Wasielica, J.; Olkowicz, M. Inhibitory effects of lingonberry (*Vaccinium vitis-idaea* L.) fruit extract on obesity-induced inflammation in 3T3-L1 adipocytes and RAW 264.7 macrophages. *J. Funct. Foods* **2019**, *54*, 371–380. [CrossRef]
7. Debnath, S.C.; Arigundam, U. In vitro propagation strategies of medicinally important berry crop, lingonberry (*Vaccinium vitis-idaea* L.). *Agronomy* **2020**, *10*, 744. [CrossRef]
8. Foley, S.L.; Debnath, S.C. Influence of in vitro and ex vitro propagation on anthocyanin content and anti-oxidant activity of lingonberries. *J. Hortic. Sci. Biotechnol.* **2007**, *82*, 114–118. [CrossRef]
9. Marschner, H. *Marschner's Mineral Nutrition of Higher Plants*; Academic Press: New York, NY, USA, 2012.
10. Reich, L. Lingonberry: Dainty Looks, Sturdy Disposition, and Tasty Berries. *Arnoldia* **2004**, *63*, 18–25. [CrossRef]
11. Penhallegon, R.H. *Lingonberry Production Guide for the Pacific Northwest: Oregon State University Extension Bulletin Number PNW 583- E*; Oregon State University: Corvallis, OR, USA, 2006.
12. Gustavsson, B. Lingonberry breeding and cultivation (*Vaccinium vitis-idaea* L.). *Acta Hortic.* **1993**, *346*, 311–313. [CrossRef]
13. Eeva, T.; Holmström, H.; Espín, S.; Sánchez-Virosta, P.; Klemola, T. Leaves, berries and herbivorous larvae of bilberry Vaccinium myrtillus as sources of metals in food chains at a Cu-Ni smelter site. *Chemosphere* **2018**, *210*, 859–866. [CrossRef]
14. Grelet, G.A.; Alexander, I.J.; Proe, M.F.; Frossard, J.S.; Millard, P. Leaf habit influences nitrogen remobilization in Vaccinium species. *J. Exp. Bot.* **2001**, *52*, 993–1002. [CrossRef]
15. Karlsons, A.; Tomsone, S.; Lazdāne, M.; Osvalde, A. Effect of fertilization on growth of lingonberry (*Vaccinium vitis-idaea* L.). *Agron. Res.* **2021**, *19*, 1039–1051. [CrossRef]
16. Nestby, R.; Krogstad, T.; Joner, E.; Vohnik, M. The effect of NP fertilization on European blueberry (*Vaccinium myrtillus* L.) development on cultivated land in mid-Norway. *J. Berry Res.* **2014**, *4*, 147–157. [CrossRef]
17. Bujor, O.C.; Ginies, C.; Popa, V.I.; Dufour, C. Phenolic compounds and antioxidant activity of lingonberry (*Vaccinium vitis-idaea* L.) leaf, stem and fruit at different harvest periods. *Food Chem.* **2018**, *252*, 356–365. [CrossRef] [PubMed]
18. Havas, P.; Kubin, E. Structure, growth and organic matter content in the vegetation cover of an old spruce forest in northern Finland. *Ann. Bot. Fenn.* **1983**, *20*, 115–149.
19. Lähdesmäki, P.; Pakonen, T.; Saari, E.; Laine, K.; Tasanen, L.; Havas, P. Changes in total nitrogen, protein, amino acids and NH_{4+} in tissues of bilberry, *Vaccinium myrtillus*, during the growing season. *Ecography* **1990**, *13*, 31–38. [CrossRef]
20. Lehmushovi, A. Trials with the cowberry in Finland. *Acta Hortic.* **1976**, *61*, 301–308. [CrossRef]
21. Trajkovski, V. Facts about lingonberries (cowberries, partridgeberries). *Fruit Var. J.* **1987**, *41*, 39.
22. Holloway, P.S. Studies on Vegetative and Reproductive Growth of Lingonberry, *Vaccinium vitis-idaea* L. Ph.D. Thesis, University of Minnesota, Minneapolis, MN, USA, 1983.
23. Gustavsson, B.A. Genetic variation in horticulturally important traits of fifteen wild lingonberry *Vaccinium vitis-idaea* L. populations. *Euphytica* **2001**, *120*, 173–182. [CrossRef]
24. Debnath, S.C.; Keske, C. Technological advances in the propagation and improvement of Newfoundland and Labrador berries. In *Food Futures: Growing a Sustainable Food System for Newfoundland and Labrador*; Memorial University Press: St. John's, NL, Canada, 2018; pp. 381–409.
25. Ross, K.A.; Godfrey, D.; Fukumoto, L. The chemical composition, antioxidant activity and α-glucosidase inhibitory activity of water-extractable polysaccharide conjugates from northern Manitoba lingonberry. *Cogent Food Agric.* **2015**, *1*, 1109781. [CrossRef]
26. Chester, A.L.; McGraw, J.B. Effects of nitrogen addition on the growth of *Vaccinium uliginosum* and *Vaccinium vitis-idaea*. *Can. J. Bot.* **1983**, *61*, 2316–2322. [CrossRef]
27. Sharifi, M.; Salimi, K.; Rosa, D.; Hart, M. Screening Cover Crops for Utilization in Irrigated Vineyards: A Greenhouse Study on Species' Nitrogen Uptake and Carbon Sequestration Potential. *Plants* **2024**, *13*, 1959. [CrossRef] [PubMed]
28. Ingestad, T. Mineral nutrient requirements of *Vaccinium vitis idaea* and *V. myrtillus*. *Physiol. Plant.* **1973**, *29*, 239–246. [CrossRef]
29. Teär, J.I. *Vegetativ och Fruktifikativ Utveckling hos Vildväxande och Odlade Lingon*; Alfa-Laval: Tumba, Sweden, 1972.
30. Davenport, J.R. The effect of nitrogen fertilizer rates and timing on cranberry yield and fruit quality. *J. Am. Soc. Hortic. Sci.* **1996**, *121*, 1089–1094. [CrossRef]
31. Read, D.J. The structure and function of the ericoid mycorrhizal root. *Ann. Bot.* **1996**, *77*, 365–374. [CrossRef]

32. Mäkipää, R. Response patterns of *Vaccinium myrtillus* and *V. vitis-idaea* along nutrient gradients in boreal forest. *J. Veg. Sci.* **1999**, *10*, 17–26. [CrossRef]
33. Mäkipää, R. Effects of nitrogen fertilization on the humus layer and ground vegetation under closed canopy in boreal coniferous stands. *Silva Fenn.* **1994**, *28*, 81–94. [CrossRef]
34. Taiz, L.; Zeiger, E.; Møller, I.M.; Murphy, A. *Plant Physiology and Development*, 6th ed.; Sinauer Assosiates, Inc.: Sunderland, MA, USA, 2015.
35. Smith, S.E.; Read, D.J. *Mycorrhizal Symbiosis*; Academic Press: Cambridge, MA, USA, 2010.
36. Cakmak, I.; Römheld, V. Boron deficiency-induced impairments of cellular functions in plants. *Plant Soil* **1997**, *193*, 71–83. [CrossRef]
37. Kochian, L.V.; Hoekenga, O.A.; Pineros, M.A. How do crop plants tolerate acid soils? Mechanisms of aluminum tolerance and phosphorous efficiency. *Annu. Rev. Plant Biol.* **2004**, *55*, 459–493. [CrossRef]
38. Hendershot, W.; Lalande, H.; Duquette, M. Soil reaction and exchangeable acidity. In *Soil Sampling and Methods of Analysis*, 2nd ed.; Carter, M.R., Gregorich, E.G., Eds.; Canadian Society of Soil Science, CRC Press: Boca Raton, FL, USA, 2008.
39. McLean, E. Soil pH and lime requirement. In *Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties*; Page, A.L., Ed.; American Society of Agronomy: Madison, WI, USA, 1982.
40. Havlin, J.L.; Beaton, J.D.; Tisdale, S.L.; Nelson, W.L. *Soil Fertility and Fertilizers: An Introduction to Nutrient Management*, 8th ed.; Pearson Education India: Hoboken, NJ, USA, 2014.
41. Scagel, C.F.; Schreiner, R.P. Changes in the Concentration of Nutrients and Irrigation Solution Electrical Conductivity during Container Production of Rhododendron and Blueberry. *HortScience* **2006**, *41*, 1793–1801.
42. Rosen, C.J.; Bierman, P.M. *Nutrient Management for Fruit and Vegetable Crop Production: Using Manure and Compost as Nutrient Sources for Vegetable Crops*; University of Minnesota Extension: St Paul, MN, USA, 2005.
43. Cain, J. Blueberry chlorosis in relation to leaf pH and mineral composition. *Proc. Amer. Soc. Hort. Sci.* **1954**, *64*, 61–70.
44. Colgrove, M.S.; Roberts, A.N. Growth of the azalea as influenced by ammonium and nitrate nitrogen. *Am. Soc. Hortic. Sci.* **1956**, *68*, 522–536.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.