Cloudberry cultivation in cutover peatlands: hydrological and soil physical impacts on the growth of different clones and cultivars

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SUMMARY

Cloudberry (*Rubus chamaemorus* L.) cultivation is receiving increasing attention as a means of revitalising regional economy and rehabilitating cutover peatlands. The study reported here investigated the necessary soil physical and hydrological conditions, the compatibility of cloudberry cultivation with restoration of mined peatlands, and the performance of newly commercialised Norwegian cultivars in North America. Terraces at two levels were landscaped in peatland after vacuum extraction of peat to create different growing conditions in terms of hydrology and soil properties, then planted with two Norwegian cultivars (Fjordgull and Fjellgull) and two local (east Canadian) clones of cloudberry in a randomised block experiment. After three years, both the clones and the cultivars grown on the lower terrace had more leaves per m^2 due to lower soil bulk density combined with higher average water level. Mulching, inherent to restoration, reduced the number of leaves produced during the year following planting. The Fjordgull cultivar had a higher survival rate than Fjellgull and local clones. Overall, the number of living rhizomes decreased over the years following planting. These results suggest that soil properties (bulk density and porosity) significantly influence cloudberry establishment and growth. Rhizomes should be planted two or three years after peatland restoration to avoid the initial negative effects of the mulch.

KEY WORDS: Canada, mulching, peatland restoration, *Rubus chamaemorus*, water table.

INTRODUCTION

Cloudberry (*Rubus chamaemorus* L.; Rosaceae) is a dioecious low-growing shrub. It has a circumpolar distribution and is found mainly in bogs. The cultivation of this species has received some attention over the last 50 years, mainly in Finland (Mäkinen & Oikarinen 1974, Kortesharju & Rantala 1980, Kortesharju & Mäkinen 1986) and Norway (Østgård 1964, Rapp 1992). The raspberry-like berries are considered a delicacy, especially in Fennoscandia, while other parts of the plant are prized by a number of circumpolar indigenous peoples as sources of herbal medicines (Moerman 2002, Murray *et al.* 2005, Parlee *et al.* 2006). Interest in this predominantly wild plant has increased during the last few years because its commercialisation could revitalise regional economies (Kärenlampi *et al.* 2001, Boxall *et al.* 2003, Korpelainen *et al.* 2006). Cloudberry cultivation could also be an interesting option for the after-use of decommissioned peat extraction areas, adding value to the reclamation approach.

Under natural conditions, cloudberry has a low and variable productivity, usually 0–30 kg ha^{-1} (Kortesharju 1988). Natural stand yield has been increased by fertilisation (Rapp & Steenberg 1977), clone selection (Rapp 1991) and general cultivation techniques (Rapp 2004). However, the success of these approaches has been variable. According to the Norwegian growers' guide (Rapp 2004), cloudberry should be grown in slightly decomposed peat (H2–H4 on the von Post humification scale) with pH in the range 3.5–4.5 (Lohi 1974) and water table 30–50 cm below the ground surface. The substrate should be well aerated and water should be readily available to the plants. These conditions are common at locations where cloudberry grows in the wild (Metsävainio 1931). However, as peat humification increases, air content, pore size, and water availability decline whereas bulk density increases (Boelter 1969, Brandyk *et al.* 2002, Price *et al.* 2005). Since soil hydrological and physical properties are important determinants of plant growth (White 1978, Houlbrooke *et al.* 1997) and soil physical properties can vary even within the recommended growing range on the von Post scale, three factors (i.e. degree of decomposition, pH and water level) might be insufficient to describe organic soils which are to be used for cloudberry cultivation, especially when the primary aim is to reclaim cutover peatlands.

Soil conditions in cutover *Sphagnum* peatlands are harsh for the plants that are re-introduced when implementing the moss transfer restoration approach (Quinty & Rochefort 2003), especially because the new hydrological conditions favour frost heaving (Groeneveld & Rochefort 2005). One method for increasing survival involves the application of protective mulches over re-introduced moss material. Straw mulch increases water potential at the peat surface, reduces evaporation, maintains the water table closer to the surface, and keeps peat water content higher than would be the case for bare peat throughout the growing season (Price 1997, Price *et al.* 1998). This improvement in water-related properties at the soil surface promotes *Sphagnum* recolonisation, but its effect on re-introduced vascular plants has been studied very little so far. In natural cloudberry stands, straw mulch increases female flower number (Kortesharju 1986) and yield (Huikari 1972). Furthermore, Finnish researchers have found that *Sphagnum* moss is one of the best mulches for preventing weed competition in cloudberry plantations (O. Iivanainen, MTT Agrifood Research Finland, pers. comm. 2004), but the impact of mulching on cloudberry has not been tested under the climatic conditions of eastern Canada.

Four cloudberry cultivars have been selected in Norway in order to increase plant productivity and berry yield (Rapp 1991). Of the two female cultivars, Fjordgull is intended for cultivation in fjord regions whereas Fjellgull is intended for inland areas. The two male cultivars are Apolto and Apollen. These cultivars have yet to be assessed in the Canadian climate.

The purpose of our study was to establish cloudberry plantations of different provenances under different peat soil conditions, and to evaluate the compatibility of cloudberry cultivation with the moss layer transfer restoration approach for *Sphagnum* peatlands.

METHODS

Study area

The experimental site is located in the Pointe-Lebel peatland, in the Côte-Nord region, Québec (QC), Canada (49° 10' N, 68° 12' W). The average annual temperature is 1.5°C, with monthly averages of 15.6°C for July and -14.4°C for January. Annual precipitation averages 1,014 mm of which 67% falls as rain (Environment Canada 2002). The 2 ha experimental peat field chosen had been mined by Premier Horticulture Ltd for about 18 years using the vacuum peat extraction technique, and was abandoned six years prior to this study. It was located between a cutover section and a part of the peatland where active peat extraction was still in progress. Drainage ditches around the site were active prior to establishment of the plots.

Experimental design

The effects of water level and mulching on the establishment of four clone/cultivar provenances of cloudberry were tested in a randomised block split-split-plot experiment, which was replicated four times. The eight main plots (26 m x 8 m) offered two different water levels, and each was divided into sub-plots (13 m x 8 m) with and without mulch and sub-sub-plots (6.5 m x 4 m) planted with cloudberry rhizomes of four different origins.

Water table levels were chosen to test the upper (25 cm) and lower (50 cm) ends of the range recommended for Norway (Rapp 2004). To achieve this, a tractor-driven horizontal auger removed peat down to the frozen layer, which was about 20 cm below the ground surface. The surplus peat was rolled over and levelled by the tractor to create an upper (added peat) and a lower (frozen surface) terrace with an altitude difference of 23 ± 4 cm (mean ± SE) between the terraces. The drainage system of the cutover peatland was dammed in order to obtain water table depths of 25 cm and 50 cm relative to the surfaces of the upper and lower terraces respectively, early in the growing season when the water level was at its annual maximum. Although the water table fluctuated due to drying-out of the dammed ditches in summer, there was always a difference in water table depth between the two terraces (data not provided here). The two water table depth treatments will be referred to as 'upper terrace' and 'lower terrace'.

Half of each terrace was left bare, and the other half restored by applying the *Sphagnum* moss layer transfer technique (Quinty & Rochefort 2003). Essentially, plant material collected from a *Sphagnum fuscum* dominated (not cutover) part of the Pointe-Lebel peatland was transferred to the sub-plots, spread manually, and then covered with straw. Moss growth was good in most sub-plots and moss cover reached 26 ± 6% by area after two years (L. Rochefort, unpublished data).

Site preparation, which included the restoration procedures, was carried out in spring 2004. One year later (spring 2005), all sub-sub-plots were planted with cloudberry rhizomes. East Canadian clones were obtained from the Pointe-Lebel peatland (QC) and from Pokesudie Island in the Acadian peninsula, New Brunswick (NB). For these two provenances, rhizomes were dug up from single *ca*. 3 m^2 patches of female cloudberry. Genetic diversity is usually low in cloudberry patches (Korpelainen *et al.* 1999), so we regarded each of these patches as a single clone. The rhizomes were cut into sections 15 cm long as recommended by Rapp (2004). Female Norwegian cultivars, Fjordgull (FD) and Fjellgull (FL), were purchased as 15 cm long rhizomes from the *Eggen Gartneri* nursery (Fauske, Norway). Each sub-sub-plot was planted with 24 female rhizomes of a single clone/cultivar, arranged in two rows. There were 12 rhizomes per row, within-row spacing was 30 cm and between-row spacing was 60 cm. The rhizomes were planted 10 cm below the peat surface (Rapp *et al.* 2000, Rapp 2004). The frozen layer was at least 15 cm below the surface at the time of planting, so that no rhizomes were planted in frozen peat. The 1:9 male:female ratio required for pollination (Rapp 2004) was provided by planting the male cultivars Apolto and Apollen beside each sub-sub-plot.

It has been recommended that fertiliser should be applied in holes 15–20 cm deep at a density of one hole m^{-2} (450 kg ha^{-1}), once every 10 years (Rapp 2004). Slow release solid fertiliser was applied in mid-June 2005, in holes located at least 30 cm from the closest planted rhizomes. The formulation was 11% N (6.5% as NH_4^+ and 4.5% as NO_3^-), 5% P, 17.6% K, 2.3% Mg, 2.3% Ca (as $CaCl_2$), 9.5% S, 0.3% Mn, 0.03% B, 0.03% Zn and 0.002% Mo. This application rate was adapted from Norwegian practice (I. Martinussen, Bioforsk Holt, Norway, pers. comm. 2004).

Growth measurements

Once all ramets had sprouted and leaves had reached full size, growth measurements were carried out at the end of July in three consecutive years. The number of plants that survived (number of planted rhizomes that produced at least one ramet) and the number of leaves were counted. During the first year of measurements, total leaf area in each sub-sub-plot was also determined. Leaf area was estimated by measuring leaves diagonally from an inferior lobe to the opposite superior lobe and converting this distance to area using Equation 1 (n = 27, r^2 = 0.93). To establish this equation, 27 leaves with diagonal measurements of less than 4 cm were harvested from two different sites at the Pointe-Lebel peatland. The leaves were kept refrigerated for less than 48 hours before leaf area was measured using a LI-COR 3100 area meter (LI-COR Biosciences, Lincoln, NE, USA). Parameter estimates were obtained using non-linear regression in SAS (NLIN procedure, SAS version 9.1, SAS Institute, Cary, NC, USA), yielding the equation:

$$LA = 0.5242\, e^{(0.7158\, D)} \qquad [1]$$

where LA is leaf area in cm^2 and D is the diagonal measurement in cm. All leaves measured in the different experimental plots had $D < 4$ cm, and so fell within the validity range of the equation.

Soil hydrological properties

Water table depth was recorded only as an indicator of soil wetness, since Price (1997) had already reported that ‘water table depth … was not a good indicator of water availability at the surface’ of the bog. Furthermore, a greenhouse experiment carried out during the winter of 2005, i.e. a few months before fieldwork commenced (Théroux Rancourt 2007), showed that there were no differences in plant growth at the upper (-25 cm) and lower (-45 cm) limits of the water table range stipulated by Rapp (2004), whereas plant growth was influenced by both the degree of peat decomposition and the water-related physical properties of the soil. Accordingly, the principal field measurements used to assess water availability in the two terraces were water potential and water content. Water table depth in wells on the different terraces was measured only occasionally, but these data indicated that the water table was always higher in the lower terraces than in the upper terraces of a given block.

Soil water potential was measured with horizontal (1 cm diameter ceramic porous cup) or vertical (2 cm diameter ceramic porous cup) tensiometers which were inserted 5 cm or 10 cm into the substrate, i.e. at the depths where sprouts and new roots were growing. One pair of tensiometers (one at 5 cm and one at 10 cm depth) was inserted in each sub-plot. Water potentials were recorded with a digital reader (Tensimeter, Soil Measurement Systems, Tucson, AZ, USA). Volumetric soil moisture content was determined by frequency domain reflectometry using a WET-2 probe and a HH2 digital reader (Delta-T Devices Ltd., Cambridge, UK). The probe was inserted horizontally, at 5 cm and 10 cm depth, into the wall of a single pit dug in each sub-plot for each reading. Measurements were carried out between 11 June and 30 July 2005 with a final set of measurements on 14 September, for a total of seven days for water potential and five days for water content.

The WET-2 probe was custom calibrated to increase the precision of moisture content measurement in peat. The calibration procedure was a modified form of the recommended soil-specific calibration for WET sensors (Delta-T Devices Ltd. 2007). Twelve vertical soil cores, each 10 cm in diameter and 10 cm long (785 cm^3), were randomly collected from the study site in lengths of PVC tubing. In the laboratory, the samples were gradually saturated from the bottom upwards by standing them, almost completely immersed, in demineralised water for 48 hours. They were then removed from the water, moisture content (θ, cm^3 cm^{-3}) was determined gravimetrically, and three readings of soil dielectric constant (ε_v) taken using the WET-2 probe. The samples were then allowed to dry for two days at room temperature and thereafter dried to constant weight at 60°C, repeating the θ and ε_v measurements frequently throughout. This procedure yielded readings at a higher number of water contents near container capacity (i.e. after gravity drainage), thereby increasing the resolution of the calibration equation over the range of θ normally encountered in the field. The linear relationship between θ and ε_v (n = 108, r^2 = 0.99) was:

$$\theta = 0.14\sqrt{\varepsilon_v} - 0.21 \qquad [2]$$

Soil physical properties

Two soil cores (10 cm diameter, 10 cm long) were collected from the surface of each bare peat sub-plot (16 cores in total). Four additional cores were taken from the cloudberry rhizome donor site for comparison with the sub-plot cores. The lower end of each core was covered with nylon mesh and the cores were packed to avoid disturbance during transport to the laboratory, where they were stored at 4°C prior to analysis.

Soil water desorption curves were constructed in order to determine the water retention characteristics of the two terraces. The cores were re-wetted from below by standing in demineralised water for 24 hours, drained, then re-wetted for another 24 hours. Water content at saturation was measured with the WET-2 probe. The cores were then drained for approximately five minutes before being placed on a tension table filled with glass beads of median diameter 20 μm, according to the design of Topp & Zebchuk (1979). The pressure head was controlled by adjusting the height of the open end of a water column. The pressure head initially applied was -10 cm (-1 kPa), i.e. water table at the base of the cores, or container capacity (Cassel & Nieilsen 1986). The pressure head was then reduced progressively down to -100 cm relative to the upper surface of the core, using the increments and equilibration intervals suggested by Topp & Zebchuk (1979). At each step, the cores were removed from the tension table and weighed. The tension table was re-wetted to re-establish good hydrological contact before returning the cores for subsequent measurements. Air-filled porosity (θ_a) (cm^3 cm^{-3}) was calculated using the equation:

$$\theta_a = \theta_{sat} - \theta_{cc} \qquad [3]$$

where θ_{sat} and θ_{cc} are the volumetric water contents (cm^3 cm^{-3}) at saturation and container capacity (water potential -10 cm) respectively.

The degree of peat decomposition was then evaluated for each core using the von Post scale (Parent & Caron 1993). When the sample could not be clearly assigned to a single class, a half-class value (e.g. H3.5) was assigned. Three measurements were averaged for each core.

The cores were then oven-dried at 105°C for 48 hours and weighed to obtain the bulk density (BD, g cm^{-3}, Parent & Caron 1993). Particle density (PD, g cm^{-3}), i.e. the total volume of solids, was measured for two sub-samples from each core using a method adapted from Blake & Hartge (1986). Ten grams of crushed and dried peat were placed in a 100 ml graduated cylinder. Sufficient kerosene was added to cover the sample and the cylinder was sealed to prevent evaporation. After 30 minutes, the sample was shaken and the walls of the cylinder washed with kerosene. After one hour of soaking, more kerosene was added to bring the contents of the cylinder up to the final (standard) volume. Particle density PD (g cm^{-3}) was then calculated using the following equation:

$$PD = \frac{M_{soil}}{V_{total} - V_{\text{ker}}} \qquad [4]$$

where M_{soil} is the mass of the dried and crushed peat (g), V_{total} is the total volume (cm^3) of the solution and V_{ker} is the volume (cm^3) of kerosene added, calculated as:

$$V_{\text{ker}} = \frac{M_{total} - \left(M_{cyl} + M_{soil}\right)}{\rho_{\text{ker}}} \qquad [5]$$

where M_{total} is the mass of the cylinder with its contents of peat and kerosene, M_{cyl} is the mass of the empty cylinder, and ρ_{ker} the density of the kerosene

(0.7754 g cm^{-3}), determined by weighing 100 ml of the kerosene at room temperature. Once *BD* and *PD* were known, the total volume of the pores or total porosity (*TP*, cm^3 cm^{-3}) was calculated following Danielson & Sutherland (1986), using the equation:

$$TP = 1 - \left(\frac{BD}{PD}\right) \qquad [6]$$

Statistical analysis

The data were analysed using REML with the MIXED procedure in SAS, using a split-split-split-plot ANOVA design. Main effects and interactions between water level, mulching, clone or cultivar provenance and sampling year were tested, assuming α = 0.05. Normality of the data was assumed when the value of the Shapiro-Wilk statistic P was greater than 0.01, and homoscedasticity was assessed by plotting residuals against predicted values. If data transformation was needed to improve normality or homoscedasticity, a square-root transformation was applied. When significant differences among means were detected for main effects and interactions, least square means were compared. Simple main effects contrasts were analysed when an interaction was significant. If data were transformed, they were back-transformed in SAS, and a correction factor computed from the mean of the squares of the residuals was added to improve accuracy of the estimates.

Soil water potential and moisture content were also analysed using the MIXED procedure of SAS. A split-split-split-plot design was used to analyse the data, with the following factors: water level, mulching, sampling depth and sampling date. Normality and homoscedasticity were tested as above. For water potential, homoscedasticity problems were avoided by pooling data to form two data groups: spring (3 days, 11–13 June) and summer (4 days, 10 July to 14 September). Normality and homoscedasticity of water content were improved by analysing the dielectric constant (ε_v) rather than water content, which was derived from ε_v. Significant differences were tested as above.

Soil physical properties (von Post, BD, PD, TP) were analysed using the GLM procedure of SAS. Since sampling was done only in the bare peat sub-plot, the experimental design model adopted in this case was a randomised complete block with four blocks and water level (terraces) as the treatment.

For the soil water retention curves, the MIXED procedure of SAS was again used. The analysis was done using repeated measures for the various water potentials imposed during the desorption process. Soil cores from the cloudberry donor site were not included in the statistical analysis. Normality, homoscedasticity and significant differences were tested and analysed as above.

RESULTS

Plant growth

Water level affected plant survival only in Year 2, when more plants were observed on the lower terrace (P=0.055; Figure 1a, Table 1). However, the number of living plants generally decreased over time, regardless of the treatment. Average survival was less than 25% in Year 1 and had declined to about 15% by Year 3. The number of leaves per m^2 on the lower terrace increased between Year 1 and Year 2, and then remained stable in Year 3 (Figure 1d). On the upper terrace, there was a slight decrease in the second year, but the number of leaves per m^2 in the third year returned to the values observed during the first year. Differences between the two terraces were significant from Year 2 onwards.

Mulching did not affect survival (Figure 1b, Table 1), but had a negative effect on the number of leaves per m^2 (F=11.6, P=0.01 for the first sampling year, data not presented in Table 1; Figure 1e) and a positive impact on leaf area in the first sampling year (Table 1). There were more leaves per m^2 on the bare peat treatment, but leaves were larger under the mulch (1.19 *vs*. 0.88 $cm^2 \pm 0.04$ cm^2; Table 1). However, when combining the data from the three sampling years, the significant difference between the two mulching treatments disappeared for the number of leaves per m^2 (P=0.07). Figure 2 shows typical leaf size and density in bare peat plots after two years of growth in the study site, and in two other experimental plantations in Norway and Finland. Cloudberry cover was still sparse and leaf size smaller than in natural stands near our study site, where typical leaf sizes were in the range 5–8 cm^2 (Bellemare *et al*. 2009).

Clones and cultivars differed in their survival rates, but all tended to decrease in number over the years. FD cultivar had the highest survival rate at 45%, followed by NB clones, FL cultivar and QC clones, which were all less than 20% three years following planting (Figure 1c, Table 1). In direct relation to survival, FD exhibited the highest number of leaves per m^2 (close to 10), whereas NB, FL and QC all had four or fewer leaves per m^2 (Figure 1f). Leaf diagonal was similar in all clones and cultivars in the year of planting (Table 1).

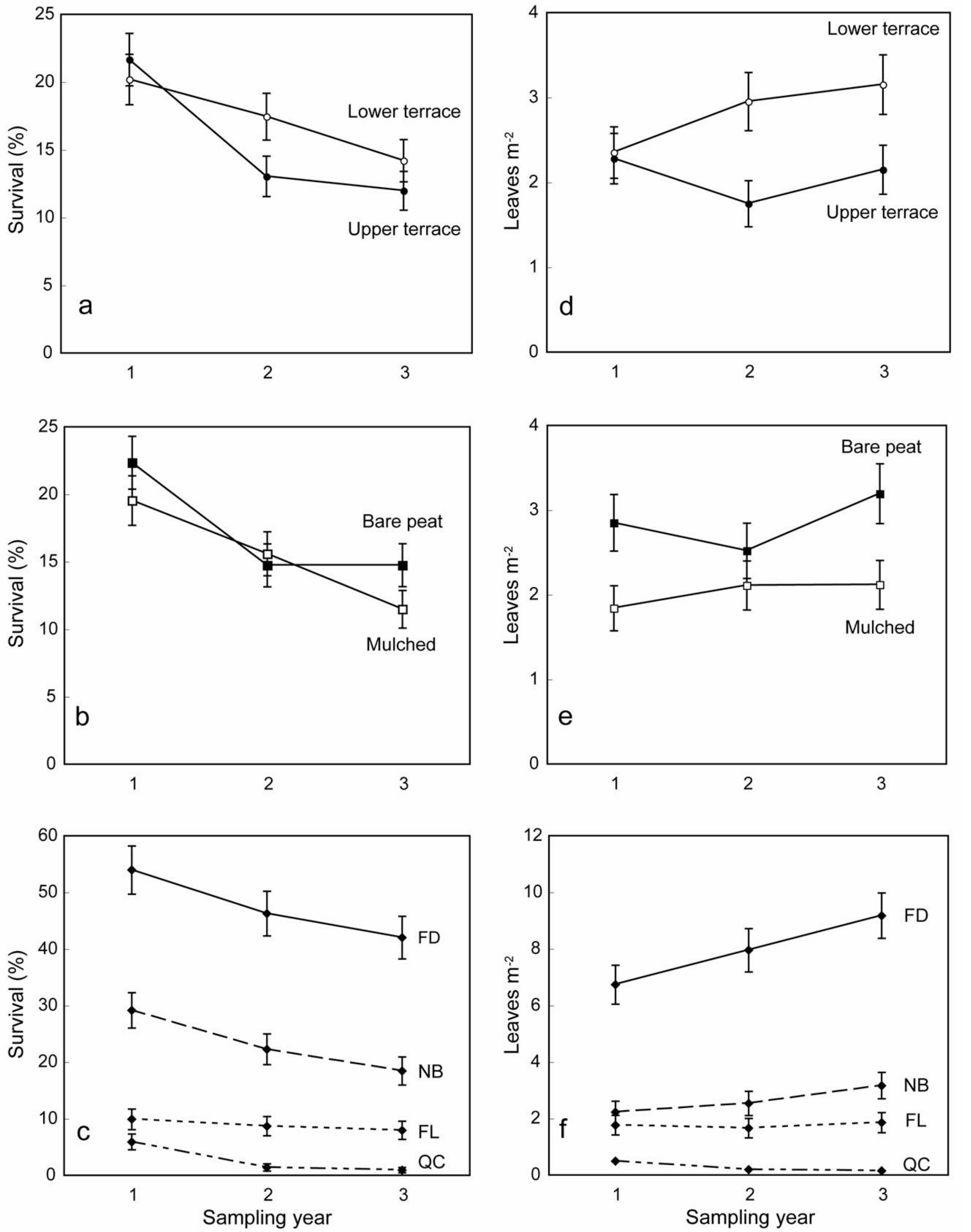

Figure 1. Variation over time of survival and number leaves m^{-2} for the different water table levels (terraces), mulching and clones or cultivars (mean ± SE). Mulching significantly affected the number of leaves m^{-2} in Year 1 only (P=0.01). See Table 1 for the other statistical results. QC: Pointe-Lebel clone; NB: New Brunswick clone; FL: Fjellgull cultivar; FD: Fjordgull cultivar.

Table 1. Type-III fixed effects of water levels (terraces), mulching and type of clone/cultivar on cloudberry survival, number of leaves and leaf diagonal. Leaf diagonal was measured during the first sampling year only.

Effect	NDF*	No. of individuals that survived			No. of leaves			Leaf diagonal (cm)	
		DDF**	F	P > F	DDF**	F	P > F	F	P > F
Water levels	1	3	0.83	0.429	3	4.04	0.138	0.36	0.593
Mulching	1	6	0.69	0.438	6	4.84	0.070	29.7	**0.002**
Water × Mulch	1	6	0.10	0.761	6	0	0.995	2.72	0.150
Clone	3	36	84.1	**<0.0001**	36	80.0	**<0.0001**	0.86	0.472
Water × Clone	3	36	0.69	0.567	36	1.70	0.185	0.78	0.512
Mulch × Clone	3	36	0.13	0.941	36	0.84	0.482	2.21	0.105
Water × Mulch × Clone	3	36	0.43	0.731	36	0.61	0.615	0.92	0.444
Year	2	96	36.8	**<0.0001**	91	1.75	0.180		
Water × Year	2	96	5.13	**0.008**	91	4.91	**0.010**		
Single main effect contrasts for years									
1	1	96	0.30	0.584	91	0.03	0.863		
2	1	96	3.76	0.055	91	7.66	**0.007**		
3	1	96	1.10	0.296	91	4.91	**0.029**		
Single main effect contrasts for water levels									
Lower terrace	2	96	10	**0.0001**	91	4.27	**0.017**		
Upper Terrace	2	96	31.91	**<0.0001**	91	2.29	0.107		
Mulch × Year	2	96	3.22	**0.044**	91	1.60	0.208		
Single main effect contrasts for years									
1	1	96	1.10	0.298					
2	1	96	0.14	0.707					
3	1	96	2.4	0.125					
Single main effect contrasts for mulch									
Bare peat	2	96	19.8	**<0.0001**					
Mulched	2	96	20.2	**<0.0001**					
Water × Mulch × Year	2	96	1.93	0.151	91	1.29	0.279		
Clone × Year	6	96	3.03	**0.009**	91	4.11	**0.001**		
Single main effect contrasts for years									
1	3	96	60.7	**<0.0001**	91	38.0	**<0.0001**		
2	3	96	71.5	**<0.0001**	91	56.5	**<0.0001**		
3	3	96	68.1	**<0.0001**	91	75.2	**<0.0001**		
Single main effect contrasts for clone									
Fjordgull (FD)	2	96	7.14	**0.001**	91	6.24	**0.003**		
Fjellgull (FL)	2	96	1.03	0.360	91	0.18	0.838		
New Brunswick (NB)	2	96	11.7	**<0.0001**	91	2.86	0.063		
Québec (QC)	2	96	26.0	**<0.0001**	91	4.77	**0.011**		
Water × Clone × Year	6	96	1.68	0.135	91	0.54	0.776		
Mulch × Clone × Year	6	96	1.31	0.259	91	0.83	0.552		
Water × Mulch × Clone × Year	6	96	0.84	0.543	91	0.43	0.854		

*NDF: Numerator Degrees of Freedom; **DDF: Denominator Degrees of Freedom.

Figure 2. Two-year-old plantations of cloudberry on cutover peatlands in a) Norway (Andøy Island); b) Finland (Kuhmo) and c) Canada (Pointe-Lebel; Fjordgull in non-mulched plots on the lower terrace). Photos courtesy of G. Théroux-Rancourt, L. Rochefort and J. Zhou.

Soil hydrological properties

The two terraces differed in water potential, with the upper terrace having a lower water potential at the beginning of the growing season (Days 162 to 164 (June 11–13); Figure 3b, Table 2). Mulching attenuated the summer decrease in potential, as compared to bare peat (Figure 3a). In early autumn, after frequent rain, neither water level nor mulching affected soil water potential near the ground surface.

Soil water content did not differ between the two terraces, except on Day 209 (July 28; Table 3, Figure 3d), even though the water table levels were different (data not shown). Water content was lower under bare peat than under mulch throughout the growing period (0.68 *vs*. 0.79 cm^3 cm^{-3}; Figure 3c, Table 3), with differences increasing during the drier summer period. Both soil water content and water potential were higher (i.e. the soil was wetter) at 10 cm than at 5 cm below the surface [soil water content: 0.67 (5 cm) *vs*. 0.73 (10 cm) ± 0.01 cm^3 cm^{-3}, F=18.25, P=0.001; water potential: -17.3 (5 cm) vs. -15.5 (10 cm) ± 1.2 cm, F=5.60, P=0.037 in spring].

Soil physical properties

The von Post value for the upper terrace was slightly higher than for the lower terrace, indicating that the peat on the upper terrace tended to be more decomposed (Table 4). Soil bulk density was higher for the upper terrace, whereas total porosity was lower. However, particle density did not differ between the two terraces. Water retention curves indicated higher water retention for the upper terrace at water potentials lower than -20 cm (Figure 4), which is within the range of values measured in the field during the 2005 growing season (Figure 3). The donor site for the QC cloudberry clones had much lower water retention capacity than either terrace. The peat here had higher particle density than either terrace, bulk density and total porosity similar to the lower terrace, and intermediate decomposition values.

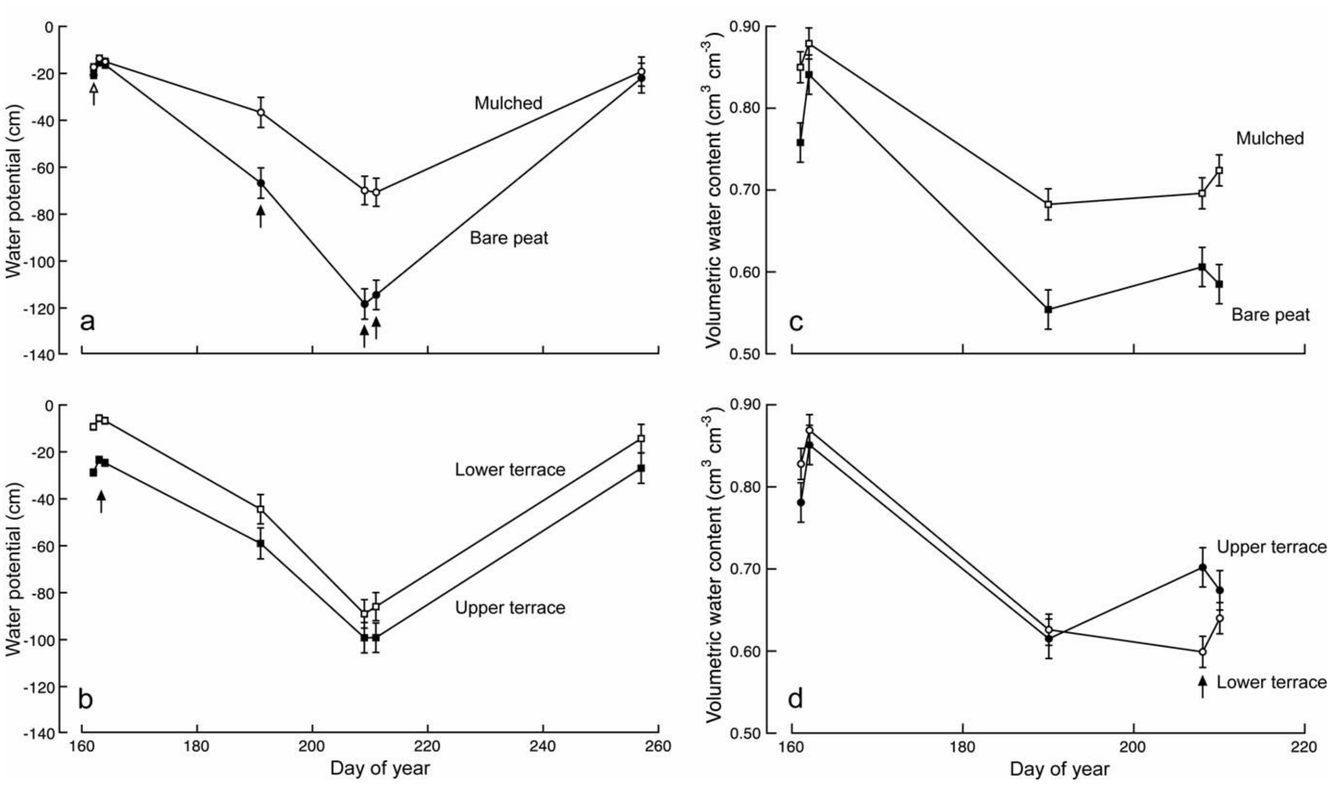

Figure 3. Soil water potential and water content during the first growing season for the bare peat and mulched plots, and for the two water level treatments (terraces). There was a significant difference in volumetric water content between the mulching treatments throughout the growing season (P=0.002). See Tables 2 and 3 for the other statistical results. P < 0.05 (hollow arrow); P < 0.01 (solid arrows). Bars indicate standard error. Standard error is less than ± 2 cm for Days 162–164. Water potential was measured from 11 June to 14 September, and volumetric water content from 11 June to 30 July.

Table 2. Type-III fixed effects of water level (terraces), mulching, sampling depth and sampling date on soil water potential in the first growing season. To maintain adequate homoscedasticity, data were pooled to form two groups: spring (3 days, 11–13 June) and summer (4 days, 10 July to 14 September).

Effect	Spring (3 days)				Summer (4 days)			
	NDF*	DDF**	F	P > F	NDF*	DDF**	F	P > F
Water levels	1	3	195	**0.001**	1	3	6.09	0.090
Mulching	1	5	2.67	0.163	1	5	37.1	**0.002**
Water × Mulch	1	5	4.78	0.081	1	5	0	0.970
Sampling depth	1	11	5.60	**0.037**	1	11	0.04	0.837
Water × Depth	1	11	0.39	0.544	1	11	0	0.993
Mulch × Depth	1	11	0.04	0.841	1	11	0.05	0.834
Water × Mulch × Depth	1	11	0.23	0.638	1	11	0.01	0.944
Sampling date	2	44	65.2	**<0.0001**	3	54	222	**<0.0001**
Water × Date	2	44	2.74	0.076	3	54	0.14	0.935
Mulch × Date	2	44	3.53	**0.0378**	3	54	18.6	**<0.0001**
Single main effect contrasts for sampling date (Day of year)								
162	1	44	5.88	**0.020**				
163	1	44	1.51	0.226				
164	1	44	0.92	0.342				
191					1	54	18.9	**<0.0001**
209					1	54	53.8	**<0.0001**
211					1	54	47.7	**<0.0001**
257					1	54	0.18	0.676
Single main effect contrasts for mulching								
Bare peat	2	44	44.8	**<0.0001**	3	54	177	**<0.0001**
Mulched surface	2	44	22.3	**<0.0001**	3	54	59.5	**<0.0001**
Water × Mulch × Date	2	44	0.15	0.861	3	54	0.43	0.731
Depth × Date	2	44	0.14	0.872	3	54	0.35	0.792
Water × Depth × Date	2	44	0.18	0.839	3	54	0.45	0.719
Mulch × Depth × Date	2	44	0.19	0.831	3	54	0.14	0.933
Water × Mulch × Depth × Date	2	44	0.66	0.521	3	54	0.42	0.741

* NDF: Numerator Degrees of Freedom; ** DDF: Denominator Degrees of Freedom

Table 3. Type-III fixed effects of water level (terraces), mulching, sampling depth, and sampling date on volumetric water content in the first growing season. The analyses were carried out on the dielectric constant (ε_v) readings from the WET-2 probe.

Effect	NDF*	DDF**	Water content	
			F	P > F
Water levels	1	3	0.33	0.606
Mulching	1	5	33.4	**0.002**
Water × Mulch	1	5	2.51	0.174
Sampling depth	1	11	18.25	**0.001**
Water × Depth	1	11	0.00	0.995
Mulch × Depth	1	11	0.10	0.758
Water × Mulch × Depth	1	11	0.38	0.548
Sampling date	4	88	79.5	**<0.0001**
Water × Date	4	88	5.36	**0.001**
Single main effect contrasts for sampling date (Day of year)				
162	1	88	3.47	0.066
163	1	88	0.55	0.462
191	1	88	0.13	0.719
209	1	88	12.2	**0.001**
211	1	88	1.41	0.238
Single main effect contrasts for water levels				
Lower terrace	4	88	59.6	**<0.0001**
Upper terrace	4	88	27.7	**<0.0001**
Mulch × Date	4	88	1.83	0.131
Water × Mulch × Date	4	88	0.49	0.742
Depth × Date	4	88	0.77	0.550
Water × Depth × Date	4	88	0.68	0.611
Mulch × Depth × Date	4	88	2.09	0.088
Water × Mulch × Depth × Date	4	88	0.35	0.840

* NDF: Numerator Degrees of Freedom; ** DDF: Denominator Degrees of Freedom

Table 4. Some soil physical properties for the two terraces and the cloudberry rhizome donor site. Donor site data are shown for comparative purposes and were not included in the statistical analysis. The data given are least squares means with standard errors in parentheses. BD: Bulk Density; PD: Particle Density; TP: Total porosity.

Terrace	von Post	BD (g cm^{-3})	PD (g cm^{-3})	TP (cm^3 cm^{-3})
Rhizome donor site	3.5	0.106	1.386	0.922
Lower terrace	3.25 (0.14)	0.098 (0.005)	1.287 (0.040)	0.923 (0.005)
Upper terrace	3.78 (0.14)	0.138 (0.005)	1.353 (0.040)	0.898 (0.005)
P > F	0.053	0.001	0.574	0.037

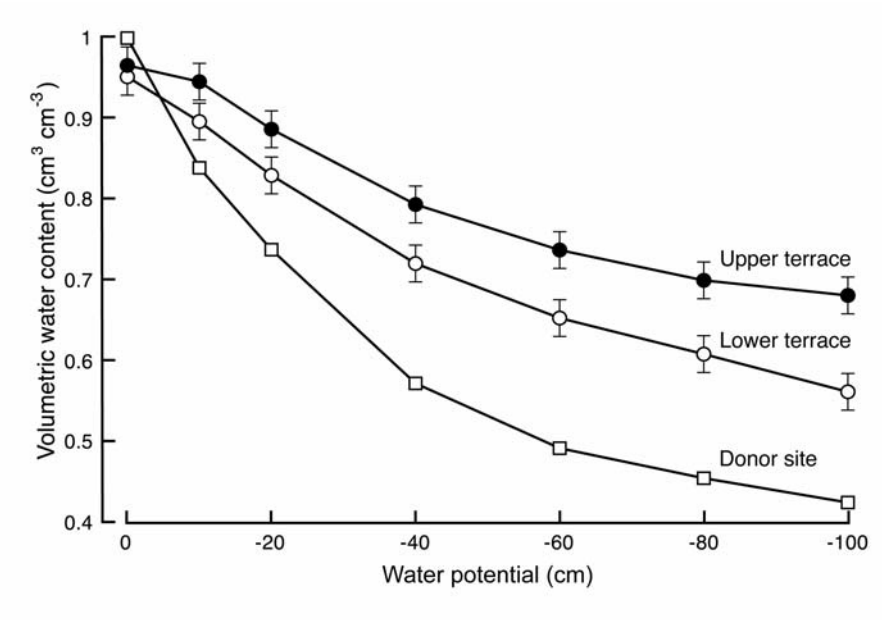

Figure 4. Water retention curves for the soil on each terrace and for the cloudberry rhizome donor site. Data for the Pointe-Lebel donor site are shown for comparative purposes and were not included in the statistical analysis. There were significant differences ($P \leq 0.05$) between the terraces for each applied water potential except at saturation (water potential = 0 cm). Bars indicate standard errors.

DISCUSSION

Effect of water table on cloudberry establishment

Survival of Norwegian cultivars and local clones was similar on the two terraces. We can conclude that survival does not vary across the range of water levels recommended by Rapp (2004). However, over time, plant size (leaf number) increased on the lower terrace, whereas there was growth stagnation on the upper terrace. Thus, on the basis of water level only, it appears that a higher water table would be beneficial for growth and rhizome extension.

There were differences in physical and hydrological properties between the two terraces. In the first growing season, soil water potential in the spring was higher (i.e. soils were wetter) on the lower terrace. However, as the water level in the blocked ditches receded (by at least 1 m) during the summer, near-surface soil water potential became similar in the two terraces. An increase in bulk density is usually coupled with a decrease in pore size and an increase in water holding capacity (Price 1997, Schlotzhauer & Price 1999), and our results were consistent with this principle. Bulk density was about 40% higher, and thus total porosity lower, on the upper terrace than on the lower one. The upper terrace was created from loose peat removed from what became the lower terrace. This translocated peat was already slightly more humified than the subsurface material which became the lower terrace because it had been not only previously exposed at the surface, but also disturbed and thus oxidised during peat extraction operations such as harrowing (Ilnicki & Zeitz 2002). After translocation, the loose peat was compacted by the tractor operations required to level the upper terrace. The lower terrace, on the other hand, probably suffered only slight disturbance and compaction because it was still frozen. It is known that less compact mineral and organic soils soils give higher tree or crop yields (White 1978, Douglas 1994, Wronski & Murphy 1994, Houlbrooke *et al.* 1997). As the peat on the lower terrace had higher porosity and lower bulk density than that on the upper terrace, it was more favourable for cloudberry growth and rhizome extension. Similar results have been obtained from six cloudberry farms in Finland (G. Théroux Rancourt, 2006, MTT Agrifood Research Finland, unpublished data). Thus, water table level should not be used as the main criterion for cloudberry cultivation as it is not a good indicator of water availability at the surface (Price 1997), and soil physical properties should be investigated further in order to determine the most suitable conditions.

Compatibility with peatland restoration

Cloudberry rhizome segments exhibited reduced growth when planted in restored plots. Straw mulch is essential to restoration of cutover peatlands in Canada because it increases the survival of *Sphagnum* fragments (Rochefort *et al.* 2003). However, the number of cloudberry leaves produced during establishment was apparently lower with mulch. Shoot growth in natural cloudberry stands is slower when spring temperatures are low (Lohi 1974). Organic mulches reduce the amplitude of temperature fluctuations at the peat surface, and this is particularly important in spring when the darker colour of bare peat means that it absorbs about 15% more radiation than straw mulch (Price *et al.* 1998). In other perennial species, sprout survival and sprout growth rate have been shown to be reduced at lower soil temperatures (Satorre *et al.* 1996, Li *et al.* 2000). However, after three years, the straw mulch was becoming degraded and differences in leaf number had almost vanished. Furthermore, cloudberry buds naturally form at the peatland surface, which is warmer than the peat at 10 cm depth in which they were planted. The initially higher leaf area was most probably due to the shading effect of the mulch, as leaves from sheltered sites are usually larger (Lohi 1974). Straw covered about 75% of the surface during the first year (G. Théroux Rancourt, pers. obs.), and this was probably sufficient to shade the small cloudberry plants. This effect should also fade as mulch density decreases through decomposition of the straw.

Other factors might also have contributed to the reduction of both survival and growth of cloudberry. The rhizomes were probably planted too deep for optimal sprouting. Bellemare (2007) reported that rhizomes planted 5 cm beneath the soil surface had higher survival rates and leaf densites than rhizomes planted at 10 cm as in the present study. Mulching, combined with deep planting, might strongly reduce bud sprouting capacity in early spring. Improved rhizome establishment might also be achieved with autumn rather than spring planting (Bellemare 2007).

As in other peatland restoration studies (Price *et al.* 1998), soil water potential under mulch remained high throughout the season. Mulched and bare peat plots had very high water potential early in the season, so that differences in water availability near the surface cannot explain the overall decrease in leaf number. Therefore, we suggest that cloudberry should be planted two or three years after peatland restoration, i.e. once a *Sphagnum* carpet has begun to establish and when straw mulch density has considerably decreased. Cloudberry would then benefit from the improved hydrological conditions under the newly developed moss carpet and avoid the initial negative impact of the straw mulch.

Clone or cultivar provenance

Climatic conditions in Norway and eastern Canada differ considerably. Local clones are adapted to the climatic conditions, but clones that have undergone a selection process and are now cultivars have superior growth characteristics. In the present study, Fjordgull had the highest survival rate, whereas Fjellgull performed more or less similarly to the local populations from Pointe-Lebel (Quebec) and New Brunswick. The slow growth rate of Fjellgull in Norway was discussed by Rapp & Martinussen (2002). Both local clones had low survival rates under cultivation, even though they were harvested from dense patches, suggesting that they had inherently good growth rates. Low survival rates might have resulted from too great a change in environmental characteristics such as the bulk density and air content of the soil. The cloudberry donor site had a lower water-holding capacity than the two experimental terraces, even though its soil physical properties were similar to those of the lower terrace (Figure 4 and Table 4). Thus, air content at the donor site would have been higher than in the experimental terraces at similar water potentials. Fjordgull might be better adapted to the soil conditions of the experimental set-up, explaining the increase in leaf number over the years. Rhizomes of the Norwegian cultivars were probably younger (three years old and less) than rhizomes of local clones, which would normally be 1–10 years old (Metsävainio 1931), although care was taken to select rhizomes that seemed viable. The axillary buds of older rhizomes have been inhibited for a longer period of time, which make them more difficult to stimulate (Mitchell 1953). Thus, selecting clones from the local climate as well as those adapted to the soil conditions encountered in cutover peatlands should maximise survival and growth and reduce financial losses from rhizome death.

CONCLUSIONS

Cloudberry cultivation is still in its infancy worldwide. This study provides information about the effects of hydrology and substrate on cloudberry survival and growth. Recommendations arising from this project are summarised as follows:

1) Soil physical properties influence plant growth more than water table level *per se*. Soil with low bulk density and high porosity should be sought when selecting a site. Care should be taken during site selection, choosing peatland sectors that have not been too compacted over time and by reducing machinery compaction during site preparation.

2) Cloudberry should be planted 2–3 years after peatland restoration techniques have been applied in order to minimise the negative impact of the straw mulch on cloudberry rhizome establishment.

3) Fjordgull seems to be the only commercially available cultivar suitable for planting as rhizomes in cutover peatland at the moment. However, survival rates of planted rhizomes are still too low to permit large-scale cultivation and more work is needed to identify the optimal conditions for plant survival and growth.

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