Vegetative propagation of sugar maple: Relating stem water content and terminal bud developmental stage to adventitious rooting of stem cuttings

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Tousignant, D., Richer, C., Rioux, J.-A., Brassard, N. and Mottard, J.-P. 2003. **Vegetative propagation of sugar maple: Relating stem water content and terminal bud developmental stage to adventitious rooting of stem cuttings.** Can. J. Plant Sci. **83**: 859–867. The objective of this study was to define the optimum period for collecting sugar maple (*Acer saccharum* Marsh.) stem cuttings. In 1999 and 2000, shoot development was monitored on young trees from a plantation established in 1993. Stem base water content and the number of pairs of terminal bud scales changed over time, reflecting meteorological characteristics of both years. In 1999, rooting percentage was high regardless of collection date, within a 7-wk period. The 2000 rooting trial covered a longer time frame and identified an optimal window during which rooting percentages reached 60 to 83%. Rooting success dropped below 30% for cuttings harvested too early or too late. Thus the optimal time for collecting sugar maple cuttings spans several weeks, but with significant year-to-year variations. For both years, optimal rooting was associated with a stem base water content lower than 75% but higher than 55%, and with the presence of one to three pairs of apical bud scales. This stage is reached when at least 270 degree-days above 5°C are accumulated. Using these indicators, practitioners can consider local conditions and year-to-year climatic variations to harvest sugar maple cuttings at an optimum stage of development.

Key words: *Acer saccharum*, bud scales, collection date, cutting propagation, stem water content, vegetative propagation

Tousignant, D., Richer, C., Rioux, J.-A., Brassard, N. et Mottard, J.-P. 2003. **Propagation végétative de l'érable à sucre: Effet du contenu en eau de la tige et du développement du bourgeon terminal sur l'enracinement des boutures de tiges**. Can. J. Plant Sci. **83**: 859–867. Cette étude vise à définir la période optimale pour la récolte de boutures d'érable à sucre (*Acer saccharum* Marsh.). En 1999 et 2000, le développement des pousses a été suivi sur des arbres d'une plantation établie en 1993. La teneur en eau de la base de la tige et le nombre de paires d'écailles du bourgeon terminal ont évolué linéairement dans le temps, tout en reflétant les particularités météorologiques de 1999 et de 2000. En 1999, l'enracinement des boutures a été élevé pour toutes les récoltes sur une période de sept semaines. L'expérience de 2000 couvrait une période plus longue, ce qui a permis d'identifier une fenêtre optimale, où les pourcentages d'enracinement atteignent 60 à 83 %, contrairement aux faibles succès obtenus (< 30 %) lorsque les boutures ont été récoltées trop tôt ou trop tard. La période propice à la récolte de boutures d'érable à sucre s'étend donc sur plusieurs semaines, mais varie d'une année à l'autre. Cette période correspond à une teneur en eau à la base des boutures inférieure à 75 % mais supérieure à 55 %, et à la présence d'une à trois paires d'écailles sur le bourgeon terminal. Ce stade est atteint lorsqu'au moins 270 degrés-jours ont été accumulés au-dessus de 5° C. Ces indicateurs permettent de récolter des boutures d'érable à sucre en tenant compte du climat local et des variations annuelles.

Mots clés: *Acer saccharum*, bouturage, date de récolte, écailles du bourgeon, teneur en eau de la tige, multiplication végétative

In the northeastern United States and eastern Canada, sugar maple (*Acer saccharum* Marsh.) is an economically important tree species, not only for its high quality wood, but also because its sap is used commercially to produce maple syrup. Canada accounts for 83% of the world production of maple sugar products, with a value reaching Can $ 140 million in 2001. The province of Quebec represents 93% of Canada's production (Agriculture and Agri-Food Canada 2002).

For several decades, efforts have been made to increase the syrup yield of sugar maple stands through either tree breeding (Gabriel 1972; Kriebel 1989,1990; Laing and Howard 1990; Rainville 1995; Krasny et al. 2001) or silvicultural treatments (Pothier 1995). Superior sugar-producing trees can be selected, mainly on the basis of sap sugar concentration. Unfortunately, this can only be done on mature subjects, since only adult trees are tapped commercially, and mature trees are difficult to reproduce vegetatively by cuttings (Chaperon 1979; Roulund 1981; Greenwood and Hutchison 1993). Traditionally, breeding of improved sugar maple varieties consists of grafting superior trees and establishing seed orchards from these grafts (Kriebel 1989, 1990; Rainville 1995). However, grafting is a very expensive propagation technique, and this approach is

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quite time-consuming, because of the number of years required for the grafts to reach reproductive maturity and produce seeds. Work has been carried out recently, aimed at developing genetic markers allowing for an early selection of superior sugar maple trees based on sap sugar concentration (Larochelle et al. 1998; Roy et al. 1998).

To benefit from these recent developments, cutting propagation protocols applicable on a large scale are needed for sugar maple. Many variables have been studied, without fully explaining the difficulties in rooting this species: cutting collection date (Dunn and Townsend 1954; Donnelly and Yawney 1972; Donnelly 1977), length or diameter (Anstey 1969; Morsink 1971b; Donnelly 1974; Greenwood et al. 1976), and number of internodes (Kling and Meyer 1983), clonal differences (Dunn and Townsend 1954; Gabriel et al. 1961; Donnelly 1971; Greenwood et al. 1976), growth regulators (Donnelly 1971; Donnelly and Yawney 1972; Greenwood et al. 1976; Yawney and Donnelly 1981; Chong 1982), basal stem wounding (Donnelly 1971; Morsink 1971a; Donnelly and Yawney 1972), light conditions during rooting (Donnelly and Yawney 1972; Donnelly 1974, 1977), and etiolation or blanching of cuttings on the stockplant (Maynard and Bassuk 1987).

Greenwood et al. (1976) hypothesised that the ability of sugar maple to form adventitious root meristems varies with the annual cycle of cambial activity, with a peak in June. Cutting propagation is feasible, as observed for other maple species and cultivars (Humphrey and Dummer 1966), provided that shoots are harvested at a precise developmental stage, during a short period in the growing season: at the end of spring, when rapid shoot elongation has ceased (Farmer 1974). According to Donnelly and Yawney (1972), the optimal stage for rooting sugar maple cuttings occurs when the apical leaves have reached their final size and colour, the stem is still green, and a terminal bud has just begun to form, measuring about 2 mm long and showing only one pair of visible brown scales. However, other authors have successfully rooted cuttings of sugar maple (Morsink 1971a), *A. saccharinum* and its cultivars (Humphrey and Dummer 1966), as well as *A. palmatum* (Van Klaveren 1969), collected at an earlier stage, i.e., when the bottom leaves of the cutting are fully developed but with the apical meristem still actively growing. Geographical differences and year-to-year climatic variations also prevent the application of results of studies to other contexts. Thus, some ambiguity persists concerning the ideal stage for harvesting sugar maple cuttings.

Shoot water content has been related to the progression of phenological events such as bud dormancy and frost hardiness of trees (Little 1970; Ritchie and Shula 1984; Bigras et al. 1989; Colombo 1990), and also to rooting ability of softwood cuttings of *Forsythia* sp., *Weigela florida* (Bunge) A.DC. (Loach and Gay 1979) and *Ilex crenata* Thunb. (Rein et al. 1991). In *Picea mariana* (P. Mill.) B.S.P., shoot water content decreased steadily as shoot lignification progressed and appeared to be inversely related to rooting ability (Tousignant 1995). This quantitative indicator may also be related to rooting ability of sugar maple.

The aim of this study was to identify quantitative indicators of the best moment for harvesting sugar maple cuttings. In two companion studies, clonal effects, hormonal treatments and etiolation of stockplants have also been examined (Richer et al. 2003, Rioux et al. 2003).

MATERIALS AND METHODS

Origin of the Cuttings

Cuttings were collected from 8-yr-old sugar maple trees established from 2-yr-old seedlings on a private experimental plantation in Beaumont, Quebec, Canada (46°50′45″ North, 70°57′20″ West). Mean tree height was 4.2 m in 1999 (ranging from 2.7 m to 5.3 m), and 5.0 m in 2000 (3.2 m to 6.3 m).

Morphological Measurements

In 1999, during the period of rapid shoot elongation and shoot lignification (until the terminal bud was well developed), cuttings of current-year's shoots were collected around 0800 on 48 randomly selected trees within the plantation. In 2000, 40 of the same trees were sampled in an identical manner. For each tree and each collection date, 10 to 16 lateral shoots were harvested on randomly selected branches within the bottom half of the crown (no more than two shoots collected on a same branch). On average, they measured 7.5 cm long, with a diameter of 3 mm. Terminal shoots were excluded because of their excessively variable length. For the morphological survey, seven harvests were conducted in 1999 (26 May, 2, 9, 16, 23, 30 June and 7 July), and five in 2000, covering a longer period than the first year (24 May, 14 June, 5, 26 July and 16 August). Cuttings were placed in plastic bags, misted with water and transported in a cooler. In the laboratory, a sample of the harvested cuttings was set aside for morphological measurements. The rest was were used in the rooting trials (described below).

For each cutting harvested in 1999, length, diameter, and number of internodes of the stem, length and width of the largest and smallest leaf were measured. The stage of terminal bud development was assessed by recording the number of pairs of visible bud scales. In 2000, in light of the first year's results, only the terminal bud was characterised, as it was the most significant indicator of shoot developmental stage.

In both years, the basal 2-cm section of each cutting was removed, weighed, oven-dried for 48 h at 65°C, and reweighed; only the stem base was used to avoid bias caused by the highly variable length of the shoots. Stem base water content was expressed as percent fresh mass:

$$\textit{Water content} = \frac{(\textit{Fresh mass} - \textit{Dry mass})}{\textit{Fresh mass}} \times 100 \qquad (1)$$

Rooting Trials

Experimental Design

In 1999, each experimental unit (multi-cell container) contained 24 cuttings, one from each of 24 trees selected randomly among the 48 used for the morphological survey. These 24 cuttings were distributed randomly within the container, noting their positions so that the tree of origin could be retraced for

each cutting. Five of the seven collection dates of the morphological survey were included in the rooting trial, spanning over the entire survey period. Cuttings were rooted under a tent holding 20 experimental units, and covered with clear polyethylene. Experimental units were placed according to a randomised complete block design, with each of the four blocks containing the five collection dates.

In 2000, each experimental unit contained 26 cuttings. All five collection dates of the morphological survey were included. The greenhouse was set up with three replicate rooting tents of 10 experimental units each. The experimental units were placed according to a randomised complete block design within each tent, with two blocks per tent, each containing the five collection dates.

Cutting Preparation and Rooting Conditions

Cuttings were inserted in multi-cell containers filled with a peat:vermiculite (1:1 vol:vol) substrate, after dipping the stem base in a commercial 4000 ppm Indole-3-butyric acid powder (Stim-Root® #2), and placed in rooting tents in a greenhouse. Day/night air temperatures were set at 22°C/18°C ± 3°C with an 18 h/6 h thermoperiod. Misting was automatically controlled by a timer, set to give four 15-s impulses per hour. All containers were placed inside the rooting tents at the onset of the experiment, even though the actual dates for cutting insertion varied over time. This minimised spatial effects due to empty containers. During the rooting phase, all cuttings received a weekly fungicide application (Benlate 50WP. E.I. Du Pont de Nemours & Co., Inc., USA).

Rooting Evaluation

Rooting was evaluated 12 wk after each collection date. In 1999, percentage of cuttings with at least one root ≥ 2 mm, as well as number of main roots per rooted cutting, were counted using all available cuttings. In 2000, rooting percentage was first evaluated non-destructively, so that a majority of cuttings could be repotted for a subsequent experiment (not presented here). Five of the rooted cuttings in each experimental unit were then sampled randomly to determine the number of main roots and root biomass per rooted cutting.

Meteorological Data

In order to quantify the climatic differences observed between 1999 and 2000 on the plantation site, daily precipitation and temperature reports were obtained for both years from the nearest governmental weather office (Environment Canada, Laval University Station, 46°47′ north, 71°17′ west).

Statistical Analysis

All the statistical analyses in this report were generated using SAS/STAT software, Version 8 of the SAS System for Windows (©1999 SAS Institute Inc., Cary, NC, USA).

Morphological Traits

A correlation analysis of 1999 morphological data was performed to find potential indicators of cutting development throughout the season. Pearson's correlation coefficients were calculated for all the morphological variables.

Stem Water Content

For both years, variations of stem base water content through time were analysed using the MIXED procedure. The model for 1999 is presented in Eq. 2:

$$Y_{ijk} = \mu + \tau_i + \delta_j + \tau\delta_{ij} + \varepsilon_{ijk} \quad (2)$$

where Y_{ijk} is the stem water content of the *k*th stem of the *j*th tree (δ, random effect, 24 levels) on the *i*th date (τ, fixed effect, 7 levels), μ is a constant and ε is the residual error term. In this mixed model, the date effect is tested with $\tau\delta_{ij}$ as the error term. The model used in 2000 is presented in Equation 3:

$$Y_{ij} = \mu + \tau_i + \varepsilon_{ij} \quad (3)$$

where Y_{ij} is the stem water content of sample *j* from the *i*th date (τ, fixed effect, 5 levels), μ is a constant and ε is the residual error term.

Number of Pairs of Bud Scales

Because the number of pairs of bud scales is an ordinal and categorical variable (ranging from 0 to 6), analysis was done using a frequency table, crossing date with number of pairs of bud scales. The data of both years were treated separately. For the 1999 data, the average value of the two subsamples for each tree was used in the analysis, rounding off to the lower integer when necessary. For the 2000 data, cuttings were treated individually. The CATMOD procedure was used to fit a linear model on the mean function of response frequencies, and a chi-square test to obtain significance levels for each factor.

Rooting Trials

An analysis of variance was used to identify significant treatment effects on rooting data, using the MIXED procedure ($P = 0.05$). Multiple comparisons were done on significant effects, adjusting the P values with the Tukey's method. The data from both years were treated separately. In all cases, statistical analyses were done on the mean value per experimental unit. In 1999, rooting percentage and mean number of roots per rooted cutting were analysed using the model presented in Eq. 4:

$$Y_{ij} = \mu + \tau_i + \beta_j + \varepsilon_{ij} \quad (4)$$

where Y_{ij} is the analysed variable at the *i*th date (τ, fixed effect, 5 levels) and in the *j*th block (β, random effect, 4 levels), μ is a constant and ε is the residual error term.

In 2000, rooting percentage, mean number of roots per rooted cutting, and root biomass were analysed using the model presented in Eq. 5:

$$Y_{ijk} = \mu + \delta_{j(k)} + \gamma_k + \tau_i + \varepsilon_{ij(k)} \quad (5)$$

where Y_{ijk} is the mean of the plants in the container of the *j*th block (δ, random effect, 6 levels) nested within the *k*th tent (γ, random effect, 3 levels) and the *i*th collection date (τ, fixed effect, 5 levels), μ is a constant, ε is the residual error term.

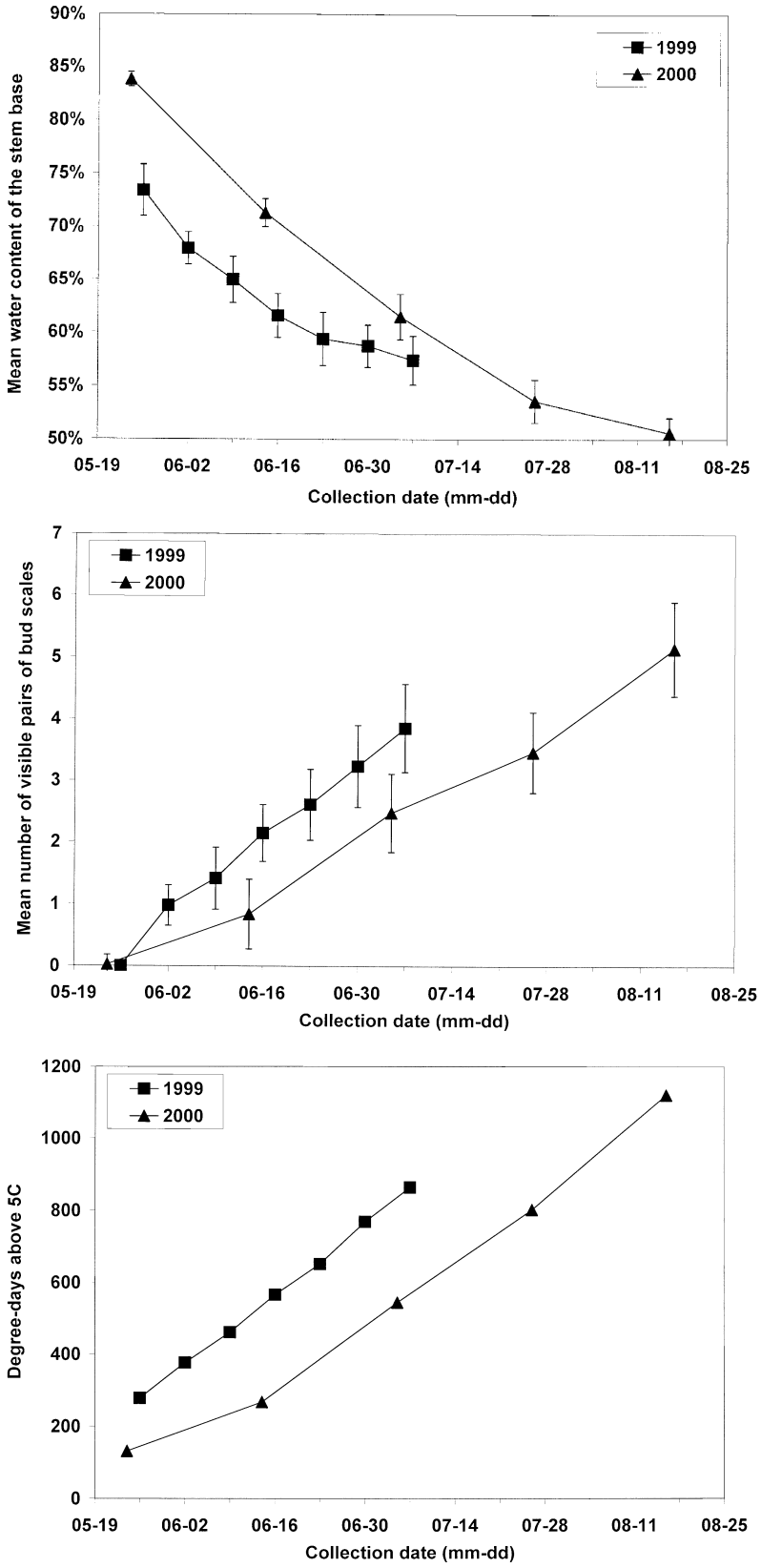


Fig. 1. Comparison of the 1999 and 2000 growing seasons in terms of (a) changes in stem base water content and (b) development of the apical bud of sugar maple cuttings, and c) accumulation of degree-days above 5°C (for a) and b), mean ± standard deviation).

RESULTS

Morphological Traits

The terminal shoot bud appeared at the end of the shoot elongation phase. Once the stem began to lignify, stem diameter increased gradually. Shoot length and diameter, number of internodes, length and width of the largest and smallest leaf showed considerable variation and no clear trends over time (data not presented). In contrast, basal stem water content showed a clearly linear decrease over time (Fig. 1a), while number of pairs of visible bud scales (Fig. 1b) increased.

Several significant correlations were observed between the morphological traits examined in 1999 ($P < 0.0001$, Table 1). However, only those stronger than ± 0.4 were considered meaningful. The number of pairs of bud scales is closely and negatively correlated with stem base water content ($r = –0.857$). As expected, shoot length also shows a strong correlation with shoot diameter ($r = 0.793$) and a weaker correlation with number of internodes ($r = 0.518$). Shoot diameter, much more than shoot length, is correlated with the number of pairs of bud scales ($r = 0.444$) and stem base water content ($r = –0.471$). The length and width of the largest and smallest leaves showed no significant correlation with the other examined variables.

Stem Water Content and Apical Bud Development

For both years, the ANOVA on stem base water content shows a highly significant main effect of collection date ($P < 0.0001$), with highly significant linear and quadratic components ($P < 0.0001$). The differences between successive dates are always significant at the 0.05 level, except in 1999, between the 5th and 6th harvests. In 1999, stem base water content dropped from 73% on 26 May to 57%, 7 wk later (Fig. 1a). In 2000, although the harvests began on approximately the same date as in 1999, the initial stem base water content, at 85%, was 11% higher than the previous year (Fig. 1a). By mid-August 2000, stem base water content had dropped to 51%.

During both years, the apical shoot bud developed rapidly and the number of pairs of visible bud scales increased steadily through time (Fig. 1b). The chi-square tests confirm that the changes through time are highly significant for both years ($P < 0.0001$), and that all dates differ significantly from one another, with only one exception in 1999, for two consecutive dates. In 1999, there were virtually no bud scales visible at the onset of the experiment, but an average of 3.8 pairs of scales were visible by 6 July (Fig. 1b). In 2000, there were also no bud scales visible at the first harvest, and an average of 5.1 pairs of scales on the buds by mid-August.

The accumulation of degree-days was much slower in 2000 than in 1999 (Fig. 1c). Accordingly, stems and buds developed more slowly in 2000 than in 1999, since at comparable dates, there was higher stem base water content in 2000 (Fig. 1a) and an average of 1.3 fewer pairs of scales in 2000 than in 1999 (Fig. 1b).

Rooting Trials

In general, rooting success was high, with rooting percentages above 75% after 12 wk, on several collection dates in 1999 and 2000. There were no significant effects of the ANOVA model for the number of main roots per rooted cutting, and thus, these results are not presented.

Table 1. Correlation analysis of the variables measured during the 1999 morphological survey on sugar maple cuttings (Pearson *r*; *n* = 672; *P* values are indicated in parentheses)

	Shoot length	Shoot diameter	Number of internodes	Length of largest leaf	Width of largest leaf	Length of smallest leaf	Width of smallest leaf	Number of pairs of bud scales	Stem base water content
Shoot length	1.000								
Shoot diameter	0.793 (< 0.0001)	1.000							
Number of internodes	0.518 (< 0.0001)	0.460 (< 0.0001)	1.000						
Length of largest leaf	0.044 (0.2529)	0.081 (0.0351)	0.024 (0.5272)	1.000					
Width of largest leaf	0.231 (< 0.0001)	0.415 (< 0.0001)	0.262 (< 0.0001)	0.260 (< 0.0001)	1.000				
Length of smallest leaf	–0.039 (0.3153)	0.051 (0.1895)	–0.221 (< 0.0001)	0.033 (0.3931)	0.186 (< 0.0001)	1.000			
Width of smallest leaf	–0.056 (0.1456)	0.047 (0.2272)	–0.269 (< 0.0001)	0.025 (0.5191)	0.201 (< 0.0001)	0.929 (< 0.0001)	1.000		
Number of pairs of bud scales	0.179 (< 0.0001)	0.444 (< 0.0001)	–0.004 (0.9183)	0.027 (0.4793)	0.036 (0.3478)	0.106 (0.0060)	0.113 (0.0035)	1.000	
Stem base water content	–0.240 (< 0.0001)	–0.471 (< 0.0001)	–0.071 (0.0651)	0.024 (0.5341)	–0.010 (0.7956)	–0.002 (0.9554)	–0.019 (0.6211)	–0.857 (< 0.0001)	1.000

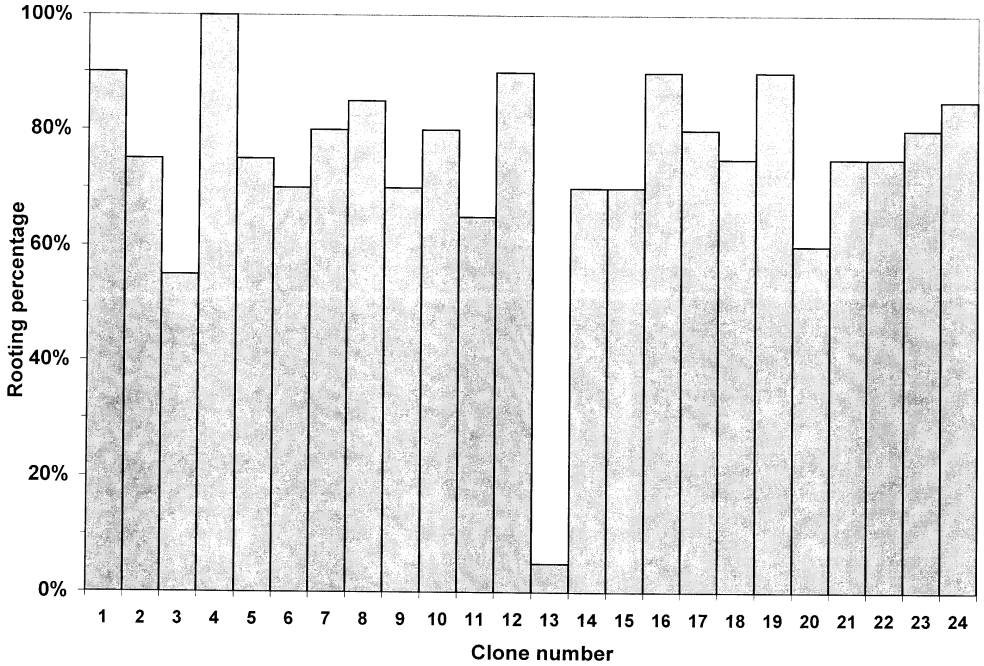


Fig. 2. Overall rooting percentage of the 24 clones in the 1999 rooting trial.

1999 Experiment

Overall, in 1999, 75% of all cuttings rooted in the first rooting trial, with no significant differences between the five collection dates ($P = 0.1236$) (Fig. 3a). No significant correlation was found between rooting percentage and the morphological traits measured at the time of cutting collection (data not shown).

Although the effect of clone could not be included in the ANOVA model, the mean rooting percentage of the 24 clones was estimated, over all the dates tested, by retracing their position within the experimental units (Fig. 2). Individual trees showed rooting percentages ranging from 5 to 100% over all collection dates, indicating very important clonal effects.

2000 Experiment

In the second rooting trial, good rooting results were obtained for several collection dates, over a period of several weeks. However, in contrast to the previous year, the 2000 trial reveals significant effects of collection date on rooting percentage and root biomass per rooted cutting ($P < 0.0001$ and $P = 0.0247$, respectively). Unlike the first year, very poor rooting results (25%) were obtained at the first date of collection in 2000, although both experiments started at a similar time (Fig. 3a). Rooting percentage was highest at the second and third dates of collection (means of 83 and 66% on 14 June and 5 July, respectively), with no significant differences between these two dates. Mean root biomass also peaked at the second and third harvests (means of 55 mg and 69 mg, respectively), though differences between means were not significant at the 0.05 level (Fig. 3b). An intermediate rooting percentage (56%) was obtained at the fourth harvest, on 26 July, but was associated with lower root biomass (40 mg). Cuttings from the first and last harvests rooted significantly less (25 and 28% on 24 May and 16 August, respectively), and had less root biomass (30 mg and 40 mg, respectively).

DISCUSSION

Morphological Indicators

Morsink (1971a,b), Donnelly and Yawney (1972), and Farmer (1974) identified the end of stem elongation and the onset of bud formation as the best harvest period for cutting propagation of sugar maple. Stem water content has been used to monitor the development of softwood cuttings in several coniferous species, such as black spruce (Tousignant 1995) and hybrid larch (D. Tousignant, unpublished results). In the 1999 trial, among all the morphological variables examined, two were identified to quantify the developmental stage of sugar maple shoots from week to week, namely, stem base water content and number of pairs of visible bud scales. In 2000, in order to confirm these findings, the survey was conducted over a longer period, from the end of May to the middle of August. For both water content and number of bud scales, the linear trends observed in 1999 continued steadily through mid-August of 2000.

The two studies highlight the importance of using quantitative measurements, rather than simply consulting a calendar, to precisely identify a given stage of development of sugar maple cuttings. In Quebec, the 1999 spring season was exceptionally warm, while the 2000 spring was cool and rainy. The accumulation of degree-days was considerably slower in 2000 than in 1999 (Fig. 1c, Table 2), and twice the amount of rain fell in May 2000 than in 1999 (Table 2). Correspondingly, during the last week of May of both years, stem base water content of the cuttings shows striking differences, with shoots being much more lignified in 1999 than in

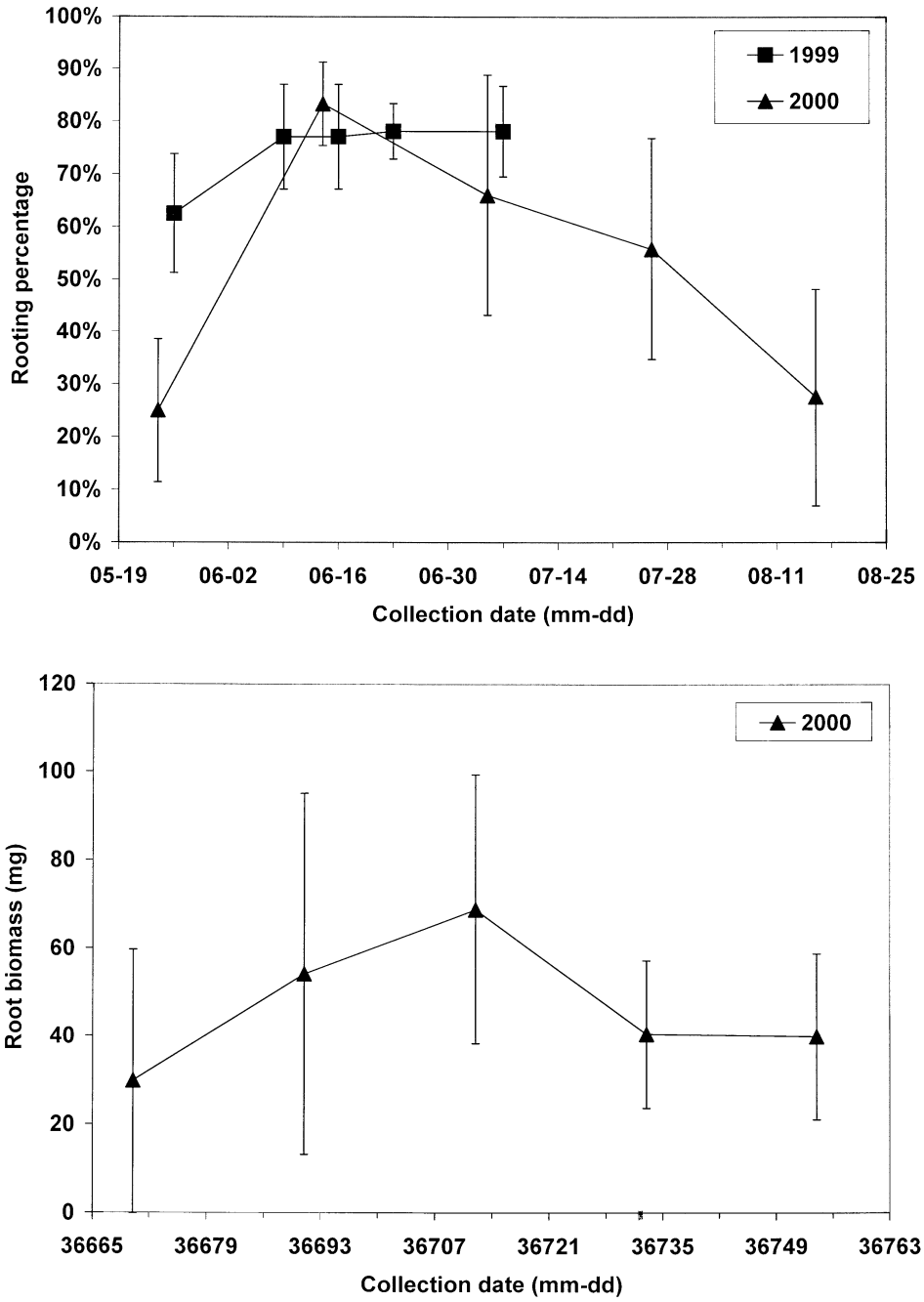


Fig. 3. Mean rooting percentage (a) and mean root biomass (b) obtained for sugar maple cuttings, by collection date (n = 6 experimental units; error bars indicate standard deviation. Root biomass data was not evaluated in 1999).

2000. The first visible signs of apical shoot bud development also appeared 2 wk later in 2000 than in 1999. These observations imply that either the hot weather in the spring of 1999 accelerated the development of sugar maple shoots, or that the cold weather in the spring of 2000 retarded it, or a combination of both. Furthermore, the date at which a precise developmental stage is reached can show considerable variations, depending on local climatic conditions.

The combined use of stem base water content and number of bud scales could be very useful in situations where it is important to know and compare the developmental stage of cuttings taken at various dates within the same season, at different seasons, or to compare the phenology of trees growing on different sites. Stem water content has the advantage of being inexpensive to measure, but is destructive, and requires a 48-h delay. In contrast, counting the

Table 2. Cumulative degree-days and monthly precipitation in the Quebec City area, for the period of the two morphological surveys (source of data: Environment Canada)

	Cumulative degree-days above 5°C		Total monthly precipitation (mm)	
Month	1999	2000	1999	2000
May	358.1	182.7	51.6	110.4
June	768.9	485.3	114.8	130.6
July	1232.7	901.0	187.2	74.0
August	1615.8	1305.9	67.6	124.8

number of visible bud scales is simple, non-destructive and can be done in the field, using a hand-held magnifying lens.

Rooting Results

Considering the reputation of sugar maple as a difficult to root species, rooting percentages obtained in this study were higher than expected. A likely cause for this success is the relatively young age of the trees (Dirr and Heuser 1987; Hartmann et al. 1997). One important conclusion of the 1999 rooting trial is that there were no differences in rooting between the five collection dates we compared. It was possible to harvest cuttings and root them with success over at least a 7-wk period, from the end of May (i.e., as soon as shoots reached a length of about 5 cm) to the beginning of July (i.e., when elongation had ceased and shoot lignification, as well as development of the terminal bud, were well underway, with three or more visible pairs of bud scales). Since the literature suggested a much smaller window in time for this species, limited by the appearance of the first pair of bud scales (Donnelly and Yawney 1972), these results were unexpected. Because of the precocious spring of 1999, and since the first collection date did not cover all possible developmental stages, the experiment was repeated a second time. The 2000 rooting trial confirmed that the optimal window for the collection of sugar maple cuttings spanned several weeks, but identified other periods when rooting success was much less successful.

The optimal developmental stage for collecting sugar maple cuttings can be recognised using two morphological indicators, namely, by a stem base water content below 75% but above 55%, and correspondingly, by the presence of one to three pairs of visible bud scales on the shoot apex. Meteorological data suggest that, for both years, high rooting percentages were obtained, starting when approximately 270 degree-days had been accumulated above 5°C. The end of this optimal window is more difficult to delimit, however, without further replication of the experiment. These results confirm but expand the phenological window proposed by Donnelly and Yawney (1972), and highlight the close relationship between the rate of progression of cutting development and the prevailing climate and temperature conditions.

The 1999 rooting results also confirm the important clonal effects frequently reported in the literature for this particular species (Dunn and Townsend 1954; Gabriel et al. 1961; Donnelly 1971; Greenwood et al. 1976).

This method of choosing a propagation date must still be validated by studying the further growth and survival of the rooted cuttings. Like many other authors, (Dunn and Townsend 1954; Anstey 1969; Donnelly and Yawney 1972; Farmer 1974; Goodman and Stimart 1987), we encountered severe difficulties when overwintering sugar maple rooted cuttings (data not presented).

CONCLUSION

The optimal period for collecting sugar maple cuttings in Quebec extends over several weeks in late spring and early summer, which is a longer time span than previously suggested in the literature. However, this period can vary from year to year. Its beginning is associated with the end of rapid stem elongation and the appearance of the terminal shoot bud. Stem base water content and number of visible bud scales can be used to monitor shoot development and identify the optimal period for cutting harvest, in order to ensure rooting success. Accumulation of degree-days may also be an effective indicator of this optimal rooting period, but further investigation is required to clarify this relationship.

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