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A comparison of pre-planting treatments on hardwood cuttings of four hybrid poplar clones

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Abstract. Rooting and early growth of four hybrid poplar clones (*Populus spp*.) planted in a greenhouse were examined after applying 40 pre-rooting treatment combinations to dormant cuttings. Treatments included 2 cutting lengths (5 and 10 cm), 5 soaking times (0, 2, 4, 8, and 12 days), and 4 dips (chitosan, rooting hormone powder, liquid rooting hormone added to the soaking water, and none). Significant differences in both rooting percentages and growth were shown between clones after 7 weeks of growth. Ten cm cuttings had 29% greater rooting success, 28% more above-ground growth, and 12% lower root/shoot ratios than 5 cm cuttings. Cuttings planted without soaking had the lowest rooting success, at less than 45% on average. Commercial rooting hormones decreased the number of rooted cuttings but increased root/shoot ratios. For optimal rooting, we recommend using 10 cm cuttings, soaked for 2 days in water (4 days for the Jackii10 clone) without any additional dipping/hormone substance.

Introduction

Plantations of hybrid poplars under intensive management systems are becoming of increasing interest for rapid fiber production in latitudes north of 49° (Khalil 1984; Lester 1995). The ever-increasing demand for wood products and the social pressures on the forest industry to sustainably and ecologically manage native forests has provided a strong incentive to expand the establishment of 'fiber farms' to these regions. In general, hybrid poplars in the Aigeiros and Tacamahaca sections of the genus *Populus* respond well to intensive silviculture systems, with potential growth rates exceeding native trees by as much as ten times (e.g., 16–25 $m^3\ ha^{-1}\ yr^{-1}$ versus 2 $m^3\ ha^{-1}\ yr^{-1}$ for boreal regions; Jarvis (1968)).

In the Prairie Provinces of Canada, hybrid poplars, predominantly with a *P. deltoides* background, have been used for over 50 years as shelter-belt trees, planted in single or double tree rows. These trees have been selected and distributed to farmers by the Prairie Farm Rehabilitation Administration (PFRA) of Agriculture Canada, Saskatchewan. Many of these clones, as well as native hybrid selections of *P. balsamifera* × *P. deltoides* (*P.* × *jackii*), are providing the foundation material for new plantation programs in the boreal forest regions of Western Canada. Several

forestry companies plan to produce from 250–400,000 m^3 yr^{-1} of their annual fiber requirements from these intensively-managed hybrid poplar plantations (Lester 1995), with rotation lengths ranging from 15 to 25 years (Thomas et al. 1998).

In order to meet these goals, several million trees will need to be produced each year for commercial scale-up. South of the Canadian border and in the Pacific Northwest, poplars are typically field-planted as unrooted dormant cuttings (Krinard and Randall 1979; Dickmann and Stuart 1983). However, the relatively dry and cold climatic conditions of Northern Alberta, with mean annual precipitations of 450 mm and less than 80 frost-free days (Anonymous 1982), are not optimal for field rooting. First year survival rate of field-planted unrooted cuttings is typically in the range of 50% in the Prairie Provinces (Bill Shroeder, PFRA, pers. comm.). Studies by Dumant (1979) and Hansen (1986) have shown that poplar cuttings require soils warmer than 10–15 °C for rooting. Even in mounded sites of Northern Alberta, these soil temperatures are not reached until mid- to late June (Figure 1). Given the combined effects of relatively dry climatic conditions and a short growing season, the advantage of using dormant rooted cuttings becomes apparent, despite the additional cost of greenhouse propagation.

In the year 2000 growing season, commercial nurseries contracted by Alberta-Pacific Forest Industries Inc. (Al-Pac) achieved cutting survival rates averaging only 55% over all clones propagated. Cutting material limitations, as well as the cost of collecting and planting extra stock to insure quantities, resulted in the need to identify optimal pre-rooting treatments. In an effort to maximize the rooting success and early growth of four of the hybrid poplar clones being used operationally, we examined the greenhouse performance of dormant cuttings subjected to 40 different

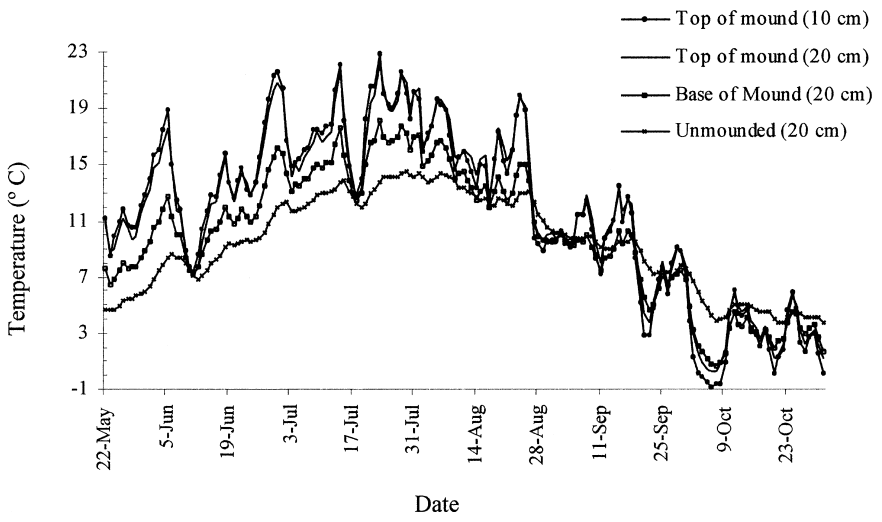

Figure 1. Seasonal soil temperature of a mounded plantation site in Northern Alberta, Canada, measured 10 or 20 cm below the soil surface in year 2000.

Table 1. Clone name, parentage and cross name of the four hybrid poplars.

Clone Name	Female Parent	Male Parent	Cross Name
Walker	*P. deltoides*	*P. nigra* (putative)[1]	*P. x euramericana*
P38P38	*P. balsamifera*	*P. simonii*	no cross name
Jackii10	*P. balsamifera*	*P. deltoides*	*P. x jackii*
Berlin42	*P. laurifolia*	*P. nigra*	*P. x berolinensis* and *P. x petrowskyana*

[1]Khasa et al. (2001)

pre-rooting treatment combinations, including different soaking times, rooting hormone dips and cutting sizes.

Soaking poplar cuttings in water before planting has been shown to stimulate the development of latent root primordia (Petersen and Phipps 1976; Hansen et al. 1993; Riemenschneider 1997). Cuttings can also be dipped in anti-desiccant or pesticide solutions, rooting hormones, fungicides, or some combination to affect rooting success (Nordine 1984). In addition, cutting size, from a single-bud cutting to the entire 1-year-old growth (Krinard and Randall 1979) can be used. However, the evidence to justify the use of any compounds or of the existence of a set of 'ideal' pre-planting treatment combinations is lacking. Caution must also be used when extrapolating performance based on the testing of a single clone, since clonal variability in rooting ability is a trade-mark of poplars, particularly with *P. deltoides* hybrids (Ying and Bagley 1977; Dickmann and Stuart 1983).

Methods

In early November 2000, dormant cuttings, 5 and 10 cm in length, were collected from 1 year-old growth of four poplar clones (Walker, P38P38, Jackii10 and Berlin42). These were growing in 2-year-old production stoolbeds (high-density beds of shoots [stools] cutback each year for cutting production) located at the Al-Pac millsite (54°N, 112°W). Clones with different parentage were selected (Table 1), to reflect a range in rooting potential. The stools had undergone approximately two weeks of below freezing temperatures prior to the November harvest. Since position in the stool can affect rooting ability (Bloomberg 1959; Smith and Wareing 1974; Schroeder and Walker 1991), each cutting was collected from the same location in different stools of similar size, 30 cm above the base. All cuttings had a vegetative bud located within 1 cm of the top. The cuttings were stored in sealed plastic bags for a maximum of 20 days at 2 °C, until the experiment started.

The experiment was designed as a $5 \times 4 \times 4 \times 2$ factorial with 5 soaking times (0, 2, 4, 8 and 14 days), 4 clones (Walker, P38P38, Jackii10, and Berlin42), 4 dips (chitosan [1% solution w/v mixed with glutamic acid], hormone powder [Stim-Root No.3™ rooting powder at 0.8% IBA], hormone liquid [Stim-Root No.3™ liquid rooting hormone at 0.5% IBA], and no-dip) and 2 cutting lengths (5 and 10 cm). The

Table 2. Analysis of covariance for height, basal diameter growth, and rooting 7 weeks after planting.

Source of variation	Growth					Rooting		
	Height			Basal diameter				
	df[1]	MS[2]	*P*	MS	*P*	df	MS	*P*
Clone (C)	3	372.12	< 0.001	0.98	0.003	3	2.55	< 0.001
Length (L)	1	171.53	< 0.001	7.43	< 0.001	1	16.54	< 0.001
Soak (S)	4	64.36	< 0.001	0.42	0.09	4	1.44	< 0.001
Dip (D)	3	3.87	0.83	0.42	0.11	3	6.83	< 0.001
C × L	3	5.99	0.71	0.02	0.97	3	0.44	0.04
C × S	12	10.64	0.62	0.11	0.90	12	0.30	0.03
C × D	9	43.05	< 0.001	0.61	0.002	9	0.41	0.01
L × S	4	9.28	0.58	0.15	0.58	4	0.36	0.06
L × D	3	19.47	0.21	0.30	0.23	3	0.68	0.005
S × D	12	21.24	0.08	0.26	0.24	12	0.22	0.15
C × L × S	11	11.28	0.56	0.21	0.45	12	0.10	0.79
C × L × D	9	12.70	0.45	0.34	0.11	9	0.20	0.24
C × S × D	34	18.24	0.07	0.32	0.03	36	0.13	0.75
L × S × D	12	13.82	0.38	0.23	0.34	12	0.12	0.71
C × L × S × D	20	9.25	0.81	0.16	0.73	36	0.15	0.51
Original cutting diameter	1	264.97	< 0.001	0.17	0.37	1	0.12	0.39
Error	327	12.88		0.21		639	0.16	

[1]df: degrees of freedom; [2]MS: mean square

160 combinations were randomly distributed and repeated in 5 different blocks (800 cuttings in total). The cuttings were soaked at room temperature in the greenhouse, placed vertically in cold tap water, covering $\frac{3}{4}$ of their length. The water was replaced daily with fresh cold water until the treatment was complete. For the 'liquid hormone' dip treatment, the cuttings were soaked for their respective number of soaking days in a 0.1% dilution of the liquid hormone dip (0.0005% IBA). For the 0 soaking days, hormone liquid dip treatment combination, the cuttings were dipped for 5 s in the undiluted liquid hormone dip and planted immediately. The chitosan and hormone powder dips were applied by dipping the base of the cuttings in the product and gently tapping off any excess before planting.

All cuttings were planted on the same day, after their respective soak and dip treatments, in a commercial potting mix (Metromix™, Ajax, Ont.), consisting of equal amounts of peat moss, vermiculite, sand and perlite with a pH of 7. Styroblock™ (Beaver Plastics, Edmonton, Alberta) containers with 123 ml plugs (15.2 cm depth × 3.9 cm diameter) were used. The entire length of the cutting was planted in the soil, and the diameter of the cutting at the soil surface measured. The cuttings were grown for a period of 7 weeks in a greenhouse, with natural and artificial lighting (450 μmol photons $m^{-2}s^{-1}$ photosynthetically active radiation [PAR] at pot level), to provide a 16-h photoperiod. Day temperatures were adjusted to 21 °C and night 18 °C. The cuttings were fertilized on days 14, 28 and 42 with a solution of 28N-14P-14K mixed at a concentration of 200 ppm.

Height and basal diameter of the new shoots were measured 7 weeks after sticking the cuttings, before all plants were destructively harvested. The soil media

Table 3. Mean original cutting diameter (mm) and percent rooting for each clone, 7 weeks after planting.

Clone	Cutting Diameter (standard deviation)	Rooting
Walker	6.43[b] (0.79)	59.8[b]
P38P38	5.63[c] (0.59)	70.3[c]
Jackii10	7.48[a] (0.82)	33.7[a]
Berlin42	5.64[c] (0.68)	69.8[c]

Note: Numbers with the same letter are not significantly different at $P < 0.05$.

was gently washed from the roots under running water using a fine mesh sieve to avoid loss of fine roots. All plant parts including the original cutting, roots, stem and leaves were oven-dried to constant weight at 75 °C, and dry weights were measured to the nearest 0.001g.

Statistical analysis of the data was performed using SAS 8.0 (Sas Institute Inc., Cary, NC). All treatments were considered as fixed factors and were analysed in an analysis of covariance using the general linear model procedure (proc GLM). Original cutting diameter was used as a covariate in the data analysis of all measured traits to compensate for the variation in original cutting size. Comparisons of means were done using least square means (lsmeans) with the least significant difference (LSD) comparison procedure. A significance level of $P < 0.05$ was chosen.

Results

Rooting

After a period of 7 weeks, all live cuttings had produced roots. Overall rooting was 58.4%, and significantly differed among the clones (Tables 2 and 3). Ten cm cuttings showed greater rooting success (72.8%) than 5 cm cuttings (44.0%). The difference in rooting success between long and short cuttings was greatest for the Berlin clone (42%) and least for the Walker clone (19%) (Figure 2), causing a significant interaction between clone and cutting length (Table 2). Generally, the hormone powder dip treatment resulted in the poorest rooting, while the chitosan and no-dip treatments gave the best results (Figure 3a). Rooting of the cuttings treated with the liquid hormone dip showed a significant clonal effect such that maximal rooting occurred with Jackii10 and Berlin42, intermediate for Walker and the lowest with P38P38 (Figure 3a), resulting in a significant interaction between dip treatment and clone (Table 2). There was also an interaction between dip treatment and cutting length (Table 2), due to the greater rooting of the 10 cm cuttings that received the liquid hormone dip, compared to the 5 cm cuttings (Figure 4).

Rooting was also affected by the length of time the cuttings were soaked (Table 2). Direct planting of the cuttings, without soaking, generally produced the lowest rooting success (43.8%) but once again, there were rooting differences in response to soaking among the clones (Figure 5). The greatest rooting percentage was

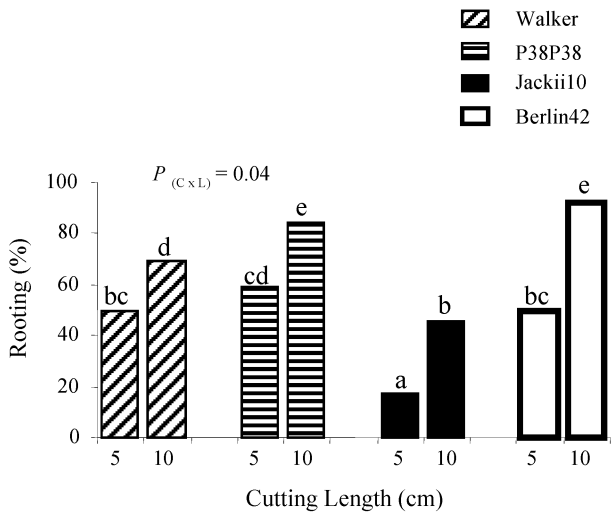

Figure 2. Percent rooting success of 5 and 10 cm dormant hybrid poplar cuttings 7 weeks after planting ($P_{(C \times L)}$ = P value of the interaction between clone and cutting length). Bars with the same letter are not significantly different at $P = 0.05$.

obtained with 2–14 days soak for P38P38 and Berlin42, 2–8 days for Walker and 4 days for Jackii10 (Figure 5). However, the interaction between soaking time and clone became non-significant when the Jackii10 clone was removed from the data set ($P = 0.09$).

For all clones and cutting lengths combined, rooting climbed to 87.5% with the combination of a 4-day soak and the chitosan dip, and to 82.5% with 2–4 soaking days and no-dip treatments, while other combinations of soak and dip gave rooting rates $< 75\%$ (Table 4). There was no interaction between soaking time and dip treatment for percent rooting with all clones combined (Table 2). However, the interaction was significant when Jackii10 was removed from the data set (Figure 6), showing the lowest rooting with the 0-day soak and a decrease in rooting percentages with increasing soaking time after 2 days for the liquid hormone and no-dip treatments.

Within each clone, percent rooting was not related to cutting diameter at planting ($P = 0.15$), however larger cuttings had lower rooting rates ($P < 0.001$) with all four clones combined, reflecting the original differences in cutting diameter between the clones (Table 3).

Growth

Clonal differences in height and basal diameter were already present after the 7-week growing period (Table 2, Figure 7). Ranking of the four clones changed

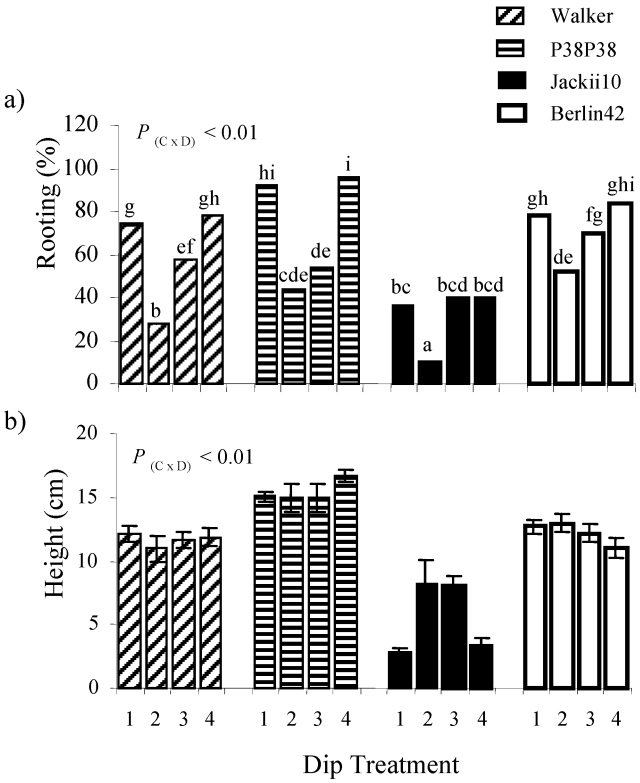

Figure 3. a) Percent rooting success and b) mean height (± se) of dipped [1) chitosan, 2) hormone powder, 3) liquid hormone and 4) no-dip] dormant hybrid poplar cuttings, 7 weeks after planting, for each clone ($P_{(C \times D)}$ = *P* value of the interaction between clone and dip treatment). Bars with the same letter are not significantly different at $P = 0.05$.

depending on which trait, height or basal diameter, was used for comparison of clone means (Figure 7). Height growth also differed among the clones in response to the dip treatment (Table 2), accounted for by the greater height growth of the Jackii10 with the hormone dip treatments (Figure 3b). No interaction was detected between clone and dip treatments when this clone was removed from the data set ($P = 0.58$). Height growth significantly increased with days of soaking (Figure 8). The 10 cm cuttings had greater height and basal diameter growth (Figure 9a), and greater leaf and shoot mass ($P < 0.001$) than the 5 cm cuttings (data not shown).

Although there was no difference between the clones in their root/shoot ratios ($P = 0.25$), there was a strong trend for shorter cuttings to have a higher root/shoot ratio (Figure 9b), reflecting the greater shoot mass (shoot and leaves combined) of the longer cuttings (Figure 9c). The dip treatments containing hormones produced greater root/shoot ratios (Figure 10). No differences were detected in root/shoot ratios among the soaking treatments ($P = 0.43$).

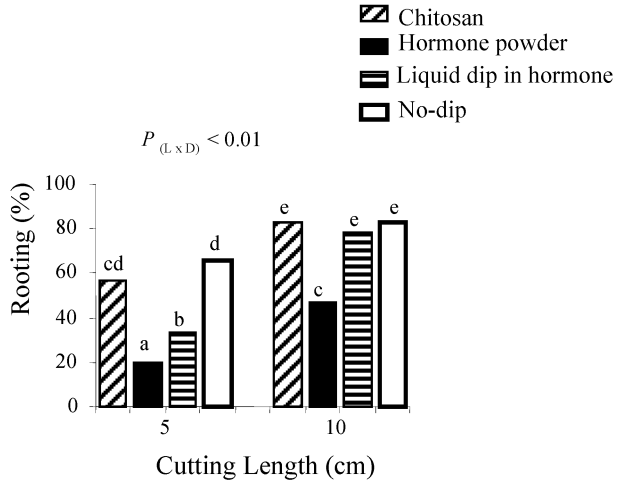

Figure 4. Percent rooting success of dormant hybrid poplar cuttings for each dip and cutting length treatment combinations, all clones combined, 7 weeks after planting ($P_{(L\times D)}$ = *P* value of the interaction between cutting length and dip treatment). Bars with the same letter are not significantly different at $P = 0.05$.

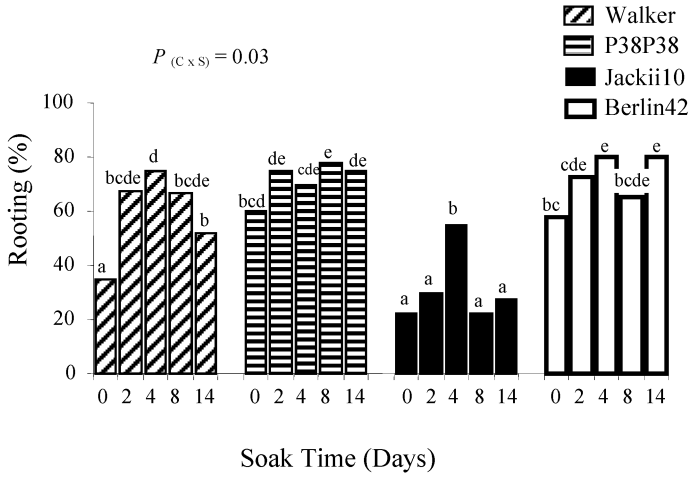

Figure 5. Percent rooting success of dormant hybrid poplar cuttings for each soak and clone treatment combinations, 7 weeks after planting ($P_{(C\times S)}$ = *P* value of the interaction between clone and soak treatment). Bars with the same letter are not significantly different at $P = 0.05$.

Discussion

Overall, the results of this study show that rooting ability is strongly correlated with clonal identity (Table 3). Therefore, to ensure maximum rooting and optimal growth, care must be taken in extrapolating results beyond the material tested.

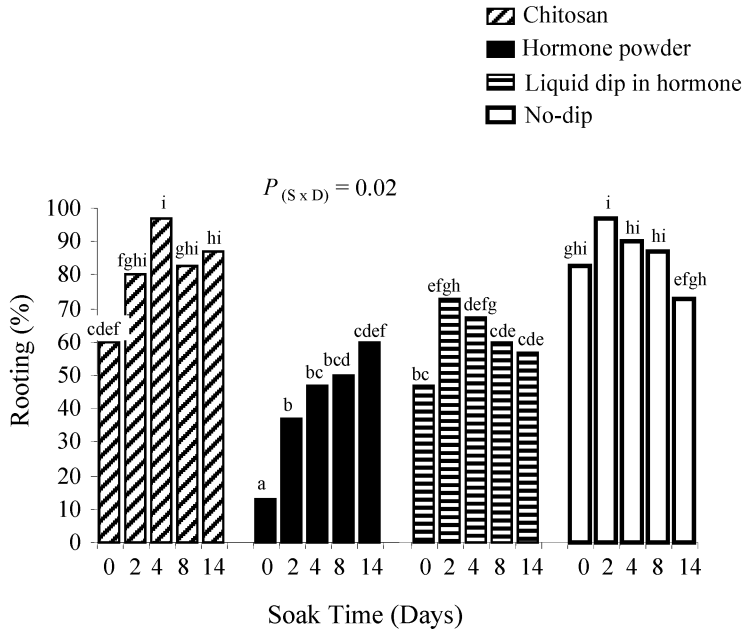

Figure 6. Percent rooting success of dormant hybrid poplar cuttings for each dip and soak treatment combinations, excluding the Jackii10 clone, 7 weeks after planting ($P_{(S \times D)}$ = P value of the interaction between soak and dip treatment). Bars with the same letter are not significantly different at $P = 0.05$.

Table 4. Percent rooting for each dip and days soaked combination, all four hybrid poplar clones and cutting lengths combined.

Dip–Days soaked	0	2	4	7	14	Mean (%)
Chitosan	52.5	70.0	87.5	67.5	72.5	70.0
Hormone Powder	12.5	30.0	40.0	37.5	47.5	33.5
Liquid soak/dip	40.0	62.5	70.0	55.0	50.0	55.5
None	70.0	82.5	82.5	72.5	65.0	74.5
Mean (%)	43.8	61.3	70.0	58.1	58.8	58.38

Bearing that in mind, we observed a range from 12.5% to 87.5% rooting across the different treatment combinations for all clones combined (Table 4) indicating that substantial improvements can be made in the rooting success of operationally grown hybrid poplars through selection of the appropriate combination of pre-planting treatments.

A simple 2-day soak in water was sufficient to increase rooting from less than 45% to 82.5% (Table 4). Soaking leaches compounds that inhibit rooting and stimulates ethylene production of the cuttings (Blake et al. 1982). It has been shown that water extracts from *P. nigra* 'Italica' could inhibit root production on cuttings of other plants (Leclerc and Chong 1983), which emphasizes the importance of daily water replacements during the treatment period to remove these inhibitors from the soaking water. Soaking also rehydrates the cuttings, which might be critical for

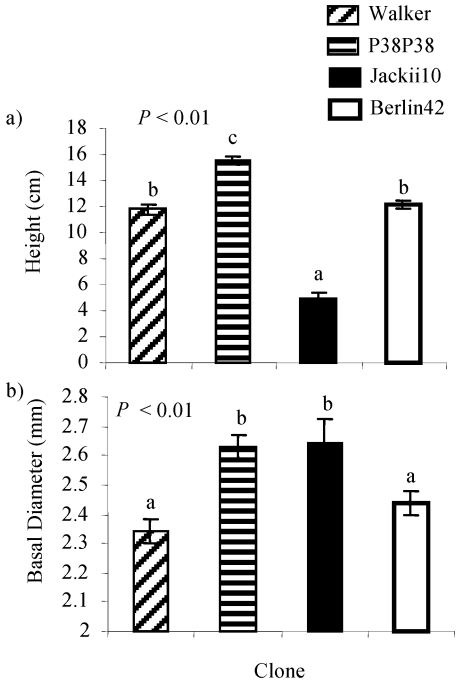

Figure 7. Mean a) height (± se) and b) basal diameter (± se) growth of the four hybrid poplar clones, 7 weeks after planting (n = 467). Bars with the same letter are not significantly different at $P = 0.05$.

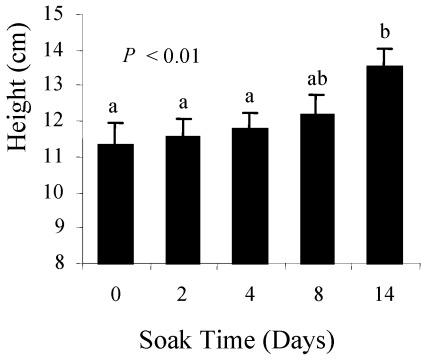

Figure 8. Mean height (± se) for each soak treatment, all clones and dip treatments combined, 7 weeks after planting.

cutting material grown in non-irrigated stoolbeds. Others have recommended longer soaking periods, 5 days (Krinard and Randall 1979), and 5–10 days (Hansen et al. 1993) for various *P. deltoides*, and DN (*P. deltoides* × *P. nigra*) clones. In our study, apart from the Jackii10 clone, soaking in water for more than 2 days did not

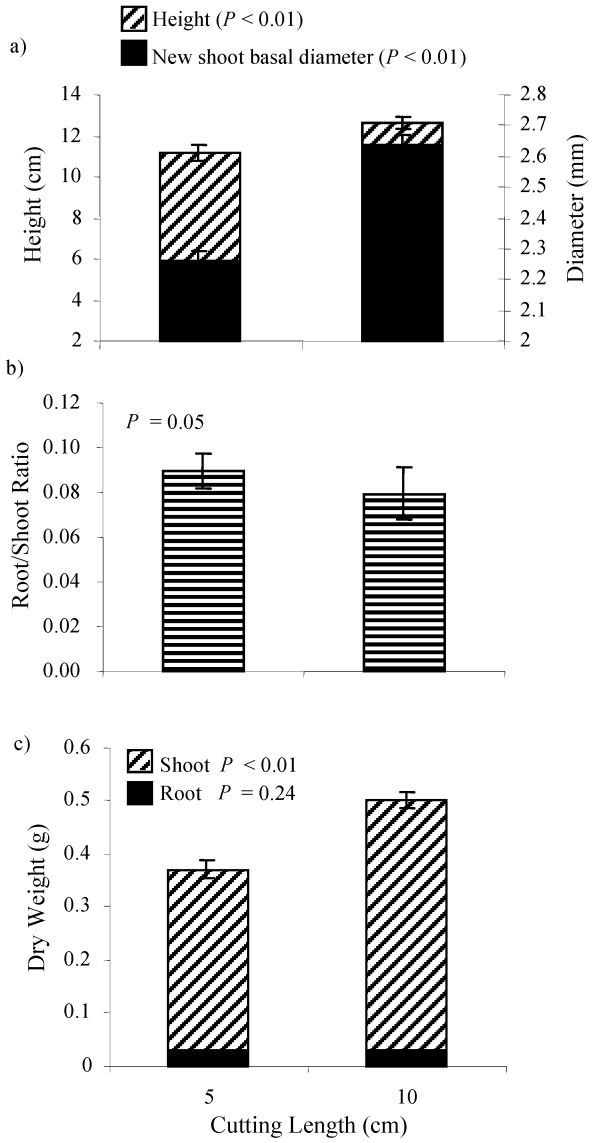

Figure 9. Mean a) height and new shoot basal diameter (± se), b) root/shoot ratio (± se) and c) shoot and root dry weight (± se) of 5 and 10 cm hybrid poplar cuttings, 7 weeks after planting.

significantly increase rooting (Figure 6). Perhaps the larger size of the Jackii10 cuttings required longer soaking to fully hydrate.

The increase in height growth observed with longer soaking periods (Figure 8) may only be due to the corresponding increase in time that cuttings were exposed to warmer greenhouse conditions, compared to cuttings assigned to none or shorter

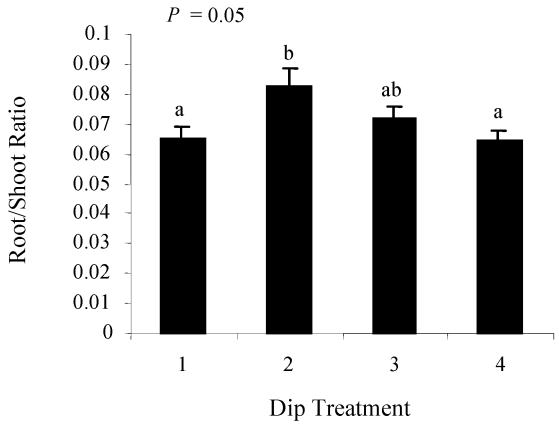

Figure 10. Mean root/shoot ratio (± se) of the combined hybrid poplar clones for each dip treatment [1) chitosan, 2) hormone powder, 3) liquid hormone and 4) no-dip], after 7 weeks of growth. Bars with the same letter are not significantly different at $P = 0.05$.

soaking periods (they were kept at 2 °C until treatments were applied). Addition of liquid rooting hormone in the soaking water is not recommended since it lowered rooting for all clones but the Jackii10 (Figure 3a).

Unexpectedly, the commercial rooting hormones (the powdered form in particular) negatively affected the number of cuttings that rooted (Figure 3a). This lead us to believe that the indolebutyric acid (IBA) concentration contained in these commercial formulas, recommended for using with hardwood cuttings, were too high for the clones investigated. Indolebutyric acid (IBA) acts as a root growth inhibitor at high concentrations (Kozlowski and Pallardy 1997). Howard (1974) recommended dipping hardwood cuttings as shallowly as possible in the rooting compound when using it at high concentrations of IBA (5000 ppm). In our study, the bottom 2 cm of the cutting was dipped in the rooting hormone at a concentration of 8000 ppm (0.8% IBA), which may have been toxic. In contrast, Chong (1981) found significant increases in rooting using much higher IBA concentrations (between 10,000 and 40,000 ppm) for different horticultural species. Soaking in a weaker solution of rooting hormone (5 ppm IBA) gave better rooting success compared to the rooting powder, but it did not improve rooting beyond the no-dip treatment (Figure 3a). The fact that cuttings that survived the rooting hormone treatments had better root/shoot ratios (Figure 10), suggests that the use of commercial dips could be beneficial at concentrations low enough to avoid the root growth inhibitory effect of high auxin concentrations (Tuckey 1979).

The use of chitosan glutamate, a complex sugar, has been shown to increase root growth and resistance to root pathogens in some plants (Harada et al. 1995; Chibu et al. 1999; Laflamme et al. 1999). It did not, however, improve rooting or root mass of the hybrid poplar clones used in this study compared to the no-dip treatment (Figure 3a). Krinard and Randall (1979) also found that the addition of sugar-based

substances (5 or 0.5% sucrose solutions) did not increase rooting of cuttings compared to a simple water soak for various *P. deltoides* clones.

Longer cuttings can contain larger carbohydrate reserves, which is likely related to the greater height and basal diameter attained by the 10 cm-long cuttings after only 7 weeks of growth (Figure 9, Tuckey 1979; Berthelot 1990). Interestingly, both cutting lengths produced the same amount of roots (Figure 9c), thus showing a preferential allocation of carbon to above-ground parts with the larger cuttings, and consequently producing plants with smaller root/shoot ratios (Figure 9b). Hence, choosing longer cuttings might not be a good strategy when considering out-planting into drier climates, since their larger above-ground biomass will increase evapo-transpiration demand and could make them more susceptible to desiccation. Poor performance and wilting of lush-looking hybrid poplar trees soon after out-planting could, in part, be a result of poor root/shoot ratios.

Within the range of sizes used in this study (Table 3), cutting diameter was not critical for rooting. One might expect that larger cuttings would root more easily than small diameter cuttings, since they contain more carbohydrate reserves (absolute amount). However, Okoro and Grace (1976) reported that failure to root in hard-to-root *P. tremula* clones was not likely due to a low carbohydrate content, but rather due to a failure to translocate assimilates to the bottom of the cuttings. Similarly, Robison and Raffa (1996) found that cutting diameters greater than 6 mm did not have a significant impact on survival in a variety of hybrid poplar clones. They suggested that cutting mass might be a more useful index of potential survival, hence, larger diameter cuttings could be cut to a shorter length than small-diameter cuttings. Although clonal variability could account for the difference, our results do not agree with this idea, since the reduction in survival from long to short cuttings was also important for the largest diameter clone, Jackii10 (Figure 2, Table 3). Testing a wider range of cutting diameters might have shown the importance of diameter size for rooting. However, since larger cuttings likely come from the base of stools, increased rooting rates of large-diameter cuttings found elsewhere (Dickmann et al. 1980) could be accounted for by the position in the stool from where cuttings originated. Cuttings originating from the base of stools, are known to have more root primordia and higher rooting rates than cuttings coming from the top end of stools, which are usually smaller (Smith and Wareing 1974; Schroeder and Walker 1991). In our study, all cuttings where taken from the same stool position, i.e. 30 cm above the base, thereby standardizing position, which could explain why cutting diameter did not affect rooting. Hansen and Tolsted (1981) showed that although the most important factor for survival in difficult-to-root *P. alba* seemed to be cutting diameter, it was position in the branch that mattered most, especially for small diameter cuttings.

The use of longer cuttings is typically recommended for direct field planting of hybrid poplars to maximize survival and productivity (Rossi 1991). Longer cuttings can hold more water and proportionally less of their surface area is cut and exposed to air, and therefore they are less subject to drying until roots are formed. Even under greenhouse controlled conditions, where cuttings are less likely to desiccate, this study demonstrated that rooting of 10 cm cuttings was superior to that of 5 cm

or 'single-bud' cuttings (Figure 2). Since buds produce root-promoting hormones (Kozlowski and Pallardy 1997), the presence of more vegetative buds on the longer cuttings could account for an improvement in rooting. In *P.* × *robusta*, Smith and Wareing (1972) observed that the presence of swelling buds caused a more rapid growth of root primordia and a greater production of new root meristems than in cuttings where the buds had been removed. Again, although we found that longer cuttings rooted more readily than the 5 cm cuttings (Figure 2), there was no difference in root mass between long and short cuttings (Figure 9c). This indicates that root growth is regulated by different mechanisms than those regulating root initiation (Tuckey 1979).

In summary, greenhouse rooting of dormant cuttings is a management alternative to overcome the challenge of a short and cold growing season, and appears to be necessary for the establishment of hybrid poplar plantations in Northern regions. The use of previously rooted, over-wintered dormant cuttings allows for earlier planting in the spring, better access to moisture left by the snowmelt, increased survival and an extended growing season. Based on the results we obtained with the four clones studied, we recommend the following pre-rooting treatment combination to maximise greenhouse rooting success of dormant cuttings:

- 10 cm – long cuttings
- A two day soak in water, refreshed daily, four days for the Jackii10 clone
- No additional dipping substance

To maximise root/shoot ratios:

- 5 cm-long cuttings
- Rooting hormones at low IBA concentrations

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