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Field Performance of Hybrid Aspen Clones Planted in Summer

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We investigated the possibility to plant clonal hybrid aspen (*Populus tremula* × *tremuloides*) during the summer of propagation when the plants are 20–25 cm tall and only a few months old. In four experiments carried out in years 1998–2001, survival of summer-planted hybrid aspens was at least as high as that of hybrid aspen planted in autumn and spring. In all experiments, compared to planting in September or the following May, height growth was greater with planting in July and early August. Root egress of hybrid aspens planted in July and August was also greater than that of aspens planted in autumn or the following spring. Summer planting was thus possible both with plants produced by micropropagation and with those produced from root cuttings.

Keywords growth, hybrid aspen, micropropagation, planting date, *Populus*, root cutting, root egress, survival
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1 Introduction

During the last decade, interest in planting hybrid aspens (*Populus tremula* L. × *P. tremuloides* Michx.) has increased both in Finland and in the Baltic countries. In 1997–2003 hybrid aspens were planted on about 1000 hectares in Finland and about 500 hectares in Estonia (Holm 2004). One-year-old container plants of hybrid aspens are usually planted in May. Since hybrid aspen grows rapidly, the planted hybrid aspens have been tall (50–100 cm) and have therefore been grown in trays with large-volume cavities (500–600 cm^3). Thus, the growing space needed in a nursery is large; and handling, transportation and planting of tall hybrid aspens are difficult. In addition, tall hybrid aspens are expensive.

Rikala (1996) and Luoranen et al. (2003) showed that container seedlings of silver birch (*Betula pendula* Roth) can be planted in summer without decreased survival. At the time of planting, summer planted, actively growing birch seedlings are about 20–30 cm tall. This means that seedlings can be grown in small-volume trays. In addition, summer-planted seedlings have been shown to grow better during the few first years after planting (Rikala 1996, Luoranen et al. 2003).

Our aim here was to determine whether actively growing hybrid aspen can be planted successfully in July and early August without lowering the rates of growth or survival. We investigated the growth and survival of actively growing hybrid aspen clones planted on different planting dates and produced either by micropropagation or from root cuttings. To determine the best period to plant in summer, in one experiment we also monitored the root egress of plants. An additional, more theoretical, aim was to analyze the initial growth dynamics of hybrid aspen.

2 Material and Methods

2.1 Experiments at Suonenjoki

In 1998, four (A, B, C, D) and in 1999, three (A, B, C) hybrid aspen (*Populus tremula* L. × *P. tremuloides* Michx.) clones (Table 1) were micropropagated in the laboratory of the Foundation for Forest Tree Breeding (Haapastensyrjä, Finland, 67°25´N, 33°59´E, altitude 125 m a. s. l) on April 28 (half of clone C in 1998) and 11–19 May. In 1998, micropropagated hybrid aspens were rooted and then transplanted into Tako-913 trays (22 cavities per tray, 580 cm^3 per cavity, 92 cavities per m^2, Metsä-Serla, Finland) on 25 May (half of clone C plants) and on 3–4 June. In 1999, micropropagated hybrid aspens were planted directly into either Tako-913 trays or Plantek 25 trays (25 cavities per tray, 380 cm^3 per cavity, 156 cavities per m^2, Lännen Tehtaat, Finland) filled with fertilized sphagnum peat (Kekkilä Oyj, Finland).

Table 1. Provenances of mother and father of hybrid aspen clones, their latitudes and longitudes (unknown for most) used in experiments in years 1998–2001.

Clone	Mother (*P. tremula*)	Father (*P. tremuloides*)
A	E1732 Finland, Tuusula	U2554 Canada, Ontario (45°17´, 78°58´)
B	E295 Finland, Tuusula	U2502 Canada, Ontario
C	E200 Finland, Tuusula (24°59´, 60°22´)	U2551 Canada, BC, Aleza Lake
D	E295 Finland, Tuusula	U2502 Canada, Ontario
A	E1732 Finland, Tuusula	U2554 Canada, Ontario (45°17´, 78°58´)
B	E295 Finland, Tuusula	U2502 Canada, Ontario
C	E200 Finland, Tuusula (24°59´, 60°22´)	U2551 Canada, BC, Aleza Lake
E	E1571, Finland, Hirvensalmi	U2566, Canada, Ontario
F	E1446, Finland, Helsinki	U2565, Canada
G	(*P. tremuloides*) U2006, Sweden, Göteborg’s botanical garden	(*P. tremula*) E294, Finland, Tuusula (24°57´, 60°22´)

The plants were grown in an unheated greenhouse until they were transported to Suonenjoki Research Station (62°39´N, 27°04´E, altitude 120 m a.s.l.) on 23 June 1998 or 22 June 1999. A total of 25 Tako-913 trays with 550 plants in each clone in 1998 and 10 Plantek 25 with 250 plants and 10 Tako-913 trays with 220 plants in 1999 were grown for the experiments. In Suonenjoki, the plants were irrigated regularly and fertilized one to three times in an outdoor growing area until planting. Until the end of the 1998 growing season each plant received (both base and liquid fertilization) 129 mg N, 70 mg P, 175 mg K plus micronutrients. In 1999 until the end of the growing season, each Plantek 25 -plant received 76 mg N, 45 mg P, 118 mg K plus micronutrients and each Tako-913 -plant 111 mg N, 68 mg P, 175 mg K plus micronutrients. In 1999, the hybrid aspens were sprayed against aphids with Bioruiskute (pyretrins and piperonylbutoxide 10%, Kemira agro Oy, Finland) on 24 June and against aspen leaf and twig blight (*Venturia tremulae* Aderhold) with Euparen M (tolylfluanid 0.2%, Berner Oy, Finland) on 20 July. After the leaves were shed, hybrid aspens for spring planting were packed in plastic bags and stored frozen at –3 °C.

For the planting experiments, a former nursery field (fine sandy soil) was harrowed and tilled just before planting. Hybrid aspens were planted weekly in Suonenjoki from 13 July to 7 September in 1998 (EXP98) and from 8 July to 2 September in 1999 (EXP99). In spring, the hybrid aspens were planted either on 14 May 1999 or 5 May 2000. In 1999, hybrid aspens grown in Plantek 25 trays were planted until 5 August; and those grown in Tako-913 trays were planted from 5 August until 2 September and the following May. Thus, on 5 August, hybrid aspens from both Plantek 25 and Tako-913 were planted. Each week two trays for planting were randomly selected from among the total batch of each clone. A randomized block design was used with 4 (1998) or 5 (1999) plants [0.8 m between plants in a row, 0.5 m between planting dates (rows = plots)] in each clone (subplot) per 10 (EXP98) or 11 (EXP99) plots (planting date) and 6 blocks. Thus, in 1998 a total of 96 plants were planted on each planting date and in 1999 a total of 90 plants on each date. In both years, the experimental area was fenced to give protection against hares but in EXP98 not until the beginning of August. No vegetation treatments were given during the study period.

In 1999, on each planting date 10 hybrid aspens from one of the clones (due to the limited number of plants per clone) were randomly selected for the root-egress test. On the first date, the tested plants were from clone A, on the second date from clone C, on the third from clone B, on the fourth from A, etc. On 5 August, 10 plants of clone B grown in both Plantek 25 and Tako-913 trays were tested. The tested plants were planted in sand-filled plastic pots (2.2 litres) and grown in an unheated greenhouse under natural photoperiod and light conditions. The plants were watered with tap water as needed. After three weeks, roots growing out from the peat plug into the sand were cut and washed, dried in an oven for 24 hours at 105 °C and weighed to an accuracy of 1 mg.

2.2 Experiment at Haapastensyrjä

In 2000 (EXP00), two clones (E, F) of micropropagated hybrid aspens were transplanted into Plantek 25 trays filled with fertilized (46 mg N, 36 mg P, 73 mg K in each cavity) sphagnum peat (Kekkilä Oyj, Finland) 10–43 days before planting. After transplanting, the plants were moved to an outdoor growing area and irrigated as needed. In the outdoor growing area the plants were not fertilized. Hybrid aspens were planted every second week into a former agricultural field (fine sandy mull soil) near the nursery at Haapastensyrjä (67°25´N, 33°59´E, altitude 125 m a.s.l). At the time of planting, hybrid aspens were 20–30 cm tall on all planting dates except 10 August, at which time the height was 40 cm. Just before planting the field was harrowed and tilled. On each planting date, 10 plants (on 10 August only 8) of each clone were planted into 6 randomized blocks [0.8 m between plants in a row, 0.8 m between planting dates (rows)], a total of 120 (on 10 August only 96) plants on each date. Each plant was protected against voles by a plastic shelter, and the experimental area was fenced against hares. Each year the weeds were mowed in August.

2.3 Root-cutting Experiment at Suonenjoki

In 2001 (EXP01), plants were produced by root-cuttings as described by Stenvall et al. (2004), but with some modifications. The 3 cm-long and ≥2 mm-thick pieces of root cuttings from two-year-old stock plants were stuck horizontally into Jiffy-96 trays (96 pellets in each tray, 400 pellets per m^2, cell volume 115 cm^3, Jiffy Products, Norway) filled with unfertilized sphagnum peat pellets on 2–3 May and 3–4 May 2001 for clone B and clone G (see Table 1), respectively. From 2 May to 20 May the hybrid aspens grew in a heated greenhouse (average daily temperature 21 °C) under natural photoperiod (day length from 16 hours 30 min to 18 hours 20 min) and light conditions; they were then moved to an unheated greenhouse. From 28 June when the average height of hybrid aspens in a tray was about 10 cm, the trays were moved to an outdoor growing area. The hybrid aspens were irrigated according to normal nursery practice and, depending on the planting date, fertilized four to eight times with liquid fertilizer. If fertilized all eight times, each plant received a total of 13 mg N, 3 mg P, 14 mg K plus micronutrients.

Eight randomly selected hybrid aspens with average height of 20 cm in both clones were planted into 5 randomized blocks [0.8 m between plants in a row, 0.8 m between planting dates (rows)] on the harrowed, tilled and fenced nursery field (coarse sandy soil) at two-week intervals from 10 July to 4 September 2001 and the following spring on 16 May 2002. On each date the total number of hybrid aspens planted was 80. Hybrid aspens for spring planting overwintered outdoors. No vegetation treatments were given during the study period.

2.4 Measurements

In all experiments, the height and diameter of each plant were measured at planting and at the end of September for three or four years after planting. The height was measured to the nearest 0.5 cm from ground level to the top of the plant. Diameter was measured to an accuracy of 0.1 mm 2 cm above the soil surface. Each autumn, the survival of plants was also evaluated.

2.5 Weather Conditions

Summer 1998 was colder than the long-term average in Suonenjoki; and precipitation, especially

Table 2. Monthly mean daily temperature (°C), precipitation (mm), 30-year averages and temperature sums (degree days) during planting summers at Suonenjoki Research Station (1998, 1999, 2001) and at Haapastensyrjä (2000).

Month	1998	1999	2000	2001	1974–2003
	Temperature, °C				
May	8.2	6.4	9.8	7.6	9.0
June	13.8	18.4	13.1	14.2	14.2
July	16.2	17.3	15.1	18.7	16.5
August	12.9	13.4	13.0	14.6	14.2
September	10.0	10.6	5.8	10.4	9.1
Temperature sum, d.d.	1161	1391	1106	1346	1220
Date of first autumn frost	27 Sep	17 Oct	7 Sep	25 Sep	
	Precipitation, mm				
May	22.4	27.6	38.6	55.3	37.5
June	54.0	48.9	64.5	61.3	67.6
July	143.2	92.3	84.6	81.4	83.8
August	96.2	25.1	81.2	80.4	80.3
September	17.7	37.5	61.1	60.4	57.8

in July, was very high (Table 2). The summers of 1999 and 2001, on the other hand, were warm. In 1999, the precipitation in August and September was low.

2.6 Statistical Analysis

All experiments were established according to a split-plot design within randomized blocks. In each block, the main effect in the main plots (rows) was planting week and in the subplots (subrows) it was clones. In each block, each planting week was applied once. In a split-plot design within blocks there is random variation between blocks, between main plots and between subplots. A fourth level of variation is the random variation between plants. This kind of split plot experiment is usually analysed using subplot averages as subplot measurements. In such an analysis, both subplot effects and plant effects will be confounded, but the analysis of treatment effects is valid despite the correlations of plants within the same subplot (experimental unit). In this study, plants were kept in the analysis for two reasons. First, not only the effects due to planting time and to clone but also the variation between plants is interesting as such. Second, due to mortality, the number of plants in different subplots and in different years was different; thus assumption of equal variance of subplot averages would not be valid. Data with this kind of multilevel variation can be analyzed using mixed linear models, which also take into account the implied correlations of measurement units (plants) within the same experimental unit (subplot) and the unequal numbers of plants in different experimental units. SPSS 13.0 for Windows was used for computations. Parameters were estimated using the restricted maximum likelihood method (REML). Fixed effects were tested using the F test statistics. Pairwise comparisons of fixed effects were made by the Bonferroni method.

For data in each year and variable (height, diameter, height and diameter growth) the final model used was

$$y_{ijkl} = \mu + w_j + c_k + wc_{jk} + \gamma_{ijk} + \varepsilon_{ijkl} \quad (1)$$

where μ is the general mean, w_j is the fixed effect of planting week j, c_k is the fixed effect of clone k, wc_{ij} is the interaction of planting week j and clone k, γ_{ijk} is the random subplot effect for the subplot where clone k is planted during week j within block i, ε_{ijkl} is the random effect (residual error) of plant l. Random effects are assumed to have zero mean and constant variance. The initial model tested also included random block effect and random main plot effect, but these were not significant and were excluded from the final model (this also makes interpretation of the results more straightforward). Plants of a clone were in most cases taken into a subplot from one or two trays. Thus in the subplot effect γ_{kij}, both the tray effect (correlation of plants within the same tray) and the true subplot effect (similarity of growing conditions within the same subplot) were confounded.

An interesting question in the analysis of growth curves is how the average curves in different plots diverge and how the curves of individual plants within a plot diverge. The curves diverge if there are both variation in growth and high correlation of growth with previous height (and previous growth). The combination of high variance in growth with low correlation merely causes short-term irregularity in growth curves, but not divergence. Depending on the magnitudes of the plot and plant effects on growth, there are different combinations; e.g. in the different plots the curves can diverge, but within a plot the plant curves are similar. Similar analysis was also applied to the development of diameter.

Root egress was analyzed by one-way analysis of variance. Data for survival and numbers of plants with shoot-tip dieback were not normally distributed and were thus analyzed by nonparametric Kruskall-Wallis test.

3 Results

3.1 Survival and Health of Plants

In most experiments, planting date did not affect the survival of hybrid aspens. In EXP98, before the planting area was fenced in the beginning of August, hares ate all or part of 22 plants. When these plants were excluded, there were no differences in survival between planting dates during

Table 3. Percentage of hybrid aspens with shoot-tip dieback in each clone planted on different dates in 1999 and monitored in the autumn of 2000.

Planting date	Clone A	Clone B	Clone C	Means
8 July	3	3	0	2
16 July	10	3	0	4
22 July	13	3	3	6
29 July	3	7	7	6
5 Aug (PL 25)	13	20	7	13
5 Aug (Tako 913)	30	20	33	28
12 Aug	17	3	17	12
19 Aug	37	13	27	26
26 Aug	7	3	0	3
2 Sep	7	0	0	2
5 May	7	3	7	6
Means	13	7	9	10

Table 4. Mixed model analysis of variance, fixed effects of clone c and planting date w and random subplot effect γ and residual error ε on height (H) at planting (0) and four years (1–4) after planting in the EXP98 experiment.

Variable	Fixed: Source	Fixed: F	Fixed: p	Random: Effect	Random: Estimated variances	Random: p
H0	μ	5610	<0.001	ε	99	<0.001
	w	69	<0.001	γ	76	<0.001
	c	53	<0.001			
	$w \times c$	4	<0.001			
H1	μ	20242	<0.001	ε	120	<0.001
	w	58	<0.001	γ	81	<0.001
	c	33	<0.001			
	$w \times c$	3	<0.001			
H2	μ	13009	<0.001	ε	330	<0.001
	w	4	<0.001	γ	193	<0.001
	c	17	<0.001			
	$w \times c$	1	0.284			
H3	μ	9177	<0.001	ε	868	<0.001
	w	13	<0.001	γ	629	<0.001
	c	10	<0.001			
	$w \times c$	1	0.384			
H4	μ	6709	<0.001	ε	1844	<0.001
	w	11	<0.001	γ	1741	<0.001
	c	7	<0.001			
	$w \times c$	1	0.546			

the three first years (data not shown). In this experiment, three years after planting the survival of the plants was 97%. On the other hand, during the first growing season after planting at the end of September 1999, more hybrid aspens planted in spring had shoot-tip dieback (18%, $p<0.001$) than did those planted in the previous year (from 0% to 3%). In EXP99, clone A had lower survival (92%) than the other clones (99%). In clone A, the hybrid aspens that died were mainly those planted on the first (survival 80%), second (80%) and fifth (70%) planting dates. In clones B and C, survival was high for all planting dates (data not shown). In EXP99, more hybrid aspens with shoot-tip dieback were found, especially for planting dates in August (Table 3). In EXP00, in clone E no significant differences in survival were found between planting dates (survival 96%). In clone F, however, when hybrid aspens had been planted in September, 32% of the plants survived. For other dates, survival after three years was 94%. In EXP01, survival after three years was 99%, and no differences in survival were found between planting dates (data not shown).

3.2 Growth

When hybrid aspens were planted in July, their height and diameter growth increased compared to seedlings planted in August, September or the following spring (Table 4, Figs. 1, 2, 4, 5). In 1998 and 1999, the later in July (the older) the hybrid aspens were planted the taller and thicker they were (Figs. 1 and 2) at the time of planting. Hybrid aspens planted in August and September differed little in height or diameter at the time of planting, but were 30–50 centimetres (cm) taller and 2–3 millimetres (mm) thicker than those planted in July. During the following seasons, hybrid aspens planted before mid-August were 10–50 cm taller and 1–5 mm greater in diameter compared to hybrid aspens planted in late August, September or the following May (Figs. 1 and 2). In 1999, the root egress of clones B and C was also better in hybrid aspens planted in July and early August than in those planted in the end of

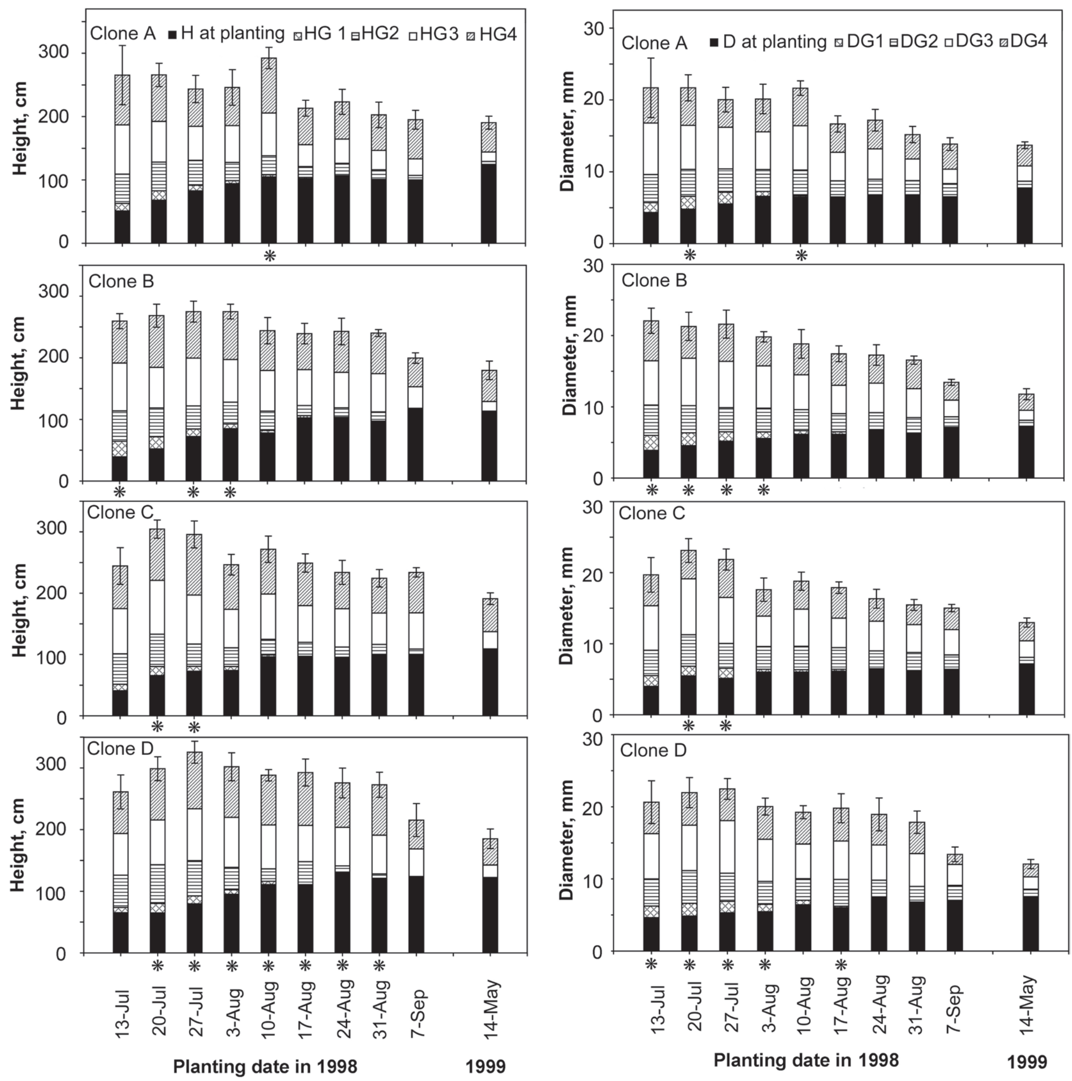

Fig. 1. Annual height and diameter growth of four clones of hybrid aspens planted on an old nursery field in Suonenjoki from mid-July to the beginning of September 1998 and in May 1999. Micropropagated hybrid aspens were grown in 580 cm^3 cells until planting. Error bars indicate ±1 standard errors (SE) of block means (n = 6) of final height or diameter in each clone and planting date. *Statistically significant differences ($p < 0.05$) in total height after 4 years compared to spring planting.

August or in September (for week effect (later referred to as *w*) $p < 0.001$, Fig. 3).

In EXP00, height at the time of planting differed from 19 to 42 cm between planting dates (for *w* $P < 0.001$, Fig. 4). At the time of planting, hybrid aspens of clone F were 1–6 cm shorter and 0.2–0.6 mm thinner than those of clone E (for *c* $P < 0.001$). In later years, however, hybrid aspens in clone F grew 1 to 23 cm more in height (for *c* $P < 0.001$, $P = 0.518$, $P = 0.001$, $P < 0.001$ in the first, second, third and fourth year, respectively) and were taller (for *c* $P < 0.001$) three years after planting. Diameter growth did not differ between clones. After planting in the first summer, hybrid

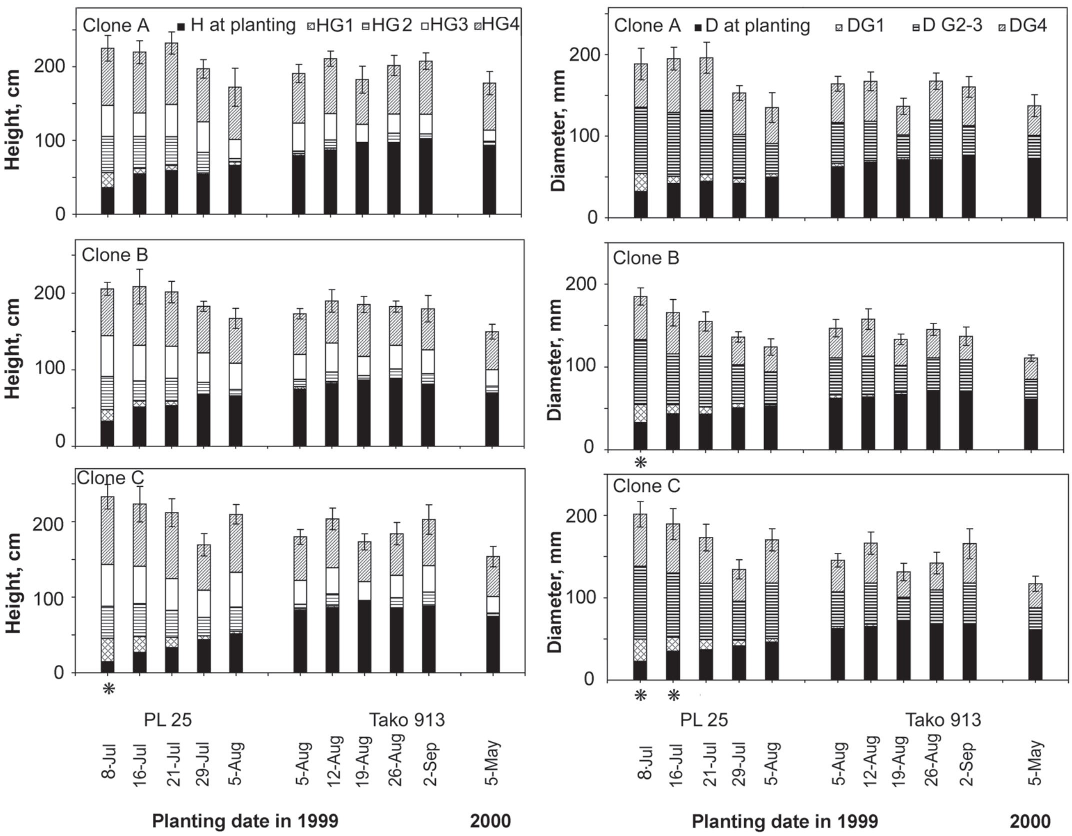

Fig. 2. Annual height and diameter growth of three clones of hybrid aspens planted on an old nursery field in Suonenjoki from mid-July to the beginning of September 1999 and in May 2000. On the first five planting dates, plants grown in smaller containers (380 cm^3) and on later dates (on 5th August both types) plants grown in larger containers (580 cm^3) were planted. Error bars indicate ±1 SE of block means (n=6) of final height or diameter in each clone and at each planting date. *Statistically significant differences ($p<0.05$) in total height after 4 years compared to spring planting.

aspens planted in June and July continued their height growth, but those planted in August and early September did not (for *w* $P<0.001$). Diameter growth of hybrid aspens continued longer, and only hybrid aspens planted in September did not grow after planting (for *w* $P<0.001$). During the following seasons, height growth (for *w* $P<0.001$) was 13–30 cm and diameter growth (for *w* $P<0.001$) was 1–4 mm greater in hybrid aspens planted from the end of June to mid-August than in those planted in September.

In EXP01, height of the plants differed (for *w* $P<0.001$) at the time of planting, but the difference between mean height on different dates was only 1–8 cm. In later years, the later in the growing season the hybrid aspens were planted (the older they were) the less they grew in height (Fig. 5; for *w* $P<0.001$ in all years) and diameter (data not shown; for *w* $P<0.001$ in all years) compared to hybrid aspens planted in September and the following May.

Initially there was little variation in height between plants or between plots (Fig. 6). After planting, when the plants started to grow, the variation in accumulated height increased as did the variation in height growth, but only slightly. The standard deviation of the plant effects on growth was about as large as the standard deviation of the

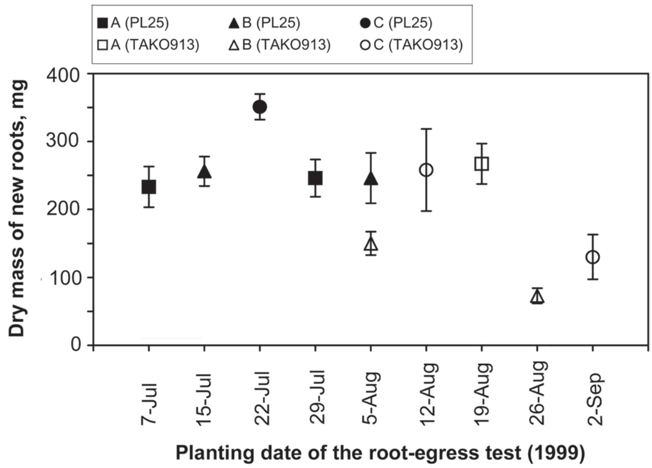

Fig. 3. Dry mass of roots grown out from the peat plug of micropropagated hybrid aspens after three weeks of a root-egress test. Each week, the root egress of one clone was tested. The error bars indicate ±1 SE of root dry-mass means (n = 10 plants in each date).

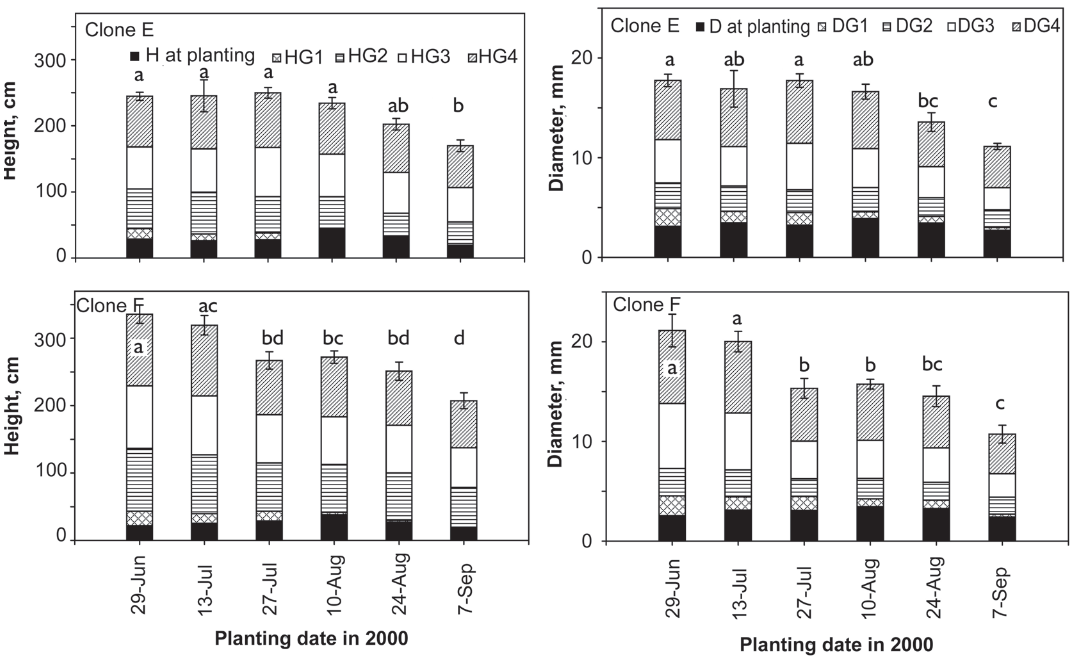

Fig. 4. Annual height and diameter growth of two clones of hybrid aspens planted on a former agricultural field at Haapastensyrjä from the end of June to the beginning of September 2000. For each planting date, aspens were transplanted into Plantek25-trays (cell volume 380 cm^3) filled with Sphagnum peat. Mean height at planting was about 25 cm. Error bars indicate ±1 SE of the block means (n = 6) of final height or diameter in each clone and at each planting date. *Statistically significant differences ($p < 0.05$) in total height after 4 years compared to spring planting.

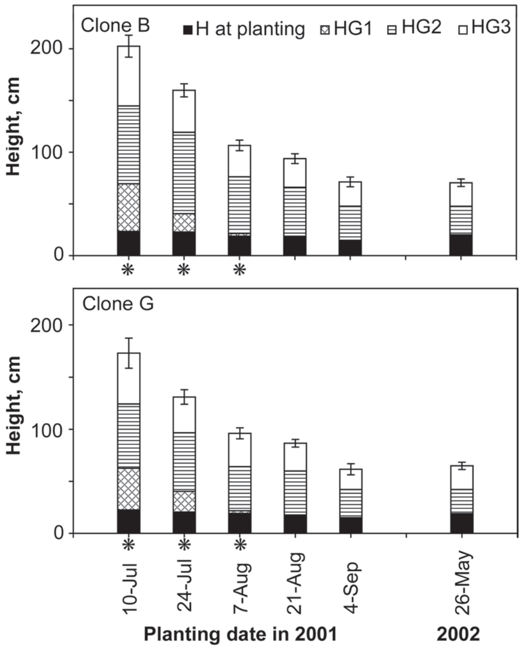

Fig. 5. Annual height growth of two clones of hybrid aspen produced from root cuttings stuck into Jiffy 96 trays (cell volume 115 cm^3) and planted on an experimental field in Suonenjoki from mid-July to mid-September 2001 and in May of 2002. For each planting date, hybrid aspens about 20 cm tall were sampled from both clones. Error bars indicate ±1 SE of the block means (n = 5) of final height in each clone and planting date. *Statistically significant differences ($p < 0.05$) in total height after 3 years compared to spring planting.

plot effects; but for EXP00, where nearby forest shaded the plots and the plants for the blocks were selected according to height, the standard deviations of the plot effects were high.

4 Discussion

Height and diameter growth of summer-planted hybrid aspens was greater than the corresponding growth of those planted in autumn and spring (Figs. 1, 2, 4, 5). The best planting time for both micropropagated hybrid aspens and for those produced from root cuttings was July. At that time, the plants rooted rapidly (Fig. 3) and were not too tall (Figs. 1, 2, 4, 5) in relation to the volume of the root plug. A previous Decision of the Ministry of Agriculture and Forestry set size limits on seedlings for sale in Finland. Quality requirements in the decision determined the acceptable range for median height of a seedling lot in relation to growing density (closely related to cavity volume) for different tree species (Rikala 2000). Seedling lots that did not fulfil these requirements were not sold. The field performance of too-tall seedlings in relation to growing density in the nursery can decrease, as Aphalo and Rikala (2003) showed with silver birch container seedlings. Survival of hybrid aspens planted in summer was at least the same as the survival of those planted in autumn and spring (Table 4). After planting, if the hybrid aspens were healthy at the time of planting and there was no long period of drought after planting, hybrid aspens planted in summer also had decreased risk of shoot-tip dieback.

The present results overestimate the survival potential of hybrid aspen clones in practical plantations, since all experiments were established near the nurseries, the plants were protected against hares and voles by fencing, and in EXP00 the vegetation was controlled each year. In EXP98, hares ate some plants before the area was fenced. Usually, if areas are not fenced, browsing damage is the main reason for low survival of hybrid aspen (Viherä-Aarnio 1999). In addition, competition from field vegetation can damage such aspens (Viherä-Aarnio 1999). In other studies of hybrid aspen with protection, the survival after three to five growing seasons has been about 95% (Hynynen et al. 2002).

In earlier studies of hybrid aspen it was found that many plants experience shoot-tip dieback. In the experiments of Hynynen et al. (2002), for example, after three to five seasons 6% to 23% of the hybrid aspens had shoot-tip dieback. In our study, experiments established in 1998 and 2000, however, only a few plants had shoot-tip dieback. In the experiment established in 1999, one year after planting the rate of shoot tip dieback for hybrid aspens planted in August was high. In that experiment, hybrid aspens had signs of aspen leaf and twig blight in the nursery. Although no infected plants were planted, some plants might

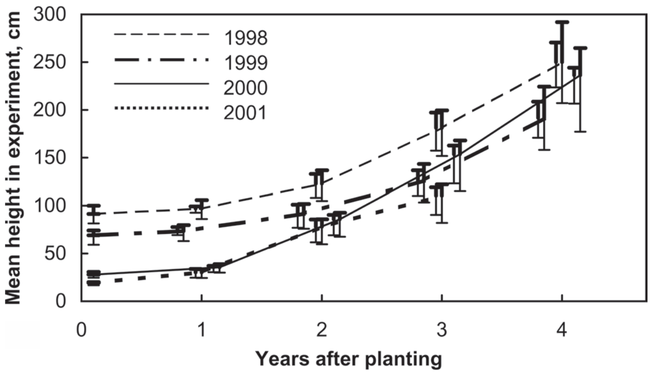

Fig. 6. Mean height in each experiment and standard deviations of random plot and plant effects in different experiments (lines named according to year of establishment). Thick bars indicate deviations of plot effects, and bars of normal thickness below the lines indicate the deviation of plant effects. Bars on the left indicate growth and on the right total height during each autumn when measurements were made.

have been contaminated. In addition, the low level of precipitation in August 1999 (Table 2) exposed the plants to drought after planting. That, together with early night frost (the first on 14 September), may have impaired the health of plants and caused shoot-tip dieback. Hybrid aspens were also tall (>50 cm) at the time of planting (Fig. 2) and had a large leaf area for transpiration (not measured). Although the plants still had quite rapid root egress (Fig. 3), the root volume compared to the leaf area may have been unfavourable during dry and warm weather.

In EXP00, many plants of clone F that were planted in September died. In this experiment parental origin probably explains the difference between clones. The mother of clone F was from Helsinki, while the mother of clone E was from Hirvensalmi (Table 1). The locations of the fathers were not known with certainty, but probably there were not as big differences in location for the fathers as for the mothers. Thus, clone F was more southern than clone E. In 2000, the first autumn frost was on 7 September, and hybrid aspens planted in September were probably not hardy enough to survive autumn frost. Before they can harden, woody plants have to stop their height growth and form buds (Weiser 1970). On the other hand, height growth of first-year woody plants usually ceases when a certain species- and provenance-specific temperature sum has accumulated i.e. the plants are old enough and the night is longer than the critical night length (Koski and Sievänen 1985). There are no studies on hybrid aspens, but if we suppose that the length of the growing season from propagation to cessation of height growth should be at least as long as [probably it is even longer since the total length of growth period of hybrid aspen clones is 41 days longer than that of local aspen (*P. tremula*) in southern Finland (Yu et al. 2001)] in origins of silver birch from southern Finland, it should be 60 days (Partanen 2004). Thus, those hybrid aspens transplanted to trays on 31 July and grown five weeks in the nursery before planting were too young to survive autumn frost.

At planting, hybrid aspens planted in July and early August were shorter and younger (less time since planting of micropropagated plants) than those planted later in autumn and the following spring in EXP98, EXP99 and EXP01 (Figs. 1, 2, 5). Especially in EXP98 and EXP99, those plants that were not planted early did not grow as much during the planting summer as did hybrid aspens that were planted later and were in the nursery longer. In the second season, however, the hybrid aspens planted earlier in summer grew better than the taller and older hybrid aspens planted in autumn and spring (Figs. 1, 2, 5). The growth results found here correspond to those for silver birch (Rikala 1996, Luoranen et al. 2003). In Finland, the soil temperatures are highest during July and August (Luoranen et al. 2003). These temperatures favour the growth of seedlings (Lyr 1996); and when root egress of newly planted hybrid aspens was rapid in July (Fig. 3), hybrid aspens planted in summer rooted well during the planting season. After the middle of August root egress was retarded and rooting was not as good as it had been earlier (Fig. 3). For silver birch seedlings it has been shown that leafless, dormant seedlings have slow root egress (Luoranen et al. 2003), that they use their carbohydrate reserves for leaf growth and that their roots can grow when the leaves have reached full size (Abod et al. 1991). For these reasons, in later years well-rooted plants planted in summer can grow better than those planted in autumn and spring.

For summer planting, hybrid aspens should not be too tall in relation to the plug volume used; otherwise the risk of drought damage increases. Thus, in EXP00 we tried to produce plants of a certain size for each planting date. We noticed, however, that when micropropagation is used, it is not easy, and may be impossible, to predict the condition of seedlings when the plants are ready for planting in summer. In EXP00, our aim was to produce plants separately for each planting date so that they would be 25 cm tall, lignification of the lower part of stem would have started, and the roots would be strong enough to keep the peat plug in one piece at the time of planting. Due to the fact that the weather in the summer of 2000 was rainy and cool, we did not attain this aim (Table 2). Thus, growth after transplanting took longer than expected. For instance, it was not possible to plant seedlings produced for 10 August on that date, but those grown for the previous date were planted instead. However, this probably did not affect the development of hybrid aspens after planting. On the other hand, in EXP01 plants were grown in small-volume plugs, whereupon the long growth period in the nursery before planting may have affected the growth of hybrid aspens planted in August and May (Fig. 5).

Since the plants in EXP00 were about the same size and age on each date, it was possible to analyze the ‘real’ effect of planting date. The increased growth of hybrid aspens planted in July was clear (Fig. 4).

The best site for hybrid aspen is a very fertile, and sites must not have problems with a high water table (Holm 2004). In the Suonenjoki experiments, the sites were not as rich they should have been, but this probably did not affect the aim of this study, which was the comparison of planting dates.

In conclusion, hybrid aspens can be planted in summer without decreased survival and with increased growth (compared to ones planted in autumn and spring) both by using micropropagation and by production from root cuttings. For planting, hybrid aspens produced by micropropagation in the laboratory are expensive, but seedling cost may be reduced by producing hybrid aspens from root cuttings. The method for production of plants from root cuttings could be developed so that the hybrid aspens would be stuck directly into the growing containers, then grown for 2–3 months and planted in summer. For example, Schier (1978) and Stenvall et al. (2004) described how to produce new plants from root cuttings. However, more studies of this production method – in Scandinavian conditions and with present nursery techniques – are needed.

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