Effect of Lifting Date and Time of Storage on Survival and Die-Back in Four Deciduous Species[1]

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Abstract

Woody landscape plants transplanted in urban areas frequently show poor establishment and high mortality rates. The importance of lifting date in combination with cold storage was tested in a trial with four species, European white birch (*Betula pendula* Roth.), red-osier dogwood (*Cornus sericea* L. 'Flaviramea'), singleseed hawthorn (*Crataegus monogyna* Jacq.) and English oak (*Quercus robur* L.). Plants were lifted at 14-day intervals during the fall and divided for different purposes including assessment of root growth potential (RGP) before and after four months of cold storage; evaluation of survival and damages after four months of cold storage; and for evaluation of survival, damage and shoot growth in a field trial. Early lifting in combination with cold storage was negative for the survival and damage to the four species. A longer period of cold storage had a further negative effect on plants lifted early. RGP assessed in the fall could indirectly be used to predict lifting date of European white birch, English oak and red-osier dogwood. RGP after storage could be used to predict field performance in European white birch and English oak. Singleseed hawthorn did not show any differences in RGP.

Index words: plant vitality, physiological quality, dormancy, field survival, root growth potential, lifting date, cold storage.

Species used in this study: European white birch (*Betula pendula* Roth. syn. *B. verrucosa* Ehrh.); red-osier dogwood (*Cornus sericea* L. 'Flaviramea' syn. *C. stolonifera* Michx. 'Flaviramea'); singleseed hawthorn (*Crataegus monogyna* Jacq.); English oak (*Quercus robur* L.).

Significance to the Nursery Industry

Many external factors including plant desiccation, rough handling of plants, high temperatures, and soil compaction at the planting site influence planting. Another important factor is the vitality of the plant and its ability to withstand stress. Plants lifted early in the fall have a lower stress tolerance compared to plants lifted later. European white birch, English oak and red-osier dogwood plants lifted early (mid-September) had both a higher mortality and more die-back injuries, while singleseed hawthorn plants had more die-back injuries, than plants lifted later. We concluded that plants should be lifted when they are dormant and have developed sufficient hardiness. The ideal lifting date could vary among species. In nurseries the ideal physiological lifting date can be in conflict with the time required to manage the harvests.

Results from this study demonstrated that root growth potential (RGP) can be used indirectly for predicting the most appropriate lifting date for European white birch, English oak and red-osier dogwood. RGP cannot be used as a general tool for assessing root growth and plant vitality after storage, but it can be used for specific species such as European white birch and English oak.

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Introduction

In commercial Swedish nurseries, most bare-root plants are lifted during the fall and early winter. Plants are kept in cold storage and shipped in the spring. Several studies have demonstrated that the time of lifting seems to affect the vitality of plants. Sønderhousen and Bøvre (17) demonstrated that lifting date, in combination with cold storage, were important for the survival and time to bud burst in *Fagus sylvatica* L. Puttonen (10) concluded that the effect of a given period of cold storage on survival and growth of *Pseudotsuga menziesii* Franco depended on the lifting date. McKay (8), in studying *Pseudotsuga menziesii*, found that early lifting gave more fine root deterioration during cold storage than late lifting.

Root growth potential is a method introduced by Stone (15) to measure the ability of plants to develop new roots in an optimal environment. This method has been used and modified by several scientists (4, 7, 12), mostly on coniferous species. The ability to develop new roots is considered a key attribute of plant quality (11). RGP can predict field survival of plants, but it has also been argued that RGP predicts only the physiological quality of plants, not the field performance (14). RGP can possibly be used as a tool to measure the state of dormancy in plants. Ritchie et al. (13) showed that in lodgepole pine (*Pinus contorta* Loud.) and interior spruce (a complex of populations with introgressive hybridization of *Picea glauca* (Moench) Voss and *Picea engelmannii* Parry), new root production was higher in October and early November, dropped rapidly at the end of December to its lowest value, and thereafter gradually increased. The results were associated with the onset of dormancy, peaking in late December, then a gradual release followed by subsequent growth.

The aim of this study was to investigate the effects of lifting date in combination with cold storage on four deciduous species. European white birch, singleseed hawthorn and English oak are trees that characteristically have low field survival. Red-osier dogwood is a shrub with no known problems withstanding the stress of standard handling practices. The shrub was included to compare root development and survival with the tree species. The aim was to demonstrate if RGP measured before storage could be used as a quantitative method of predicting the best possible lifting date, and to determine if RGP measured after storage is a reliable method for the assessment of plant vitality in these species.

Material and Methods

One-year-old seedlings of European white birch (*Betula pendula* Roth. prov. Halstenbeck, Germany) and singleseed hawthorn (*Crataegus monogyna* Jacq. prov. Frankfurt, Germany), two-year-old seedlings of English oak (*Quercus robur* L. prov. Uppsala, Sweden), and one-year-old rooted cuttings of red-osier dogwood (*Cornus sericea* L. 'Flaviramea', syn. *C. stolonifera* 'Flaviramea') were purchased from a commercial nursery and were planted in a research field in southern Sweden during the spring of 1996. The soil at the location is classified as a sandy loam, according to USDA classification system (3), containing 2.5% organic matter. Irrigation was used when needed.

During the fall and early winter of 1996, plants were lifted at intervals of 14 days, on seven different occasions starting September 18 for European white birch, red-osier dogwood and singleseed hawthorn, and on six different occasions beginning October 2 for English oak. To avoid additional stress in connection with lifting, plants were kept in a humid and cold environment during the entire period of handling. Plants were lifted in the morning and directly packed in plastic bags. Within two to three hours they were transferred to cold storage. During the handling process, plants were never exposed to room temperature or low humidity. After lifting, plants of each species were taken for immediate assessment of RGP. The number of plants of each lifting date, event and species is shown in Table 1. The remaining plants were packed in open plastic bags and transferred to cold storage. The cold storage was of a jacket cooling type and the temperature was maintained at 0C ± 0.5C with a relative humidity of 100%. The plant packages were kept in darkness during storage.

After four months of storage, plants of each species were removed from storage for a new assessment of RGP. Plants of European white birch, red-osier dogwood and singleseed hawthorn were planted at the same time in containers and put in greenhouse for evaluation of shoot survival. The remaining plants were removed from storage in May and planted in a field trial for evaluation of shoot survival and growth (Table 1) .

Root growth potential before storage and after four months storage. RGP was measured using the standard method (11) described by Stone et al. (16). The testing equipment used was as described by Mattsson (7). Plants were root pruned 20 cm (8 in) below the root neck and planted in stainless steel trays, 3 plants in each tray, filled with a peat and sand (1:1 by vol) substrate. The peat used was mixed with 2 kg/m^3 of dolomite lime. After planting, the water-tight trays were immersed in 20.0C (68.0F) ± 0.5C water baths. Temperature was controlled by a thermostat-regulated immersion heater. Water baths were kept in a growth chamber with an air temperature of 20.0C (68.0F) ± 1.0C, day length of 16 hr and with a light intensity of 100 μmol m^{-2} s^{-1} (cool-white fluorescent tubes, 40W, Phillips). After 28 days, plants were lifted and the root systems examined. As root initiation and root elongation are two different processes (6), two measuring methods were used in this study. To consider both processes, the number of new roots were counted and the three longest were measured.

Storage trial. Plants were removed from cold storage after four months and kept in a temperature of 15C (59F) for 24 hr, where roots were submerged in water, for acclimation. Plants were subsequently root pruned, planted in 3-liter containers, and placed in two replicates in a greenhouse with additional light. The light was provided by high-pressure sodium lamps with a light intensity of 200 μmol m^{-2} s^{-1}. The day length was 16 hr and the minimum temperature was 20C (68F). As the plants were in a greenhouse, the temperature and light intensity varied with natural sunlight. Plants were measured after 28 days. Survival was calculated as the number of living plants. Die-back damage on the living plants was classified according to the percent of bud burst of the stem and lateral branches, with 1 = < 50%, 2 = 50 to < 75%, 3 = 75 to < 100%, and 4 = 100%. Statistical correlation was made between the classification and the actual percentage of living stem to ensure that the classification did not conceal or falsify the actual result. The r = 0.99 in European white birch, 1.00 in English oak, 0.96 in singleseed hawthorn and 1.00 in red-osier dogwood.

Field trial. To simulate normal handling in a commercial nursery, the remaining plants of the four species were removed from cold storage at the end of May. Plants were acclimatized at a temperature of 15C (59F) for 24 hr with their roots submerged in water. Plants were subsequently root pruned and planted in three replicates in a field trial. After eight weeks, plants were measured using the same criteria as mentioned above with an additional measurement of the longest shoot of each plant.

Statistical treatment. All data were statistically analysed using SAS. RGP results were treated with analysis of variance, and Tukey's HSD test was utilized for mean separation

Table 1. Number of plants per event from each lifting date and species. The number of plants in each column is given as plants × replications.

Species	No. of liftings	RGP at lifting	RGP after storage	Greenhouse trial	Field trial	In each lifting	Total
B. pendula Roth. prov. Halstenbeck	7	3 × 3	3 × 3	2 × 8	3 × 8	58	406
C. sericea L. cult. 'Flaviramea'	7	3 × 3	3 × 3	2 × 9	3 × 9	63	441
C. monogyna Jacq. prov. Frankfurt	7	3 × 3	3 × 3	2 × 8	3 × 8	58	406
Q. robur L. prov. Uppsala	6	3 × 2	3 × 2		3 × 6	30	180
Total		33	33	50	93	209	1433

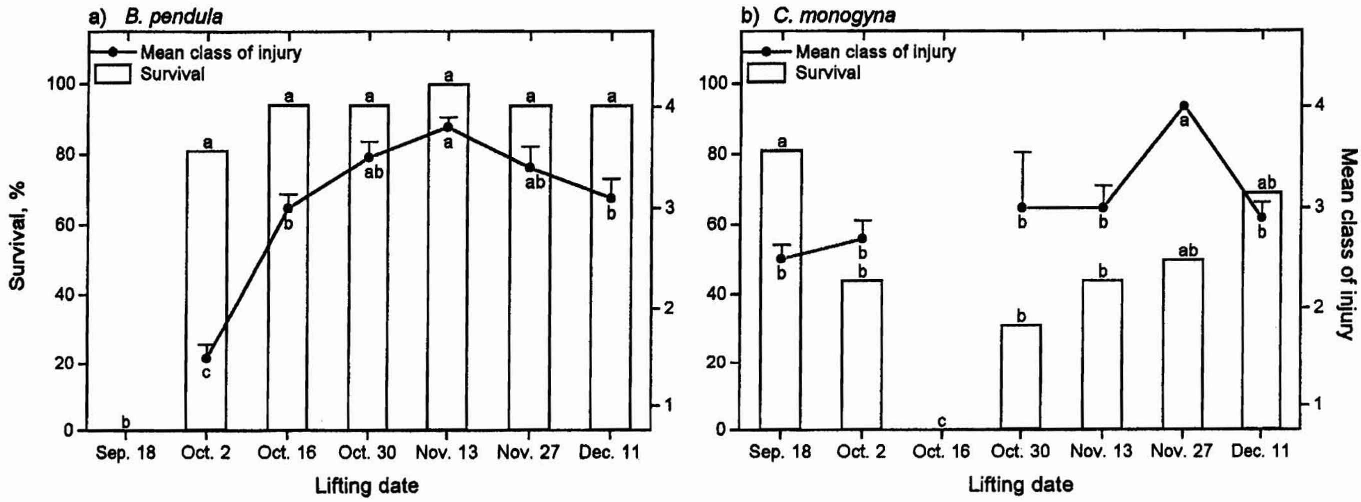

Fig. 1. **Survival and die-back damages related to lifting date and four months of cold storage, in 0C ± 0.5C and 100% relative humidity, for *Betula pendula* Roth. (a) and *Crataegus monogyna* Jacq. (b). Die-back damages are classified from 1 to 4, where 1 is bud burst to <50% of stem and lateral branches and 4 is full bud burst. Error bars represent the standard error of means. Tukey's HSD test was utilized for mean separation of treatments at the 5% level. Different letters show a significant difference.**

of treatments at the 5% level. The same procedures were used for both greenhouse and field trials to determine classification and shoot length. The survival data were treated with tests of homogeneity (2). Correlations were made between the different tests and trials.

Climate. The climate during the fall and early winter was favorable for the development of dormancy, with clear days and relatively cold nights. Differences between the mean maximum temperature and the mean minimum temperature were nearly 10C (50F) in September. Rainfall during this period was 70% of the average and concentrated to short periods.

Results and Discussion

Influence of lifting date in combination with four months storage. All birch plants from the first lifting date died, but plants from the second lifting date had a survival rate of over 80% (Fig.1a). Survival of the plants from the later lifting dates were ≥ 90%. Hawthorn plants had the highest survival when lifted in early or late fall (Fig. 1b), and lowest survival occurred in the third lifting date when all plants died. For red-osier dogwood, lifting date did not seem to have any effect on survival. All plants, independent of lifting date, survived (data not shown).

Birch plants from the second lifting date suffered from extensive die-back (Fig. 1a). The later lifting dates had die-back < 25%, with the best result in plants from the fifth lifting date. Singleseed hawthorn did not show any differences in the amount of die-back, except for the sixth lifting date at which time the plants exhibited no damage (Fig. 1b). Red-osier dogwood plants from the first lifting date showed slight die-back injury, while plants from the remaining lifting dates did not exhibit any damage (data not shown).

There was a strong correlation between survival and the amount of die-back injury in European white birch (r = 0.97), but not in singleseed hawthorn (r = –0.35). In red-osier dogwood the correlation was not quantifiable as there was no difference in survival between lifting dates.

Influence of lifting date and field planting. Time of cold storage ranged from eight months for plants from the first lifting date to five months for plants from the last date. The results demonstrated that early lifting in combination with a long period of cold storage is negative for the survival of European white birch, English oak and red-osier dogwood. Birch plants lifted at the two first occasions were almost completely dead. Only 8% survived from the second lifting (Fig. 2a). The survival of birch plants increased to 95% at fourth lifting and thereafter. Dogwood plants generally had a high survival, with only a relatively small amount of dead plants from the two first lifting dates (Fig. 2b). Similar results were obtained for the English oak plants with the exception of a lower survival in plants from the last lifting date (Fig. 2d). No difference in survival was found in hawthorn between the lifting dates (Fig. 2c).

The amount of die-back was higher for plants lifted early in the fall than lifted later. European white birch had the greatest amount of injury in plants from the second and third lifting. Red-osier dogwood plants showed injuries in the two first lifting occasions. There were more injuries in singleseed hawthorn plants from the first lifting date, with similar results for English oak (Fig. 2a–d).

There was a strong positive correlation between survival and the amount of die-back in European white birch (r = 0.96), redosier dogwood (r = 0.99), and English oak (r = 0.96), but not in singleseed hawthorn, (r = –0.08). The correlation between the greenhouse trial, after four months storage, and the field trial, comparing both survival and injury classes had a Pearson correlation coefficient >0.80, except for singleseed hawthorn in comparing injury classes (Table 2). In red-osier dogwood the correlation between the survival in the two trials was not measurable for reasons previously mentioned.

In comparing the two trials, the results indicated that the effect of a longer period of storage was negative for survival of European white birch but negligible for die-back injury. Red-osier dogwood demonstrated both lower survival and larger amount of die-back with longer period of storage.

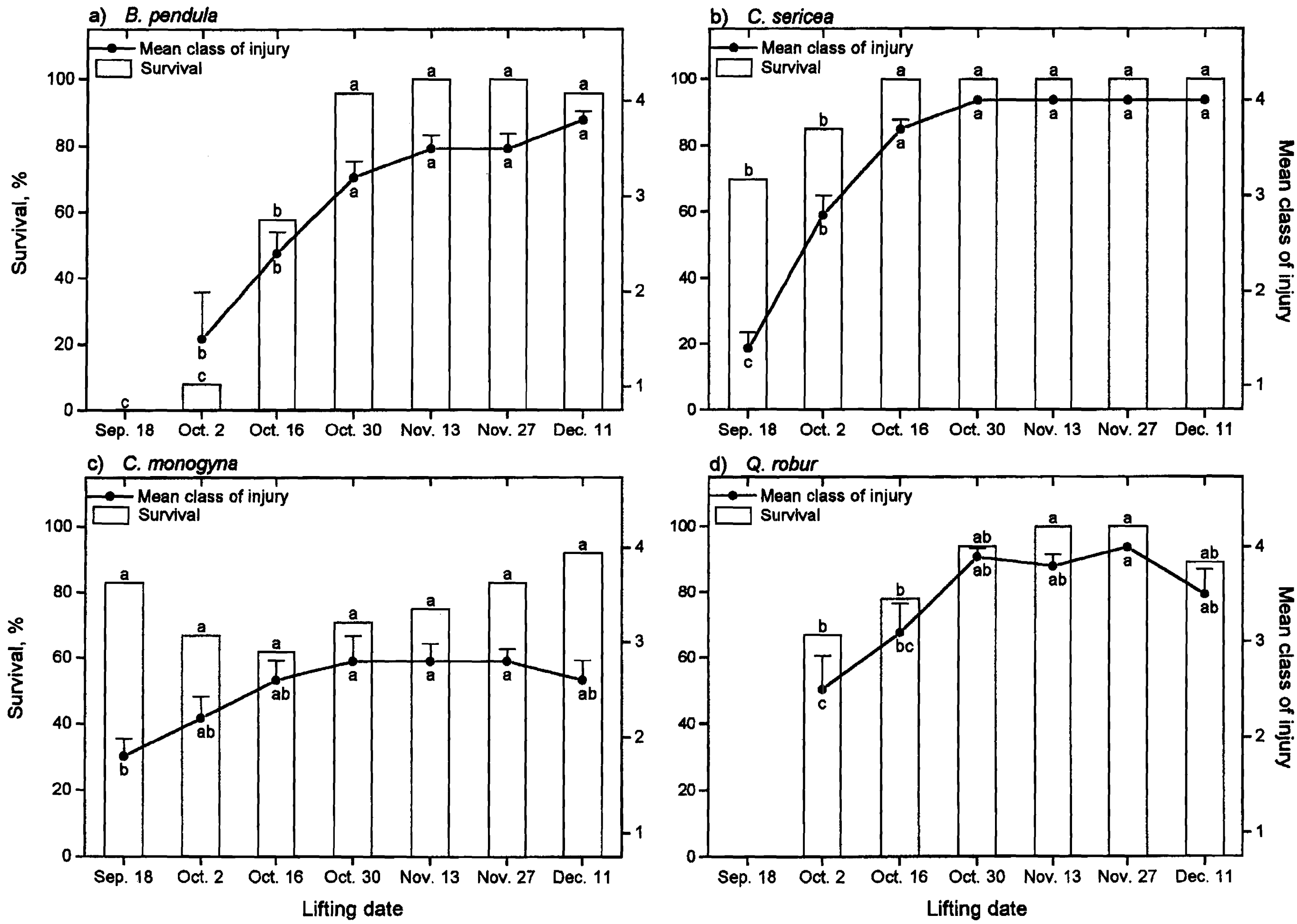

Fig. 2. Survival and die-back injuries related to lifting date and different length of cold storage, in 0C ± 0.5C and 100% relative humidity, with a synchronous planting date in the end of May, for *Betula pendula* Roth. (a), *Cornus sericea* L. (b), *Crataegus monogyna* Jacq. (c.) and *Quercus robur* L.(d). Die-back damages are classified from 1 to 4, where 1 is bud burst to <50% of stem and lateral branches and 4 is full bud burst. Error bars represent the standard error of means. Tukey's HSD test was utilized for mean separation of treatments at the 5% level. Different letters show a significant difference.

Table 2. Correlation, given as Pearson's correlation coefficients, between field trial results and results from RGP at lifting, RGP after storage, and greenhouse trial with four months storage for *Betula pendula* Roth., *Cornus sericea* L. 'Flaviramea', *Crataegus monogyna* Jacq., and *Quercus robur* L.

			Pearson's correlation coefficient					
			RGP at lifting		RGP after storage		Green-house trial	
Species			No. of roots	Root length	No. of roots	Root length	Survival	Class of injury
B. pendula	field trial	survival	–0.48	–0.52	0.97	0.90	0.88	
		class of injury	–0.11	–0.13	0.89	0.76		0.88
C. sericea	field trial	survival	–0.70	–0.71	–0.18	–0.11	—[z]	
		class of injury	–0.75	–0.74	–0.27	–0.19		0.89
C. monogyna	field trial	survival	0.86	0.64	0.48	0.20	0.84	
		class of injury	–0.10	–0.50	0.43	0.74		0.73
Q. robur	field trial	survival	–0.68	–0.32	0.95	0.91		
		class of injury	–0.80	–0.39	0.93	0.92		

[z]No correlation could be made between field trial and greenhouse trial in survival for *C. sericea* due to the lack of difference in survival between different treatments in the greenhouse trial.

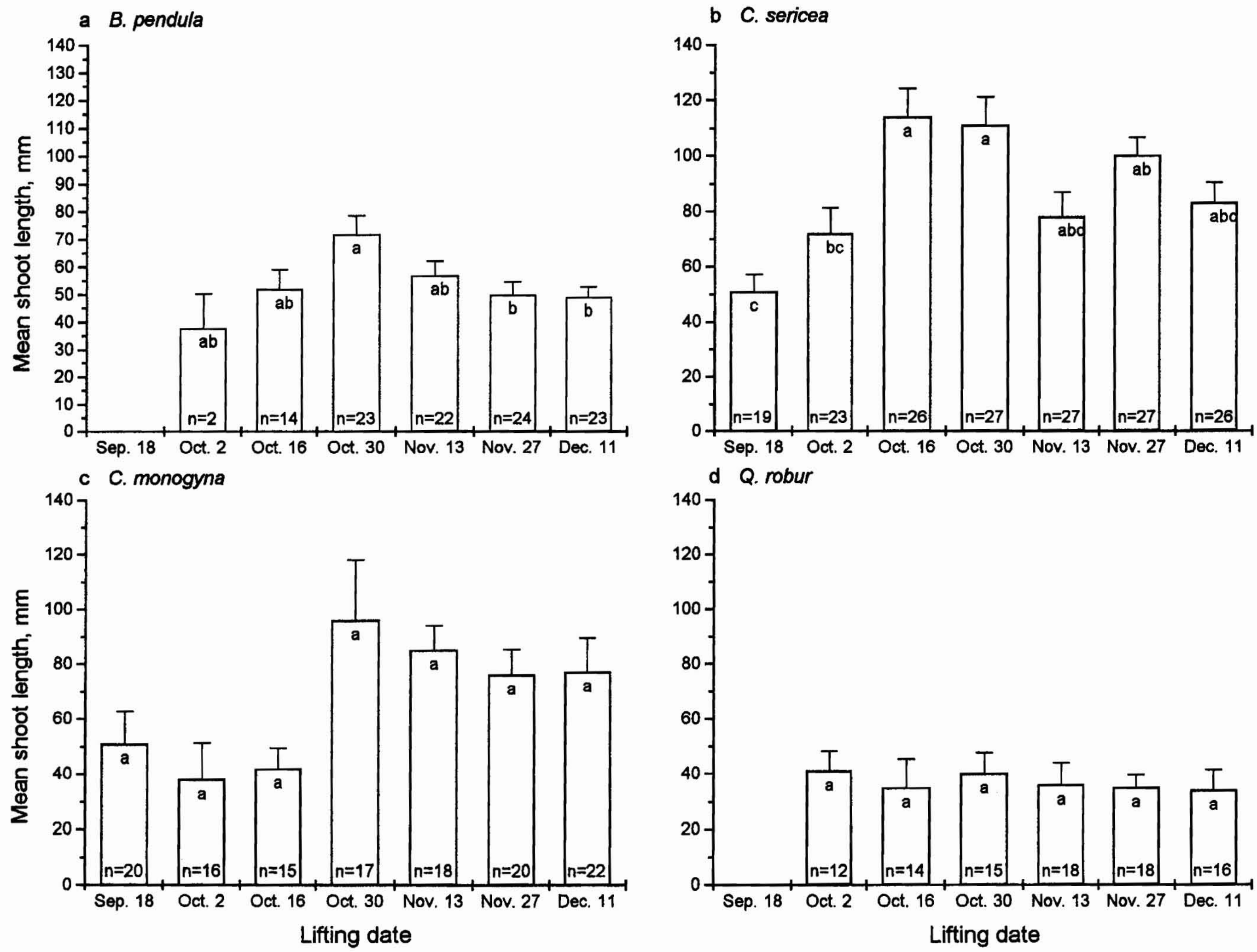

Fig. 3. Shoot growth related to lifting date and different length of cold storage, in 0C ± 0.5C and 100% relative humidity, with a synchronous planting date in the end of May, for *Betula pendula* Roth. (a), *Cornus sericea* L. (b), *Crataegus monogyna* Jacq. (c.) and *Quercus robur* L. (d). Error bars represent the standard error of means. Tukey's HSD test was utilized for mean separation of treatments at the 5% level. Different letters show a significant difference.

Results from singleseed hawthorn were more difficult to interpret. In the four-month storage trial there was a 100% mortality in plants from the third lifting date, while there were no differences in survival in the field trial. The greenhouse environment has strong stress factors, with higher temperatures on sunny days with a high solar radiation and a subsequent decrease in relative humidity. There is a possibility that singleseed hawthorn has a higher rate of water loss from the shoots than other species, which makes it more sensitive in the greenhouse environment. Murakami et al. (9) showed that Washington hawthorn (*Crataegus phaenopyrum* Med.) is desiccation sensitive throughout a period from October to February, with only a small decrease in sensitivity in December. Bates et al. (1) showed that Washington hawthorn had a larger stem water loss than Norway maple (*Acer platanoides* L.) during storage, especially during the first two weeks. It may be that singleseed hawthorn is also sensitive to desiccation and can lose too much water through the shoots in an environment with a low relative humidity. Nevertheless, the survival trend, although not statistically significant, was similar in both the field and the greenhouse, which is shown by a Pearson correlation coefficient of 0.84. Singleseed hawthorn plants from the first lifting date had a high survival rate, compared to the other species. As previously mentioned, plants in this study were handled with great care to avoid exposure to desiccation stress. Results might differ if the plants had been handled according to normal nursery practices and exposed to more severe stress. The surviving hawthorn plants from the first lifting date suffered from extensive die-back, indicating they were weak and probably could not withstand more exposure to stress. Yet the high survival percentage was surprising, and if the amount of die-back is due to the time in cold storage, then the result may indicate that singleseed hawthorn could be lifted early in the fall and successfully replanted immediately or within a few days.

The longest shoots in European white birch were found in plants from the fourth lifting date (Fig. 3a). The lack of statistical difference between plants from the second lifting date and plants from the fourth lifting date was probably due to low survival rate, i.e., a small number of observations from the second lifting. Red-osier dogwood had its longest shoots in plants from the third and fourth lifting occasions (Fig. 3b). No differences were observed in singleseed hawthorn and English oak (Fig. 3c–d). Growth peak for European white birch and red-osier dogwood appears in the beginning of the period of lifting occasions when there is zero-to-minor damage to the plants and zero-to-few dead plants. For the birch plants, later lifting dates resulted in a decrease in growth.

Root growth potential at the time of lifting. According to the General Linear Models procedure, there were differences at a 5% significance level between lifting dates for number of roots in European white birch. These differences were not apparent in a mean separation of treatments using Tukey's HSD-test as this test was not strong enough to show the differences. A linear regression test showed a clear difference between lifting date 1 to 5, $Pr > |T| = 0.002$. Furthermore, a difference became apparent when using a 95% confidence interval of a contrast of means between lifting date five and lifting dates six and seven. There was a decrease in number of new roots from the first lifting date to the fifth, then an increase in the two last occasions (Table 3). The increased number of new roots in the later lifting dates is in agreement with the results of Harris et al. in their study on paper birch (*Betula papyrifera* Marsh.). Harris et al. showed that root initiation increased with increased storage, up to 10 weeks, in plants lifted in mid-November (5). In English oak the number of new roots were lower in plants from the two last lifting dates than in plants from the first (Table 3). Red-osier dogwood had a higher root growth, i.e., both number of roots and root length, in plants from the three earliest lifting dates (Table 3). There was no differences in root growth of singleseed hawthorn (Table 3).

Results from the number of new roots for European white birch, English oak and red-osier dogwood agree with that of Ritchie et al. (13) with lodgepole pine and interior spruce, i.e., a high number of new roots in October, followed by a decrease in number of new roots to its lowest value in December, and thereafter an increase. European white birch differed from the results of Ritchie et al. (13) as the lowest RGP value appeared in mid-November as opposed to late December, probably due to different species, provenances, and climates during the trials. For English oak and red-osier dogwood, the lowest number of new roots were obtained in mid-November, but there was no increase in number of new roots in the later lifting dates. The differences in number of new roots for European white birch and English oak were small, though significant, while the difference was quite clear in red-osier dogwood, with a $P > F = 0.0001$ in the analysis of variance. This demonstrates quite clearly the advantage of using clonal material compared to seedlings.

In European white birch and red-osier dogwood there was a close relationship between mean number of new roots and mean root length (Table 3). The relationship between field performance and RGP at lifting was not very close for European white birch (Table 2), while red-osier dogwood and English oak had a stronger correlation. For these three species the correlation was negative, indicating that RGP at lifting could be used to predict the most appropriate lifting date for these species. Singleseed hawthorn had a good positive correlation between field survival and the RGP results, but as there were no differences in field survival or in RGP, RGP cannot be used for predicting the lifting date.

Root growth potential after cold storage. European white birch had almost no root growth in plants from the two first lifting dates. After the second lifting date, root growth increased rapidly and reached its maximum in plants from the fourth lifting date. In English oak, maximum root growth occured in plants from the fifth lifting date (Table 4). Red-osier dogwood had its root growth peak in plants from the third lifting date, then root growth decreased steadily until the seventh lifting date where there appeared to be no root growth. There were no differences in root growth between lifting dates in singleseed hawthorn. In all four species there was a close relationship between the mean number of new roots and mean root length (Table 4).

There was a close relationship between field performance, both in survival and amount of die-back, and RGP after storage for European white birch and English oak (Table 2). Red-osier dogwood and singleseed hawthorn had little correlation between field performance and RGP after storage. All species except singleseed hawthorn had weak root growth

Table 3. Root growth in RGP test, measured as mean number of new roots (a) and as mean length of the three longest roots (b), immediately after lifting for *Betula pendula* Roth., *Cornus sericea* L. 'Flaviramea', *Crataegus monogyna* Jacq. and *Quercus robur* L.

	B. pendula		*C. sericea*		*C. monogyna*		*Q. robur*	
Lift date	a Mean number of roots (n = 9)	b Mean root length mm (n = 9)	a Mean number of roots (n = 9)	b Mean root length mm (n = 9)	a Mean number of roots (n = 9)	b Mean root length mm (n = 9)	a Mean number of roots (n = 6)	b Mean root length mm (n = 6)
September 18	20a[z]	59a	50a	123ab	11a	19a	—	—
October 2	16a	38a	50a	159a	7a	15a	28a	68a
October 16	11a	34a	46a	106b	5a	6a	12ab	57a
October 30	5a	20a	15b	31c	8a	16a	16ab	55a
November 13	3a	12a	0c	0c	11a	9a	14ab	51a
November 27	16a	51a	0c	0c	8a	11a	10b	68a
December 11	20a	40a	1c	5c	18a	20a	10b	52a
Correlation coefficients between a and b	0.91[y]		0.98		0.62		0.48	

[z]Tukey's HSD test was utilized for mean separation of treatments at the 5% level. Different letters show a significant difference.

[y]Correlation between mean number of new roots and mean length of the three longest roots is given as Pearson's correlation coefficients.

Table 4. **Root growth in RGP test, measured as mean number of new roots (a) and as mean length of the three longest roots (b), after four months cold storage, in 0C ± 0.5C (32 F) and 100% relative humidity, for *Betula pendula* Roth., *Cornus sericea* L. 'Flaviramea', *Crataegus monogyna* Jacq. and *Quercus robur* L.**

	B. pendula		*C. sericea*		*C. monogyna*		*Q. robur*	
Lift date	a Mean number of roots (n = 9)	b Mean root length mm (n = 9)	a Mean number of roots (n = 9)	b Mean root length mm (n = 9)	a Mean number of roots (n = 9)	b Mean root length mm (n = 9)	a Mean number of roots (n = 6)	b Mean root length mm (n = 6)
September 18	1b[z]	4c	14ab	18ab	23a	17a	—	—
October 2	1b	15c	11b	13bcd	6a	9a	7b	32b
October 16	24a	61bc	25a	32a	22a	30a	17ab	74ab
October 30	42a	149a	14ab	21ab	28a	49a	25ab	76ab
November 13	38a	87ab	6b	15bc	17a	23a	30a	90a
November 27	32a	95ab	1b	3cd	32a	44a	25ab	94a
December 11	32a	94ab	0b	0d	28a	34a	22ab	71ab
Correlation coefficients between a and b	0.95[y]		0.97		0.89		0.92	

[z]Tukey's HSD test was utilized for mean separation of treatments at the 5% level. Different letters show a significant difference.

[y]Correlation between mean number of new roots and mean length of the three longest roots is given as Pearson's correlation coefficients.

and weak field performance in plants from the early lifting dates, then the root growth increased and field performance increased to the peak point or plateau, which occurred at the same lifting date for each species (Fig. 2 a, b, and d and Table 4). The decrease in root growth in plants lifted at later lifting dates can perhaps be explained by a relationship between dormancy and root growth, with renewed activity and increased sink strength in the buds as proposed by Ritchie et al. (13). The results indicated that RGP after storage cannot be used as a general tool for predicting field performance, but it could be applicable for specific species, such as European white birch and English oak.

The lifting date, in combination with a period of cold storage, is important for survival and plant damage of the four species investigated in this study. Plants lifted early in the fall had a higher mortality in European white birch and English oak, and more die-back damage in all four species, than plants lifted late in the fall. Longer periods of cold storage for plants lifted early in the fall had a further negative effect on survival in European white birch, English oak and red-osier dogwood, and on plant damage in all four species. If the increased root growth in the beginning of the fall was due to the plants not yet having achieved rest as proposed by Ritchie et al. (13), then the lifting date in the fall or early winter, when plants have none or little root growth, should indicate dormant plants with the highest possible stress tolerance. Finally, results of this study showed that RGP at lifting could be used for indirectly predicting the most appropriate lifting date for European white birch, English oak and red-osier dogwood. RGP after storage can be used to predict survival and plant damage in European white birch and in English oak.

Literature Cited

1. Bates, R.M., A.X. Niemiera, and J.R. Seiler. 1994. Cold storage method affects root and shoot water potential of bare-root hawthorn and maple trees. J. Environ. Hort. 12:219–222.

2. Blom, G. 1989. Probability and Statistics, Theory and Applications. Springer-Verlag. NY.

3. Brady, N.C. 1984. The Nature and Properties of Soils. Macmillan Publishing Company, Inc. NY.

4. Burdett, A.N. 1979. New methods for measuring root growth capacity: their value in assessing lodgepole pine stock quality. Can. J. For. Res. 9:63–67.

5. Harris, J.R., N.L. Bassuk, and T.H. Whitlow. 1993. Effect of cold storage on bud break, root regeneration and shoot extension of Douglas fir, paper birch and green ash. J. Environ. Hort. 11:119–123.

6. Larson, M.M. 1975. Pruning northern Red oak nursery seedlings: effects on root regeneration and early growth. Can. J. For. Res. 5:381–386.

7. Mattsson, A. 1986. Seasonal variation in root growth capacity during cultivation of container grown *Pinus silvestris* seedlings. Scand. J. For. Res. 1:473–482.

8. McKay, H.M. 1993. Tolerance of conifer fine roots to cold storage. Can. J. For. Res. 23:337–342.

9. Murakami, P., T.H.H. Chen, and L.H. Fuchigami. 1990. Desiccation tolerance of deciduous plants during postharvest handling. J. Environ. Hort. 8:22–25.

10. Puttonen, P. 1987. Abscisic acid concentration in Douglas-fir needles in relation to lifting date, cold storage. And postplanting vigor of seedlings. Can. J. For. Res. 17:383–387.

11. Ritchie, G.A. 1984. Assessing seedling quality. pp. 243–259. *In*: Forest Nursery Manual: Production of Bareroot Seedlings. Dr. W. Junk Publishers, The Hague, Netherlands.

12. Ritchie, G.A. and J.R. Dunlap. 1980. Root growth potential: its development and expression in forest tree seedlings. N. Z. J. For. Sci. 10:218–48.

13. Ritchie, G.A., J.R. Roden, and N. Kleyn. 1985. Physiological quality of lodgepole pine and interior spruce seedlings: effects of lift date and duration of freezer storage. Can. J. For. Res. 15:636–645.

14. Simpson, D.G. and G.A. Ritchie. 1997. Does RGP predict field performance? A debate. New Forest 13:253–277.

15. Stone, E.C. 1955. Poor survival and the physiological condition of planting stock. Forest Sci. 1:90–94.

16. Stone, E.C., J.L. Jenkinson, and S.L. Krugman. 1962. Root regenerating potential of Douglas-fir seedlings lifted at different times of the year. Forest Sci. 8:288–297.

17. Sønderhousen, E. and O. Bøvre. 1980. Vinteropbevaring af bøg (*Fagus sylvatica* L.). (Winter storage of European beech (*Fagus sylvatica* L.)). Statens Planteavlsforsøg, vol. 82, report 1552.