EFFECTS OF STORAGE TEMPERATURES AND DURATION ON THE PERFORMANCE OF BARE-ROOT DECIDUOUS HARDWOOD TREES

by John M. Englert, Leslie H. Fuchigami and Tony H. H. Chen

Abstract. Two-year-old Norway maple (*Acer platanoides*), red oak (*Quercus rubra*), European mountain ash (*Sorbus aucuparia*), paper birch (*Betula papyrifera*), and Washington hawthorn (*Crataegus phaenopyrum*) seedlings were stored bare-root at temperatures of +4, 0 -2, and -4C for 0, 3, or 6 months. Survival and regrowth of plants stored at 0, -2, or -4C was better than at +4C. Survival, root regrowth, and % budbreak were maintained at pre-storage levels when Norway maple, red oak, European mountain ash, and paper birch were stored at -4C, and when Washington hawthorn was stored at -2C. Among the species tested, Norway maple and European mountain ash appeared most tolerant, red oak slightly less tolerant, and paper birch and Washington hawthorn the least tolerant of postharvest cold storage. Among Norway maple, red oak, and Washington hawthorn, tolerance to postharvest handling conditions appeared to be related to the depth of dormancy and a lower natural xylem water potential during the winter season. Increasing the length of time in storage reduced root regrowth and % budbreak, and increased plant mortality, stem dieback and the number of days to budbreak for most species stored at all test temperatures.

Index Words: Cold storage, budbreak, root regrowth

Bare-root nursery plants harvested in the fall and winter are often stored for up to six months in cold storage. Several studies have found that there are differences in the performance of different conifer and hardwood species after long-term cold storage (9,13). Species differences are often associated with differences in physiological status and genetics of plants. Ritchie et al. (9) found that lodgepole pine (*Pinus contorta*) acquired deeper rest, had a higher root growth potential, was more desiccation resistant, and had higher performance ratings than interior spruce (*Picea glauca engelmannii* complex) after 6 months of -1°C storage.

Most woody plants are stored at temperatures at or near freezing. The optimum temperature to ensure maximum performance after long-term storage can differ between species. Webb and von Althen (13) found the optimum temperature for storage of *Fraxinus*, *Acer*, *Quercus*, and *Betula* species to be around 0.5°C, but 5°C for *Juglans*. Long-term storage at -5 and -10°C was generally detrimental to the survival of these species.

The objectives of this study were to determine the effects of storage temperatures and storage duration on the survival and performance of five species of deciduous hardwood trees varying in storability in regular nursery facilities. In addition, dormancy status and xylem water potential were monitored with three of these species through one winter season to determine if differences in these physiological conditions were related to differences in storability among species.

Materials and Methods

Physiological Status of Plants. One-year-old seedlings of Norway maple (*Acer platanoides*), red oak (*Quercus rubra*), and Washington hawthorn (*Crataegus phaenopyrum*) were harvested bare-root monthly from 17 Sept. 1990 to 12 Apr. 1991 at the J. Frank Schmidt Nursery, Boring, Oregon. Immediately after harvest, 10 cm length terminal stem tip was excised from 10 plants of each species, and mid-day xylem water potential was measured with a pressure chamber (PMS Instrument Co., Corvallis, Oregon). Soil was washed from the roots of 15 additional plants of each species, and the seedlings were placed in polyethylene bags (0.035 mm [1.4 mil] thickness), and transported to Corvallis, Oregon. The seedlings were then potted into 3.8-liter plastic pots in a medium of peat:loam soil:washed sand:#8 screened pumice (1:1:1:2 v/v). Plants were placed in a greenhouse with a 21/15°C (day/night) regime and a daylength extended to 16 h with sodium vapor lamps. Media moisture was maintained near container capacity. Light intensity at plant height measured 1200 hours was approximately 100 $\mu E/m^2/S$ (475 fc). The number of days to first budbreak was recorded for each plant and used as a measure of the dormancy status of each species (3). In these studies, dormancy (rest, endodormancy) refers to the inability of plants to grow under optimum conditions, i.e. taking longer than 10 days to first budbreak.

Cold Storage Experiments. Two-year-old seedlings of Norway maple, red oak, Washington hawthorn, European mountain ash (*Sorbus aucuparia*), and paper birch (*Betula papyrifera*) were harvested bare-root in Dec. 1990 or Jan. 1991 at Schmidt's Nursery. After harvest, plants were stored on pallets in a cold room maintained at 1°C and ca. 98% relative humidity. On 8 Feb. 1991, 135 plants of each species were placed in polyethylene bags and transported to Corvallis, Oregon. Fifteen plants of each species were immediately potted and placed in a greenhouse as previously described; the remainder of the plants were stored overnight in polyethylene bags in a cooler maintained at 0°C. The following day, plants in each species were randomly assigned to groups to be stored at +4, 0, -2, and -4°C for 3 or 6 months. Plants were placed in double-layered polyethylene bags (total of 0.07 mm (2.8 mil) thickness) and then stored in one of the four storage chambers. Relative humidities, measured with a hygrothermograph (Model H311, Weather Measure Corp., Sacramento, California), were approximately 95, 95, 85, and 50% in the +4, 0, -2, and -4°C storage rooms, respectively. After storage plants were potted and placed in a greenhouse as previously described.

The number of days to first budbreak was recorded for each potted plant. After three months, all plants were evaluated for survival and regrowth by four criteria, including A) *Survival*, where 0 = dead and 1 = root or shoot growth present; B) *Dieback/plant*, where 1 = no stem dieback, 2 = budbreak from the base to the top 3/4 of the stem, 3 = budbreak from the base to the middle of the stem, 4 = budbreak at the base of the stem, and 5 = no budbreak, the plant was dead; C) *% budbreak*, where budbreak = buds broken/total number of buds; and D) *Root regrowth*, where 0 = no new root growth, 1 = new primary roots <10 mm in length, 2 = primary roots >10 mm, secondary roots beginning to form, 4 = root ball forming, and 5 = root mass well developed.

Statistical Design and Analysis. Storage duration (TIME) and storage temperature (TEMP) variables were implemented in a 3 x 4 factorial arrangement for each species. Three replications of five plants/replication were used for each treatment. Survival and regrowth data were subjected to an analysis of variance using general linear model (GLM) procedures of SAS (10). The least significant difference (LSD) at $P = 0.05$ was used to separate means for TIME and TEMP treatments within each species. LSD bars were not included in figures when the model was insignificant or there was no significant difference between the means.

Results

Dormancy Status. Based on the regrowth test results, maximum rest (endodormancy) was acquired in mid-October for Norway maple and red oak, and mid-November for Washington hawthorn (Fig. 1). Norway maple achieved the deepest degree of rest (>300 days to first budbreak), followed by red oak (165 days to budbreak), and lastly Washington hawthorn (30 days to budbreak) (Fig. 1). All species had overcome rest by December.

Xylem Water Potential. Xylem water potentials (XWP) of field-grown Norway maple, red oak, and Washington hawthorn seedlings were higher than -0.6 MPa in Oct. 1991 (Fig. 2). XWP of maple seedlings became more negative in November, and remained ca. -1.5 MPa until returning to the initial level in mid-March. XWP of red oak steadily became more negative, reaching a maximum of -3.4 MPa in mid-February and then became higher (less negative), though not to the initial level. XWP of Washington hawthorn changed only slightly from October through April, and was never below -0.6 MPa.

Effects of Storage Duration on Plant Performance. There were significant ($P>F = 0.01$) differences between species, time in storage, and storage temperatures for nearly all survival and regrowth measurements (Table 1). Changes in

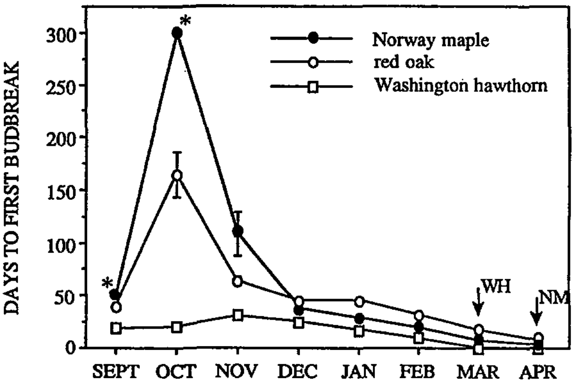

Fig. 1. Changes in dormancy (measured by days to budbreak) of field harvested one-year-old Norway maple, red oak, and Washington hawthorn seedlings. Asterisk (*) indicates that DBB was not evaluated longer than the time indicated. Arrows indicate approximate time of budbreak in the field. Vertical bars indicate SE; lack of bars indicates low SE.

survival and regrowth after 3 and 6 months storage are presented for 0C storage only, as this is the temperature most commonly used by nurserymen. Measurements at +4, -2, and -4°C followed trends similar to 0°C (data not presented).

Norway maple, red oak, mountain ash, and paper birch trees which were potted without being stored (0 months) had 100% survival, while only 60% of the Washington hawthorn trees survived (Fig. 3A). Survival of all five species decreased as the time of storage at 0C increased, though this decrease was not significantly lower within species (Fig. 3A). Survival of Washington hawthorn trees after each storage treatment was poorest among the species tested (Fig. 3A). Stem dieback increased as the time in storage increased, and was consistently highest with Washington hawthorn trees (Fig. 3B). Similarly, root regrowth declined as storage time increased (Fig. 3C).

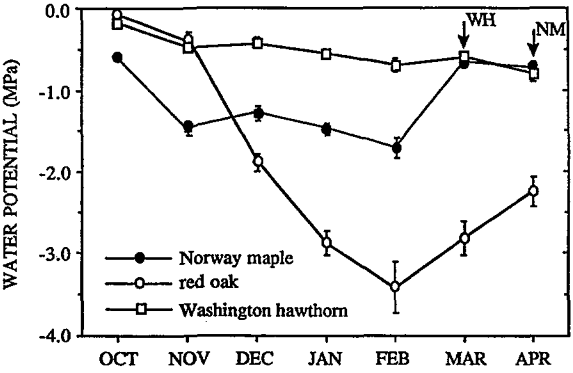

Fig. 2. Changes in xylem water potential of field-grown one-year-old Norway maple, red oak, and Washington hawthorn seedlings. Water potential was measured using the terminal 10 cm of stems from 10 seedlings. Arrows indicate approximate time of budbreak in the field. Vertical bars indicate SE; lack of bars indicates low SE.

Table 1. ANOVA summary and level of significance of survival and regrowth measurement.

source	df	survival	dieback	%BB[z]	DBB[y]	root regrowth
SPECIES	4	**	**	**	**	**
TIME	2	**	**	**	NS	**
TEMP	3	**	**	**	**	**
SPEC*TIME	8	NS	NS	**	NS	**
SPEC*TEMP	11	NS	NS	NS	NS	*
TIME*TEMP	3	**	*	NS	**	NS

z % BB - budbreak = # buds broken after 90 days/total number of buds.
y DBB - days to budbreak.
NS,*,** Nonsignificant, or significant at the $P = 0.05, 0.01$ level, respectively.

There was approximately 15-20% budbreak for Norway maple, red oak, paper birch, and Washington hawthorn, and 70% for mountain ash prior to cold storage (Fig. 4A). Storage at 0°C decreased % budbreak of all species except paper birch, which had an increase, then decrease in % budbreak at 3 and 6 months, respectively (Fig. 4A). Norway maple, mountain ash, and Washington hawthorn trees stored for 6 months took longer to break bud than those which were not stored (Fig. 4B). Red oak and paper birch trees took the same number of days to first budbreak after 0 or 6 months storage, but either broke bud sooner (red oak) or later (paper birch) after 3 months storage (Fig. 4B).

Effect of Storage Temperature on Plant Performance. Storage temperature had a significant (P>F = 0.01) effect on all regrowth measurements (Table 1). TIME*TEMP interactions were also significant for most regrowth measurements (Table 1), but the trends for 3 and 6 months were similar. The differences in the effect of storage temperature were more dramatic with 6 months storage, hence, only these data are presented (Figs. 5 and 6).

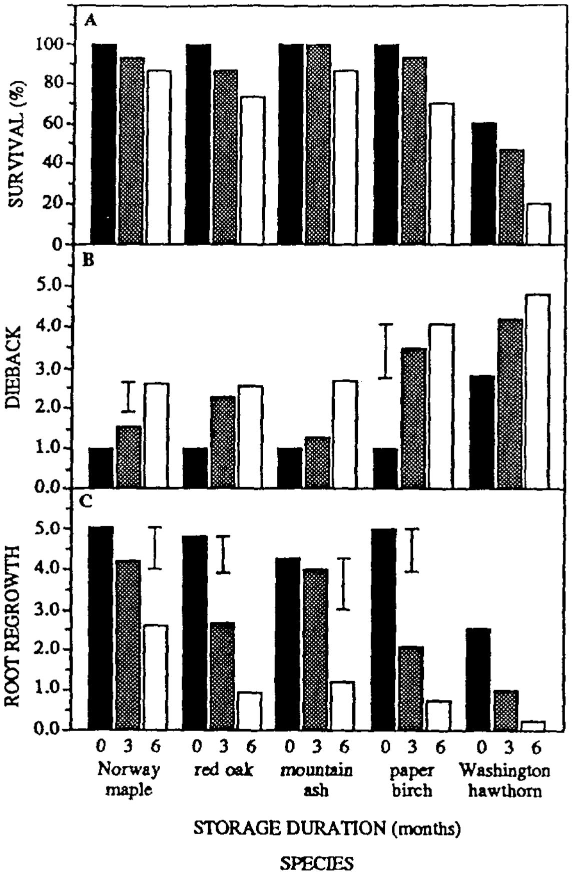

Fig. 3. The effect of storage duration on the survival (A), stem dieback (B), and root regrowth (C) of two-year-old Norway maple, red oak, European mountain ash, paper birch, and Washington hawthorn seedlings. Plants were stored at 0°C for 0, 3, or 6 months. Stem dieback was measured where 1 = no dieback and 5 = plant was dead. Root regrowth scale: 0 = no new roots, 5 = root mass well developed. Vertical bars indicate $LSD_{.05}$ between means within a species. Lack of LSD bar indicates that the model or difference between means was not significant.

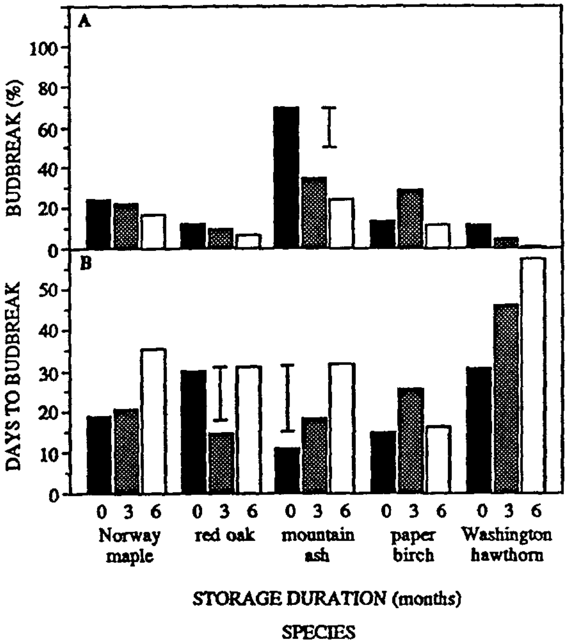

Fig. 4. The effect of storage duration on the % budbreak (A) and days to first budbreak (B) of two-year-old Norway maple, red oak, European mountain ash, paper birch, and Washington hawthorn seedlings. Plants were stored at 0°C for 0, 3, or 6 months. Budbreak (%) = number of buds broken/total number of buds. Vertical bars indicate $LSD_{.05}$ between means within a species. Lack of LSD bar indicates that the model or difference between means was not significant.

Among the storage temperatures tested, survival (Fig. 5A) and root regrowth (Fig. 5C) were lowest and dieback highest for plants stored at +4°C (Fig. 5B). The survival of paper birch was less effected by different temperatures, although dieback was much higher and root regrowth lower than other species over all test temperatures (Fig. 5). Washington hawthorn did not survive storage for 6 months at +4°C, but had the best survival and root regrowth, and lowest amount of stem dieback when stored at -2°C (Fig. 5). Percent budbreak was highest for Norway maple and mountain ash stored at 0, -2, or -4°C, and lowest for red oak and paper birch at these temperatures (Fig. 6A). Storage at -2°C improved the budbreak of Washington hawthorn (Fig. 6A). Storage of Norway maple and mountain ash at -2 or -4°C significantly promoted earlier first budbreak (Fig. 6B). In contrast, storage temperature did not affect time of first budbreak for red oak, paper birch, or Washington hawthorn trees (Fig. 6B). Differences in dormancy status, based on the days to first budbreak data, indicated that on 8 Feb. 1991 all species except mountain ash were dormant (Fig. 4B). Chilling at +4 or 0°C increased the length of time to budbreak for most species (Fig. 6B). Chilling red oak at 0°C for 3 months appeared to overcome dormancy, but after 6 months storage increased the time to budbreak (Fig. 4B). Storage at -2 and -4°C significantly reduced the number of days to budbreak for

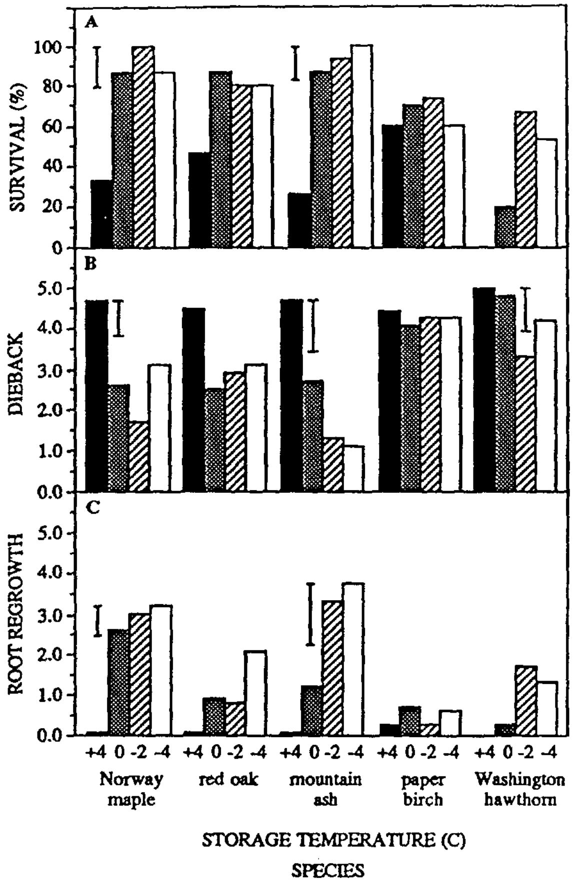

Fig. 5. The effect of storage temperature on the survival (A), stem dieback (B), and root regrowth (C) of two-year-old Norway maple, red oak, European mountain ash, paper birch, and Washington hawthorn seedlings. Plants were stored for 6 months at 4, 0, -2, or -4°C. Stem dieback was measured where 1 = no dieback and 5 = plant was dead. Root regrowth scale: 0 = no new roots, 5 = root mass well developed. Vertical bars indicate $LSD_{.05}$ between means within a species. Lack of LSD bar indicates that the model or difference between means was not significant.

Norway maple (Fig. 6B).

Discussion

Physiological changes, e.g. dormancy status (2,12,13), root regeneration potential (7,12), carbohydrate levels (1,7), cold hardiness (1), and desiccation resistance (9), occur in bare-root woody plants during cold storage. In general the performance of plants decreased with increasing storage duration, especially at +4 and 0C. Although the water status of plants from storage was not assessed, previous studies (13) suggest the primary cause of poor performance following storage at temperatures above freezing might be due to desiccation. Stems examined immediately after storage appeared to be more dehydrated for plants stored at +4 and 0C than plants stored at -2 and -4°C. Webb and von Althen (13) found that storage of plants at 5 or 10°C caused more negative XWPs, ie. greater stem dehydration, than storage at 0.5, -5, or -10°C. In their studies, the differences between these temperature regimes did not affect survival and performance. In our experiments, however, greater stem dieback and mortality occurred at the higher temperatures (Fig. 5).

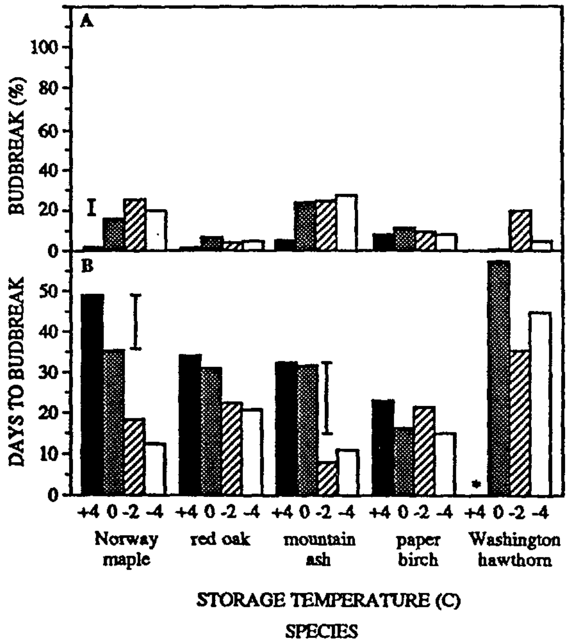

Fig. 6. The effect of storage temperature on the % budbreak (A) and days to first budbreak (B) of two-year-old Norway maple, red oak, European mountain ash, paper birch, and Washington hawthorn seedlings. Plants were stored for 6 months at 4, 0, -2, or -4°C. Budbreak (%) = number of buds broken/total number of buds. Asterisk (*) indicates that plants never broke bud. Vertical bars indicate $LSD_{.05}$ between means within a species. Lack of LSD bar indicates that the model or difference between means was not significant.

Storing bare-root plants at freezing temperatures appears to be beneficial for maintaining growth potential. Storage at -2 and -4°C maintained the survival of plants at levels similar to that found at the beginning of the experiment (compare Fig. 3, 0 months, with Fig. 5). Similar results were noted with dieback, root regrowth, and % budbreak, though to a lesser extent. Root regrowth generally decreased with increasing storage duration at all test temperatures, but was best for all species at -2 or -4°C (Figs. 3C and 5C). Similarly, Ritchie et al. (9) reported that root growth potential decreased in lodgepole pine after storage for 6 months at -1°C.

There were significant differences between the different species in performance following storage. Based on overall performance at all storage temperatures, Norway maple and mountain ash were most tolerant, followed by red oak and lastly by paper birch and Washington hawthorn. Differences in plant tolerance to storage treatments are thought to be related to the physiology of the plants. Ritchie et al. (9) found that differences in root growth potential and stress tolerance between lodgepole pine and interior spruce were positively associated with regrowth performance after freezer storage and transplanting. Murakami et al. (6) reported that Norway maple seedlings achieved deeper dormancy and a more negative XWP under field conditions in mid-winter than did Washington hawthorn seedlings. The differences in dormancy and water potentials between these two species were positively associated with the greater cold hardiness and desiccation tolerance of Norway maple as compared to Washington hawthorn. Other studies have noted that some species of plants have a lower stem water content during the winter season (4,8,11). Such changes in water status may indicate that other physiological or biochemical changes are taking place which will ultimately improve stress tolerance. Natural reductions in plant tissue water content have been thought to improve desiccation tolerance (6) and cold hardiness (14).

In the current studies, dormancy and XWP were determined for Norway maple, Washington hawthorn, and red oak seedlings from October through April (Fig. 2). Washington hawthorn, which did not reach the same level of dormancy (Fig. 1) or as negative of a XWP (Fig. 2) as the other species tested, performed the poorest after cold storage. Even without any storage, survival of Washington hawthorn was only 60% (Fig. 3A). The lower ability of Washington hawthorn to tolerate postharvest handling is generally associated with its lower desiccation tolerance (6). It appears that the failure of Washington hawthorn to make physiological adaptations, i.e. develop a high degree of rest and/or make changes that would cause a more negative XWP, may be one cause for its poor postharvest performance. Based on the differences in XWP of the three species (Fig. 2), and the similarity in performance of Norway maple and red oak after storage, it appears that a certain level of natural reduction in XWP, i.e. around -1.0 MPa, might be indicative of better tolerance to postharvest handling.

Natural stem dehydration could be caused by a variety of factors. Reduction in water uptake during winter is believed to be caused by changes in root resistance and changes in the viscosity of water at lower temperatures (5). The fields where plants were grown maintained moisture levels at or above field capacity throughout the test period. Due to the proximity of the plants growing at the nursery, there was presumably no difference in the temperature of soil water between Norway maple, red oak, and Washington hawthorn which would have affected water uptake. Therefore, it can be assumed that there may be differences between Washington hawthorn, Norway maple and red oak in the resistance of roots to water uptake.

Storage temperature was found to be important for maintaining the growth potential of bare-root nursery plants. Plant performance was best following storage at -2 and -4°C and poorest at higher temperatures. Washington hawthorn was much less tolerant of storage than the other species, which appears to be related to differences in physiological adaptations. These studies suggest that some species, e.g. Washington hawthorn, require alternative methods to improve the survival after postharvest handling.

This study shows significant differences among plant species in the development of dormancy, water status, and storage ability. Red oak and Norway maple had pronounced dormancy while Washington hawthorn had only a slight degree of dormancy. The results suggest that the performance of plants during establishment may be related to their ability to develop dormancy. In another study we also found that the desiccation tolerance of plants may be related to plants ability to develop dormancy (6). To the arborist this may explain why some plants are more difficult to transplant than other plants. In addition to genetic differences in postharvest performance of barerooted nursery plants, marked differences in plant performance was found depending on the duration of storage, and storage temperatures. To the arborist these studies indicate that transplanting plants immediately upon receipt from nurseries may be beneficial to plant performance particularly when proper cold storage facility is not available.

Literature Cited

1. Cannell, M.G.R., P.M. Tabbush, J.D. Deans, M.K. Hollingsworth, L.J. Sheppard, J.J. Philipson, and M.B. Murray. 1990. *Sitka spruce and Douglas fir seedlings in the nursery and in cold storage: root growth potential, carbohydrate content, dormancy, frost hardiness and mitotic index.* Forestry 63(1):9-27.
2. Donnelly, J.R. 1973. *Duration of cold storage alters time required for seedling bud-break.* Tree Planters Notes 24(4):25-26.
3. Fuchigami, L.H. and C.C. Nee. 1987. *Degree growth stage model and rest-breaking mechanisms in temperate woody perennials.* HortScience 22(5):836-845.
4. Kozlowski, T.T. 1958. *Water relations and growth of trees.* J. Forestry 56:498-502.
5. Kramer, P.J. 1940. *Root resistance as a cause of decreased water absorption by plants at low temperatures.* Plant Physiol. 15:63-79.
6. Murakami, P., T.H.H. Chen, and L.H. Fuchigami. 1990. *Desiccation tolerance of deciduous plants during postharvest handling.* J. Environ. Hort. 8(1):22-25.
7. Ritchie, G.A. 1982. *Carbohydrate reserves and root growth potential in Douglas-fir seedlings before and after cold storage.* Can. J. For. Res. 12:905-912.
8. Ritchie, G.A. and R.G. Shula. 1984. *Seasonal changes in tissue-water relations in shoots and root systems of Douglas-fir seedlings.* For. Sci. 30(2):538-548.
9. Ritchie, G.A., J.R. Roden, and N. Kleyn. 1985. *Physiological quality of lodgepole pine and interior spruce seedlings: effect of lift date and duration of freezer storage.* Can J. For. Res. 15:636-645.
10. SAS Institute. 1985. SAS/STAT guide for personal computers, version 6 edition. SAS Institute, Inc., Cary, N.C.
11. Tyree, M.T., Y.N.S. Cheung, M.E. MacGregor, and A.J.B. Talbot. 1978. *The characteristics of seasonal and ontogenic changes in the tissue-water relations of Acer, Populus, Tsuga, and Picea.* Can. J. Bot. 56:635-647.
12. Webb, D.P. 1976. *Effects of cold storage duration on bud dormancy and root regeneration of white ash (Fraxinus americana L.) seedlings.* HortScience 11(2):155-157.
13. Webb, D.P. and F.W. von Althen. 1980. *Storage of hardwood planting stock: effects of various storage regimes and packaging methods on root growth and physiological quality.* N.Z. J. For. Sci. 10(1):83-89.
14. Weiser, C.J. 1970. *Cold resistance and injury in woody plants.* Science 169:1269-1278.

Department of Horticulture
Oregon State University
Corvallis, OR 97331-2911

Résumé. Des semis de deux ans de *Acer platanoides, Quercus rubra, Sorbus aucuparia, Betula papyrifera* et *Crataegus phaenopyrum* étaient entreposés à racines nues sous des températures de 4, 0, -2 et -4°C durant 0, 3 ou 6 mois. La survie et la reprise de croissance des plants entreposés à 0, -2 et -4°C étaient supérieures à celles des plants entreposés à 4°C. Les taux de survie, de reprise de croissance des racines et le pourcentage d'éclosion des bourgeons étaient maintenus à ceux d'avant l'entreposage dans les cas de Acer, Quercus, Sorbus et Betula lorsqu'ils étaient entreposés à -4°C et de Crataegus lorsque entreposé à -2°C. Parmi les espèces testées, Acer et Sorbus apparaissaient être plus tolérants, Quercus légèrement moins, et Betula et Crataegus le moins à un entreposage à froid après récolte. Un accroissement de la durée d'entreposage diminuait la reprise de croissance des racines et le pourcentage d'éclosion des bourgeons, et augmentait la mortalité des plants, le dépérissement des tiges ainsi que le nombre de jours nécessaires à l'éclosion des bourgeons, et ce pour la plupart des espèces entreposées à quelque température que ce soit.

Zusammenfassung. Zweijährige *Acer platanoides, Quercus rubra, Sorbus aucuparia, Betula papyrifera* and *Crataegus phaenopyrum* Sämlinge wurden mit unbedeckten Wurzeln bei temperaturen von +4, 0, -2, und -4 °C für 0, 3 oder 6 Monate eingelagert. Überleben und erneutes Wachstum der eingelagerten Pflanzen war bei 0, -2 oder -4 °C besser als bei +4 °C. Überleben, Wurzelwachstum und Prozentsatz des Knoßpentreiben hielt sich bei Acer, Quercus, Sorbus und Betula bei -4 °C und bei Crataegus bei-2 °C auf dem gleichen Niveau wie vor der Linlagerung. Von den getesteten species reagierten Acer und Sorbus sehr tolerant, Quercus etwas weniger und Betula und Crataegus sehr wenig tolerant auf die Kaitlagerung nach der Rodung. Eine Verlängerung der Lagerungszeitraums reduzierte das Wurzelwachstum und den Prozentsatz des Knospentreibens und beschleunigte die Pflanzenmortalität, das Zurücksterben und die Zeitspanne bis zum Knospentreiben für die meisten der eingelagerten species bei allen getesteten Temperaturen.