STORAGE OF HARDWOOD PLANTING STOCK: EFFECTS OF VARIOUS STORAGE REGIMES AND PACKAGING METHODS ON ROOT GROWTH AND PHYSIOLOGICAL QUALITY

D. P. WEBB and F. W. von ALTHEN

Great Lakes Forest Research Centre, P.O. Box 490, Sault Ste. Marie, Ontario, Canada P6A 5M 7

(Received for publication 25 January 1980)

ABSTRACT

Results of two experiments conducted between 1977 and 1979 on overwinter storage of seven temperate zone hardwood species commonly planted in southern Ontario indicate that temperature of storage and method of packaging can markedly affect physiological quality of planting stock. Root growth capacity and overall growth potential of cold-stored stock at 0.5 and 5°C were comparable with those of normal spring-lifted controls. Storage at temperatures of —5 and —10°C resulted in low root growth capacity and was generally detrimental to seedling performance in comparison with spring-lifted nursery control stock that had been exposed to winter chilling out of doors. At 10°C there was considerable root and bud growth during the storage period from November to April. Of the five packaging methods examined, seedlings totally enclosed, or seedlings with only their roots enclosed within Kraft bags with a plastic liner, with moist peat surrounding the roots, showed the least shoot water stress and generally had the highest root growth capacity. Root growth capacity of stored seedlings of **Acer saccharum** Marsh., **Acer saccharinum** L., **Fraxinus americana** L., **Quercus rubra** L., **Juglans nigra L.,** and **Betula papyrifera** Marsh. was significantly correlated with shoot xylem water potential at time of removal from storage. Shoot xylem water potential appears promising as a rapid measure of physiological quality.

It is recommended that autumn-lifted nursery stock of **Fraxinus americana**, **Acer saccharinum**, **Quercus rubra**, **Tilia americana** L., **Betula papyrifera**, and **Acer saccharum** be stored at a temperature of 0.5°C and **Juglans nigra** at 5°C with a relative humidity of 70-85%. Roots should be surrounded by moist peat and the total seedling tightly enclosed within a Kraft bag with a polyethylene liner.

INTRODUCTION

Silvicultural techniques have been developed for the successful establishment of a wide range of upland temperate zone hardwood species on open field sites in southern Ontario (von Althen, 1979). Although improved growth of most hardwood species can be obtained by cultural treatments such as site preparation and weed control, these treatments have been only partially successful with some species such as sugar maple (*Acer saccharum* Marsh.). The dependence of survival and subsequent shoot growth of outplanted seedlings upon the rapid establishment of a vigorous root system is now well recognised. However, damage to root systems and poor root growth remain frequent causes of seedling stagnation and contribute to the ineffectiveness of many cultural practices (Lyr and Hoffmann, 1967; Webb and Dumbroff, 1978; Webb and von Althen, 1978). Growth check following planting is especially common with a number of hardwood species and has led to several investigations of root development and seedling establishment (Farmer, 1975; Larson, 1970, 1975, 1977; Rietveld and Williams, 1978; Webb, 1976a, b, 1977; Webb and von Althen 1978). These studies indicate that early shoot extension of several species of hardwood planting stock is strongly correlated with the plant's ability to produce new roots at time of outplanting.

Recent attempts to establish sugar maple on open-field sites in southern Ontario have shown that time of spring planting is critical to successful establishment (Webb and von Althen, 1978). This species undergoes an early spring flush of root growth (Taylor and Dumbroff, 1975) and under current planting practice in Ontario, seedlings are lifted and planted after this burst of root activity has occurred (Dumbroff and Webb, 1978). Improved establishment of this species was obtained by planting seedlings with a high capacity for root growth obtained from early spring lifting of nursery stock or from cold storage of autumn-lifted stock (von Althen and Webb, 1978). Cold storage of autumn-lifted sugar maple, silver maple (*Acer saccharinum* L.), and basswood (*Tilia americana* L.) has proven a useful technique for the maintenance of high roots growth capacity and overall seedling growth potential (Webb, 1976b, 1977). Planting of cold-stored autumn-lifted sugar maple planting stock overcame the shoot growth stagnation or check condition common to normal plantings of this species and allowed extension of the planting season into June with little loss of shoot growth (von Althen and Webb, 1978).

At present little information is available on the environmental conditions required for overwinter storage of hardwood nursery stock and their effects on physiological quality. The present paper outlines results of two experiments on the effect of various storage temperatures and packaging methods on physiological quality of seven of the more commonly planted hardwood species in Ontario.

MATERIALS AND METHODS

Experiment No. 1

This experiment consisted of seedlings from six species and transplants from one species exposed to five storage temperatures × three packaging treatments. Nursery stock of 2 + 0 white ash (*Fraxinus americana* L.), 2 + 0 silver maple, 2 + 0 red oak (*Quercus rubra* L.), 1 + 0 black walnut (*Juglans nigra* L.), and 3 + 0 and 2 + 2 sugar maple was obtained from the Ontario Ministry of Natural Resources, St. Williams Nursery, St. Williams, Ontario and 2 + 0 basswood was obtained from Midhurst Nursery, Midhurst, Ontario on 23 November 1977. At time of lifting all stock was leafless and dormant, and was transported directly to Sault Ste. Marie, Ontario. Each species was graded for size and randomly allocated to the various storage temperatures and packaging treatments. Temperature treatments consisted of —10, —5, 0.5, 5, and 10°C ± 0.5°C. Relative humidities at these treatments were between 70 and 85%. Within each temperature treatment, seedlings were subjected to the following three packaging methods: (1) Seedling roots were surrounded with moist peat and enclosed in Kraft bags with polyethylene liners sealed around the stem just above the root collar, (2) Seedlings were totally enclosed in sealed Kraft bags with polyethylene liners with moist peat surrounding the roots, and (3) Seedlings were totally enclosed in sealed Kraft bags with polyethylene liners without peat. Nursery stock of each species was lifted the following spring from the nursery after normal winter exposure and was included as the spring-lifted controls.

In April of 1978, 12 seedlings from each of the storage treatments and spring-lifted controls were observed for the number of new white lateral roots that had formed during storage, visual presence of terminal and lateral bud swell, and presence of fungal growth. Fresh and dry weights of the roots and shoots were measured and moisture contents were calculated. Xylem water potential was determined on the terminal 10 cm of the shoot using the pressure chamber technique of Scholander *et al.* (1965). Root growth capacity measurements were obtained on 12 seedlings of each species and age class for each treatment according to Webb (1977). Seedlings were planted in 20 cm plastic pots in a soil/sand/peat mixture (2 : 1 : 2 v/v) and placed in the greenhouse under extended photoperiods of 16 hours and a temperature of approximately 18°C (night) and 28°C (day). After 30 days, the seedlings were removed from the pots by gently washing the soil from the roots with a fine spray of water. Root growth capacity, i.e., the number of new white first and second order lateral roots produced during the 30-day growth period, was recorded. The presence of terminal and lateral bud flush and of foliar damage was also assessed.

Experiment No. 2

Nursery stock of white ash (2 + 0), silver maple (2 + 0), red oak (2 + 0), black walnut (1 + 0), sugar maple (3 + 0), and white birch (*Betula papyrifera* Marsh.) (2 + 0) was obtained from the Ontario Ministry of Natural Resources, St. Williams Nursery on 27 November 1978. Seedlings of each species were graded for size and randomly assigned to one of the following five packaging treatments.

1. Seedlings were stored bare root with no coverings.
2. Seedling roots were enclosed in Kraft bags with plastic liners. Bags were then sealed around the stem just above the root collars.
3. Seedling roots were enclosed in Kraft bags with plastic liners with moist peat surrounding the roots. Bags were then sealed around the stems just above the root collars.
4. Seedlings were totally enclosed in sealed Kraft bags with plastic liners and with moist peat around the roots.
5. Seedling roots were surrounded by moist peat, wrapped in wax paper, and enclosed in burlap.

Black walnut seedlings were cold stored at 5°C and a relative humidity of 84%; all other species were stored at 0.5°C and a relative humidity of 71%. For each species except white birch, stock was lifted in the spring from the nursery after normal winter exposure and was included as the spring-lifted controls.

In April of 1979, eight seedlings from each of the storage treatments and spring-lifted controls were observed for the number of new white lateral roots that had formed during storage, for the presence of terminal and lateral bud swell, and for the presence of fungal growth. Xylem water potential was determined on the terminal 10 cm of the shoot and on one main lateral root per seedling, using the pressure chamber technique of Scholander *et al.* (1965). Root growth capacity measurements were made on 16 seedlings for each treatment as outlined in Experiment No. 1.

The data were subjected to analysis of variance and the significance of treatment means ($P \geqq 0.05$) was identified by Tukey's procedure. Non-measurement data were subjected to Chi-square test of significance.

RESULTS AND DISCUSSION

Experiment No. 1

Growth During Storage

Previous results from cold storage of autumn-lifted hardwood nursery stock (Webb, 1977) indicated that bud swell and new root development would take place in storage within the range of temperatures employed in the various storage treatments of this experiment. As expected, terminal and lateral bud swell and lateral root initiation occurred. Significant differences were obtained between species and between temperatures of storage (Tables 1 and 2). The method of packaging had no significant effects. Seedlings with bud swell and root initiation in storage were restricted mainly to storage treatments of 10 and 5°C. Little bud swell or root initiation was observed either at —5 and —10°C or in spring-lifted controls. Bud swell in storage at 0.5°C or lower was confined to basswood and sugar maple (3 + 0), whereas root growth occurred only with sugar maple and silver maple at these temperatures.

Moisture content of the roots and shoots was highly variable and no significant effects were observed between species, storage temperatures, or packaging method. In contrast, shoot xylem water potential differed significantly between species, storage temperatures, and packaging methods (Table 3). Seedling shoot moisture stress was lowest for seedlings in the 0.5°C temperature treatment enclosed within the bag with a plastic liner and roots surrounded by moist peat.

Fungal growth on seedlings in the various treatments was minimal and was restricted to the packaging treatments that enclosed the seedling within the bag. Only in the case of black walnut was fungal growth observed on the roots and this was restricted to the lower 0.5 and —5°C treatments where, on several seedlings, root damage and root exudation were observed.

Growth Response After 30 Days in Greenhouse Environment

Seedlings from the various storage treatments that had been exposed to the greenhouse environment for 30 days showed variable flushing of terminal and lateral

TABLE 1—Percent of seedlings with terminal or lateral bud swell at time of removal from overwinter storage (Nov-April)

Species		Storage temperature (°C) +10	+5	+0.5	—5	—10	Control
Fraxinus americana	T[b]	64[a]	3	0	0	0	0
	L	19	0	0	0	0	0
Acer saccharinum	T	53	22	0	0	0	0
	L	67	36	0	0	0	0
Quercus rubra	T	44	0	0	0	0	0
	L	44	0	0	0	0	0
Tilia americana	T	75	81	22	0	0	0
	L	78	67	22	3	3	0
Juglans nigra	T	72	3	0	0	0	0
	L	31	0	0	0	0	0
Acer saccharum (3 + 0)	T	75	97	56	0	0	0
	L	83	83	19	0	0	0
Acer saccharum (2 + 2)	T	50	72	0	0	0	0
	L	100	83	0	0	0	0

[a] Data are means of 36 trees.
[b] T — terminal; L — lateral

TABLE 2—Mean number of new white lateral roots per seedling at time of removal from overwinter storage (Nov-April)

Species	Storage temperature (°C) +10	+5	+0.5	—5	—10	Control
Fraxinus americana	4.5^{*}_{a}	0.1_{a}	0_{a}	0	0	0
Acer saccharinum	25.4_{a}	1.3_{a}	0.6_{a}	0.6_{a}	0	0
Quercus rubra	0.8_{a}	0_{a}	0_{a}	0	0	0
Tilia americana	10.9_{a}	0.4_{a}	0_{a}	0	0	0
Juglans nigra	1.9_{a}	0_{a}	0	0	0	0
Acer saccharum (3 + 0)	58.0_{a}	10.7_{b}	1.5_{c}	0_{c}	0_{c}	1.6_{bc}
Acer saccharum (2 + 2)	94.6_{a}	20.0_{b}	0.3_{c}	0.0_{c}	0.1_{c}	0.0_{c}

Within species, means with similar letters are not significantly different.
* Data are the means of 36 trees.

TABLE 3—Effects of various storage treatments on shoot xylem water potential

Treatment	Shoot xylem water potential (—kPa)
Species	
A. saccharinum	1872[a]
A. saccharum (2 + 2)	1869
F. americana	1187
T. americana	1173
A. saccharum (3 + 0)	988
Q. rubra	982
J. nigra	885
Temperature	
5°C	1892[b]
10°C	1670
—10°C	1159
—5°C	1014
Control	1014
0.5°C	749
Packaging Method	
1 Roots in moist peat enclosed in Kraft bag with polyethylene liner (shoots exposed)	1967[c]
2 Seedling in bag with liner, no peat	1039
3 Seedling in bag with liner, roots surrounded with moist peat	885

[a] Mean of 48 determinations.
[b] Mean of 63 determinations.
[c] Mean of 105 determinations.
Vertical lines connect means that are not signicantly different.

buds (Table 4). Significant differences were observed between species and storage temperatures. Packaging treatments had no significant effects. The optimum temperature for breaking bud dormancy of most woody species is between 1 and 10°C and it is generally thought that the degree of chilling required is restricted to an upper temperature value below which any temperature is equally effective, except for extremely low temperatures which may retard the process of dormancy removal (Samish, 1954). In the present experiment, temperatures of 10, 5, and 0.5°C were equally effective in breaking bud dormancy as shown by the bud flush data in Table 4. Although a chilling temperature of —5°C broke bud dormancy of most species examined, it was less effective. Fewer numbers of seedlings broke bud after treatment at —5°C than at the warmer chilling temperatures. The —10°C treatment did not appear effective in dormancy removal. The small numbers of seedlings that flushed terminal or lateral buds after storage at this temperature may have done so in response to the 16 hr photoperiods of the greenhouse environment.

Bud flush in storage comparable to that with spring-lifted controls was obtained at temperatures of 5 and 0.5°C. In some species, e.g., black walnut, a significantly

TABLE 4—Percent of seedlings that flushed terminal and lateral buds after 30 days' growth in greenhouse conditions

Species		Storage temperature (°C)					Control
		+10	+5	+0.5	—5	—10	
Fraxinus americana	T[b]	78[a]	94	97	89	0	92
	L	100	100	100	75	3	100
Acer saccharinum	T	78	92	72	61	8	100
	L	94	92	92	75	11	100
Quercus rubra	T	56	86	78	3	0	33
	L	78	86	81	25	0	83
Tilia americana	T	72	100	92	42	0	100
	L	100	97	100	81	0	100
Juglans nigra	T	100	100	92	6	0	50
	L	72	64	47	0	0	75
Acer saccharum (3 + 0)	T	78	82	82	53	6	92
	L	92	94	94	64	0	100
Acer saccharum (2 + 2)	T	28	56	56	22	0	28
	L	94	94	100	50	0	33

[a] Data are means of 36 trees.
[b] T — terminal; L — lateral.

higher number of seedlings flushed terminal buds at the non-freezing storage temperatures than in spring-lifted control plants. This may have been a result of a possible difference between optimum temperature for breaking dormancy of terminal and lateral buds as demonstrated in peach by Erez and Lavee (1971) where maximum rest-breaking efficiency was found at 8°C for terminal buds and at 6°C for lateral buds.

The lowest temperature at which maximum numbers of seedlings showed normal leaf development was 0.5°C for all species with the exception of black walnut where 5°C was more suitable (Table 5). No significant differences were obtained between seedlings stored at these temperatures and nursery-lifted controls.

Root growth after 30 days in greenhouse conditions, like the other parameters measured, varied with species and temperature of storage (Table 6). No significant effects of packaging method were observed. Storage temperatures of —5 and —10°C were usually inhibitory to root growth, the effect being similar to that of temperature on bud dormancy removal. With sugar maple, in contrast to the other species, the higher temperature of 10°C was also inhibitory to root growth. This temperature is considerably above the minimum for root growth of this species and most new roots were produced in storage rather than after transfer to greenhouse conditions. No significant differences in the number of new roots produced was observed between

TABLE 5—Percent of seedlings showing normal leaf development after 30 days' growth in greenhouse conditions

Species	Storage temperature (°C)					Control
	+10	+5	+0.5	—5	—10	
Fraxinus americana	100[a]	100	100	86	0	100
Acer saccharinum	100	100	100	100	6	100
Quercus rubra	78	100	97	11	0	100
Tilia americana	100	97	100	86	33	100
Juglans nigra	97	100	86	0	0	100
Acer saccharum (3 + 0)	94	97	100	75	6	100
Acer saccharum (2 + 2)	94	94	100	50	0	100

[a] Data are mean of 36 trees.

TABLE 6—Root growth capacity of hardwood nursery stock stored at various temperatures

Species	Storage temperature (°C)					Control
	+10	+5	+0.5	—5	—10	
Fraxinus americana	148.7^{*}_{a}	146.1_{a}	114.2_{a}	50.0	0.0	136.4_{a}
Acer saccharinum	117.9_{a}	117.6_{a}	108.0_{a}	69.7_{b}	2.3	96.6_{ab}
Quercus rubra	14.8_{ab}	12.0_{b}	21.0_{a}	1.0_{c}	0.0_{c}	20.1_{ab}
Tilia americana	64.0_{a}	51.6_{a}	52.0_{a}	16.2_{b}	0.7_{b}	67.8_{a}
Juglans nigra	42.4_{a}	41.7_{a}	21.6_{b}	0.0_{c}	0.0_{c}	12.8_{bc}
Acer saccharum (3 + 0)	7.5_{b}	63.8_{a}	61.0_{a}	7.3_{b}	0.1_{b}	84.3_{a}
Acer saccharum (2 + 2)	0.0_{b}	67.2_{a}	91.0_{a}	19.4_{b}	0.0_{b}	142.8

Within species, means followed by the same letter are not significantly different.

* Data represent mean number of new lateral roots produced after 30 days' growth in greenhouse conditions.

seedlings stored at temperatures of 5 and 0.5°C and spring-lifted controls. However, black walnut produced significantly higher numbers of new roots at 10 and 5°C than in controls.

In general, a storage temperature of 0.5°C was the most beneficial for maintenance of physiological quality of silver maple, sugar maple, white ash, basswood, and red oak, although 5°C was equally beneficial to red oak. A storage temperature of 5°C was best for black walnut.

Experiment No. 2

This experiment was designed to examine a range of possible packaging methods for cold storage of hardwood nursery stock at temperatures found to be the most beneficial for maintenance of physiological quality. In the previous experiments, method of packaging had no significant effects on root growth capacity and seedling quality of cold-stored stock. However, a significant effect on shoot xylem water potential was observed. It was felt that the lack of significant effect on root growth capacity was the result of the high variability in root growth capacity measurements. In the current experiment, seedling sample size for root growth measurements were increased to allow for greater precision in measurement and statistical analysis.

Growth During Cold Storage

Bud swell and new root initiation during storage were minimal over all treatments and were confined to seedlings of sugar maple and silver maple.

In the other species the storage temperature was sufficient to maintain seedlings in a state of quiescence or imposed dormancy. No bud or root growth was noted. Fungal growth in storage was not a problem.

Significant differences in shoot and root xylem water potential were observed between packaging treatments in all species tested (Table 7). As observed in the previous experiment, seedlings enclosed in Kraft bags with a plastic liner with the roots surrounded by moist peat exhibited the least amount of shoot water stress and generally were not significantly different from the spring-lifted controls. Seedlings stored bare root, with both roots and stems exposed to the storage environment, exhibited the greatest amount of shoot water stress. In this treatment, all species except silver maple exhibited shoot xylem water potentials of —6500 kPa, the maximum limit of the pressure chamber. Shoot xylem water potential values of —6500 kPa were associated with desiccated shoots. With white birch, all packaging treatments that exposed the shoots to the storage environment resulted in shoot damage and in low shoot xylem water potential values in the terminal 10 cm of the shoot.

Growth Response After 30 Days in Greenhouse Test Environment

Packaging treatments significantly affected root growth capacity of all species tested (Table 8). In general, seedlings enclosed within the bag and roots surrounded by moist peat produced the highest number of new roots after 30 days' growth in greenhouse conditions. Root growth capacity of seedlings in this treatment was equal to or higher than that in spring-lifted control stock. Most species showed no significant differences between treatments that enclosed the total seedling or root portion of the seedling within the bag with or without peat. However, white birch demonstrated significantly greater root growth capacity when stored with the entire seedling enclosed within the bag and moist peat surrounding the roots in comparison with the other treatments.

Root growth capacity was strongly correlated with shoot xylem water potential (Fig. 1). Linear regression and correlation coefficients are based on six pairs of sample means requiring an r value of 0.754 and 0.874 at $P \geqq 0.05$ and 0.01, respectively,

TABLE 7—Shoot and root xylem water potential (—kPa) of cold-stored hardwood nursery stock subjected to various packaging treatments

Species		Packaging treatment (see Materials & Methods page 85)					
		Bare root 1	Roots in bag no peat 2	Roots in bag moist peat 3	Seedlings totally enclosed in bag with moist peat 4	Roots wrapped in burlap 5	Control
Fraxinus americana	Shoot	6500_{a}	140_{b}	90_{b}	110_{b}	160_{b}	200_{b}
	Root	181_{a}	288_{a}	231_{a}	131_{a}	303_{a}	247_{a}
Acer saccharinum	Shoot	3582_{b}	3663_{b}	357_{c}	625_{c}	6500_{a}	625_{c}
	Root	306_{b}	238_{b}	238_{b}	544_{b}	1334_{a}	475_{b}
Quercus rubra	Shoot	6500_{a}	3438_{b}	1225_{c}	1950_{cb}	6500_{a}	3506_{b}
	Root	597_{b}	2272_{a}	1066_{ab}	1331_{ab}	1547_{ab}	1767_{ab}
Betula papyrifera	Shoot	6500_{a}	6500_{a}	6500_{a}	109_{b}	6500_{a}	—
	Root	419_{ab}	953_{a}	661_{ab}	233_{b}	852_{a}	—
Juglans nigra	Shoot	6500_{a}	525_{c}	169_{c}	1169_{c}	3938_{b}	1417_{c}
	Root	159_{b}	913_{a}	519_{ab}	991_{a}	1103_{a}	457_{ab}
Acer saccharum	Shoot	6500_{a}	1071_{b}	752_{b}	513_{b}	6500_{a}	344_{b}
	Root	277_{ab}	91_{b}	371_{ab}	219_{ab}	736_{a}	294_{ab}

Means followed by the same letter in each horizontal line are not significantly different.

TABLE 8—Root growth capacity of cold-stored hardwood nursery stock subjected to various packaging treatments

Species	Packaging treatment (see Materials & Methods page 85)					
	Bare root 1	Roots in bag no peat 2	Roots in bag moist peat 3	Seedlings totally enclosed in bag with moist peat 4	Roots wrapped in burlap 5	Control
Fraxinus americana	0.0*	87.9_{a}	74.7_{ab}	69.1_{ab}	53.4_{bc}	40.4_{c}
Acer saccharinum	27.2_{b}	29.6_{b}	66.4_{a}	69.5_{a}	25.2_{b}	61.4_{a}
Quercus rubra	0.0_{d}	7.3_{bc}	14.7_{a}	11.3_{ab}	0.4_{cd}	4.3_{bcd}
Betula papyrifera	0.3_{b}	8.1_{a}	12.2_{a}	28.2	6.5_{ab}	—
Juglans nigra	0.0_{b}	21.8_{a}	18.3_{a}	16.8_{a}	12.2_{ab}	16.2_{a}
Acer saccharum	0.0_{c}	66.4_{a}	46.0_{b}	52.1_{ab}	5.8_{c}	43.9_{b}

Within species, means followed by the same letter are not significantly different.

* Data represent mean number of new lateral roots produced after 30 days' growth in greenhouse conditions.

for significance. Thus, although the correlation coefficients appear high they are just significant at the designated level of probability and should be interpreted in that light. Further data are required particularly for intermediate values to reinforce these relationships. Although significant correlations were obtained with shoot xylem water potential and root growth capacity for all species tested, root xylem water potentials were markedly higher (less negative) than shoot xylem water potentials and were not significantly correlated with root growth capacity.

The significant correlation of shoot xylem water potential with root growth capacity of the hardwood species examined in this study indicates that shoot xylem water potential may be a useful and relatively rapid measure of seedling physiological quality. Measurements of xylem water potential using the pressure chamber technique of Scholander *et al.* (1965) is relatively simple and adaptable to field use. Studies are in progress to examine the feasibility of using shoot xylem water potential for possible routine monitoring of physiological quality of cold-stored hardwood nursery stock.

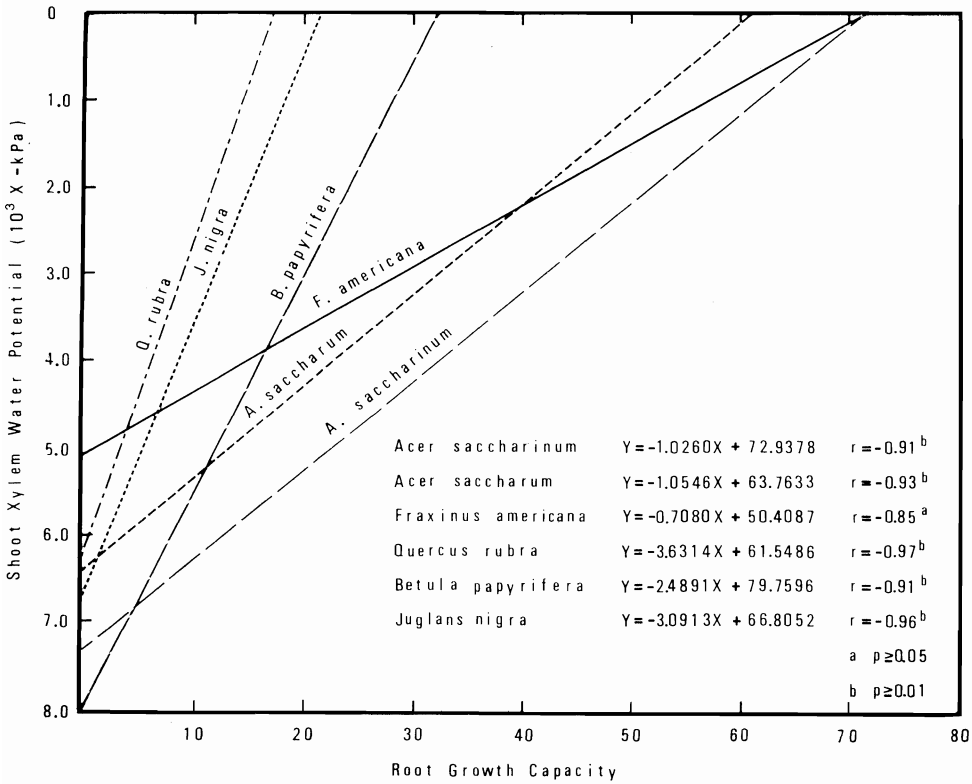

FIG. 1—Linear regression of root growth capacity and shoot xylem water potential.

CONCLUSIONS

The present study demonstrates that temperature of overwinter storage and method of packaging can markedly affect physiological quality of a range of temperate zone hardwood species. Root growth capacity and overall growth potential of stock stored at 0.5 and 5°C were comparable with those of normal spring-lifted nursery stock that had been exposed to winter chilling out of doors. Root growth capacity of cold-stored seedlings of sugar maple, silver maple, white ash, red oak, black walnut, and white birch was significantly correlated with shoot xylem water potential at time of removal from cold storage. Shoot xylem water potential may offer a useful and rapid measure of seedling physiological quality.

It is recommended that autumn-lifted nursery stock of white ash, silver maple, red oak, basswood, white birch, and sugar maple be stored at a temperature of 0.5°C and black walnut at 5°C with a relative humidity of 70-85%. Roots should be surrounded by moist peat and the total seedling tightly enclosed within a Kraft bag with a polyethylene liner.

ACKNOWLEDGMENTS

The above report forms part of a co-operative study undertaken by the Ontario Ministry of Natural Resources and the Great Lakes Forest Research Centre, Canadian Forestry Service. Special thanks are extended to Mr R. Laupert, St. Williams Nursery and Mr E. F. Johnston, South-western Region, Ontario Ministry of Natural Resources for encouragement, technical assistance and supply of nursery stock. The technical assistance of Mr D. Marles and Mr G. Mitchell is gratefully acknowledged.

REFERENCES

DUMBROFF, E. B. and WEBB, D. P. 1978: Physiological characteristics of sugar maple and implications for successful planting. **For. Chron. 54**: 92-5.

EREZ, A. and LAVEE, S. 1971: The effect of climate conditions on dormancy development of peach buds. I. Temperature. **J. Am. Soc. Hort. Sci. 96**: 711-4.

FARMER, R. E. Jr. 1975: Dormancy and root regeneration of northern red oak. **Can J. For. Res. 5**: 176-85.

LARSON, M. M. 1970: Root regeneration and early growth of red oak seedlings: influence of soil temperature. **For. Sci. 16**: 442-6.

——— 1975: Pruning northern red oak nursery seedlings: effects of root regeneration and early growth. **Can. J. For. Res. 5**: 381-6.

——— 1977: Growth of outplanted northern red oak nursery stock related to shoot characteristics in the seedbed. **Tree Plant. Notes 28**: 21-3.

LYR, H. and HOFFMANN, G. 1967: Growth rates and growth periodicity of tree roots. p. 181-236 **in** J. A. Romberger and P. Mikola (Ed.). International Review of Forestry Research, Vol. 2, Acad. Press, New York.

RIETVELD, W. J. and WILLIAMS, R. D. 1978: Dormancy and root regeneration of black walnut seedlings: Effects of chilling. **USDA For. Serv. Res. Note NC244.** 3p.

SAMISH, R. M. 1954: Dormancy in woody plants. **Annu. Rev. Plant Physiol. 5**: 183-204.

SCHOLANDER, P. F., HAMMEL, H. T., EDDA, D., BRADSTREET, E. D. and HEMMINGSEN, E. A. 1965: Sap pressure in vascular plants. **Science 148:** 339-46.

TAYLOR, J. S. and DUMBROFF, E. B. 1975: Bud, root, and growth-regulator activity in **Acer saccharum** during the dormant season. **Can. J. Bot. 53**:321-31.

von ALTHEN, F. W. 1979: Preliminary guide to site preparation and weed control in hardwood plantations in southern Ontario. Can. For. Serv., Sault Ste. Marie, Ont. Report O-X-288. 22p.

von ALTHEN, F. W. and WEBB, D. P. 1978: Effects of root regeneration and time of planting on sugar maple plantation establishment. p. 401-11 **in** P. E. Pope (Ed.). Proc. Cent. Hardwood For. Conf. November 14-16, 1978, West Lafayette, Indiana.

WEBB, D. P. 1976a: Root growth in **Acer saccharum** Marsh. seedlings: Effects of light intensity and photoperiod on root elongation rates. **Bot. Gaz. 137**: 211-7.

——— 1976b: Effects of cold storage duration on bud dormancy and root regeneration of white ash (**Fraxinus americana** L.) seedlings. **Hort. Science 11**: 155-7.

——— 1977: Root regeneration and bud dormancy of sugar maple, silver maple and white ash seedlings: Effects of chilling. **For. Sci. 23**: 474-83.

WEBB, D. P. and DUMBROFF, E. B. 1978: Root growth in seedlings of **Acer saccharum**. IUFRO Root Physiology and Symbiosis, Nancy, France (in press).

WEBB, D. P. and von ALTHEN, F. W. 1978: Establishment of high quality hardwoods on open-field sites in southern Ontario. p. 177-89 **in** H. Oswald (Ed.). Symposium on establishment and treatment of high-quality hardwood forests in the temperate climatic region. Proc. IUFRO Div. 1, Sect. Group S1.05-00. Nancy-Champenoux, France, 11-15 Sept. 1978.