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Lifting Date Affects Black Walnut Planting Stock Quality

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LIFTING DATE AFFECTS BLACK WALNUT PLANTING STOCK QUALITY

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Instead of lifting hardwood planting stock in the spring, more and more forest tree nurserymen are lifting it in the fall and keeping it in cold storage overwinter. Lifting stock in the fall has several advantages: (1) soil conditions are often more favorable; (2) work loads can be spread over a longer period and steady work can be provided for fewer, better-trained employees; (3) earlier and more accurate inventory of available stock is possible; and (4) timing of deliveries with optimum planting periods is facilitated. All of these advantages improve efficiency and convenience of nursery operation. This trend creates a need for a better understanding of how fall lifting and overwinter storage affect seedling physiology so that consistently high quality planting stock can be produced.

If we are to optimize the physiological quality of hardwood nursery stock, we must have a method to measure the effects of various nursery cultural and storage treatments on physiological quality. Also, we need to know the relation between physiological quality of planting stock and field performance so we can set standards for stock grading. Finally, we need to know how the physiological quality of planting stock interacts with various silvicultural treatments —e.g. site selection, site preparation, weed control, and planting methods—so we can understand why some plantations are successful and others are unsuccessful. Root regeneration potential (RRP), a measure of the ability of seedlings to initiate and elongate new roots when planted in a favorable environment, has been used to assess the physiological condition of nursery stock and its suitability for outplanting (Stone and Schubert 1959, Stone and Jenkinson 1971, Webb and von Althen 1980). Measuring RRP has the advantage of assessing seedling growth potential in terms of the rapidity and amount of root regeneration, a factor regarded as highly important if transplanted seedlings are to survive and grow rapidly.

Effective physiological preconditioning of planting stock depends on lifting at the proper time, storing under appropriate conditions, and planting in an environment favorable to growth when seedling growth potential is highest. Although we know that seedlings must be cold-hardened before they are ready for lifting and overwinter storage, we do not know how much cold-hardening they need. Some nurserymen wait a period of time after leaf fall, some wait for the first hard frost, and others wait for a few frosts. Black walnut (*Juglans nigra* L.) is one of the first species to be lifted in the fall because leaf fall occurs early. However, leaf fall is only an indicator that dormancy has begun and is not an indicator of optimal lifting time. Thus, lifting and storing guidelines are needed based on convenient criteria for identifying seedling readiness.

This paper reports the results of a study on lifting date, storage duration, and field performance of black walnut. It includes an assessment of (1) RRP as a measure of the physiological quality of lifted and stored planting stock, and (2) the relation between physiological quality of planting stock and field performance.

METHODS

Eleven liftings of 1-0 black walnut seedlings were made between October 6, 1976 and April 25, 1977, from the Vallonia Forest Nursery near Brownstown, Indiana. The first lifting was about 7 days before leaf fall and the last one was about 10 days after flushing. Only those seedlings with a stem caliper $\geq$ 0.7 cm were used in the study, and roots were pruned to 22 cm. Twelve seedlings from each lifting date were potted and tested for RRP at each of the following times: immediately; 4, 8, and 12 weeks after lifting; and on December 8, March 8, and May 12. Seedlings that were not potted immediately were stored at 3°C.

Additionally, 25 seedlings lifted on each date were stored at 3°C until they were field planted on December 8, March 8, and May 12.

RRP was determined by a method similar to that of Stone and Schubert (1959). Potted seedlings were placed in a greenhouse for 4 weeks. In the greenhouse, air temperature varied seasonally (minimum 16°C), soil temperature was held at 24°C by pumping water maintained at that temperature through coiled tubing in each pot, and a 16-hour photoperiod was maintained by supplemental fluorescent and incandescent lighting. At the end of the 4 weeeks, the seedlings were unpotted and total shoot elongation, stem caliper 2.5 cm above root collar, ovendry weight of all new roots, and ovendry weight of the total root system were determined for each seedling. Differences in responses among lifting dates and storage treatments were tested for significance by analysis of covariance using total root dry weight as the covariable for root growth response and stem caliper as the covariable for shoot growth response.

The field planting was located on the Shawnee National Forest in southern Illinois on a deep, well-drained silt loam soil suitable for good black walnut growth. On each planting date the 25 stored seedlings from each lifting date were divided evenly among 5 randomized complete blocks and planted with KBC tree planting bars. Data collected were flushing date (December 8 and March 8 plantings only), initial shoot elongation, and total height at the end of the first and second growing seasons.

RESULTS AND DISCUSSION

Seasonal Pattern of RRP

Black walnut seedlings required exposure to cold temperatures for a minimum amount of time before any growth was observed. The seedlings that were lifted and potted immediately showed little growth response for any lifting date until late March when the growth response increased abruptly (fig. 1). Total shoot elongation and ovendry weight of new roots steadily increased with successive liftings during the spring and continued to increase beyond the time of flushing at the nursery. Our data showed two declines in shoot elongation but they were probably due to technique errors. Seedlings lifted on April 25 had as much as 10 cm of new shoot growth at the time of lifting but no new root growth. Existing new shoots died back during the RRP test, but shoot regrowth and root regeneration surpassed that of all previous lifting dates. Thus, no peak was found in RRP of

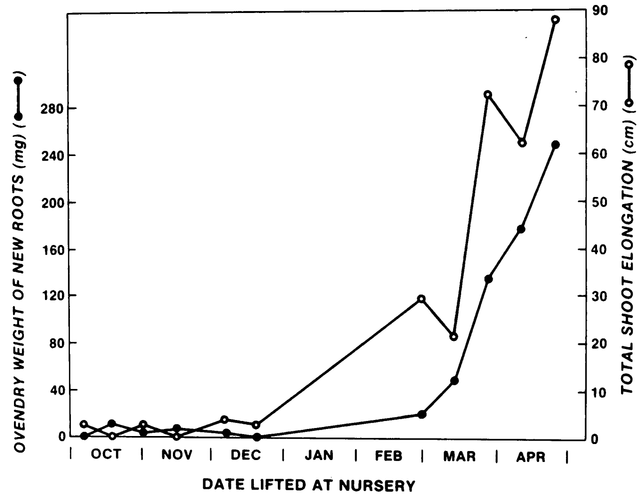

Figure 1.—*Total shoot elongation and ovendry weight of new roots for black walnut seedlings lifted on 11 dates in 1976-1977 and immediately tested for RRP under favorable conditions in a greenhouse.*

freshly lifted seedlings. Note that these responses represent root and shoot growth potential under favorable growing conditions in a greenhouse. Seedlings lifted after flushing grew poorly in the field test.

In the RRP tests, root growth was strongly related to shoot growth ($r = +0.95$, $P \leq 0.00001$)—root regeneration increased as shoot growth increased (fig. 1). Although active root and shoot growth occurred simultaneously, it is not apparent which process began first because the initiation of root growth was not observed.

RRP of Seedlings Lifted and Stored to Planting Time

Seedlings lifted between October 6 and December 8 and planted on December 8 had almost no RRP because of inadequate chilling. By March 8 chilling was minimal and RRP was low. In contrast, root regeneration and shoot growth of seedlings stored to May 12 were vigorous and differed significantly among lifting dates (fig. 2). Growth responses may be divided into two significantly distinct groups: (1) seedlings lifted on October 6 and 18 had low root and shoot growth during the 4-week test; and (2) seedlings lifted between November 1 and April 25 had high root regeneration and moderate shoot growth in fall-lifted and significantly higher shoot growth in spring-lifted seedlings. Thus, seedlings lifted before November 1 had reduced vigor when they were tested

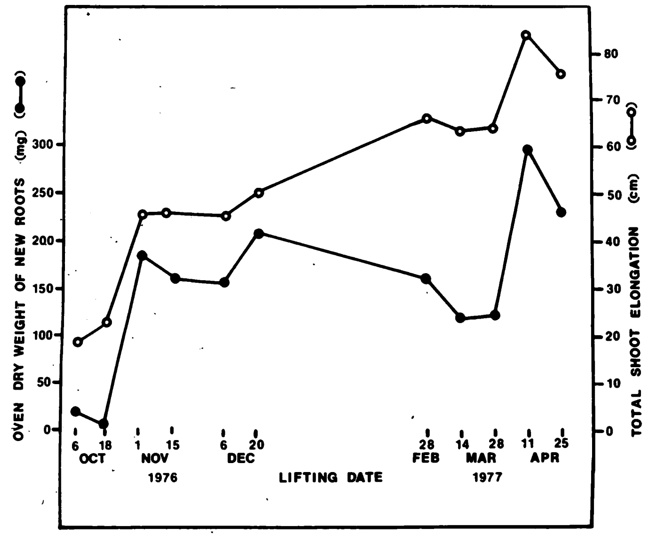

Figure 2.—*Mean 4-week root regeneration and shoot growth potential of black walnut seedlings lifted on different dates and stored to May 12, 1977. Each data point represents 12 seedlings.*

in late spring. Seedlings lifted after November 1 and stored overwinter had RRPs comparable to those of seedlings freshly lifted and tested on April 11 and 25 ($P \leq 0.05$) (fig. 1). This suggests that black walnut planting stock fall-lifted when sufficiently dormant has comparable physiological quality to spring-lifted stock. This finding agrees with the results of Webb and von Althen (1980) who found that RRP of black walnut, white ash (*Fraxinus americana* L.), sugar maple (*Acer saccharum* Marsh.), red oak (*Quercus rubra* L.), and paper birch (*Betula papyrifera* Marsh.) seedlings lifted on November 23 and cold-stored at 0.5 or 5°C to April was comparable to that of freshly lifted seedlings.

Both ovendry weight of new roots and total shoot elongation were strongly related to chilling time, $r = +0.82$ ($P \leq 0.05$) and $r = +0.90$ ($P \leq 0.01$), respectively. Seedlings lifted on November 1 and stored until March 8 had been stored at 3°C for approximately 3,100 hours, excluding exposure to cold temperatures in the nursery prior to November 1 (Rietveld and Williams 1978). This is the minimum amount of chilling required before any growth response occurred; the longer the seedlings remained in cold storage, the more rapidly they resumed growth and the greater the growth response during the 4-week test period. By May 12, after 4,600 hours at 3°C, the peak response had not yet been reached.

The extremely long chilling requirement of black walnut seedlings raises the question whether planting stock overwintered outside is adequately chilled during a mild winter. Growth could be sluggish the following growing season. It is known that maximum RRP varies from year to year and from nursery to nursery (Stone *et al.* 1963); this may be due in part to yearly differences in amount of effective chilling. There is generally thought to be a temperature threshold for chilling, below which any temperature is equally effective. On the other hand, extremely cold winters do not necessarily increase chilling. According to Samish (1954), the optimum temperature for breaking bud dormancy in most woody species is between 1 and 10°C, and extremely low temperatures may retard the process of breaking dormancy. Additional research is needed to determine the adequacy of natural chilling in mild winters and its effects on growth, compared with that of seedlings fall-lifted and cold-stored overwinter.

Freshly Lifted Versus Stored Seedlings for Spring Planting

Storage effects were evaluated for spring-planted seedlings only, by (1) comparing RRP of freshly lifted seedlings to that of seedlings that had been previously lifted (after February 28) and stored; and (2) comparing RRP of seedlings stored to later dates, up to late June, to that at lifting time.

The differences in RRP between seedlings freshly lifted during the period March 28 to April 25 and seedlings previously lifted and stored were not significant based on analysis of covariance (0.05 level). Seedlings stored for extended periods of time displayed variable, but acceptable, RRPs. Seedlings lifted on April 11 (just before bud swell) and stored, maintained the highest physiological quality in extended storage. Dry weight of new roots for April 11-lifted seedlings was 177 mg at lifting, 197 mg after 5 weeks of storage, and 311 mg after 8 weeks of storage. In contrast, dry weight of new roots for seedlings lifted on April 25 (after flushing) was 249 mg at lifting, 231 mg after 3 weeks of storage, and 118 mg after 8 weeks of storage. The lowest value would be considered "unacceptable" when compared to the average of 182 mg for seedlings lifted between November 1 and April 25 (fig. 2).

These results suggest that black walnut seedlings may be lifted in late winter or early spring and stored for late spring or early summer planting. The best time to lift and store for late planting appears to be just before the buds begin swelling.

Field Performance of Stored Seedlings

Bud burst.—For both December 8 and March 8 plantings, seedlings lifted earliest, and therefore stored longest before planting, were physiologically more responsive to favorable growing conditions in the spring.

Lifting date	Days to bud burst[1]	
	Planted Dec. 8	Planted Mar. 8
Oct. 6	5.4	[2]6.7 a
Oct. 18	7.2	12.8 bc
Nov. 1	7.0	12.4 abc
Nov. 15	10.5	13.1 c
Dec. 6		14.7 c
Dec. 20		14.9 c
Feb. 28		11.7 abc
Mean	[3]6.1	12.3

Fall-planted seedlings that overwintered outside resumed growth approximately 1 week sooner than early spring-planted seedlings ($P \leq 0.01$). The reason for these responses is not clear. Seedlings overwintered in cold storage received more total chilling because they were continuously exposed to effective chilling temperatures. Thus, they would be expected to be more responsive in the spring, especially when compared to seedlings overwintered outside during a mild winter. However, seedlings overwintering outside during the winter of 1976-1977 were exposed to abnormally cold temperatures, which resulted in an unknown amount of effective chilling. This factor, counterbalanced by the fact that seedlings lifted and stored during mild fall weather between October 6 and November 1 received additional chilling, may account for the observed flushing pattern.

Survival.—Survival of fall-planted seedlings averaged 16 percent lower than spring-planted seedlings for the first 2 years after planting (table 1). This was mainly due to frost-heaving of fall-planted stock. Survival did not differ between the March 8 and May 12 plantings.

Differences in survival due to lifting date were not significant. Seedlings planted in early spring survived well regardless of lifting date, while seedlings lifted on October 6 and 18 and April 25 had lower survival when planted in late spring. Black walnut seedlings are tenacious and can survive difficult growing conditions, although they typically die back and grow poorly. Thus, in contrast to many coniferous species, seedling survival may not be a good criterion for distinguishing differences in vigor for black walnut seedlings.

Height growth.—Although fall-planted seedlings flushed earlier, mean terminal shoot elongation measured in mid-June did not differ significantly among the three planting times. First-year total height of seedlings planted December 8 was significantly higher than that of seedlings planted March 8, which in turn was significantly higher than that of seedlings planted May 12 (table 2). Second-year total height was significantly lower for the May 12 planting than for the other two plantings.

Analysis of variance of first and second year total height among lifting dates revealed no consistent significant differences within the three planting times (table 2). Seedlings planted in early spring grew well regardless of lifting date. Orthogonal comparisons of weighted mean total height within the May 12 planting of the October 6, October 18, and April 25 lifting dates versus the November 1 through April 11 lifting dates revealed no significant difference in the first year and a significant difference at the 0.05 level in the second year. The mean total heights for the two groups were 55.2 and 67.0 cm, respectively. Thus, seedlings lifted before November 1 and after April 11 generally grew less, when planted in late spring, than seedlings lifted within that period. This agrees with the RRP data and suggests that seedlings lifted too early or too late can physiologically deteriorate in storage (fig. 2). Additionally, planting in late spring under less favorable conditions appears to emphasize any differences in seedling vigor, resulting in a better evaluation of seedling quality in the field.

Based on overall survival and growth, early spring appears to be the best planting time. Lifting date did not affect survival and growth of seedlings planted in early spring. The principal disadvantage of late fall planting was lower survival caused by frost-heaving; seedlings that survived grew well. Spring frost-heaving may limit success of early-spring planting in some areas.

DETERMINING LIFTING TIME

Although seedlings lifted and stored before November 1, 1976, received more chilling than seedlings lifted later, RRP at planting time and field performance were significantly lower. This lack of vigor is clearly attributable to the seedlings being

[1]*Time of bud burst is expressed as days after April 1; each value is the mean of 25 seedlings.*

[2]*Means followed by same letter are not significantly different (5 percent level) by multiple range tests.*

[3]*Means significantly different at 5 percent level.*

Table 1.—*First and second year survival of black walnut seedlings lifted on different dates and stored until planted on December 8, March 8, or May 12*
(In percent)

Lifting date	Planting date: December 8 — First year	December 8 — Second year	March 8 — First year	March 8 — Second year	May 12 — First year	May 12 — Second year
Oct. 6	72	64	100	92	[1]88 ab	84 ab
Oct. 18	84	84	96	84	80 ab	68 b
Nov. 1	76	68	96	96	96 a	92 a
Nov. 15	76	72	92	84	100 a	100 a
Dec. 6			84	84	92 ab	84 ab
Dec. 20			96	96	92 ab	88 ab
Feb. 28			100	92	92 ab	92 ab
Mar. 14					100 a	96 b
Mar. 28					96 a	96 a
Apr. 11					92 ab	92 ab
Apr. 25					76 b	68 b
Mean	[2]77**	72**	95	90	91	87

[1]Means within a column followed by same letter are not significantly different (5 percent level) by multiple range tests.
[2]**Means at bottom of columns significantly lower than comparable means at 1 percent level.

Table 2.—*First and second year total height of black walnut seedlings lifted on different dates and stored until planted on December 8, March 8, or May 12*
(In centimeters)

Lifting date	Planting date: December 8 — First year	December 8 — Second year	March 8 — First year	March 8 — Second year	May 12 — First year	May 12 — Second year
Oct. 6	31.6	65.7	[1]50.8 ab	74.0	38.6 c	58.2 c
Oct. 18	54.2	83.0	54.6 a	78.5	42.0 bc	54.7 c
Nov. 1	49.1	78.2	51.7 ab	72.7	52.8 bc	69.4 ab
Nov. 15	58.9	74.8	38.9 b	76.8	40.7 bc	65.6 abc
Dec. 6			45.9 ab	77.6	38.8 c	59.7 bc
Dec. 20			44.0 b	75.1	46.3 bc	61.5 bc
Feb. 28			46.0 ab	68.9	41.6 bc	65.9 abc
Mar. 14					59.5 a	
80.3 a						
Mar. 28					54.6 b	68.9 ab
Apr. 11					39.2 bc	65.0 abc
Apr. 25					33.6 c	52.7 c
Mean	[2]53.5**	75.4	47.4**	74.8	44.3**	63.8**

[1]Means within a column followed by same letter are not significantly different (5 percent level) by multiple range tests.
[2]**Means at bottom of columns significantly lower than comparable means at 1 percent level.

lifted before they were sufficiently cold-hardened. Therefore, lifting date is an important factor affecting physiological quality of black walnut planting stock. Because the time when seedlings are ready for lifting varies from year to year and from nursery to nursery, an independent criterion is needed to determine lifting date. Research is underway to develop these guidelines. In the meantime, an approximate criterion would be to lift black walnut seedlings 1 month after leaf fall.

RRP AS A MEASURE OF SEEDLING PHYSIOLOGICAL QUALITY

RRP appears to be a sensitive method to detect differences in seedling vigor resulting from various lifting and storage treatments of black walnut planting stock, providing the seedlings have been adequately chilled. For a vigorous and definitive RRP test, seedlings should be exposed to approximately 3,600 hours of 3°C temperatures. Additionally, the results of the late-spring field planting suggest that growing conditions that induce seedling stress may encourage expression of differences in vigor among treatments. In their proposed RRP-type vigor test of coniferous planting stock, Hermann and Lavender (1979) state that the physiological quality of seedlings becomes more apparent if the seedlings are stressed.

An inherent problem and confounding factor that introduces high variability into RRP tests of bare root seedlings is physiological shock—the disruption of seedling physiological processes caused by the multiple injuries sustained during lifting, storing, and planting. Such shock expresses itself as retarded root regeneration and minimal shoot growth or dieback. The severity of shock creates problems in regeneration research because we can account for it only as experimental error. The following methods can be used in RRP tests to reduce the variable effects of physiological shock: (1) chill seedlings well (at least 3,600 hours at 3°C); (2) use a testing environment favorable to growth and uniform within and among tests; (3) use well drained and well aerated growing medium; and (4) reduce the variation due to seedling size differences by grading seedlings to uniform size and using covariance analysis.

Three conspicuous problems with conducting RRP tests are: (1) they are costly—in terms of facilities, space, manpower, and money; (2) they are time consuming—4 weeks or longer are needed for the growth responses to occur, and thus for the results of the test; and (3) they are laborious—the growth responses are difficult to measure. A faster-developing, more conveniently measured variable is clearly needed. We have found that both days to bud-burst and total shoot elongation are highly related to root regeneration and will pursue developing a relation that incorporates these variables. Also, Webb and von Althen (1980) have reported that shoot xylem water potential is significantly related to RRP of hardwood seedlings at the time of removal from storage. Thus, shoot xylem water potential appears promising as a rapid measure of physiological quality.

RELATION BETWEEN RRP AT PLANTING AND FIELD PERFORMANCE

Seedlings lifted on October 6 and 18 had low RRP and below average survival, shoot elongation, and total height (fig. 3). These seedlings were not sufficiently hardened-off when lifted, so they deteriorated in storage and showed reduced vigor in RRP and field tests. RRP of seedlings lifted after November 1 increased markedly and field performance of these seedlings was generally acceptable. Second-year survival and height were similar to those of the first year, suggesting that seedling physiological quality at planting time determines subsequent growth (fig. 3).

In contrast to the similar pattern of RRP and field growth responses for fall-lifted seedlings, the opposite was true for spring-lifted seedlings (fig. 3). Seedlings lifted and stored during the period from February 28 through March 25 showed reduced RRP, followed by a marked increase just before bud-burst, then a decline in seedlings lifted after bud-burst. Field survival and growth showed just the opposite trend through March 28 or April 11 liftings, then declined sharply for the April 25 lifting. Shoot elongation potential was highest for the April 11 lifting date, while field survival and growth were highest for March 14 lifted seedlings.

Simple correlation coefficients for relations of ovendry weight of new roots or total shoot elongation in RRP tests of fall-lifted seedlings with field growth responses range between +0.45 and +0.79 (table 3). All are nonsignificant, probably because they are based on only six lifting dates. Thus, this study failed to establish a significant relation between RRP at planting time and field performance. More frequent sampling and larger numbers of seedlings will be

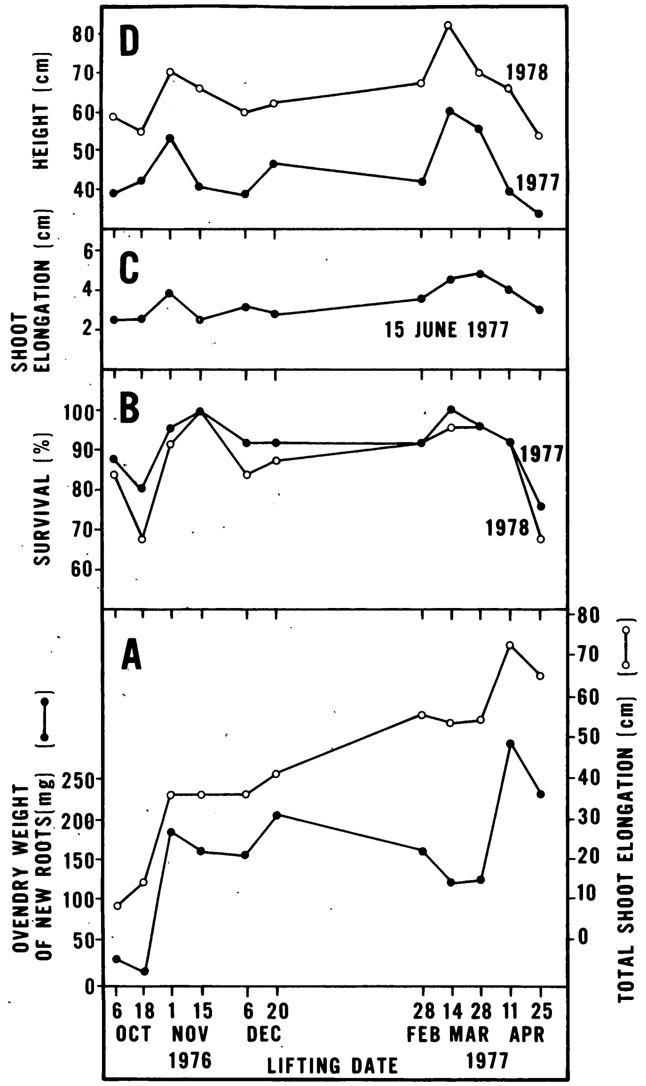

Figure 3.—*Comparison of several response variables for black walnut seedlings in relation to lifting date: (A) root and shoot regeneration potential; (B) survival at the end of the first and second growing seasons; (C) initial shoot elongation; and (D) mean total seedling height at the end of the first and second growing seasons. In all cases, seedlings were in cold storage between lifting date and May 12, 1977.*

required to establish a significant relation with predictive value between RRP and performance of field-planted trees.

It would be desirable to develop a method to routinely evaluate the physiological quality of hardwood planting stock before planting time so that low vigor stock can be culled. Such a method has been proposed for coniferous planting stock by Hermann and Lavender (1979). It is based on an RRP-type test in which seedlings are potted and days to bud burst and survival after a specified period of time are related to planting stock quality. A similar method could be devised for black walnut and other hardwoods, but the extremely long chilling requirement would present a problem. While most northern and western conifers require short periods of chilling, most eastern hardwood species require 2,500-3,500 hours before they will grow vigorously. Coniferous stock can easily be tested before planting time, however, hardwood planting stock cannot be completely chilled, tested for RRP, and graded in time for early spring planting. Unless a method can be devised to accelerate the chilling process in hardwood planting stock so that tests can be completed before the spring planting season, the usefulness of RRP tests for other than research purposes is questionable.

Table 3.—*Simple correlation coefficients among selected growth responses for six fall lifting dates*[1]

	Variable Y (field performance)				
	June 15	Total height		Survival	
Variable X (RRP)	shoot elongation	First year	Second year	First year	Second year
Ovendry weight of new roots	+0.53	+0.52	+0.75	+0.79	+0.72
Total shoot elongation	+0.48	+0.45	+0.68	+0.75	+0.66

[1]None of the correlation coefficients are significant at the 5 percent level; the minimum correlation coefficient required for significance is + 0.81.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Fall-lifted and stored black walnut seedlings have a long chilling requirement—approximately 3,100 hours at 3°C—before growth will resume. This is a minimum value for any root regeneration to occur and growth rate increases markedly with additional chilling. Stored seedlings should be exposed to approximately 3,600 hours of chilling for a vigorous and definitive RRP test. Under greenhouse conditions, root growth is strongly related to shoot growth, so seedlings with rapidly elongating shoots can also be expected to have expanding root systems.

Lifting date affects the physiological quality of black walnut planting stock. The earliest date to lift seedlings for overwinter storage and early spring planting is approximately 1 month after leaf fall. Seedlings lifted from that time to the time of bud swell in spring maintain high RRP in storage. The best spring lifting date for extended storage is just before bud swell.

The best planting time appears to be early spring. Survival of fall-planted seedlings was significantly reduced by frost heaving, but surviving seedlings grew as well as early spring planted seedlings. Seedlings planted in late spring survived well, but growth was significantly lower than the other two planting times. Lifting date had no consistent effect on seedling survival and growth over the three planting times. Seedlings planted in early spring grew well regardless of lifting date, while seedlings lifted between November 1 and April 11 and planted in late spring grew significantly better than seedlings lifted earlier or later.

Root regeneration potential appears to be a good variable for assessing lifting and storage treatment effects on black walnut planting stock if the stock has been adequately chilled. Seedlings lifted early in the fall had low RRP in the spring, while those lifted when dormant had high RRP after chilling. Seedlings lifted just before and after flushing had the highest RRP at lifting, but the latter lost vitality in storage while the former did not. RRP of planting stock at planting time was positively, but not significantly, related to field survival and growth. Further research with more intensive sampling may establish a significant relation with predictive value. The usefulness of an RRP-type test to evaluate physiological quality of black walnut planting stock before planting is severely constrained by the long chilling requirement.

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Presents information for black walnut seedlings on storage chilling requirement, fall lifting for overwinter storage, spring lifting, planting times, use of root regeneration potential (RRP) to assess physiological quality of planting stock, and relation between RRP at planting and field performance.

KEY WORDS: *Juglans nigra,* nursery practices, cold storage, chilling, root regeneration potential, seedling survival, seedling growth.