# RELATING BLACK WALNUT PLANTING STOCK QUALITY TO FIELD PERFORMANCE[1]

W. J. Rietveld and J. W. Van Sambeek[2]

Abstract.--Planting stock quality and field performance of seedlings stored totally enclosed in poly-lined Kraft bags or roots only enclosed with or without moist peat were similar to those of spring-lifted seedlings. Seedlings heeled-in overwinter or cold-stored without packaging were of lesser quality. Correlations of 27 measured variables of planting stock at planting time with 10 measured field response variables revealed 13 variables strongly related to initial survival and growth.

## INTRODUCTION

"Transplant stress," i.e., retarded initial growth following outplanting, is a persistent problem with several hardwood species. Survival and subsequent shoot growth of outplanted seedlings depend on the rapid establishment of a vigorous root system (Rietveld 1989). Transplant stress has led to several investigations of planting stock quality and its relation to initial root development and subsequent seedling establishment.

Packaging and overwinter storage can markedly affect physiological quality of planting stock (Webb and von Althen 1980; von Althen and Webb 1981, 1982). Our research with packaging methods and overwinter storage of black walnut (Juglans nigra L.) planting stock reaffirms earlier work by Webb and von Althen, and identifies several potentially useful relationships between planting stock characteristics at time of planting and field performance.

---

[1]Paper presented at the seventh central hardwood forest conference [Southern Illinois University, Carbondale, March 5-8, 1989].

[2]Supervisory Plant Physiologists, Rocky Mountain Forest and Range Experiment Station, Lincoln, Nebr., and North Central Experiment Station, Carbondale, Ill., respectively. We wish to thank Dr. Jim Wichman, nurseryman at the Vallonia Forest Nursery, Brownstown, Ind., for his cooperation, Mr. David J. Polak, computer programmer, for data analysis; and the Shawnee National Forest for the planting site.

## METHODS

Black walnut (1-0) seedlings were grown at the Vallonia Forest Nursery, Ind.,(Lat. N38° 47', Long. W 86° 05'). Seedlings were randomly lifted by hand from beds of regular nursery stock on December 3, 1980, root pruned to 20 cm, randomly assigned to packaging treatments, and immediately packaged for overwinter cold storage. The packaging methods tested were: 1) roots packed in moist peat, seedlings totally enclosed in poly-lined Kraft bags; 2) roots packed in moist peat, roots enclosed in poly-lined Kraft bags tied just above the root collar; 3) no peat around roots, seedling roots enclosed in poly-lined Kraft bags tied just above the root collar; and 4) no packaging, seedlings stored bare-root. In addition, for comparative purposes: 5) one group of seedlings was heeled-in overwinter at the nursery by placing them vertically in a trench and backfilling with soil; and 6) one group of seedlings was lifted on March 3, 1981, from the same nursery beds and temporarily packaged the same as treatment 1 to serve as a spring-lifted control. Cold storage temperature was 1° C and relative humidity was kept as high as possible by frequent wetting of the floor.

In April 1981, random samples of stock from each treatment were taken for the following measurements: 1) 25 seedlings for measurement of shoot and root xylem water potential (XWP), 2) 4 seedlings for estimation of root starch concentration, 3) 24 seedlings for determination of root growth potential (RGP), and 4) 50 seedlings for a field test.

Xylem water potential (XWP) to a minimum of -3500 kPa was determined on the terminal 12.5 cm (5 in) of the shoot and one large

lateral root of each seedling, using the pressure chamber technique of Scholander et al. (1965). Root starch concentration was estimated using the sectioning, staining, and visual estimation technique of Wargo (1975).

Root growth potential (RGP) was measured using the method reported by Rietveld and Williams 1981. Eight seedlings were planted in 20-l plastic pots filled with washed river sand and set in a greenhouse (temperature >18° C <30° C) under an extended photoperiod of 16 hours. Individual seedlings were examined twice weekly for bud burst. After 32 days the seedlings were removed from the pots by gently washing the sand from the roots. Seedling shoots were immediately measured for amount of die-back on the previous year's growth (shoot tip die-back), number and total length of new shoots, and number and total length of new leaves. Seedling root systems were measured for total number, area, and length of all new roots more than 1 cm long. Area was determined with a LI-COR[1] area meter. The root system was separated into new roots, lateral roots, and taproot to determine dry weight of each. Percent of taproot discoloration or decay was visually estimated by cutting the taproot into thirds and examining the apical end of each section.

The field study, on the Shawnee National Forest in southern Illinois, was located on a deep, well-drained Ava silt loam suitable for good walnut growth. The test consisted of five randomized complete blocks containing 10 seedlings per treatment per block. Seedlings were hand planted with a planting bar at 1 m x 1.5 m spacing on April 14, 1981. Competing vegetation was effectively controlled with one application of glyphosate (3.08 kg a.i./ha = 2.75 lb/A) plus simazine (4.8 kg a.i./ha = 4 lb/A) at time of planting. Seedlings were examined twice weekly for bud burst. Total height and stem diameter 3 cm above soil line was measured at planting and at the end of the first and second growing seasons. Additional fall measurements included length of the longest new shoot (terminal shoot growth) and total length of all lateral shoots (lateral shoot growth).

All data were analyzed for significant differences by ANOVA and Duncan's new multiple range test (a = 0.05) using treatment means for individual seedling data for XWP and starch concentration, pot means for RGP, and block means for the field study. Correlation coefficients were based on six pairs of sample means; absolute r-values of 0.754 and 0.874 at $P \leq 0.05$ and 0.01, respectively, were required for significance.

[1]Trade names are included for the information of the reader and do not constitute endorsement by the USDA Forest Service.

## RESULTS AND DISCUSSION

### Growth Responses in Root Growth Potential Test

Seedlings from the various packaging and overwintering treatments showed variable flushing of terminal buds (table 1). Only eight seedlings in the cold-stored bare-root treatment burst buds during the 32-day greenhouse test, and most died back to the root collar and resprouted. Heeled-in and spring-lifted seedlings that overwintered in the nursery burst buds 4 to 10 days sooner than packaged and cold-stored seedlings. Seedlings that overwintered outside had slightly more shoot tip die-back than the packaged, cold-stored seedlings, but the differences were not significant.

Shoot growth responses of the three packaged, cold-stored treatments and spring-lifted seedlings were very similar. Responses of seedlings totally enclosed in poly-lined Kraft bags were slightly better than those of seedlings packaged with roots only enclosed or spring-lifted. Packing roots in moist peat moss had little effect. Heeled-in seedlings were generally retarded. The earlier flushing date of spring-lifted and heeled-in seedlings did not result in more growth during the 32-day test period.

We observed no significant effects of packaging and overwintering treatments on RGP responses because of the high variability of root growth responses among individual seedlings and among pots. Dry weight of new roots ranged from 0 to 214.6 mg for the packaged and cold-stored seedlings. None of the seedlings cold-stored with exposed roots had any new root growth, and only two-thirds of the heeled-in seedlings had any new root growth. Although other authors (e.g., von Althen and Webb 1978) have reported that early shoot extension of hardwood planting stock is strongly correlated with the plant's ability to produce new roots, we found that root growth (dry weight) was only weakly related to new shoot growth (dry weight) ($r^2$ = 0.2678, F = 38.4; df = 1,105). This analysis excluded the seedlings cold stored with exposed roots.

The numerical data in table 1 suggest that totally enclosing seedlings in poly-lined Kraft bags resulted in a slightly better RGP response than packaging roots only, with or without moist peat moss, or spring-lifting. Statistically, the four treatments are similar.

### Seedling Characteristics at Planting Time

Shoot and root dry weight and shoot:root dry weight ratio of seedlings in the RGP study differed significantly among the six packaging and overwintering treatments after 32 days in the greenhouse (table 2). Most of the effect

Table 1.--Growth responses in root growth potential (RGP) tests of black walnut planting stock subjected to different packaging and overwintering treatments. Data are means of 24 seedlings.

| Growth response variable[1] | Packaging Treatment | | | | | |
|---|---|---|---|---|---|---|
| | Spring lifted | Seedling enclosed in bag | Roots in bag with moss | Roots in bag no moss | Heeled in | Bare-root |
| Seedlings bursting bud (%) | 100.0a[2] | 100.0a | 100.0a | 100.0a | 79.0b | 33.0c |
| Time to bud burst (days) | 11.16 | 15.4a | 19.2a | 15.4a | 9.1b | 29.3[3] |
| Terminal shoot dieback (cm) | 1.7 | 0.1 | 0.0 | 0.0 | 1.6 | 29.4 |
| Number of new shoots | 1.8a | 1.7a | 1.5ab | 1.4b | 1.3b | 0.4c |
| Total length new shoots (cm) | 6.1ab | 6.8a | 4.1bc | 4.1bc | 3.3c | 0.9d |
| Number of new leaves | 7.3a | 8.1a | 6.6a | 7.0a | 4.7b | 0.6c |
| Total length new leaves (cm) | 71.7abc | 94.4a | 60.6bc | 82.0ab | 42.5c | 0.4d |
| Dry weight new shoots & leaves (g) | 1.344a | 1.416a | 0.984a | 1.370a | 0.712a | 0.017b |
| Number of new roots[4] | 35.3 | 36.0 | 24.6 | 23.1 | 17.7 | 0.0 |
| Total length new roots (cm) | 98.1 | 98.7 | 70.3 | 59.1 | 44.6 | 0.0 |
| Total area new roots ($cm^2$) | 5.21 | 4.99 | 3.71 | 3.68 | 2.40 | 0.0 |
| Dry weight new roots (g) | 0.037 | 0.037 | 0.029 | 0.023 | 0.011 | 0.000 |
| Average new shoot length (cm) | 3.5a | 4.0a | 3.1ab | 3.0ab | 1.9b | 0.7c |
| Average new leaf length (cm) | 10.0a | 11.8a | 9.1ab | 11.8a | 6.5b | 0.2c |
| Average new root length (cm) | 2.8 | 2.5 | 2.8 | 2.4 | 2.5 | 0.0 |
| Average new root area (cm) | 0.17 | 0.13 | 0.14 | 0.15 | 0.11 | 0.0 |
| Decay in upper taproot (%) | 5.0c | 2.5c | 0.8c | 0.4c | 27.1b | 48.3a |
| Decay in middle taproot (%) | 7.1c | 3.3c | 2.5c | 2.9c | 27.0b | 76.2a |

[1]Dead seedlings were not excluded and were assigned a value of zero for most variables.
[2]Numbers in each row followed by the same letter are not significantly different at the 5% level. Treatments not followed by a letter showed no significant differences.
[3]Only eight seedlings burst buds; the remaining seedlings were assigned a value of 32 days, the length of the test.
[4]Root data are for first order roots $\geq$ 1.0 cm in length.

was due to differences among root dry weights. We did not weigh the seedlings before potting, so we did not know if the differences at planting time resulted from initial differences in seedling weight, from overwinter depletion, or from depletion during the RGP tests. Because all seedlings were lifted at the same time and randomly assigned to treatments (except spring-lifted seedlings), and height and caliper at the time of potting were similar (table 2), we assume their initial weights were similar. The root starch concentration data from dormant seedlings (table 2) do not clearly support any of the alternative causes for the differences.

In another study, black walnut seedlings from the same population were carefully excavated from the nursery beds to retain as much of the root system as possible. One-half of the seedlings were root pruned similar to the seedlings in this study. Shoot:root ratio of the unpruned seedlings averaged 0.238 compared to 0.303 for the pruned seedlings. These results would indicate that shoot-root ratios at the end of RGP tests (including new root and shoot growth) approximate the shoot:root ratio of stored seedlings at time of planting, and that some materials were apparently translocated to the shoots during the RGP tests. As expected, shoot xylem water potential was lowest in seedlings cold-stored with roots exposed (table 2). Root xylem water potential was more difficult to measure and more variable. Xylem water potential was generally low in seedlings from all the packaging and/or overwintering treatments. Only the least favorable treatments (cold-stored bare-root and heeled-in) were statistically distinguishable from the other treatments. There were no significant differences among treatments that enclosed the total seedling or root portion of the seedling with or without peat moss.

## Field Growth Responses

At planting, soil moisture was marginal; precipitation during the previous 12 months was 47 cm below the normal of 116 cm. Significant rainfall did not occur for another 4 days, then was 27 cm above the normal 45 cm expected for the remainder of the growing season.

Table 2.--Physical and physiological characteristics of black walnut planting stock at time of planting for 6 packaging and overwintering treatments. Dry weight data are means of 24 seedlings, xylem water potential data are means of 25 seedlings, and starch concentration data are means of 4 seedlings.

| | Packaging Treatment | | | | | |
|---|---|---|---|---|---|---|
| Seedling characteristic | Spring lifted | Seedling enclosed in bag | Roots in bag with moss | Roots in bag no moss | Heeled in | Bare-root |
| Shoot length (cm) | 36.9c | 41.0b | 34.4bc | 46.6a | 35.2c | 49.2a |
| Shoot basal diameter (mm) | 8.9a | 9.3a | 8.8a | 9.2a | 8.8a | 8.2a |
| Height/diameter ratio (cm/mm) | 4.18c | 4.46bc | 4.49bc | 5.14b | 4.06c | 6.07a |
| Shoot dry weight[1] (g) | 5.835c | 7.536abc | 6.134c | 8.401a | 5.932bc | 6.439ab |
| Root dry weight[1] (g) | 10.373d | 17.374a | 13.388bc | 16.026ab | 11.867cd | 10.761cd |
| Total dry weight[1] (g) | 16.208b | 24.910a | 19.522b | 24.427a | 17.799b | 17.200b |
| Shoot/root ratio[1] | 0.56c | 0.43a | 0.46ab | 0.52bc | 0.50abc | 0.60c |
| Shoot xylem water potential (-kPa) | 16.46b | 14.30a | 15.95b | 10.93a | 14.72b | 31.40c |
| Root xylem water potential (-kPa) | 10.83a | 19.51bcd | 13.86ab | 15.61abc | 21.94cd | 25.78d |
| Root starch concentration (%) | 18.8b | 32.5a | 31.2a | 30.0a | 17.5a | 20.0b |

[1]From RGP tests, includes new growth.

As in the RGP test, spring-lifted and heeled-in seedlings that overwintered outside burst buds 3-8 days sooner than cold-stored seedlings, but the differences had no effect on net growth at the end of the growing season (table 3). Most of the unpackaged cold-stored seedlings that survived died back to the ground and sprouted from the root collar, resulting in a decrement in height and diameter growth at the end of the season.

Survival, height growth, and diameter growth data support the same ranking of treatments as in the RGP test. That is, seedlings packaged totally enclosed in poly-lined Kraft bags performed slightly better numerically, but the difference was statistically indistinguishable from the seedlings with roots only enclosed and from the spring-lifted seedlings. The heeled-in seedlings had lower survival and grew less the first year, but performed almost as well as the other treatments during the second growing season. The cold-stored bare-root seedlings had low survival and growth the first year. Survival continued to decline the second year, but seedlings that did survive grew well.

Table 3.--Field growth responses of black walnut planting stock subjected to different packaging and overwintering treatments. Data are the means of 50 seedlings.

| | | Packaging Treatment | | | | | |
|---|---|---|---|---|---|---|---|
| Growing season after planting | Growth response variable[1] | Spring lifted | Seedling enclosed in bag | Roots in bag with moss | Roots in bag no moss | Heeled in | Bare-root |
| 1 | Time to bud burst (days) | 17.9cd[2] | 21.0bc | 22.8b | 22.7b | 16.4b | 44.4a |
| 1 | Terminal shoot die-back (cm) | 3.6b | 2.1b | 2.8b | 2.2b | 4.9b | 20.6a |
| 1 | Survival (%) | 98.0a | 100.0a | 100.0a | 100.0a | 86.0b | 50.0c |
| 2 | Survival (%) | 98.0a | 100.0a | 100.0a | 100.0a | 82.0b | 26.0c |
| 1 | Terminal shoot growth (cm) | 18.1ab | 21.4a | 16.1ab | 19.6ab | 18.0ab | 13.0b |
| 1 | Lateral shoot growth (cm) | 5.6ab | 9.3a | 8.0a | 6.9ab | 3.7bc | 1.1c |
| 1 | Net height growth (cm) | 14.6ab | 20.0a | 14.1ab | 18.0ab | 12.5b | -30.5c |
| 1 | Net diameter growth (cm) | 7.0ab | 7.9a | 7.0ab | 7.9a | 6.1b | - 2.3c |
| 2 | Net height growth (cm) | 99.1a | 100.8a | 102.5a | 104.5a | 110.8a | 76.5b |
| 2 | Net diameter growth (cm) | 17.4a | 17.8a | 17.9a | 18.7a | 18.4a | 12.1b |

[1]Means exclude all dead seedlings found at the end of each growing season.
[2]Means followed by the same letter are not significantly different according to Duncan's new multiple range test.

## Relation Between Planting Stock Characteristics at Planting Time and Field Performance

Because the packaging and overwintering treatments produced planting stock of variable quality, this study allowed us to correlate numerous planting stock characteristics determined at planting time with several field growth response variables. We therefore ran simple correlations of shoot and root growth responses in RGP tests (table 1) and seedling characteristics (table 2) with field growth responses (table 3). The resultant correlations (table 4) indicate that the seedling characteristics that are highly correlated ($P \leq 0.01$) with field survival and growth are: shoot tip die-back, average new shoot length, number of new leaves, total length of new leaves, average new leaf length, dry weight of new shoots and leaves, number of new roots, average new root length, total area of new roots, average new root area, occurrence of taproot discoloration and decay, shoot basal diameter, and shoot xylem water potential. The average lengths for new shoot, new leaf, new root and average area of new roots in RGP tests were surprisingly well correlated with field survival and growth. Discoloration and decay in cross sections of the upper and middle taproot at the end of the RGP tests were also surprisingly well correlated with field survival and growth. Heeled-in seedlings had 27 percent decay at both taproot cross-sections; seedlings stored bare-root had 48 and 76 percent decay in upper and lower taproot cross sections, respectively (table 1). The remaining treatments had 0.4 to 7.1 percent decay or discoloration. Time to bud burst and shoot tip die-back seem to be good early indicators of planting stock quality, both in RGP tests and in the field.

Shoot basal diameter (3 cm above root collar) was the only seedling morphological characteristic of planting stock that was strongly correlated with field growth responses (survival and diameter growth, but not height growth). This relationship is consistent with our previous finding that basal diameter increment is strongly related to first-year root growth in dry weight (van Sambeek and Rietveld 1983). Height:diameter ratio of planting stock was also a reasonably good indicator of field performance.

Shoot xylem water potential was found to be highly correlated with field survival and is much easier to measure than RGP. Webb and von

Table 4.--Simple correlations of shoot and root growth responses in root growth potential (RGP) tests and seedling characteristics at time of planting, versus field growth responses. Correlation coefficients are based on six pairs of sample means representing the packaging/overwintering treatments. For significance at $P \leq 0.05$ and 0.01, r values of 0.754 and 0.847, respectively, are required.

| Variable X | Variable Y: Field growth response | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Time to bud burst (days) | Terminal shoot dieback (cm) | First-year survival (%) | Second-year survival (%) | Terminal shoot growth (cm) | Lateral shoot growth (cm) | Net 1st yr height growth (cm) | Net 1st yr diameter growth (mm) | Net 2nd yr height growth (cm) | Net 2nd yr diameter growth (mm) |
| A. Shoot response in RGP test | | | | | | | | | | |
| Time to bud burst (days) | .96**[1] | .80* | -.73 | -.75* | -.72 | -.40 | -.83* | -.81* | -.89** | -.85* |
| Terminal shoot dieback (cm) | .95** | .99** | -.97** | -.98** | -.80* | -.79* | -.99** | -.99** | -.93** | -.98** |
| Number new shoots | -.73 | -.76* | .80* | .80* | .75 | .70 | .77* | .77* | .50 | .62 |
| Total length new shoots (cm) | -.72 | -.78* | .81* | .81* | .83* | .79* | .80* | .80* | .52 | .64 |
| Average new shoot length (cm) | -.79* | -.87** | .89** | .89** | .89** | .87* | .89** | .88** | .65 | .76* |
| Number new leaves | -.83* | -.95** | .98** | .97** | .85* | .90** | .95** | .96** | .73 | .86* |
| Total length new leaves (cm) | -.75 | -.91** | .93** | .92** | .92** | .91** | .91** | .92** | .67 | .81* |
| Average new leaf length (cm) | -.89** | -.98** | .96** | .96** | .92** | .84* | .99** | .99** | .86* | .95** |
| Dry weight new shoots+leaves (g) | -.78* | -.91** | .94** | .94** | .88** | .85* | .91** | .93** | .67 | .82* |
| B. Root response in RGP test | | | | | | | | | | |
| Number new roots | -.80* | -.87* | .40** | .40** | .82* | .82* | .88** | .88** | .62 | .75 |
| Total length new roots (cm) | -.78* | -.85* | .89** | .88** | .78* | .82* | .85* | .85* | .58 | .71 |
| Average new root length (cm) | -.96** | -.97** | .96** | .97** | .72 | .75 | .97** | .97** | .90** | .95** |
| Total area new roots ($cm^2$) | -.80* | -.88** | .92** | .92** | .80* | .83* | .88** | .89** | .62 | .76* |
| Average new root area ($cm^2$) | -.89** | -.95** | .97** | .97** | .73 | .74 | .94** | .95** | .80* | .90** |
| Dry weight new roots (g) | -.68 | -.80* | .87* | .86* | .71 | .85* | .80* | .81* | .49 | .65 |
| Decay in upper taproot (%) | .72 | .92** | -.97** | -.96** | -.73 | -.92** | -.89** | -.92** | -.66 | -.82* |
| Decay in lower taproot (%) | .85* | .98** | -.999** | -.996** | -.79* | -.89** | -.97** | -.98** | -.80* | -.91** |
| C. Seedling characteristics | | | | | | | | | | |
| Shoot length (cm) | .75 | .61 | -.23 | -.37 | -.60 | -.57 | -.68 | -.61 | -.57 | -.59 |
| Shoot basal diameter (cm) | -.75 | -.89** | .97** | .86* | .91** | .91** | .73 | .84* | .89** | .88** |
| Height/diameter ratio | .94** | .81* | -.60 | -.51 | -.82* | -.79* | -.84* | -.80* | -.75 | -.77* |
| Shoot dry weight (g) | .03 | -.24 | .26 | .28 | -.53 | .43 | .25 | .27 | .09 | .23 |
| Root dry weight (g) | -.27 | -.53 | .54 | .52 | .73 | .77* | .54 | .55 | .37 | .47 |
| Total dry weight (g) | -.19 | -.47 | .70 | .70 | .48 | .49 | .31 | .43 | .48 | .46 |
| Shoot/root dry wt. ratio | .59 | .72 | -.70 | -.70 | -.66 | -.84* | -.73 | -.71 | -.65 | -.68 |
| Shoot xylem water potential (-kPa) | .89** | .96** | -.94** | -.94** | -.77* | -.73 | -.96** | -.96** | -.94** | -.94** |
| Root xylem water potential (-kPa) | .64 | .72 | -.78* | -.77* | -.74 | -.66 | -.73 | -.74 | -.42 | -.58 |
| Root starch concentration(%) | -.40 | -.61 | .58 | .57 | .57 | .76* | .60 | .60 | .59 | .62 |

[1] * = significant at 5% level; ** = significant at 1% level.

Althen (1980) found that RGP was also strongly correlated with shoot xylem water potential. Because the respective measurements were performed on separate seedling samples in our study, we ran simple correlations between shoot xylem water potential and 15 RGP response variables. The correlation coefficient for number of new roots, the variable used by Webb and von Althen (1980), was not significant, but average new root length and area were strongly correlated (table 5).

The weak relationship between seedling root starch concentration and field performance is similar to our previous findings (Rietveld and Williams 1982). It appears that stored starch is not a key variable affecting field survival and growth, unless it is severely depleted or seedlings are transplanted into unusually stressful environments.

We also identified early field growth response variables that were indicative of eventual establishment and growth. Days to bud burst and terminal shoot tip die-back, which can be measured early in the first growing season, were strongly correlated with the remaining growth response variables measured at the end of the first and second growing seasons in the field (table 3). These highly significant correlations, presented in table 6, should be interpreted with the understanding that the relationships may be quite different if major weather changes occur during the planting year. The correlations are much stronger with seedling growth than with seedling survival. This is expected because black walnut seedlings typically survive tenaciously but grow poorly if planting stock quality or growing conditions are suboptimal.

Several investigators (e.g., Stupendick and Shepherd 1979, Sutton 1983) have found that excessive among-seedling variation in root regeneration tests makes it very difficult to use root growth variables to evaluate planting stock quality and predict field performance. The variation may be related to the genetic diversity of normal bed-run planting stock, and variation due to such factors as edge effects, speed of germination, bed density, and presence of diseases. Nambiar and Cotterill (1982) compared RGP of eight open-pollinated families of radiata pine (Pinus radiata D. Don) at three temperatures. They found that root regeneration characters were highly heritable and interacted significantly with temperature. We submit that other investigators interested in measuring planting stock quality should consider the following: 1) utilize genetically uniform plant materials or larger (25-50 seedling) sample sizes, 2) exploit genetic differences in root regeneration and root configuration to improve survival and initial growth; and 3) consider adopting other less variable and more easily measured factors (such as shoot basal diameter, xylem water potential, and shoot growth variables in RGP tests) that are strongly related to field performance. Several such variables identified in this paper should receive additional scrutiny.

As in many field studies reported in the literature, the expression of treatment effects

Table 5.--Simple correlations between root growth potential variables and shoot xylem water potential. Correlation coefficients are based on 6 pairs of sample means representing the packaging/overwintering treatments. For significance at $P \leq 0.05$ and 0.01, r values of 0.754 and 0.874, respectively, are required.

| Response variable in RGP test | Shoot xylem water potential (-kPa) |
|---|---|
| Time to bud burst (days) | -.31 |
| Terminal shoot dieback (cm) | .97**[1] |
| Number of new shoots | -.59 |
| Total length new shoots (cm) | -.61 |
| Average new shoot length (cm) | -.73 |
| Number of new leaves | -.86* |
| Total length new leaves (cm) | -.82* |
| Average new leaf length (cm) | -.95** |
| Dry weight new shoots + leaves (g) | -.84* |
| Number of new roots > 1.0 cm | -.72 |
| Total length new roots > 1.0 cm | -.69 |
| Average new root length (cm) | -.93** |
| Total area new roots > 1.0 cm ($cm^2$) | -.75 |
| Average new root area ($cm^2$) | -.91** |
| Dry weight new roots (g) | -.64 |

[1] * = significant at 5% level; ** = significant at 1% level.

Table 6.--Simple correlations between initial field growth responses and responses measured at the end of the first and second growing seasons. Correlation coefficients are based on six pairs of sample means representing the packaging/overwintering treatments. For significance at $P \leq 0.05$ and 0.01, r values of 0.754 and 0.874, respectively, are required.

| Initial growth response variable | First-year survival (%) | Second-year survival (%) | First-year terminal shoot growth (cm) | First-year lateral shoot growth (cm) | First-year net height growth (cm) | First-year net diameter growth (cm) | Second-year net height growth (cm) | Second-year net diameter growth (mm) |
|---|---|---|---|---|---|---|---|---|
| Time to bud burst (days) | -.76*[1] | -.61 | -.94** | -.92** | -.94** | -.94** | -.87** | -.89** |
| Shoot tip die-back (cm) | -.83* | -.84* | -.99** | -.99** | -.90** | -.97** | -.99** | -.99** |

[1] * = significant at 5% level; ** = significant at 1% level.

in this study was constrained by unusually favorable testing conditions. Under these conditions, only the weakest treatments would be expected to fail. But under more stressful conditions, smaller differences in planting stock quality might be expected to result in larger differences in survival and growth.

## CONCLUSIONS

The principal conclusions of the study are summarized as follows:

1) Of the packaging and overwintering methods examined, seedlings totally enclosed or seedlings with only their roots enclosed in Kraft bags with a plastic liner showed the best root growth potential and field performance. Their growth responses were comparable with those of spring-lifted seedlings. Seedlings heeled-in overwinter or cold-stored with roots exposed were of lesser quality.

2) Simple correlations of 27 measured characteristics of planting stock at time of planting with 10 measured field growth response variables revealed 13 characteristics strongly correlated with first-year survival and height and diameter growth. Time to bud-burst and shoot tip die-back after outplanting are good early indicators of eventual survival and height and diameter growth.

3) Shoot xylem water potential is strongly correlated with several variables in RGP tests as well as with first-year survival and growth in the field, and it is much easier to measure than root growth potential.

4) Root growth responses in root growth potential tests are highly variable among seedlings, making it difficult to distinguish treatment differences. Other growth responses, e.g., days to bud-burst, terminal shoot dieback, and shoot and leaf growth, are less variable, easier to measure, and highly correlated to field survival and growth.

## LITERATURE CITED


Nambiar, E. K. Sadanandan; Cotterill, Paul P. 1982. Genetic differences in root regeneration of radiata pine. Journal of Experimental Botany 33:170-177.

Rietveld, W.J. 1989. Transplanting stress in bareroot conifer seedlings: its development and progression to establishment. Northern Journal of Applied Forestry (In press).

Rietveld, W. J.; Williams, Robert D. 1981. Lifting date affects black walnut planting stock quality. USDA Forest Service Research Paper NC-205, 8 p. North Central Forest Experiment Station, St. Paul, Minn.

Rietveld, W. J.; Williams, Robert D. 1982. Starch levels in fall-lifted hardwood planting stock and their relation to field survival and growth. p. 86-97. In Proceedings Northeastern Area Nurserymen's Conference, [Halifax, Nova Scotia, July 25-29, 1982].

Scholander, P. F.; Hammel, H. T.; Edda, D.; Bradstreet, E. D.; Hemmingsen, E. A. 1965. Sap pressure in vascular plants. Science 148:339-346.

Stupendick, J. T.; Shepherd, K. R. 1979. Root regeneration of root-pruned Pinus radiata seedlings. I. Effects of air and soil temperature. Australian Forestry 42: 141-149.

Sutton, R. F. 1983. Root growth capacity: relationship with field root growth and performance in outplanted jack pine and black spruce. Plant and Soil 71:111-112.

van Sambeek, J.W.; Rietveld, W.J. 1983. Preplant indolebutyric acid treatment of outplanted black walnut seedlings. p. 272-280 In Proceedings Seventh North American Forest Biology Workshop. [Lexington, Ky., July 26-28, 1982].

von Althen, F. W.; Webb, D. P. 1978. Effects of root regeneration and time of planting on sugar maple plantation establishment. p. 401-411 In Proceedings Second Central Hardwood Forest Conference, Philip E. Pope (ed.), Purdue University Press, West Lafayette, Ind.

von Althen, F. W.; Webb, D. P. 1981. Overwinter cold storage of hardwood nursery stock: effects on outplanting performance. p. 20-33 In Proceedings Northeastern Area Nurserymen's Conference, [Springfield, MO, July 24-27, 1981].

von Althen, F. W.; Webb, D. P. 1982. Effects of packaging methods on the survival and growth of cold-stored hardwood planting stock. p. 74-79. In Proceedings Northeastern Area Nurserymen's Conference, [Halifax, Nova Scotia, July 25-29, 1982].

Wargo, Phillip M. 1975. Estimating starch content in roots of deciduous trees -- a visual technique. USDA Forest Service Research Paper NE-313, 9 p. Northeastern Forest Experiment Station, Broomall, Penn.

Webb, D. P.; von Althen, F. W. 1980. Storage of hardwood planting stock: effects of various storage regimes and packaging methods on root growth and physiological quality. New Zealand Journal of Forest Science 10: 83-96.