AN EVALUATION OF ROOT-WRENCHED AND STORED LOBLOLLY PINE SEEDLINGS

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Abstract.--Loblolly pine (*Pinus taeda* L.) seedlings growing in nursery seedbeds were root-wrenched twice, root-wrenched four times, or left undisturbed. After lifting in January, seedlings were either immediately outplanted or outplanted after one or two months of storage. Wrenching decreased planting stock height, ground-line diameter, shoot volume, and seedling dry weight. Foliar N decreased with wrenching, whereas foliar P and K changed little. Wrenching and lengthening storage reduced seedling starch content and root growth potential. Stem electrical impedance was not significantly affected by wrenching or storage treatments. Survival of outplanted seedlings did not differ among wrenching treatments, but did decrease from 89% for non-stored seedlings to 65% for seedlings stored two months. After one growing season, height growth of seedlings wrenched four times was 6.5 cm greater than unwrenched and twice-wrenched seedlings.

Additional keywords: seedling morphology, root growth potential, starch, nutrients, survival, height growth, *Pinus taeda*.

Root wrenching in the nursery bed and cold storage after lifting are nursery practices that are used in the northwestern United States and are used to a lesser extent in the Southeast. Root wrenching involves drawing a blade, tilted at an angle, underneath the nursery seedbed to sever deep roots and to partially lift the seedlings and soil, thus aerating the seedbed and altering growing conditions (van Dorsser and Rook 1972). Cold storage permits a lengthening of time between lifting and planting, which helps ease the coordination of planting activities. Because root wrenching and cold storage change the physiological activities of the seedling, they may also alter seedling quality. This paper reports the effects of wrenching and cold storage on loblolly pine (*Pinus taeda* L.) seedling morphology, starch and nutrient content, root growth potential, and stem electrical impedance. These measures and their relation to first-year survival and growth are discussed.

METHODS

Planting stock used in this study was obtained from the Westvaco nursery in Charleston County, South Carolina. Seeds from the Westvaco seed orchard were sown in nursery beds in April, 1983. Four nursery beds were selected as

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blocks, and three treatments were established in each block. Seedbed treatments were: (a) no root wrenching, (b) root wrenching once monthly in October and November, and (c) monthly root wrenching in August, September, October, and November. All root wrenchings were done near the first day of each month using a fixed, sharpened, steel blade (1.5 m x 12.7 cm x 1.3 cm) pulled behind a tractor, at a depth of 18 to 21 cm below the seedbed surface. Following each root wrenching, beds were irrigated for 30 minutes to reduce seedling moisture loss. The beds were treated with the same cultural practices as the rest of the nursery throughout the growing season. All seedlings were top-clipped with a bushhog at 18 to 21 cm above the bed surface in September.

Approximately two hundred seedlings from each wrenching treatment, in each nursery block, were hand lifted in January, 1984 and divided into three groups: one for immediate measurement and outplanting, a second for a cold storage of 30 days, and a third for a cold storage of 60 days before measurement and outplanting. All lifted seedlings were placed in kraft-polyethylene bags. For cold storage, a walk-in cooler at a temperature of 1.5°C ± 1.0°C was used. Upon outplanting, seedlings from each root wrenching and storage treatment were again divided into three groups. Each group was used in separate tests to measure seedling quality. Generally, equal numbers from each nursery block were used in each test.

Morphological and Chemical Tests

Thirty seedlings from each root wrenching/storage treatment were measured for stem length (cm), root collar diameter (mm), shoot volume (cm^3), and root volume (cm^3). Volumes were determined by water displacement. A 5-liter beaker filled with distilled water was placed on a Mettler PT 15 balance. The beaker containing the water was tared, and the shoot or root of a seedling was immersed in the water, up to the root collar. The seedling was supported so that it did not touch the sides or bottom of the beaker. The weight of the displaced water was recorded in grams (g). This weight closely approximates the cm^3 of volume displaced, and was used as the volume measurement. After volume displacement measurements, seedlings were dried in a forced air oven at 75°C for 48 hours. For each seedling, the oven dry weight (ODW) in grams of the shoot system and the root system were recorded. After weighing, the separated tissues were pooled into six groups of five seedlings for each treatment. Each of the six groups were then ground using a small Wiley cutting mill with a 40 mesh screen. Following grinding, the tissue was stored in a freezer at -15°C for later chemical analysis.

The ground root, stem, and needle tissues from every five-seedling group were measured for percent starch using the enzymatic hydrolysis technique of Haissig and Dickson (1979). Following starch measurements, the remaining needle tissue from every five-seedling group was again pooled to represent three, 10-seedling groups for each treatment. Foliar tissues from these three groups were analyzed for N, P, and K by the Clemson University Agricultural Services Laboratory. Total N was determined by the Kjeldahl procedure, and P and K by flame spectroscopy (Ellis et al. 1975). The design of the morphological and chemical analysis was a randomized complete block design with blocking on the pooled samples.

Root Growth Potential and Stem Electrical Impedance Tests

Another thirty seedlings from each root wrenching/storage treatment were analyzed for root growth potential (RGP) as outlined by Ritchie and Dunlap (1980). Ninety seedlings were potted following lifting or at the end of each cold storage period, with three seedlings, one from each root wrenching treatment, per pot. The pots had a volume of 2.5 liters and were filled with builders sand. At potting, all white, unsuberized roots on the seedlings were removed. Total stem height and root collar diameter were measured at potting. Following potting, the seedlings were placed below a bank of flourescent lights with a day length of 16 hours and a light intensity of 35 $\mu E\ s^{-1} m^{-2}$. Seedlings were thoroughly watered every other day, with excess water draining out the bottom of the pots. Air temperatures, measured on a hygrothermograph, ranged from 20°C to 29°C with an average of 26°C. Relative humidity ranged from 30% to 100% (at watering) with an average of 40% to 50%. Seedling roots were washed free of sand 25 days after planting, and the number of new roots (those that were white and unsuberized) longer than 0.5 cm were counted. The count of roots represented the RGP meaurement. The design of the RGP test was a completely random split-plot with each split-plot representing a root wrenching level.

Stem electrical impedance (SEI) was measured on seedlings in the root growth potential experiment, one week after potting. Impedance was measured with a model 7950 Shigometer (Shigo and Shigo 1974), using two 1.5 cm-long steel needles, spaced one cm apart, as probes. The lowest probe was inserted 1.5 cm above the root collar of the stem. Probes were inserted firmly into the wood tissue. Meter readings in K ohms were obtained for each seedling. The analysis for this test was the same as that used in the RGP test.

Outplanting Measurments

Another eighty seedlings from each root wrenching/storage treatment were outplanted on a clearcut, rootraked, and fertilized upland site on the Clemson University Experimental Forest. The soil was an eroded Hiwassee clay loam, with a northwest aspect and 6% slope. Two hundred forty seedlings were hand planted with a planting bar at a spacing of 1.2 m by 2.4 m on each planting date. Fresh lifted seedlings, seedlings stored for one month, and seedlings stored for two months were planted, respectively, on each of the three planting dates. Heights and root collar diameters were measured one week after each group of seedlings were planted to allow for settling. In November, 1984, when growth had ceased, first-year field survival and height were measured. The design of the outplanting was a randomized complete block with split-plots, replicated four times, with root wrenching level as the whole plot and storage level as the sub-plot. Therefore, 20 seedlings were planted in each sub-plot.

Statistical Analysis

In each test, analysis of variance was used to detect differences due to treatment effects. Orthogonal contrasts (Steele and Torrie 1980) were used to examine differences between treatments. Relationships of response variables to field survival were examined using linear correlation techniques. Probability of a type I error (alpha) was set at 0.05.

RESULTS AND DISCUSSION

Morphology

Generally, root wrenching caused a decrease in seedling size at lifting (Table 1). The shoot system was reduced by wrenching, with wrenching causing decreases in stem height, ground-line diameter, shoot volume and dry weight. Differences in height represent growth following top clipping in September. There was no further decrease in shoot size between two and four wrenchings.

Table 1.--Loblolly pine seedling morphology for root wrenching treatments, at lifting.

Wrenching Frequency	Height	Diameter	Volume Displacement Shoot	Volume Displacement Root	Oven Dry Weight Shoot	Oven Dry Weight Root
	--cm--	--mm--	------cm^3-----		-----g------	
0	22.4	4.44	8.87	4.06	2.49	1.16
2	21.6	3.98	7.37	3.49	2.07	0.95
4	20.6	3.99	6.83	3.91	1.91	1.06
Std. error	0.4	0.07	0.28	0.19	0.08	0.05
Wrenching Contrasts [a/]						
0 vs. 2&4	*	*	*	ns	*	*
2 vs. 4	ns	ns	ns	ns	ns	ns

[a/] An * indicates a significant F and ns indicates not significant at alpha = 0.05.

In the root system, wrenching caused no significant change in root volume, and a ten percent decrease in root dry weight (Table 1). Shoot:root ratio on a volume or weight basis decreased with wrenching. Tanaka et al. (1976) found wrenched loblolly pine seedlings had a decreased top size but no change in root dry weight, even though wrenched seedlings had more fibrous lateral roots. In the present study, wrenching probably removed some of the tap and older lateral root ends, while root regrowth was young and succulent. Because of root regrowth, root volume remained unchanged, but root dry weight decreased slightly with wrenching. In Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco), Duryea and Lavender (1982) found that wrenching did not affect root dry weight, while van den Driessche (1983) observed increased root dry weight with wrenching. We suggest that competitive inhibition of root growth occurs in loblolly pine due to continued shoot growth after root wrenching. Overall, the impact of wrenching on the root system was minimal at lifting.

Starch

Starch content was affected by length of storage more than by wrenching (Fig. 1). Starch content of the foliage was not significantly affected by any of the treatments, but both stem and root starch levels were reduced up to 35% by storage. No significant change in starch levels occured between one and two months of storage. Tworkoski (1978) was not able to detect changes in root starch content in loblolly pine with length of time in storage. The results from the present study may indicate that starch use is not the same at different times during cold storage of loblolly pine.

There was an 8% decrease in stem and root starch content between zero and four wrenchings in the non-stored seedlings (Fig. 1). Rook (1971) found certain wrenching intensities increased root starch levels in radiata pine (*Pinus radiata* D. Don). These changes were not observed in loblolly pine, suggesting that loblolly pine may channel its photosynthate differently than radiata pine after wrenching. Maintenance of a shoot sink by resumption of stem growth following wrenching may prevent starch build-up in loblolly pine roots.

Nutrient

Foliar N concentrations were influenced by wrenching and storage while foliar P and K were not greatly affected (Table 2). Overall, nitrogen was reduced in wrenched seedlings, but seedlings wrenched four times had higher concentrations than twice-wrenched stock. A reduction in foliar N and P has been associated with wrenching in radiata pine (Benson and Shepherd 1977) and in Douglas-fir (Menzies 1980, van den Driessche 1983). Since wrenching involves the removal of some actively absorbing roots, the reduction in nutrient concentrations due to interrupted absorption and tissue loss seems reasonable. However, P and K were not greatly affected by wrenching in loblolly pine. Nitrogen increased in the foliage of the stored seedlings but P and K were not greatly affected (Table 2).

Root Growth Potential

Both root wrenching and storage had significant effects on RGP (Table 3). Non-wrenched seedlings had a higher RGP than wrenched seedlings, but there was no significant difference between seedlings wrenched twice and those wrenched four times. The reduction in RGP due to wrenching is different from results found with other conifer species. Nambiar *et al.* (1979) and Menzies (1980) found that wrenching stimulated new root growth in radiata pine and Douglas-fir respectively. van den Driessche (1983) found wrenching to have no effect on RGP in Douglas-fir. Results of the present study indicate that wrenching may not be a useful cultural practice for loblolly pine when the objective is to increase RGP.

Non-stored seedlings had a greater RGP than stored seedlings, but differences were small between seedlings stored one and two months. Some experimental problems were encountered, however. During the first RGP measurement, using freshly lifted seedlings, the pots were placed in a growth chamber which became inoperable after several days. Seedlings were under a condition of low light, low relative humidity, and temperatures near 35°C for approximately five days. The seedlings were then placed under artificial lights and

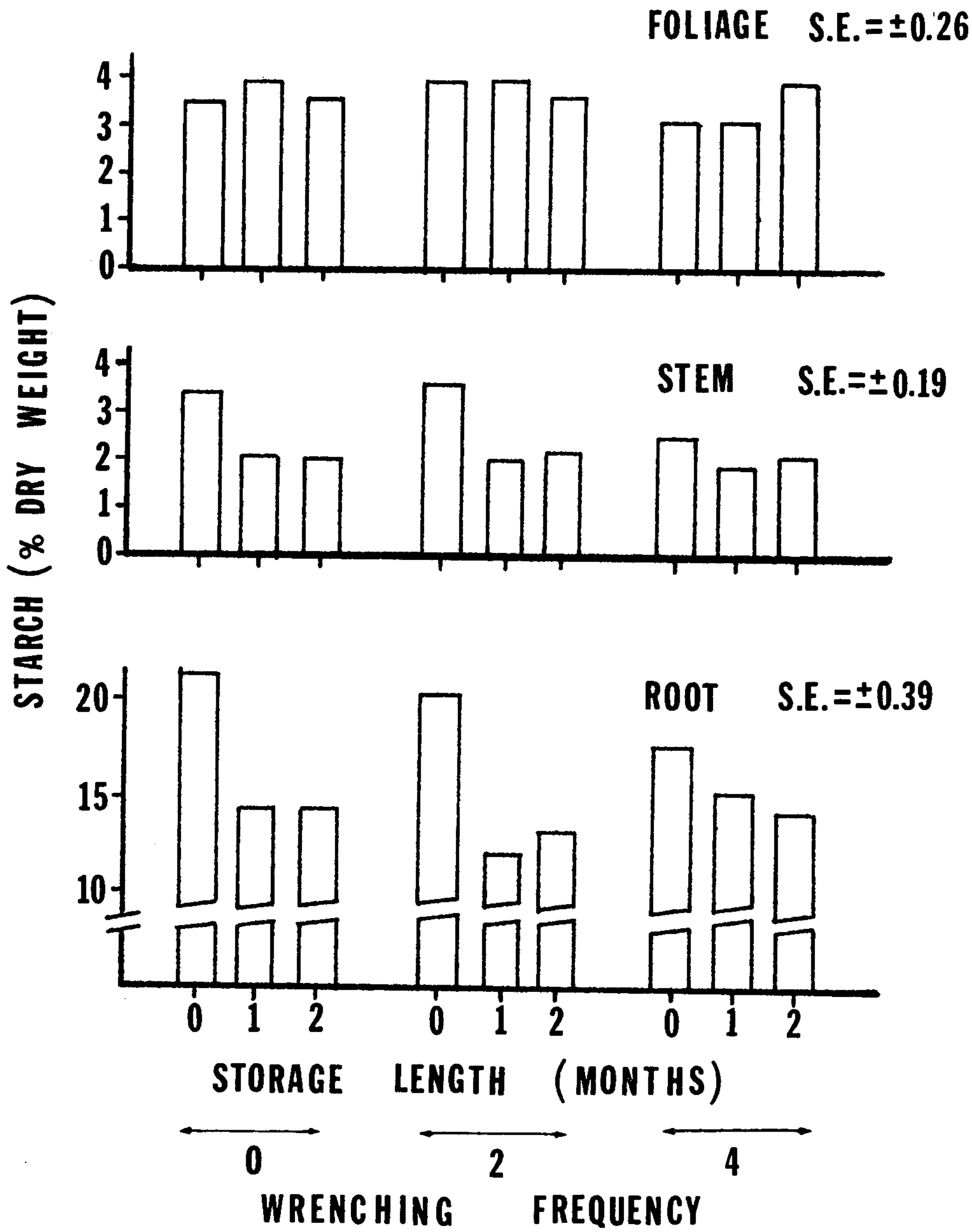

Figure 1.--Loblolly pine foliage, stem, and root starch concentrations by wrenching frequency and storage length.

Table 2.--Loblolly pine foliar nutrient content by wrenching frequency and storage length.

Wrenching	Storage	N	P	K
		-------------%	-------------	
	0	1.44	0.137	0.457
0	1	1.48	0.130	0.406
	2	1.55	0.137	0.390
	0	1.24	0.113	0.430
2	1	1.19	0.130	0.397
	2	1.39	0.130	0.430
	0	1.31	0.140	0.436
4	1	1.39	0.133	0.426
	2	1.40	0.133	0.420
Std. error		0.04	0.005	0.019
Wrenching Contrasts [a/]				
0 vs. 2&4		*	ns	ns
2 vs. 4		*	*	ns
Storage Contrasts [a/]				
0 vs. 1&2		*	ns	*
1 vs. 2		*	ns	ns

a/ An * indicates a significant F and ns indicates not significant at alpha = 0.05.

temperatures averaging 26°C for the remaining 20 days. This may be partially responsible for the large numbers of new root tips of the non-stored seedlings, and account for the lack of a significant difference between one and two months of storage. Rhea (1977) reported significant declines in RGP due to lengthening storage in loblolly pine, although the declines were linear during periods of eight months of storage.

Stem Electrical Impedance

SEI showed no clear trend with treatment for seedlings used in the RGP analysis (Table 3). There were no statistical differences in SEI between freshly lifted and stored seedlings, although seedlings stored one month had a higher mean SEI than those stored two months. Wrenching did not have an effect on SEI. Similar results have been reported by van den Driessche (1983) with wrenched Douglas-fir.

Table 3.--Loblolly pine root growth potential (RGP) and stem electrical impedence (SEI) by wrenching frequency and storage length.

Wrenching	Storage	RGP	SEI
		--no. of roots--	--K ohms--
	0	48.0	6.9
0	1	17.5	8.1
	2	18.8	7.2
	0	24.3	7.6
2	1	13.2	8.1
	2	14.2	7.2
	0	23.2	7.3
4	1	10.8	7.8
	2	11.0	7.0
Std. error		2.4	0.2
Wrenching Contrasts [a/]			
0 vs. 2&4		*	ns
2 vs. 4		ns	ns
Storage Contrasts [a/]			
0 vs. 1&2		*	ns
1 vs. 2		ns	*

a/ An * indicates a significant F and ns indicates not significant at alpha = 0.05.

Survival

Root wrenching did not have a significant effect on first year field survival (Fig. 2). In many cases, however, root wrenching has been found to increase survival, particularly on dry sites, with radiata pine (Rook 1969), Douglas-fir (Koon and O'Dell 1977) and loblolly pine (Tanaka et al. 1976). Wrenching loblolly pine seedlings did not have beneficial effects on survival for conditions encountered during the 1984 planting year.

Seedling survival differences were related to length of time in storage (Fig. 2). There was a decline in survival between non-stored and stored seedlings, as well as a decrease from one to two months of storage. However, as length of storage increased, planting date was delayed. The planting dates in this study were similar to normal operational planting dates (end of January, February, and March), and temperature and precipitation during the planting period was very near the 30-year average values of between 5.5°C and 11°C, and between 12 cm and 17 cm, respectively (USDC 1984). Monthly precipitation averages remained steady for several months after outplanting and temperatures

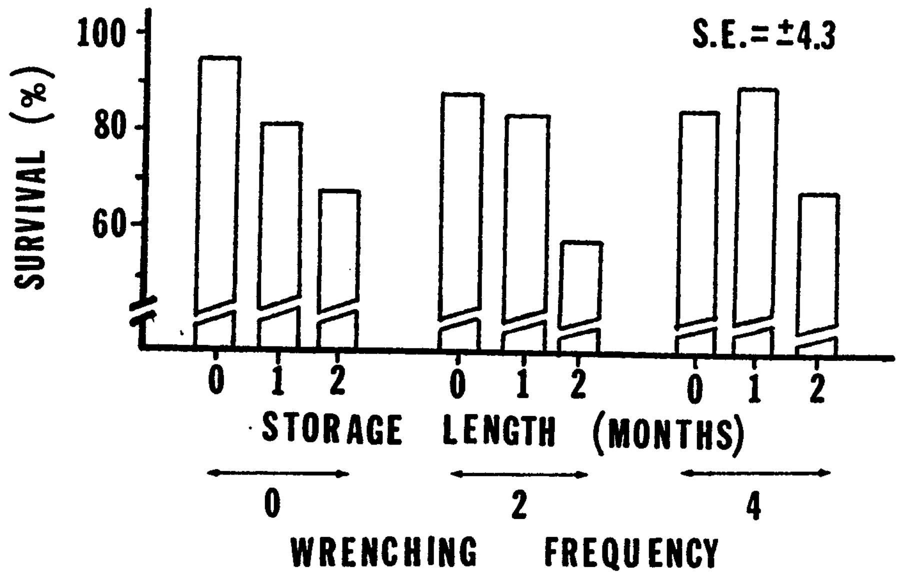

Figure 2.--First-year field survivals of loblolly pine seedlings by wrenching frequency and storage length.

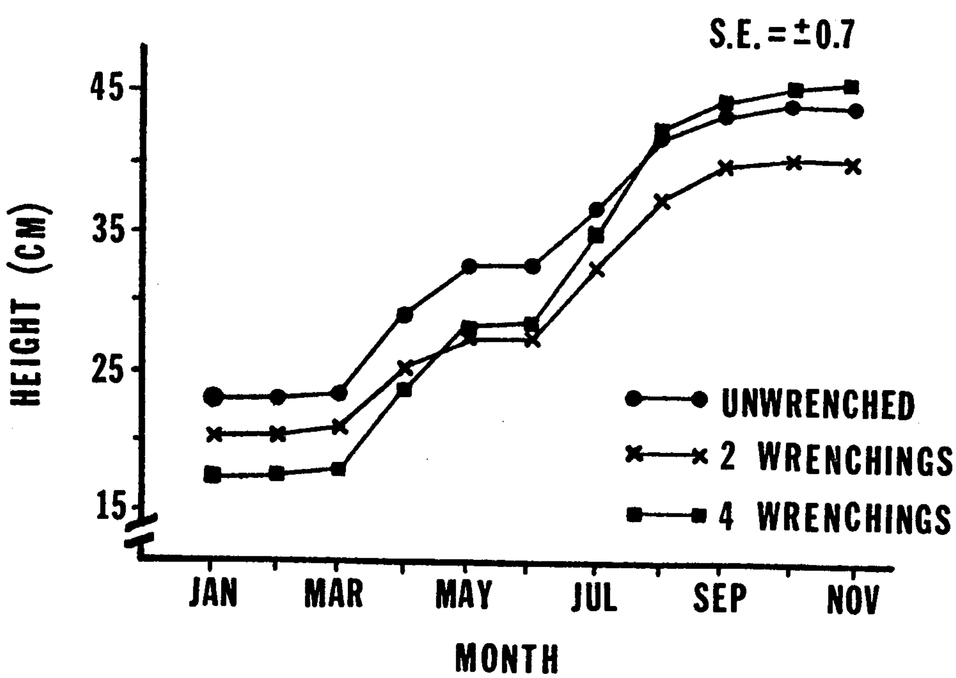

Figure 3.--First-year field height growth of loblolly pine seedlings by wrenching frequency.

rose normally. The decrease in survival with increasing length of storage is contrary to most literature on storage of loblolly pine, which has shown no decrease in survival with up to three months of cold storage (Williston 1974, Ursic *et al.* 1966, Dierauf 1984, and Tworkoski 1978). In this study, some unmeasured storage factor may have affected field survival.

Height Growth

First-year height growth in the field was affected more by root wrenching than by storage length. The seedlings wrenched four times had the greatest height growth in the field (Fig. 3). Because the seedlings wrenched four times were shorter to begin with, they were not significantly taller than non-wrenched stock after one year. It is not known if the increased field growth of the seedlings wrenched four times will continue beyond the first year in the field. Stein (1984) found that second year wrenching of Douglas-fir seedlings initially produced a smaller seedling, but then the seedlings grew as large as the unwrenched controls. Duryea and Lavender (1982) found that wrenching Douglas-fir did not improve growth or survival in the field. In this study, it appears that root wrenching may benefit growth, but benefits to survival were not evident.

Response Variable Relationships

The relationship of seedling measurements as indicators of potential field survival was investigated using mean values for the nine wrenching/storage treatment combinations. Among variables measured, RGP and root starch content showed the highest correlations with field survival (r^2 = 0.27 and 0.35, repectively), although they were not statistically significant (alpha = 0.05). Usefulness of these correlations is questionable, however, because of the confounding effects of the wrenching and storage treatments on response variables.

CONCLUSIONS

Root wrenching in the nursery bed caused a decrease in shoot size and a slight decrease in root size of loblolly pine planting stock lifted in January. Also, wrenching caused a reduction in foliar N concentration and RGP. These changes in the morphology and physiology were not clearly related to first-year survival in the field. The most intensely wrenched seedlings (four wrenchings) had the greatest height growth after outplanting, but end-of-year field height was no different than non-wrenched seedlings. Cold storage decreased seedling starch content, RGP, and first-year field survival. These results indicate that wrenching loblolly pine seedlings provides few benefits, other than an increased rate of height growth in the field. Also, storage as short as two months may have negative effects on loblolly pine seedling performance under certain outplanting or storage conditions.

LITERATURE CITED

Benson, A.D. and K.R. Shepherd. 1977. Effects of nursery practice on *Pinus radiata* seedling characteristics and field performance: II. Nursery root wrenching. N.Z.J. For. Sci. 7(1):68-76.

Dierauf, T.A. 1984. Survival of root pruned loblolly pine seedlings after long term cold storage. Virginia Div. For. Occas. Rep. 64, 2 pp.

Duryea, M.L. and D.P. Lavender. 1982. Water relations, growth, and survival of root-wrenched Douglas-fir seedlings. Can. J. For. Res. 12:545-555.

Ellis, R.J., J.J. Hanway, G. Holmgren, D.R. Kenney, and O.W. Bidwell. 1975. Sampling and analysis of soils, plants, waste waters, and sludge--Suggested standardization and methodology. Agric. Exp. Sta., Kansas State Univ., Manhattan, Res. Pub. 170. 20 pp.

Haissig, B.E. and R.E. Dickson. 1979. Starch measurement in plant tissue using enzymatic hydrolysis. Physiol. Plant. 47:151-157.

Koon, K.B. and T. O'Dell. 1977. Effects of wrenching on drought avoidance of Douglas-fir seedlings. USDA For. Serv., Tree Planters' Notes 28(2):15-16.

Menzies, M.I. 1980. Effect of nursery conditioning on the water relations of two-year-old Douglas-fir seedlings after lifting and outplanting. Ph.D. Diss., Univ. of Washington, Seattle. 208 pp.

Nambiar, E.K.S., G.D. Bowen, and R. Sands. 1979. Root regeneration and plant water status of Pinus radiata D. Don seedlings transplanted to different soil temperatures. J. Exp. Bot. 30:1119-31.

Rhea, S.B. 1977. The effects of lifting time and cold storage on root regenerating potential and survival of sycamore, sweet-gum, yellow poplar, and loblolly pine seedlings. M.S. Thesis, Clemson Univ., Clemson, SC. 108 pp.

Ritchie, G.A. and J.R. Dunlap. 1980. Root growth potential: Its development and expression in forest tree seedlings. N.Z.J. For. Sci. 10(1):218-248.

Rook, D.A. 1969. Water relations of wrenched and unwrenched Pinus radiata seedlings on being transplanted into conditions of water stress. N.Z.J. For. 14:50-58.

Rook, D.A. 1971. Effect of undercutting and wrenching on growth of Pinus radiata D. Don seedlings. J. Appl. Ecol. 8:477-490.

Shigo, A.L. and A. Shigo. 1974. Detection of discoloration and decay in living trees and utility poles. USDA For. Serv. Res. Pap. NE-294, 11 pp. Northeastern For. Exp. Sta., Upper Darby, PA.

Steele, R.G.D. and J.H. Torrie. 1980. Principles and Procedures of Statistics. 2nd ed. McGraw-Hill Book Co., New York. 633 pp.

Stein, W.I. 1984. Wrenching Douglas-fir seedlings in August: Immediate but no lasting effects. USDA For. Serv. Res. Pap. PNW-317, 12 pp. Pacific Northwest For. and Range Exp. Sta., Portland, OR.

Tanaka, Y., J.D. Walstad, and J.E. Borreco. 1976. The effect of wrenching on morphology and field performance of Douglas-fir and loblolly pine seedlings. Can. J. For. Res. 6:453-458.

Tworkoski, T.J. 1978. Early growth potential of stored yellow-poplar and loblolly pine seedlings. M.S. Thesis, Clemson Univ., Clemson, SC. 97 pp.

United States Department of Commerce. 1984. Climatological Data, South Carolina. Vol. 87, no. 1-12. National Climatic Data Center, Asheville, NC.

Ursic, S.J., H.L. Williston, and R.M. Burns. 1966. Late planting improves loblolly survival. USDA For. Serv. Res. Pap. SO-24, 12 pp. Southern For. Exp. Sta., New Orleans, LA.

van den Driessche, R. 1983. Growth, survival, and physiology of Douglas-fir seedlings following root wrenching and fertilization. Can. J. For. Res. 13:270-278.

van Dorsser, J.C. and D.A. Rook. 1972. Conditioning of radiata pine seedlings by undercutting and wrenching: Description of methods, equipment, and seedling response. N.Z.J. For. 17:61-73.

Williston, H.L. 1974. Storage of southern pine seedlings: A review. USDA For. Serv. Tree Planters' Notes 25(4):1-3.