The Effects of Pruning Treatments and Initial Seedling Morphology on Northern Red Oak Seedling Growth

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Abstract: Northern red oak (Quercus rubra L.) seedlings exhibit relatively high survival rates following planting, but their growth rates are often slow and extensive stem dieback can occur. This study was designed to investigate the growth responses of northern red oak seedlings planted with or without root-pruning or shoot-pruning. One-year-old (1-0) northern red oak nursery stock was planted without top-pruning while the two-year-old (2-0) stock was top-pruned to a shoot length of 25 cm. Both types of seedlings were planted with or without root-pruning. Morphological characteristics of each seedling were measured prior to planting to relate growth to a single or multiple morphological traits. Seedlings which were shoot-pruned had positive height growth during the first growing season and larger seedlings had greater growth than smaller seedlings. Seedlings not shoot-pruned showed varying degrees of stem dieback and larger seedlings had greater stem dieback than smaller seedlings. After one growing season, a subsample of the seedlings was excavated to evaluate root growth. Shoot-pruning reduced seedling root growth and root regeneration compared to non shoot-pruned seedlings. Although shoot-pruning reduced stem dieback, it also reduced seedling root growth

INTRODUCTION

There is increasing interest in the artificial regeneration of oak species in the eastern United States. The number and size of oak plantings have increased as marginal farmlands are converted to forest plantations. Increased emphasis has also been placed on securing oak regeneration on high quality forested sites. On these sites, oaks are often the dominant species in the overstory, but advance oak reproduction is sparse or lacking. Enhancement planting of oak seedlings is an alternative if natural regeneration is lacking or sparse.

Oak plantings, whether located on former agricultural lands or in forest situations often share two characteristics. Initial seedling survival is usually high, but growth rates are often slow (Hilt, 1977, Loftis, 1979, Loftis and McGee, 1986). Natural oak regeneration often exhibits a pattern of recurrent shoot dieback while forming an extensive root system. When a sufficient root system is established, oak stump sprouts are capable of rapid growth rates (Cobb et al., 1985). This would suggest that root-to-shoot ratios may control the growth of oak regeneration.

This study was implemented to determine the influence of shoot and root-pruning treatments on the growth of northern red oak seedlings on old field sites. Correlation analysis was used to determine the relationship between initial seedling morphological characteristics and subsequent growth of seedlings in the various pruning treatments. Seedlings were excavated after 1 growing season to determine the effects of cultural treatments on root development and growth.

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METHODS

The planting site selected for this study is located in Tippecanoe County in west-central Indiana. This area is classified as the Entrenched Valley Section of the Central Till Plain Natural Region (Homoya et al., 1985). The site is a former agricultural field in the early stages of old-field succession. This situation is common for oak plantings across the state of Indiana. The soil is a Fincastle silt-loam (fine-silty, mixed, mesic Aeric Ochraqualf) with a site index for northern red oak of 75 feet at a base-age of 50 years (Soil Conservation Service, unpublished data). The planting was enclosed in an electrical fence to reduce deer damage to the seedlings.

All seedlings used in this study were obtained from Indiana's Jasper-Pulaski State Nursery in Medaryville, Indiana and were at least 30 cm in height with a root-collar diameter of at least 6 mm. All seedlings used in this study were lifted in the fall of 1991 and stored in cold-storage at temperatures of 2-5°C. Seedling root systems were maintained in moist sphagnum moss from lifting to planting. The field planting took place on May 4, 1992. Soil conditions were dry enough to permit easy planting and refilling of the planting holes. Soil samples taken May 10th revealed that the soil moisture content was approximately 15%. Four classes of northern red oak seedlings were established at the site.

> **Class 1**: 1-0 seedlings: No shoot or root pruning. Seedlings were planted in holes 20 cm in diameter and 30 cm in depth formed by a post-hole digger.
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> **Class 2**: 1-0 seedlings: No shoot pruning, but taproot pruned to a length of 20 cm and the lateral roots pruned to 10 to 15 cm in length. These seedlings were hand planted in slits formed by a KBC planting bar.
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> **Class 3**: 2-0 seedlings: Shoot pruned to a length of 25 cm above the root-collar, but no root pruning. The seedlings were planted in holes 20 cm in diameter and 30 cm in depth formed by a post-hole digger.
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> **Class 4**: 2-0 seedlings: Shoot pruned to a length of 25 cm above the root-collar. The taproot was pruned to a length of 20 cm and lateral roots pruned to 10 to 15 cm in length. The seedlings were planted in slits formed by a KBC planting bar.

Morphological characteristics of 1-0 and 2-0 seedlings were similar and the effect of seedling age was assumed to be secondary to the treatments applied in the study (Table 1).

The following measurements were made on all seedlings that were obtained from the nursery.

1. The height from the root-collar to the terminal bud (cm).
2. The root-collar diameter (nearest 0.02 mm).
3. The number of growth flushes.
4. The number of first-order lateral roots (FOLR) with a diameter greater than or equal to 1 mm. For seedlings that were root-pruned, the number of FOLR before and after the root-pruning treatment was recorded to determine how many FOLR were removed by the root-pruning treatment.
5. Seedling stem volume (cm^3) was calculated as $1/3\ (\pi r^2 H)$ where r=radius of the root-collar and H=seedling height. Our previous studies indicate that there is a high correlation between this biomass index and stem dry weights (R^2 values from 0.77-0.98 with a mean of 0.88).

Table 1.—Initial morphological characteristics of seedlings used in the study (n = 80 per seedling class)

	Seedling type			
	Class 1 1-0	**Class 2 1-0**	**Class 3 2-0**	**Class 4 2-0**
Morphological Characteristic	**No sht pr No rt pr**	**No sht pr Rt pr**	**Sht pr No rt pr**	**Sht pr Rt pr**
Height (cm)	56.8 ab*	60.1 a	55.3 b	56.9 ab
Root collar diameter (mm)	9.35 a	9.37 a	8.54 b	9.20 a
Number of flushes	3.34 b	3.30 b	4.45 a	4.46 a
Stem volume (cm^3)	14.44 a	15.30 a	10.83 b	13.21 a
Number of FOLR before pruning	16.7 a	14.1 b	16.2 a	15.5 ab
Number of FOLR after pruning	--	10.1 a	--	11.4 a
Number of FOLR removed by pruning	--	4.0 a	--	4.1 a

*Means in the same row followed by the same letter are not significantly different at P=.05 using Duncan's Multiple Range Test.

The study design was a randomized complete block design with four seedlings (1 of each type of seedling) included in each of the 80 blocks giving a total of 320 seedlings in the study. Duncan's Multiple Range Test was used to determine if differences existed in initial seedling morphological characteristics of seedling classes (SAS Institute, 1985). Seedling height was measured at the end of the first growing season. Net height growth was the seedling height (end of the growing season) minus the initial height. For shoot-pruned seedlings, net height growth was the height at the end of the first growing season minus 25 cm. Analysis of variance tests were conducted to determine if first-year net height growth differed among seedling types. Duncan's Multiple Range Test was used to separate mean net height growth by seedling class (SAS Institute, 1985). Pearson Correlation Coefficients were calculated for the relationship between first-year net height growth and initial morphological characteristics of the seedlings.

At two week intervals from May to October, gravimetric soil moisture was determined from soil cores obtained at depths of 0-15 cm and 15-30 cm from 5 random locations in the field (Figure 1). Rainfall data was obtained from the Purdue Agronomy farm located approximately 3 miles from the planting site (Figure 1). The lines showing the soil moisture tension corresponding to a given gravimetric soil water content were developed for the Ap horizon of a Fincastle soil at the Purdue Agronomy Farm (Wiersma, 1984).

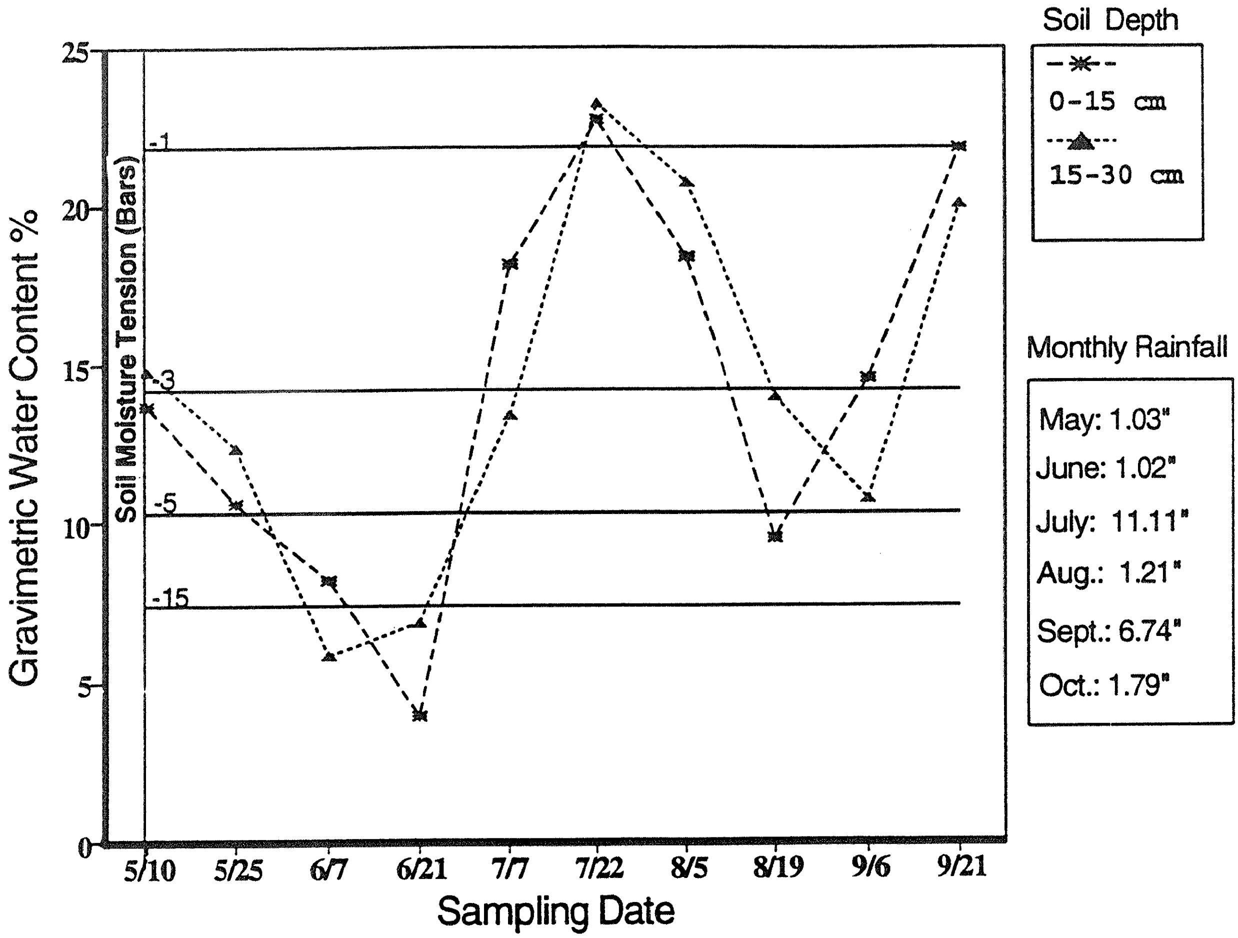

Figure 1.—Gravimetric soil water contents at 0-15 cm and 15-30 cm depths taken every two weeks. Monthly rainfall data is listed to the right of the graph.

At the conclusion of the first-growing season all surviving seedlings were measured to determine net height growth for the first season. Net height growth was defined as the living height of the seedling minus the initial height when planted. In the middle of October, 1992, five blocks of seedlings (20 total, 5 from each treatment) were randomly selected and excavated by hand. Seedlings were lifted by removing a soil volume approximately 80 cm in radius and 60 cm in depth surrounding each seedling. The root system of each seedling was carefully freed from the soil mass and washed free of soil. The following measurements were made on each root system:

1. The number of FOLR greater than 1 mm.
2. The total FOLR length (cm).
3. The total FOLR volume (cm^3) was calculated by determining the volume of each FOLR using the equaltion of a cone and summing these values to obtain the total seedling FOLR volume.
4. The change in the number of roots was calculated as the difference between the number of FOLR at the time the seedling was excavated and the number of FOLR when planted. For root-pruned seedlings this number was obtained by subtracting the number of FOLR found upon excavation minus the number present after the root-pruning treatment was applied.

RESULTS

Initial morphological characteristics for all four classes of seedlings are listed in Table 1. The mean root-collar diameter and the calculated mean stem volume of seedlings assigned to the shoot-pruned class (class 3) were significantly less than the average root-collar diameter and mean stem volume of seedlings in the three other classes. The average initial height of the shoot-pruned seedlings (class 3) was also statistically less than the average height of the root-pruned seedlings (class 2). The mean number of FOLR varied from a low of 14.1 to a high of 16.7 roots. For seedlings that were root-pruned before planting (classes 2 and 4), the root pruning treatment removed an average of 4 FOLR and 4.1 FOLR, respectively (Table 1).

Mortality was extremely low and was limited to 4 root-pruned seedlings (class 2). The overall seedling survival was 99%. First-year net heightgrowth (living height minus initial height when planted) did differ significantly among seedling types. Shoot-pruned seedlings (classes 3 and 4), whether or not they where root-pruned, averaged 2.8 cm of net height growth. Non shoot-pruned, non root-pruned seedlings (class 1) had a net dieback of -3.2 cm and root-pruned seedlings (class 2) had a net dieback of -7.9 cm (Table 2).

Table 2.—First year net height growth (cm) for the 4 types of seedlings used in the study

Seedling type			
Class 1	Class 2	Class 3	Class 4
1-0 No shoot pr No root pr	1-0 No shoot pr Root pr	2-0 Shoot pr No root pr	2-0 Shoot pr Root pr
-3.2 b*	-7.9 b	2.8 a	2.8 a

*Means followed by the same letter did not differ significantly from each other at P=.05 using Duncan's Multiple Range Test.

Significant correlations existed between seedling morphological characteristics at the time of planting and first-year net height growth (Table 3). Seedlings that were not shoot-pruned (classes 1 and 2) exhibited negative correlations between initial seedling height, the number of seedling flushes and net height growth. Root-pruned seedlings (class 2) exhibited a negative correlation between net height growth and seedling stem volume. Shoot-pruning completely changed the relationships observed for non shoot-pruned seedlings. Shoot-pruned seedlings (classes 3 and 4), regardless of the root-pruning treatment, exhibited positive correlations between net height growth and root-collar diameter, stem volume, and the number of FOLR before root-pruning. Shoot and root-pruned seedlings (class 4) also exhibited positive correlations between height growth and the number of seedling flushes and the number of FOLR remaining following root pruning (Table 3).

Table 3.—Significant correlations between initial seedling morphological characteristics and first-year net height growth for each of the four seedling classes

Class 1: 1-0 Non shoot-pruned, non root-pruned seedlings			
Characteristic	**Prob>F**	**R2**	**r**
Number of flushes	.0229	.0646	-.2542
Initial height	.0048	.0975	-.3122
Class 2: 1-0 Non shoot-pruned, root-pruned seedlings			
Number of flushes	.0277	.0606	-.2462
Initial height	.0001	.2037	-.4513
Class 3: 2-0 Shoot-pruned, non root-pruned			
Root-collar diameter	.0200	.0675	.2598
Number of FOLR	.0177	.0700	.2646
Stem volume	.0041	.1006	.3172
Class 4: 2-0 Shoot-pruned, root-pruned			
Root-collar diameter	.0016	.1206	.3473
Number of flushes	.0235	.0641	.2532
Number of FOLR before root-pruning	.0004	.1473	.3838
Number of FOLR after root-pruning	.0004	.1475	.3841
Stem volume	.0021	.1153	.3396

Seedlings were excavated in October following the first growing season and evaluated for root growth characteristics (Table 4). Seedlings that were not root-pruned (classes 1 and 3) had the greatest FOLR lengths and FOLR volumes. Root-pruned seedlings (classes 2 and 4) lost roots due strictly to the pruning treatment that were not replaced during the course of the first growing season. In addition, seedlings that were not root-pruned but were shoot-pruned (class 3) exhibited significantly lower total FOLR length compared to seedlings that were not root or shoot-pruned (class 1). The differences in root characteristics between seedling classes 1 and 3, and 2 and 4 indicate that shoot-pruning is affecting root growth and/or root regeneration. The differences observed among the root systems of excavated seedlings cannot be completely attributed to root-pruning treatments. Only root pruned seedlings (class 2) exhibited increases in the number of FOLR during the course of the first year. Seedlings in the other classes exhibited decreases in the number of FOLR during the first growing season with seedlings in the shoot-pruned class (class 3) exhibiting the greatest decrease (Table 4).

Table 4.—Root morphological characteristics of seedlings upon excavation following the first growing season (n = 5 per seedling class).

	Seedling type			
	Class 1	**Class 2**	**Class 3**	**Class 4**
Characteristic	**1-0 No sht pr No rt pr**	**1-0 No sht pr Rt pr**	**2-0 Sht pr No rt pr**	**2-0 Sht pr Rt pr**
Number of FOLR before planting	19.4 a*	14.4 a	17.4 a	12.8 a
Number of FOLR after root pruning	--	9.6 a	--	9.8 a
Number of FOLR after excavation	15.2 a	10.6 ab	9.6 ab	6.8 b
Change in number of FOLR	-4.2 bc	+1.0 a	-7.8 d	-3.0 c
Total FOLR length (cm)	248.0 a	94.9 b	124.3 b	53.2 b
Total FOLR volume (cm^3)	4.53 a	1.25 b	2.33 b	0.72 b

*Means in the same row followed by the same letter do not differ significantly from each other at P=.05 using Duncan's Multiple Range Test.

DISCUSSION

Shoot and root-pruning treatments affected both shoot and root growth patterns of northern red oak seedlings. This study reinforces the view that seedling quality is a reflection of a number of morphological characteristics. In quantifying seedling quality, it is the balance between morphological characteristics that must be considered rather than a single root or shoot characteristic. Cultural practices such as shoot or root-pruning that alter morphological characteristics should be expected to alter seedling physiology.

Shoot-pruning reduced the affects of moisture stress even under the rather severe drought conditions which occurred during the seedling establishment phase of this study. Shoot-pruned seedlings demonstrated small positive height growth increments during the first growing season while non shoot-pruned seedlings exhibited stem dieback. The results of this study, though preliminary, support the conclusions of others regarding the long term advantages of shoot-pruning. After five growing seasons, shoot-pruned oak seedlings exhibited as great or greater height growth as unpruned seedlings and perhaps more importantly, were more likely to maintain growth rates that allowed them to compete with other species (Johnson, 1984).

In our study, shoot-pruning influenced seedling growth to a greater degree than root-pruning. Root-pruning had no effect on the net height growth of seedlings that were also shoot-pruned.

Non shoot-pruned seedlings exhibited significantly greater stem dieback than shoot-pruned seedlings. There was a trend for seedlings that were also root-pruned to exhibit greater stem dieback than seedlings that were not root-pruned. Larson (1975) demonstrated that shoot growth of oak decreased as the degree of root-pruning increased. Planting treatments that reduced root biomass had the potential to reduce shoot growth. Our study utilized a very conservative root-pruning treatment, but this was still sufficient to increase stem dieback.

The seedling morphological characteristics associated with increased height growth differed depending on whether the seedlings were shoot-pruned or if the stems were left intact. If seedlings were not shoot-pruned, stem dieback increased with increasing seedling size. Larger seedlings were more prone to extensive shoot dieback than smaller seedlings. This response was completely altered when seedling shoots were clipped. In this case, as seedling size increased, growth of the shoot-pruned seedlings also increased. Growth was positively correlated with seedling characteristics which were indicators of increasing seedling biomass (root-collar diameter, stem volume, and number of FOLR). This is consistent with the work of Johnson (1984) who demonstrated that growth of shoot-pruned oak seedlings increased as initial seedling size increased. In many ways, shoot-pruned northern red oak seedlings appear to behave in a fashion similar to coppiced natural oak regeneration. Growth of small to moderate diameter coppiced oak stems has been shown consistently to increase as initial stump diameter increased (Loftis, 1990, Lowell et al., 1987, Johnson, 1979). Shoot-pruning of oak alters seedling growth responses and has the potential to promote vigorous regrowth from the stem below the pruning cut (Johnson et al., 1984).

The significance of root regeneration and root growth following outplanting is often overlooked, but this study indicates that root growth is altered by planting treatment. All seedlings in this study, with the exception of non shoot-pruned, root-pruned seedlings (class 2), exhibited decreases in the number of FOLR during the course of the first growing season. Northern red oak root regeneration is highly sensitive to both soil temperature and soil water availability (Larson, 1970). Root regeneration is greatest for northern red oak seedlings growing in soils near field capacity (Larson and Whitmore, 1970). As soil moisture decreases, root regeneration potential also decreases and root regeneration ceases altogether at a soil moisture potential of -6 bars (Larson, 1980). Stem dieback also increases as soil water potential decreases. While we have no data on soil temperatures, soil water potentials were below -6 bars within 3 weeks of planting and remained below -6 bars for over 1 month (Figure 1). Figure 2 lists daily rainfall totals for the dates from May 1 through November 1, 1992. During the month of June, soil gravimetric water contents in the top 15 cm of soil dropped to below 4% which corresponds to severe moisture stress on this soil. These levels of soil moisture potential would prevent root regeneration and also increase seedling dieback.

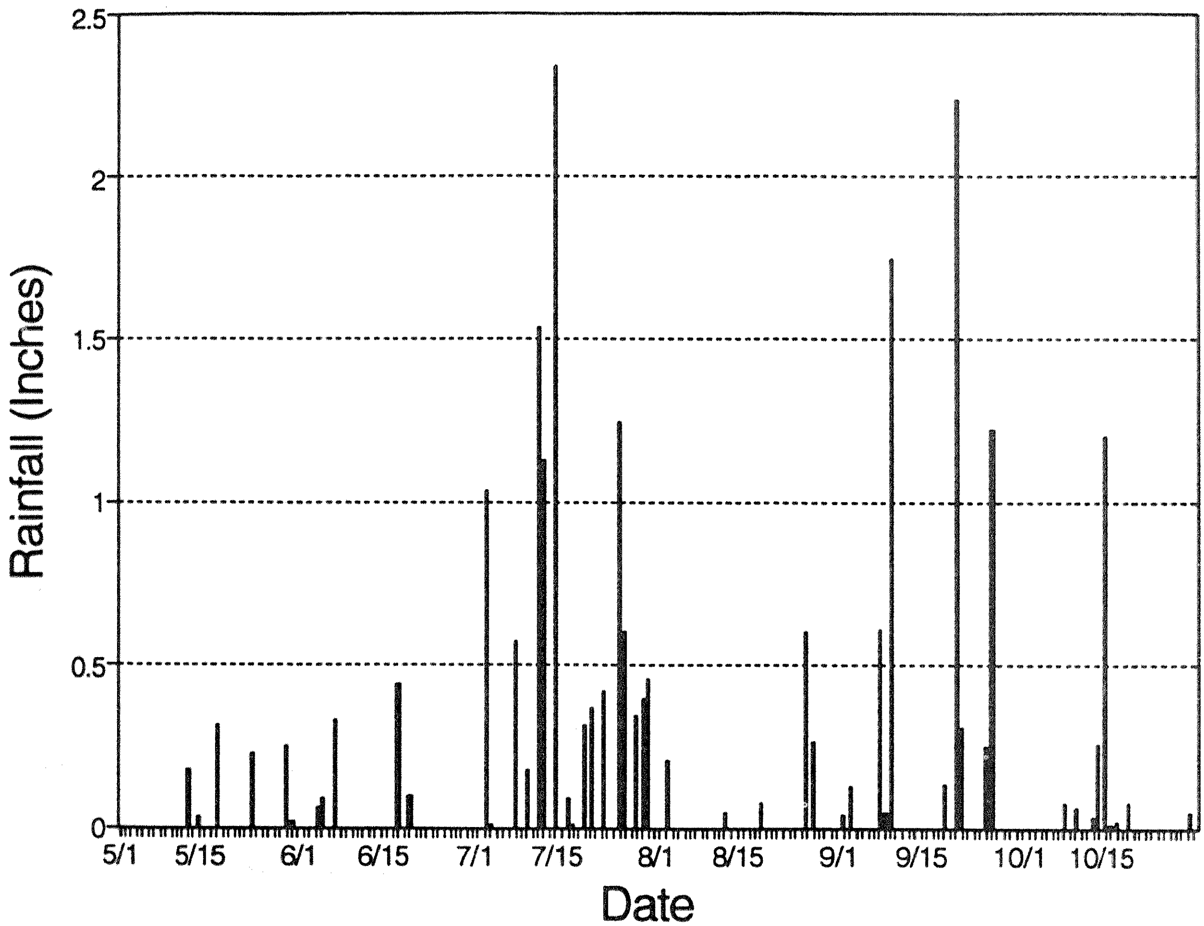

Figure 2.—Daily rainfall amounts for the period of May 1 through November 1, 1992.

Root-pruned seedlings were expected to have lower numbers of FOLR, lower total FOLR length, and lower FOLR volume unless the root-pruning treatment stimulated a proliferation of new root growth. The environmental conditions that limited water availability during the first growing season clearly were not favorable for new root initiation or root growth. Shoot pruning also appeared to influence root growth. We expected seedlings without root-pruning treatments to have the same root characteristics regardless of the shoot-pruning treatment. Instead, shoot-pruned seedlings had lower total FOLR lengths and FOLR volumes. Clearly, shoot-pruning affected root growth of the seedlings. Johnson et al. (1984) also found that shoot-pruning treatments had the potential to reduce root growth of oak seedlings. Farmer (1975) found that root regeneration of oak was dependent on growth regulators produced in intact stems of seedlings. Shoot-pruning treatments could reduce these levels of plant growth regulators and could have an inhibitory effect on root regeneration. In shoot-pruned seedlings, root regeneration may be limited until sprouts from the cut seedling develop. Visual observations in our study revealed that many shoot-pruned seedlings did not develop new shoot growth until soil moisture became favorable in July. Delays in leaf initiation may have reduced root growth and root regeneration.

CONCLUSIONS

Cultural treatments that alter the root-to-shoot ratio of seedlings may alter seedling physiology and responses to environmental stresses. It appears that seedlings with moderate biomass may exhibit less dieback than large (greater than 70 cm in height) seedlings during periods of low rainfall or on drought-prone planting sites. Soil water deficits that occurred during this study probably created relatively high levels of plant moisture stress. Under these conditions, shoot-pruned seedlings exhibited moderate, but positive shoot growth. Non shoot-pruned seedlings in contrast exhibited stem dieback and dieback was increased if the seedlings were also root-pruned. Larger seedlings generally exhibited greater regrowth than smaller seedlings if a shoot-pruning treatment was applied. In contrast, large non shoot-pruned seedlings usually had more stem dieback than smaller seedlings. Shoot-pruning reduced seedling biomass and larger seedlings exhibited greater growth than smaller seedlings. Shoot-pruning may be a method for seedlings with large biomass reserves to realize the potential growth advantage over small seedlings. There is a potential disadvantage to shoot-pruning. It appears that shoot-pruning treatments tend to reduce seedling root growth and root regeneration.

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LITERATURE CITED

Cobb, S. W., Miller, A. E., and Zahner, R. 1985. Recurrent shoot flushes in scarlet oak stump sprouts. Forest Sci. 31:725-730.

Farmer, R. E. Jr. 1975. Dormancy and root regeneration of northern red oak. Can. J. For. Res. 5:176-185.

Hilt, D. E. 1977. Introduction of black walnut and northern red oak seedlings in an upland hardwood forest in southeastern Ohio. USDA Forest Service Research Note NE-241.

Homoya, M. A., Abrell, D. B., Aldrich, J. R., and Post, T. W. 1985. The natural regions of Indiana. Proceedings Indiana Academy of Science 94:245-268.

Johnson, P. S. 1979. Shoot elongation of black oak and white oak sprouts. Can. J. For. Res. 9:489-494.

Johnson, P. S. 1984. Responses of planted northern red oak to three overstory treatments. Can. J. For. Res. 14:536-542.

Johnson, P. S., Novinger, S. L., and Mares, W. G. 1984. Root, shoot,and leaf area growth potentials of northern red oak planting stock. Forest Sci. 30:1017-1026.

Larson, M. M. 1970. Root regeneration and early growth of red oak seedlings: influence of soil temperature. Forest Sci. 16:442-446.

Larson, M. M. 1975. Pruning northern red oak seedlings: effects on root regeneration and early growth. Can. J. For. Res. 5:381-386.

Larson, M. M. 1980. Effects of atmospheric humidity and zonal soil water stress on initial growth of planted northern red oak seedlings. Can. J. For. Res. 10:549-554.

Larson, M. M. and Whitmore, F. W. 1970. Moisture stress affects root regeneration and early growth of red oak seedlings. Forest Sci. 16:495-498.

Loftis, D. L. 1979. Northern red oak performs poorly in North Carolina planting. USDA Forest Service Research Note SE-277.

Loftis, D. L. 1990. Predicting post-harvest performance of advance red oak reproduction in the southern Appalachians. Forest Sci. 36:908-916.

Loftis, D. L. and McGee, C. E. 1986. Planted oaks perform poorly in North Carolina and Tennessee. North. J. Appl. For. 8:95-98.

Lowell, K. E., Mitchell, R. J., Johnson, P. S., Garrett, H. E., and Cox, G. S. 1987. Predicting growth and "success" of coppice-regenerated oak stems. Forest Sci. 33:740-749.

SAS Institute, 1985. SAS user's guide: statistics version 5 edition. SAS Institute Inc. Cary, North Carolina. 956 pp.

Wiersma, D. 1984. Soil water characteristic data for some Indiana soil profiles. Purdue University Station Bulletin No. 452. 153 pp.