logging has substantially reduced the time required for these areas to return to their approximate preharvest bulk densities. □

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The Use of Tree Shelters with Northern Red Oak Natural Regeneration in Southern New England[1]

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ABSTRACT. The use of tree shelters with naturally established red oak seedlings was studied in southern New England mixed-hardwood stands where deer browsing limited regeneration height growth. Seedlings of three size classes (basal diameters of 5 mm, 8 mm, and 15 mm) were cut off just above ground level during the dormant season to induce sprouting. Plastic tree shelters were placed over one group in each size class; another group was left without shelters but was protected from deer browsing by fencing. In the first growing season, seedling sprouts inside shelters in the two larger size classes had double the height growth (with some terminals growing out of the 150-cm tall shelters) but less diameter growth, compared to sprouts outside shelters. The height difference was maintained but not increased over the next 2 growing seasons. Height growth for sprouts from the smaller size class was not increased by shelters. The use of tree shelters with large diameter seedlings stunted by browsing may have potential for ensuring successful red oak regeneration without the costs of planting.

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The use of tree shelters for protecting planted hardwood seedlings from deer browsing has become widespread in Great Britain over the past 10 years (Potter 1991) and is presently being studied in many other regions (Windell 1991). Tree shelters are tubes made of translucent plastic; they are available in square, circular, or hexagonal shapes, generally 7 to 15 cm in width and 100 to 150 cm in height. They are held in place over individual seedlings by stakes driven into the ground. Tree shelters were originally developed in Great Britain in 1979 by Graham Tuley (Tuley 1983, 1985), principally to protect seedlings from browsing. They provide an additional advantage by altering the microclimate inside the shelter such that seedling height growth is increased over that of unbrowsed, unsheltered seedlings. Temperature and humidity levels are higher inside shelters (Potter 1991), and carbon dioxide levels are also increased, especially if the bottom of the shelter is sealed with mounded soil (Frearson and Weiss 1987).

Studies of the operational use of shelters have focused on hardwood plantation establishment, with oak species receiving much of the attention. The use of shelters has been most quickly adopted where investment in planting of hardwoods is already a part of management, as in Great Britain. A study of shelters used for protecting planted northern red oak in Michigan has shown increased height growth over two growing seasons (Lantagne 1990).

Red oak is the most commercially important hardwood species in southern New England, occurring in mixed hardwood stands primarily with black birch, red and sugar maple, and other oak species. Natural regeneration often becomes established in the understory of these stands, but seedlings may be prevented from developing in height because of repeated browsing by white-tail deer (Kittredge and Ashton, in prep.). Under these circumstances, savannah-like conditions can develop, in which the understory growing space is usurped by woody shrubs that spread vegetatively, such as mountain-laurel, or by herbaceous ferns and grasses (Horsley 1988), further inhibiting oak seedling development. The potential exists in these situations for using shelters with naturally established oak seedlings to prevent browse damage and accelerate height growth. It would be possible to place shelters directly over the seedlings, but the stems are usually deformed from repeated browsing. An alternative is to cut the stems back to the ground during the dormant season to stimulate the development of a seedling sprout within the shelter. This approach to the use of shelters may be more compatible with the low-investment management practiced in many areas, where planting is not

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generally done The use of shelters with oak natural regeneration has not been reported in the literature.

The objective of this study was: (1) to determine the effects of tree shelters on the height and diameter growth of naturally established red oak seedling sprouts of different initial sizes, and (2) to determine the effects of shelters on the phenology and shoot growth patterns of seedlings and seedling sprouts during the first growing season.

METHODS

Our studies used natural red oak regeneration of three size classes, with mean basal diameters of approximately 5 mm, 8 mm, and 15 mm; they are referred to hereafter as small, medium, and large size classes, respectively. Two study sites were used. In both cases, regeneration in several recently created gaps (0.2–0.5 ha in size) was selected for study. The existing forest in both cases was mixed hardwood in composition, with northern red oak, red maple, and black birch predominant in the overstory. Stands were approximately 60–80 years old, and even-aged in structure.

The first location was in northeastern Connecticut at the Yale-Myers Forest, on a relatively good site with a northern red oak site index of 65 (Carmean 1978). Soils were well-drained and moist, and classified as a Paxton very stony fine sandy loam (USDA Soil Conserv. Serv. 1981). Understory vegetation was dominated by mountain-laurel and seedlings of red maple and black birch. Regeneration at this location was in the medium size class, with a mean diameter of 7.8 mm [standard error (s.e.) = 0.3 mm]. Counts of growth rings showed that stems were 7 to 11 years old; roots may have been older, because the stems may have died back and resprouted, as often occurs with oak seedlings.

The second location was on the Quabbin Watershed Reservation in central Massachusetts. The soil was a Scituate extremely stony fine sandy loam (USDA Soil Conserv. Serv. 1967) that was excessively drained. Understory vegetation was dominated by lowbush blueberry. Regeneration in both the large and small size classes was used at this site. Mean basal diameter of the small category was 4.9 mm (s.e. = 0.10 mm), with stem ages ranging from 4 to 8 years old, and mean basal diameter of the large category was 15.1 mm (s.e. = 0.4 mm), with stem ages from 8 to 12 years.

Seedlings in each size class were clipped 3 to 4 cm above ground level during the dormant season, and then were randomly divided into two treatment groups. For one group, treatment consisted of installing shelters immediately after clipping. The other group was left unprotected by shelters, but was protected from deer browsing by fencing.

Shelters were purchased from a British company and were not modified in any way for use in this study. They were made of light brown, double-walled corrugated sheet polypropylene folded into square tubes 8 cm wide and 150 cm tall. Shelters were held in place by wire fasteners attached to 100-cm-tall wooden stakes. Soil was not mounded around the base. Maintenance of shelters was done as necessary, consisting mainly of securing wire fasteners that were loosened by wind. A severe windstorm blew down many shelters in the large size class during the second winter of the study; this treatment had to be abandoned at that point, with no data collected for the third growing season. Most commercial shelter manufacturers have now incorporated plastic fasteners which are more secure than the earlier wire designs used in the present study.

The sample size of individuals in each size category varied, based on the number present that met the size criterion. In the small size class, 200 seedlings were clipped, with 100 protected by tree shelters and 100 left unprotected by shelters, but surrounded by a deer exclosure comprised of a 5-strand electric fence. A total of 75 seedlings in the medium size class were clipped; 50 were protected by shelters, and 25 were protected from deer browse by an exclosure constructed with multiple strands of barbed wire.

A total of 48 individuals in the large size class were measured; 24 were clipped at ground level in the dormant season, and 24 were left unclipped In each group of 24, 12 were protected with shelters, and 12 were left without shelters. All trees were within a 5-strand electric deer fence.

Measurements of height and basal diameter (at 3 cm above the ground) were made at the end of each growing season for sprouts developing from clipped seedlings of all size classes In all cases, mortality was noted. If more than one sprout developed from a stump, the tallest one was measured For sprouts and seedlings in the large size class, height measurements were made weekly during the first growing season. At the end of the first growing season, the total number of leaves and the height of each flush of growth were measured.

RESULTS

Height Growth of Different Size Classes

For individuals in the small size class, no significant difference was detected between height growth of sprouts inside and outside of shelters, for any of the first three growing seasons (Table 1). However, the mean basal diameter of sprouts inside shel-

Table 1. Height (cm) and basal diameter (mm) of clipped red oak natural regeneration in three size classes based upon initial basal diameter (small = 5 mm, medium = 8 mm, large = 15 mm).[a]

	Small		Medium		Large	
	Shelter	No shelter	Shelter	No shelter	Shelter	No shelter
Year 1						
n	99	99	47	25	12	12
Height	22.3	23.4 ns	75.1	32.9**	136.8	67 4**
	(1.0)	(1.0)	(4.6)	(2.0)	(11.0)	(6 0)
Diameter	3.3	4.1**	3.9	5.0**	—	—
	(0.1)	(0.1)	(0.2)	(0.3)		
Year 2						
n	94	96	32	17	9	9
Height	36.3	37.6 ns	102.5	50.5**	186.6	104 0**
	(2.0)	(1.6)	(6.7)	(4.9)	(10.3)	(7 0)
Height growth	13.7	14.2 ns	23.2	16.9 ns	31.9	32 8 ns
	(1.4)	(0.9)	(3.7)	(2.9)	(7.8)	(3 3)
Diameter	3.6	6.0**	4.2	5.6*	9.9	11 4*
	(0.1)	(0.2)	(0.2)	(0.5)	(0.7)	(0.4)
Year 3						
n	79	84	10	14	—	—
Height	46.8	51.2 ns	138.6	66.2**	—	—
	(2.9)	(2.4)	(16.1)	(7.1)		
Height growth	14.0	13.7 ns	14.8	15.9 ns	—	—
	(1.4)	(1.2)	(5.1)	(3.7)		
Diameter	3.7	6.6**	5.4	7.8*	—	—
	(0.1)	(0.2)	(0.5)	(1.0)		

[a] Results of t-test for difference between means in the same size class are given as: *ns* ($P > 0.05$), * ($P < 0.05$); ** ($P < 0.01$). Standard errors are listed in parentheses beneath each mean.

ters was significantly smaller than for sprouts outside shelters for all three years.

The seedling sprouts from the medium size class growing in shelters had more than double the height growth of their counterparts outside of shelters in the first growing season (Fig.1 Table 1). The mean height at the end of the first growing season obscures some of the more dramatic results. The maximum height growth observed for a seedling sprout in a shelter was 183.0 cm, whereas the maximum height for a sprout outside of a shelter was 51.0 cm. Although total heights inside and outside of shelters were significantly different at the end of the second growing season, the height growth that year was not significantly different. Nine of the 32 sheltered sprouts grew less than 10 cm in height. The seedlings that experienced poor height growth had been observed to exhibit second and third flushes of height growth during the end of the previous growing season. Such active height growth may have been inadequately hardened off and was possibly damaged by frost in the fall Basal diameters were again consistently greater for sprouts growing outside of shelters over the 3-year period.

In the large size class, height growth of sprouts in shelters was again approximately double that of sprouts outside of shelters during the first growing season (Table 1). Height growth during the second year was much lower for all sprouts, and there was no significant difference in growth inside compared to outside of shelters. Some sprouts had emerged from the tops of shelters by the end of the first growing season, and the mean height was above the 150 cm height of the shelters at the end of the second growing season. Basal diameters were significantly greater for sprouts outside of shelters at the end of the second growing season.

Shoot Growth Patterns of Seedlings and Sprouts

The total height growth of both seedlings (unclipped treatment) and sprouts (clipped treatment) inside shelters was significantly greater than that outside of shelters (Table 2). Shoot elongation patterns varied between sprouts and seedlings (Fig. 2). Many trees in all four treatments underwent two flushes of shoot elongation during the growing season, with most growth occurring in the initial flush. Outside of shelters, sprouts had greater height growth and a longer duration of shoot elongation during the initial flush, compared to seedlings. The same pattern existed for trees inside shelters, but with both the duration and magnitude of extension growth being much greater than outside shelters (Table 2).

With sprouts, the number of leaves produced on the leader during the initial flush was similar inside and outside of shelters. With seedlings, leader shoots inside shelters had greater numbers of leaves; this was due to two trees inside of shelters developing large numbers of leaves (24 and 35). The other trees inside shelters had a mean of 11.5 leaves, which was similar to those not in shelters.

Seedlings (i.e., nonclipped individuals) essentially had a 73-cm head start in total height (see Table 2). As a result, total height accumulated by seedlings and sprouts inside shelters was similar at the end of the first growing season, in spite of the greater height growth of the sprouts. At the end of two growing seasons, seedlings inside shelters had significantly larger basal diameters than sprouts inside shelters [12.9 mm (s.e. = 0.4) for seedlings, 9.9 mm (s.e. = 0.7) for sprouts; t-test: $P < 0.01$].

Competing Vegetation and Mortality

Prior to establishing the deer exclosures at both sites, understory vegetation was prevented from developing above about 100 cm in height by deer browsing. When protected from browsing, regeneration dominated by red maple and several birch species quickly became established and grew rapidly in height. The oak sprouts and seedlings in shelters in the medium and large size classes generally maintained dominant or codominant positions in the partially closed seedling canopy that developed in the first 3 years.

Sprout mortality was highest in the medium size class, and was higher for sprouts in shelters than those outside. Some was caused by damage to sprouts when shelters were blown down by wind; other causes appeared to be related to frost damage, insect damage, and additional unknown factors.

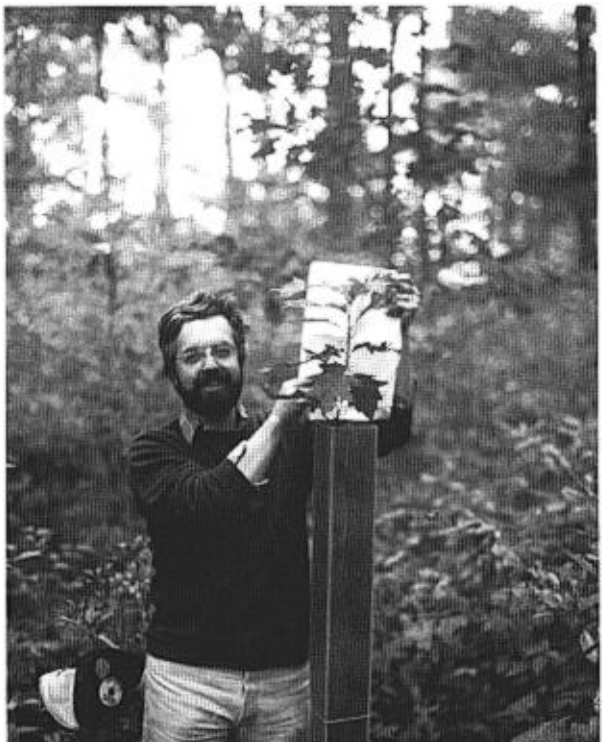

Fig. 1. An example of a red oak sprout from the medium size class at the end of the first growing season. The tree had been clipped down to ground level the previous dormant season; the shelter was installed immediately after clipping.

DISCUSSION

The greatest height growth rates occurred in established natural red oak regeneration with basal diameters of 8 to 15 mm (i.e., medium and large size classes) that had been clipped back to the ground and protected by tree shelters. Sprouts in shelters had double

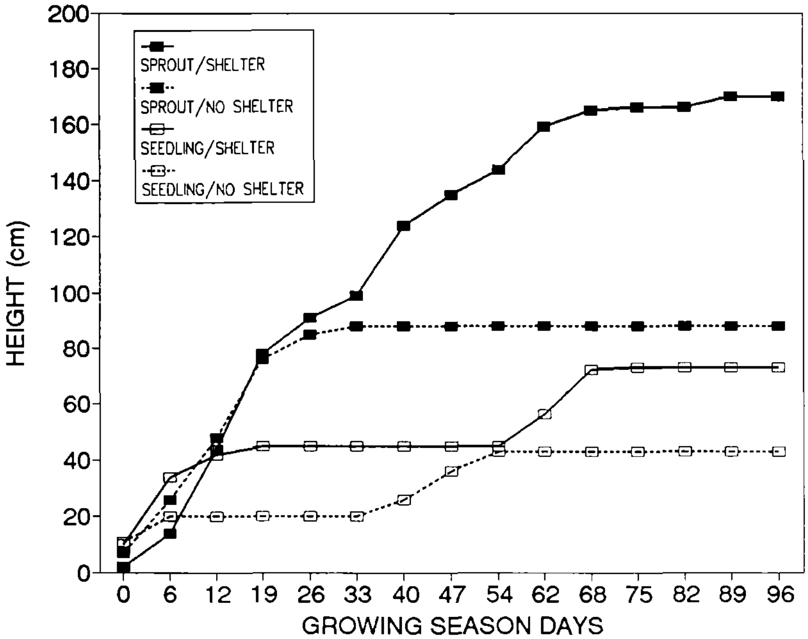

Fig. 2. Cumulative height growth of terminal shoots of four representative red oaks of the large size class during the first growing season. Sprout shoots grew from buds on root collars of stems that had been clipped back to ground level the previous dormant season; seedling shoots grew from the terminal buds of stems that had not been clipped. Measurements began on 19 May (growing season day 0), and extended until 23 August (growing season day 96). Both seedlings had two flushes with determinate growth in the initial flush. The sprout with no shelter had one flush with indeterminate growth lasting until day 33. The sprout inside a shelter had one flush of indeterminate growth lasting until day 68, followed by a second flush from day 82 to 89.

the height growth of those outside shelters, and some grew beyond the top of the 150-cm shelters during the first growing season. Their stems were straight but flexible, and their basal diameters were smaller than sprouts growing outside shelters. These tall, small-diameter stems were unable to support themselves and required the lateral support of the shelters to remain upright.

For sprouts from smaller seedlings (initial basal diameter of 5 mm), shelters did not significantly improve height growth over 3 growing seasons, but diameters were still consistently smaller for sprouts inside shelters. The lack of improved height growth in these sprouts may have resulted from their smaller root systems. Studies have shown that oak seedlings allocate most of their resources in the first few years to the development of a vigorous root system; only when an individual has achieved substantial root development will it respond to overstory removal and grow in height (Sander et al. 1984). Our results suggest that shelters do not alter this basic growth pattern.

Inherent differences in growth patterns between seedlings and sprouts influenced the level of response to shelters. Oaks generally have determinate shoot growth, with a short period of extension growth in which the internodes elongate and the preformed leaves contained in the terminal bud expand. However, sprouts and rapidly growing seedlings may exhibit indeterminate growth, in which an indefinite number of leaves are formed as the shoot expands; the number depends upon growing conditions and the amount of stored carbohydrate reserve in the root system (Wilson 1984).

In the present experiment, seedlings outside of shelters had an initial growth flush that lasted a mean of only 17 days, with 11 leaves on the leader. Most of the seedlings inside shelters maintained determinate growth and produced the same number of leaves, but internodes elongated a greater amount over a longer period of time. Only two seedlings clearly shifted to indeterminate growth, producing many late leaves. Sprouts outside of shelters grew for a mean of 36 days in the initial flush, producing 17 leaves. In shelters, the period of growth for sprouts was extended to 52 days, with the same number of leaves, the greater height growth was again the result of greater internode elongation.

Many seedlings and sprouts, both inside and outside of shelters, formed terminal buds midway through the growing season and then produced a second flush of growth later in the season. The second flushes were longer for trees inside of shelters, which added to the total height differences at the end of the growing season (Table 2). However, the differences in total height growth in the first growing season were largely due to increases in the duration and magnitude of internode elongation during the initial flush of trees inside shelters. The effect on sprouts appears to be greater because of differences in the basic growth pattern between sprouts and seedlings outside of shelters (sprouts initially have indeterminate growth and produce more leaves and internodes than do the initial flushes of seedlings).

The two basic differences in growth of trees inside shelters measured in the present study (i.e., increased height growth and decreased basal diameter growth) have been observed in sessile oak and pedunculate oak (Rendle 1985, Tuley 1985). It may seem logical to conclude that the taller stems of oaks in shelters indicate a greater total dry weight production, but Rendle

Table 2. Mean measures of the initial growth flush (duration, height, and number of leaves) and total growth during the first growing season for sprouts and seedlings of the large size class (initial basal diameter = 15 mm).[a]

	Sprouts		Seedlings	
	Shelter	No shelter	Shelter	No shelter
n	12	12	12	12
Initial ht (cm)	0	0	72.8	73.3
Duration of initial flush (days)	51.8a (2.7)	36.1b (2.5)	32.2b (5.3)	17.0c (0.8)
Height of initial flush (cm)	113.0a (9.4)	60.8b (5.1)	52.0b (8.3)	26.2c (3.5)
No. of leaves on initial flush	19.8a (2.1)	17.3a,b (1.6)	14.5b,c (2.2)	10.9c (0.9)
No. of trees with second flush	9	4	9	7
Total ht growth for season (cm)	136.8a (11.0)	67.4b (6.0)	73.8b (8.3)	38.2c (3.8)
Final ht at end of season (cm)	136.8a,b (11.0)	67.4c (6.0)	146.6a (8.3)	111.5b (3.8)

[a] Means in each row followed by different letters are significantly different ($P < 0.05$), using Tukey's studentized range test. Standard errors are listed in parentheses beneath each mean.

found that total dry weights of seedlings inside and outside of shelters were not significantly different, but that differences existed in allocation of production.

The growth changes observed in shelters are generally ascribed to alterations in temperature, humidity, and carbon dioxide levels. However, it is also possible that the protection from wind provided by shelters may also affect growth allocation. In greenhouse experiments with sweetgum (Neel and Harris 1971, 1972), seedlings that were shaken to simulate wind effects had greater height growth, less diameter growth, and longer period of extension growth prior to setting terminal buds, compared to trees that remained motionless. Similar differences were seen between staked and unstaked field-grown seedlings. The physiological mechanism of this response has not been established, but it may result from increased production of ethylene in swaying stems (Kramer and Kozlowski 1979).

Shelters in this study were beneficial to height growth in the medium and large sizes only during the first growing season. In the second year, when many of the stems had emerged from the tops of the shelters, the average growth was the same as for trees outside shelters. At that point, microclimatic effects would no longer influence the developing terminal shoot; effects of wind on shaking the stem would also begin to occur. Height and diameter growth rates and biomass allocation patterns return to levels that approach "normal" (i.e., similar to unsheltered trees) within about 2 years (Tuley 1985, Potter 1991). It is clear that shelters must be left in place for support at least 2 years after trees emerge from the tops of shelters, until they develop sturdy stems.

APPLICATION

The results of this study indicate that a potential exists for the use of tree shelters in New England mixed-hardwood stands where large red oak natural regeneration exists, but is prevented from developing in height by browsing herbivores. Clipping large-diameter seedlings (minimum basal diameters of about 8 mm) at ground level during the dormant season and protecting the resulting seedling sprouts with shelters caused oaks to grow above the range of deer browse in 1 to 3 years. The management cost of this application of shelters is less than for most uses, since there is no investment in planting stock, site preparation, or planting. It may be possible to ensure the dominance of an oak component in these stands with relatively few sheltered seedlings, perhaps as few as 100–200/ha. Red oak forms a nearly pure overstory canopy with as few as 100 trees/ha in mature stands (Oliver 1978), and has relatively low mortality rates from the sapling stage onward. Estimates of mortality rates for the transition from the sheltered sprout stage to the sapling stage would be needed in order to develop guidelines for minimum numbers of shelters needed. These estimates would best be obtained from trials of shelters used with widely spaced oaks, encompassing the range of variations normally found under operational conditions, rather than from studies of spatially grouped regeneration of uniform sizes, as reported here.

Two variations on this approach also have potential. First, smaller oak seedlings can be clipped and protected by shelters. Although height growth responses did not occur in the first 3 growing seasons for sprouts from the smaller size class in the present study, they were effectively protected from browsing and may gradually reach the size where height growth is markedly accelerated by the shelter environment. Second, shelters may be placed around the seedlings themselves, rather than the cut stump. Height growth will likely be less than for sprouts, but the seedlings have a more stable stem. An important factor in deciding between seedlings and sprouts would be how badly deformed the existing seedling is, as a result of repeated browsing. □

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