SURVIVORSHIP AND GROWTH OF NATURAL NORTHERN RED OAK (*QUERCUS RUBRA* L.) SEEDLINGS IN RESPONSE TO SELECTED TREATMENTS ON AN EXTREMELY ACIDIC FOREST SOIL

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Abstract—Natural seedlings of northern red oak (*Quercus rubra* L.) growing on extremely acidic soils are subjected to stresses resulting from the relatively inhospitable soil chemical environment, competition from other plants and herbivory by white-tailed deer (*Odocoileus virginianus* Boddaert). The objective of this study was to determine if lime and fertilizer, fencing and vegetation control could increase the growth and survivorship of natural northern red oak seedlings. Three replicate plots for each possible combination of liming and fertilization (6600 kg/ha dolomitic lime, 110 kg/ha K_20 equivalents and 220 kg/ha P_2O_5 equivalents), vegetation control (removal of fern fronds) and fencing (woven wire fencing) were established in the spring of 1995. Two years after treatment, the area was subjected to a partial cut. Without any other site treatment, vegetation control increased mortality. Lime and fertilizer treatment increased height growth before and after cutting. Vegetation control increased height growth after cutting but had no effect on height growth prior to cutting. Fencing increased seedling height growth prior to and after cutting. Seedlings that were not fenced actually lost height in the year after cutting. While seedlings were responsive to treatment, the magnitude of the growth response was low.

INTRODUCTION

Northern red oak (*Quercus rubra* L.) is a major component of mature forest stands in southwestern Pennsylvania. Oak is a valuable species for both timber and wildlife; therefore, inclusion of a large component of oak in forest regeneration after logging is an important goal of forest management in these forests. However, on many sites in Pennsylvania, northern red oak is often only a minor component of seedling regeneration (McWilliams and others 1995). Historically, 75 percent of the regeneration that developed into the current oak overstory was seedling origin (McIntyre 1936) but regeneration following recent harvests is often less than desirable. Several factors have been hypothesized to explain this lack of regeneration success. These include competition with hayscented ferns (*Dennstaedtia punctilobula* (Michx.) Moore); (Horsley 1993; Lyon 1996), browsing by deer (*Odocoileus virginianus* Boddaert); (Tilghman 1989; Marquis and Brenneman 1981) and acidic, infertile soil (Demchik and Sharpe 1996; Lyon 1996; Cronan and Grigal 1995; Joslin and Wolfe 1989).

Competition by hayscented fern is capable of impeding success of forest regeneration. Horsley (1993) has documented that although black cherry (*Prunus serotina* Ehrh.) seeds germinate after cutting, they are out-competed by hayscented fern. One factor in this competition is light. Light competition has been suggested as an important factor by Hippensteel and Bowersox (1995). They showed inhibition of white ash (*Fraxinus americana* L.) seedlings by altered light quality; however, they also reported the existence of a non-specific below ground competition. Lyon and Sharpe (1996) also found that hayscented fern limited northern red oak seedling growth as a consequence of below ground competition.

Deer browsing also constitutes a serious limitation to regeneration of oaks (Tilghman 1989; Marquis and Brenneman 1981). Both oak stump sprouts and seedlings are extensively browsed. However, even when deer browsing is limited by electric fencing, regeneration of oaks may not be successful (Demchik and Sharpe 1996; Lyon and Sharpe 1995).

Low levels of available soil bases and high levels of available aluminum may reduce the growth rates of northern red oak (DeWald and others 1990; Joslin and Wolfe 1989). Extremely acidic forest soils often have quite low levels of available calcium and high levels of available aluminum. The potential for aluminum toxicity exists when this occurs (Cronan and Grigal 1995). Indeed, Joslin and Wolfe (1989) found a reduction of growth (at ambient aluminum levels) due to increases in levels of aluminum in their test soils.

Attempts to increase growth of northern red oak seedlings with addition of lime and fertilizer have been largely successful in greenhouse trials, but field results have been mixed (Hart 1995; Hart and Sharpe 1997; Sharpe and others 1993; Pickens 1995). While field results have varied, amelioration of soil base nutrient deficiency and aluminum toxicity remains a promising technique for improving oak seedling growth.

Our study site was located in the Laurel Hill region of southwestern Pennsylvania. This region contains soil horizons with relatively high plant available Al and low Ca (Lyon and Sharpe in press; Demchik and Sharpe 1996).

The objective of this study was to determine if lime and fertilizer, fencing and vegetation control could increase

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growth and survivorship of natural northern red oak seedlings.

METHODS

The Site

An 80-85 year old stand of hardwoods was selected on the Laurel Hill in southwestern Pennsylvania. The stand was composed of 67 percent northern red oak (average diameter of 31.5 cm), 22 percent red maple (*Acer rubrum*; average diameter of 15.9 cm), 7 percent black cherry (average diameter of 30.4 cm) and 2 percent other species. There was an average of 291 trees/ha. The land was mildly sloping (0-20 percent), northeast facing ridgetop. The area is part of Pennsylvania's State Forest system managed by the Pennsylvania Bureau of Forestry. The soils are Typic Dystrochrepts of the Dekalb very stony loam series. Results from 10 hand excavated soil pits on the site revealed a mean organic layer thickness of 4.7±1.4 cm and A-horizon thickness of 7.1±3.6 cm. Site index (50 year) for oak was 19.5 - 22.5 meters. Data from an adjacent site showed soil pH values of the mineral horizon averaged 4.2 and base saturation was 3.1 percent of total exchange sites.

The site had received a light shelterwood cut 7 years prior to the beginning of this experiment, which reduced the basal area to approximately 18 m^2/ha. In addition, a salvage cut was made 3 years prior to this experiment to remove dead and dying trees. The cause of this mortality was unknown. Even though the understory cover was dominated by hayscented fern, northern red oak seedlings averaged 56,000±1000 /ha.

The Design

Twenty-four 1.25 m^2 plots each containing a minimum of 10 natural northern red oak seedlings each were established. All seedlings on the site were small (none taller than 25 cm). Ten randomly selected seedlings were tagged in each plot. These seedlings were measured for height and number of leaves immediately prior to treatment for use as a covariate. Three replicate plots of all possible combinations of the binary treatments of soil amendment, fencing and vegetation control were created. The soil amendment treatment consisted of an application of 6600 kg/ha dolomitic lime (53.5 percent calcium carbonate; 42.0 percent magnesium carbonate; 105.6 percent total calcium carbonate equivalents), 110 kg/ha K_2O equivalents and 220 kg/ha P_2O_5 equivalents applied in mid-May (shortly after bud break) or a control with no amendment. On an adjacent site, this application increased A-horizon soil pH from 4.1±0.04 to 4.5±0.04 and increased base saturation from 3.2±0.3 percent to 15.8±2.5 percent (Demchik 1998). Fencing consisted of encircling the plots with 1.25 meter tall 5 cm woven wire secured to iron reinforcement bars or a control with no fence. Vegetation control consisted of removal of all fern fronds within the plots as they appeared (approximately 3 times annually) or no vegetation control. Measurement of height, number of leaves and total leaf area of each plant was conducted in mid-August for three growing seasons. After 19 months (mid January 1997), the surrounding stand was cut to a residual of 13 m^2/ha basal area. Bolewood was removed and slash was left on site. Care was taken not to damage any of the seedlings. Nested ANCOVA was used for analysis of seedling height in a nested factorial design. Survivorship was tested with Chi-square test.

RESULTS AND DISCUSSION

Mortality

During the first growing season, no mortality occurred from the time of treatment until mid-August. During the second growing season, overall mortality was approximately 7.5 percent. No significant difference existed for mortality between treatments (Table 1). For the third growing season (first season after partial cutting), the highest mortality occurred in plots that were not limed and fertilized or fenced but received vegetation control (65 percent) (Table 1). This treatment combination consistently had the greatest mortality. Fenced plots had lower mortality (23 percent) than unfenced plots (39 percent). This response was primarily driven by the high rate of mortality for the plots that only received vegetation control (65 percent). With exclusion of these plots, unfenced plots had 30 percent overall mortality. This rate of mortality was similar to the rate for fenced plots. Plots that were limed and fertilized had less mortality (26 percent) than those that were not limed and fertilized (36 percent). When the treatment combination of no lime and fertilizer, no fencing but vegetation control was excluded rates of mortality were similar (both 26 percent).

The treatment of only vegetation control resulted in the greatest mortality. When vegetation control was applied with fencing, the rate of mortality was similar to all other treatments. Exposure of seedlings to deer browsing was therefore suggested as a contributing factor in the increased mortality on the vegetation control plots, perhaps because seedlings were more visible to the deer. This is consistent with the observations of other researchers (Tilghman 1989; Marquis and Brenneman 1981). Annual seedling mortality, even in control plots, was generally less than 15 percent before cutting and less than 40 percent after cutting, excluding the vegetation control treatment plots. This suggested that northern red oak seedlings could persist under the adverse conditions present on this site. Seedling red oaks are moderately shade tolerant (Phares 1971) and can remain viable under moderate light conditions for 8-10 years in the understory (McQuilkin 1983). However, in order for seedlings to be successful, they must grow at suitable rates.

Height Growth

Prior to partial overstory cutting, unfenced seedlings grew more slowly (annual growth of 0.8±0.04 cm) than fenced seedlings (annual growth of 1.3±0.05 cm); ($p<0.05$) (Table 2). After cutting, unfenced seedlings lost 1.1±0.06 cm of height and fenced seedlings gained 3.5±1.0 cm of height ($P<0.0001$) (Table 2). Deer browsing is well known to reduce success of forest regeneration (Tilghman 1989; Marquis and Brenneman 1981). The slow growth of fenced seedlings was surprising. When free from deer browsing, these seedlings only grew an average of 3.5 cm. This

Table 1—The effect of all possible combinations of lime and fertilizer (L&F), vegetation control (weed) and fencing on annual percentage mortality of northern red oak seedlings for two years prior to partial overstory cutting (1995 and 1996) and 1 year after partial overstory cutting (1997). Mortality is based on number of seedlings alive at the previous census

			Annual mortality		
L&F	Weed	Fencing	1995	1996	1997
			Percent		
No	No	No	0	7	23
No	No	Yes	0	13	27
No	Yes	No	0	25	65
No	Yes	Yes	0	0	27
Yes	No	No	0	7	37
Yes	No	Yes	0	0	15
Yes	Yes	No	0	0	30
Yes	Yes	Yes	0	10	23

Table 2—The effect of all possible combinations of lime and fertilizer (L&F), vegetation control (weed) and fencing on height growth of northern red oak seedlings for two years prior to partial overstory cutting (1995 and 1996) and 1 year after partial overstory cutting (1997). Annual growth is included for comparison because initial seedlings height was variable

			Total height				Annual growth		
L&F	Weed	Fence	Initial	1995	1996	1997	1995	1996	1997
			Cm						
No	No	No	14.0	14.9	15.7	13.9	0.9	0.8	-1.8
No	No	Yes	12.2	13.1	13.8	16.2	0.9	0.7	2.4
No	Yes	No	12.8	13.8	13.0	12.0	1.0	-0.8	-1.0
No	Yes	Yes	14.1	15.1	17.7	21.5	1.0	2.6	3.8
Yes	No	No	12.6	13.8	15.9	15.4	1.2	2.1	-0.5
Yes	No	Yes	12.0	12.2	14.2	18.1	0.2	2.0	3.9
Yes	Yes	No	14.1	14.1	15.5	14.5	0.0	1.4	-1.0
Yes	Yes	Yes	14.0	14.8	17.1	20.8	0.8	2.3	3.7

result suggested that deer browsing was not the only mechanism responsible for slow growth of these seedlings.

Vegetation control had no effect on height growth prior to cutting (1.1±0.06 cm for both). After cutting, seedlings that received vegetation control added more height growth (1.4±0.1 cm) than those that did not receive vegetation control (1.0±0.07 cm); ($P<0.05$) (Table 2). While these seedlings were responsive after cutting to release from aboveground competition by ferns, the magnitude of the response was small. Possibly, below ground competition was responsible for the limited response of these seedlings. Hippensteel and Bowersox (1995) found a non-specific competition between white ash (*Fraxinus americana* L.) and hayscented fern even when the fronds were removed. Likewise, Lyon and Sharpe (1996) reported below ground competition between northern red oak seedlings and hayscented ferns. While below ground competition was not tested, herbicide treatment as opposed to the frond removal treatment used in this study may generate a different response by eliminating below ground fern competition.

A vegetation control by fencing interaction was found for seedlings in 1996 and 1997. The seedlings in unfenced plots that received vegetation control grew the most slowly overall. These seedlings also experienced the highest rates of mortality. We believe that these slow growth rates and high rates of mortality are due to increased deer browsing.

Seedlings that were limed and fertilized grew more quickly prior to cutting (1.3±0.05 cm) and after cutting (1.5±0.06 cm) than those that were not limed or fertilized (0.9±0.06 cm and 0.9±0.05 cm, respectively); ($P<0.05$) (Table 2). While a response to soil amendments was found for these seedlings, its magnitude was small. These results are puzzling, since, in a companion study with planted 2-0 northern red oak nursery stock, similar treatment produced mean total 3 year growth of 61.8 cm (Sharpe and others 1998). Additional research will be necessary to ascertain why these differences were observed.

Overall, while these seedlings were responsive to all treatments, even the best possible combinations of treatments resulted in less than 4 cm of annual height growth. This rate is far from adequate. All of the factors that we addressed increased growth; however, it was apparent that additional requirements must be met to achieve a suitable rate of height growth.

Leaf Area

During the entire experiment, fenced seedlings increased in leaf area (18±6 cm^2; 64±10 cm^2, respectively) and unfenced seedlings lost leaf area (-135±20 cm^2; -180±25 cm^2, respectively) (Table 3). The factors of vegetation control and of lime and fertilizer were of limited importance to leaf area. Since deer browsing was responsible for negative height growth, reduction in leaf area would also be expected.

CONCLUSIONS

Without any other site treatment, vegetation control increased rates of mortality of natural northern red oak seedlings. Lime and fertilizer treatment increased height growth before and after cutting. Vegetation control increased height growth after cutting but had no effect on height growth prior to cutting. Fencing increased seedling height growth prior to and after cutting. Seedlings that were not fenced actually lost height in the year after cutting. While this investigation revealed statistically significant height growth gains in response to the treatments employed, the magnitude of these responses was low. Since the best growth rates were still less than 4 cm per year, other factors must have also limited height growth of these seedlings. These factors may have included but were not limited to light, soil moisture, other limiting nutrients and insect herbivory.

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Table 3—The effect on total leaf area (cm^2) of all possible combinations of lime and fertilizer (L&F), vegetation control (weed) and fencing on leaf area growth of northern red oak seedlings for two years prior to partial overstory cutting (1995 and 1996) and 1 year after partial overstory cutting (1997). Annual growth is included for comparison because initial seedlings height was variable

			Total leaf area			Annual growth	
L&F	Weed	Fence	1995	1996	1997	1996	1997
			Cm^2				
No	No	No	227	162	82	-65	-80
No	No	Yes	99	99	172	0	73
No	Yes	No	113	109	76	-4	-33
No	Yes	Yes	160	161	288	1	127
Yes	No	No	150	129	108	-21	-21
Yes	No	Yes	144	146	189	2	43
Yes	Yes	No	175	130	84	-45	-46
Yes	Yes	Yes	142	209	223	67	14

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