

FIFTH YEAR DEVELOPMENT OF NATURAL REGENERATION FOLLOWING PRE-COMMERCIAL HERBICIDE RELEASE TREATMENTS

Stephen E. Peairs and Wayne K. Clatterbuck

ABSTRACT

Land managers have a challenging time attempting to maintain the competitive status of oak reproduction following clearcutting. Early herbicide applications have the potential to assist oak reproduction in reaching competitive status at crown closure. Yellow-poplar, red oak, and white oak seedlings and saplings were re-measured for change in height and groundline diameter five growing seasons following early herbicide applications conducted immediately after clearcutting. Prior (May and August 2014) treatments around the reproduction included radial sprays using glyphosate, post-emergent release with sulfometuron methyl, and an untreated control. Though 2-year growth responses were statistically different between treatments, after 5 years no statistical difference existed between the herbicide treatments and control. A numerical difference existed for red oak change in height growth however, as chemical release did increase the mean. Findings from this study suggest that additional competition sources may be reduced by glyphosate applications around favored reproduction. The seedling growth gains from the release treatment may assist in promoting red oak establishment and improve the probability that red oak reaches dominant crown positions at crown closure.

INTRODUCTION

Clearcutting is a commonly utilized silvicultural technique to perpetuate stands of oak (*Quercus* spp.) and yellow-poplar (*Liriodendron tulipifera*). Clearcutting can promote desirable natural hardwood regeneration compared to other regeneration methods (Clatterbuck and others 1999, Jensen and Kabrick 2008, Ward and Stephens 1999), and usually results in a high reproduction establishment rate between 10,000–40,000 stems per acre (Johnson and Krinard 1988, Romagosa and Robison 2003). Yellow-poplar is proficient at seed production and can potentially occupy a clearcut site with greater than 50,000 seedlings per acre (Beck 1990). This species can also establish dominance in crown position and species composition as the stand develops following clearcutting (Brashers and others 2004, McGee and Hooper 1970). Ward and Stephens (1994) suggested that oaks showing early dominance have the best chance to survive and establish a place of prominence in the upper crown classes once the stand reaches maturity. The difficulty lays in developing and maintaining the competitive status of oak reproduction when plant competition is high. Typically, competing plants will suppress the preferred oak regeneration though yellow-poplar will normally maintain dominance within the stand. Research findings have suggested that previous stand composition changes after disturbance with shade tolerant species replacing some of

the shade intolerant and intermediate species (McGee and Hooper 1970, Zedaker and others 1989). This response is most common on higher productivity sites.

Early silvicultural tending operations such as herbaceous release and weeding may prolong a more competitive status and enhance growth for desired natural reproduction (Peairs 2018, Schuler and Robison 2006). These management actions are necessary as managers have had adversity in maintaining adequate oak reproduction on many sites following greater severity disturbances. Though a wealth of small seedlings may be present after timber removal, simply having a multitude of reproduction is not adequate to ensure oak regeneration success to form the future stand (Smith 1986, Stringer 2005). The primary reason for oak regeneration failure is likely attributed to the abundant establishment and persistence of post-disturbance competing vegetation.

Chemical vegetation control has been suggested to improve the competitive status of oaks in hardwood stands. In particular, enhanced seedling diameter and height growth may result from chemical release. Hilt and Dale (1987) concluded that increased intensity of pre-commercial thinning resulted in greater diameter growth in stands 13, 17, and 21 years of age. A study by Thompson and Nix (1993) observed that early crop tree release within a 4-year-old clearcut significantly decreased herbaceous and woody plant competition. This reduction in competition resulted

Author Information: Stephen E. Peairs, Assistant Professor, Clemson University, Clemson, SC 29634; and Wayne K. Clatterbuck, Professor, University of Tennessee, Knoxville, TN 37996.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

in increased seedling groundline diameter growth but did not improve height growth over untreated controls. Nix (2004) remeasured the released natural oak 10 years after the initial chemical release treatments and reported that four herbicide treatments significantly increased diameter growth of released oak seedlings. Likewise, circumspectly applied post-emergent herbicide applications utilizing glyphosate has improved height growth in hardwood species (Hopper and others 1993) in addition to oak seedling survival.

Competition control around oak reproduction is often an ongoing process requiring more than one application within the first decade. Adjacent woody stems will be a persistent factor limiting crop tree growth whether due to ineffective control by the chemical application or as subsequent invasion of new seed. Continued silvicultural upkeep, beyond pre- or post-harvest site preparation, will often be needed as the proliferation of light-seeded species will invade or establish from seed already present in the soil herbicide treated areas (Clatterbuck and Schubert 2007).

Previous studies (Self and others 2014, Thompson and Nix 1993) suggested that early herbaceous release can improve select species of oak's growth. Two-year measurement analyses (Peairs 2018) previously indicated significant change in height growth existed between sulfometuron methyl, glyphosate radial spray, and control plots. A difference in diameter growth was found for the sulfometuron methyl treatment versus the control and radial glyphosate release (latter two did not differ) after two growing seasons.

OBJECTIVES

This study is a continuation of a previous study that examined the impacts of chemical release applications on height and diameter growth of natural oak and yellow-poplar reproduction. Analyses aimed to determine if (1) a significant difference still exists for absolute change in seedling height growth, after five complete growing seasons, among chemical treatments applied post-harvest to clearcuts conducted in 2014; (2) a difference has become evident for absolute change in groundline diameter for natural regeneration; and (3) derive estimates of stem density creating competition for resources around the sample trees.

METHODS

Study Site

The study site was located on a private landholding in the Western Highland Rim-highly dissected plateau physiographic ecoregion of west-central Tennessee (Smalley 1984). The soils on the study site were Bodine gravelly silt loams (5 to 40 percent slopes). Site index value for white oak (*Quercus alba*) was 75 feet at base age 50.

Most undisturbed forestland in the region was dominated (80 percent or greater) by oak species. The study site was covered by a mixed-mesophytic forest, with white oak, southern red oak (*Q. falcata*), chestnut oak (*Q. montana*), black oak (*Q. velutina*), hickory (*Carya* spp.), blackgum (*Nyssa sylvatica*), red maple (*Acer rubrum*), sugar maple (*A. saccharum*), black cherry (*Prunus serotina*), and yellow-poplar forming the majority of the overstory species composition. Midstory and understory canopy layers also contained flowering dogwood (*Cornus florida*), sourwood (*Oxydendrum aboreum*), sassafras (*Sassafras albidum*), eastern hophornbeam (*Ostrya virginiana*), elms (*Ulmus* spp.), white ash (*Fraxinus americana*), and American beech (*Fagus grandifolia*). As indicated by residual stumps, one or more diameter-limit harvests probably occurred within the area (the most recent harvest likely occurred between 1990 and 1995). The research blocks had experienced five full growing seasons since clearcutting. The majority of trees within the replicated blocks have reached large seedling to sapling size class. A heavy abundance of *Rubus* spp. still exists on at least 75 percent of the research area. The heavy abundance of broomsedge (*Andropogon virginicus*) previously on site at year 2 has been displaced by shading from the developing vegetation. Large seedlings and saplings were tallied by species. The stand has not reached crown closure but is expected to do so in 2 to 3 years.

Study Design

The study incorporated a randomized complete block sampling design. Three individual blocks were replicated on sites with uniform site productivity, and these blocks were clearcut in the early spring of 2014. Six individual treatment units, approximately 0.75 acres in size, were initially installed within each block. Only three treatments were re-measured for 5-year growth response due to travel and budget restrictions. These included broadcast sulfometuron methyl, radial glyphosate sprays, and control treatment units. Eight of the nine treatment units were sampled during the winter and an adequate number of sample trees were remeasured. An attempt was made to remeasure samples in the ninth treatment unit in July of 2020. Due to a lack of sample data (previously tagged trees could not be found) the aforementioned control treatment unit in one block was dropped from the analysis. More descriptive narratives of the treatments analyzed include:

1. Chemical seedling release treatments utilizing the equivalent of 2 ounces per acre of sulfometuron methyl (SFM75® by Alligare LLC) only,
2. Radial spray release utilizing foliar sprays of glyphosate (5 percent solution), and
3. Untreated control.

The three sulfometuron methyl treatment units received applications in May-June of 2014. Glyphosate radial spray applications were conducted between July and August of 2014. Radial sprays treated vegetation in the surrounding area of approximately a 5-foot radius from the sample seedling. A stove pipe apparatus covered the seedling being released to protect foliage from incidental contact with herbicide solution. The final treatment unit (untreated control) did not receive any herbicide applications.

Approximately 150 naturally regenerated seedlings (approximately half oak species and half yellow-poplar) in each treatment unit in the three replicated blocks were measured in the fall of 2014 for overall height and ground line diameter. A total of 2,653 seedlings were initially measured. Height measurements were taken with a standard retractable ruler to the nearest half inch. Diameter was measured at groundline using handheld digital calipers. Seedlings were measured again after five full growing seasons had elapsed in December 2019 to January 2020. Stem density data was collected at the aforementioned time and in July 2020. The same methods were used to gather height and groundline diameter data. The final data collection was later in the growing season due to ramifications with the Covid-19 pandemic. Only 378 seedlings (of the 1,550 relocated during the 2017 measurement period to gather second year growth) were relocated, on 8 out of the 18 total treatment units, for measurement.

Stem density tallies were summarized by individual treatments and combined treatments. Stem density within a 5-foot radius around 155 of the sample trees in the study were collected. The 5-foot radius was representative of the distance treated in the radial glyphosate sprays. Percentages of individual species were calculated for each summarization. Overall stem density per tree as well as stem density per tree by treatments were also derived from the data.

Statistical Analyses

The experimental design was a randomized complete block with sampling using height and diameter measurements taken from white oak, red oak, and yellow-poplar seedlings. The white oak group included post oak (*Quercus stellata*), chestnut oak, and white oak species. All red oak species

(primarily black oak and southern red oak) had been designated as “red oak” since initial measurements. Analyses were run for each species group and for all seedlings combined to determine any differences between treatments. Treatment was considered a fixed variable. Random variables included blocks and seedlings. Statistical analyses were performed using linear mixed models (PROC Glimmix; SAS version 9.4) (SAS Institute 2013) with a normal distribution. The least squares means were separated using Tukey’s significant difference test. The significance level was set at $\alpha = 0.05$. A degrees of freedom test using the Kenward-Roger method was also performed.

RESULTS

The type III tests indicated no significant differences were calculated amongst treatments when all seedlings were combined for diameter ($F_{2,425} = 0.12, p < 0.8939$) or height ($F_{2,425} = 0.051, p < 0.6815$). There were no statistical differences for change in diameter growth for red oak ($F_{2,163} = 1.11, p < 0.5947$), white oak ($F_{2,161} = 5.158, p < 0.6458$), or yellow-poplar ($F_{2,99} = 3.42, p < 0.8053$). There were also no statistical differences (at $\alpha = 0.05$) for change in height growth for red oak ($F_{2,163} = 2.85, p < 0.0611$), white oak ($F_{2,161} = 3.721, p < 0.3961$), or yellow-poplar ($F_{2,99} = 3.227, p < 0.5105$). Though no statistical difference was found, a numerical difference exists between red oak height growth in control and sulfometuron methyl treatments with means of 59.97 inches and 78.19 inches, respectively (table 1). Red oak mean height growth was also greater than white oak for radial glyphosate and sulfometuron methyl released red oak having 13.44 inches and 8.44 inches greater growth over white oak species, respectively. There was minimal difference in height growth between red oak and white oak in the control. A similar trend existed for change in diameter among species and treatments. Red oak means for radial and sulfometuron methyl were 0.952 and 0.953 inches, respectively (table 2). Control had a lower mean of 0.778 inches. The white oak mean for the sulfometuron methyl treatment was highest at 0.834 inches.

Table 1—Least squares mean estimates for change in height (inches) of natural reproduction by species groups and treatments for the herbicide seedling release study on the Western Highland Rim of Tennessee

Treatment	Red oak			White oak			Yellow-poplar			Combined		
	n	LS Mean	SE	n	LS Mean	SE	n	LS Mean	SE	n	LS Mean	SE
Control	54	59.97	5.33	45	59.50	8.75	22	155.53	34.23	121	75.52	9.27
Radial	60	69.44	5.01	60	56.00	6.72	25	123.37	27.55	145	73.81	8.39
SFM 75	50	78.19	5.48	57	69.35	6.86	53	106.39	26.18	160	80.18	8.26

Treatments had no statistical difference by tree group or for all reproduction combined.

n = number of seedlings; LS Mean = least squares means; SE = standard error; Control = no treatment; SFM75 only = 2 ounces per acre rate of sulfometuron methyl only; Radial = Radial spray release utilizing foliar sprays of glyphosate (5 percent solution).

Table 2—Least squares mean estimates for change in basal diameter (inches) of natural reproduction by species groups and treatments for the herbicide seedling release study on the Western Highland Rim of Tennessee

Treatment	Red oak			White oak			Yellow-poplar			Combined		
	n	LS Mean	SE	n	LS Mean	SE	n	LS Mean	SE	n	LS Mean	SE
Control	54	0.778	0.137	45	0.697	0.107	22	1.967	0.540	121	0.952	0.142
Radial	60	0.952	0.115	60	0.781	0.090	25	1.620	0.415	145	1.010	0.110
SFM 75	50	0.953	0.118	57	0.834	0.092	53	1.526	0.391	160	1.032	0.108

Treatments had no statistical difference by tree group or for all reproduction combined.

Table 3—Competing live stem density (large seedlings and saplings) within 5 feet of sample trees within treatment units for the herbicide seedling release study on the Western Highland Rim of Tennessee

Treatment	Density	Samples	YLP	OAK	ASH	HIC	BLC	LOB	SYCA	GUM	SUMA	ELM	BASS	RBUD	HOP	DOG	Other	Totals
Control	5.23	62	89	26	41	22	7	1	12	8	36	5	17	22	29	4	5	324
			<i>27.47</i>	<i>8.02</i>	<i>12.65</i>	<i>6.79</i>	<i>2.16</i>	<i>0.31</i>	<i>3.70</i>	<i>2.47</i>	<i>11.11</i>	<i>1.54</i>	<i>5.25</i>	<i>6.79</i>	<i>8.95</i>	<i>1.23</i>	<i>1.54</i>	
Radial	2.98	45	35	19	5	19	1	6	1	1	2	3	7	5	21	4	5	134
			<i>26.12</i>	<i>14.18</i>	<i>3.73</i>	<i>14.18</i>	<i>0.75</i>	<i>4.48</i>	<i>0.75</i>	<i>0.75</i>	<i>1.49</i>	<i>2.24</i>	<i>5.22</i>	<i>3.73</i>	<i>15.67</i>	<i>2.98</i>	<i>3.73</i>	
SFM75	5.27	48	83	35	62	13	6	2	3	3	4	9	12	13	0	1	7	253
			<i>32.81</i>	<i>13.83</i>	<i>24.51</i>	<i>5.14</i>	<i>2.37</i>	<i>0.79</i>	<i>1.19</i>	<i>1.19</i>	<i>1.58</i>	<i>3.56</i>	<i>4.74</i>	<i>5.14</i>	<i>0.0</i>	<i>0.40</i>	<i>2.77</i>	
Totals	4.59	155	207	80	108	54	14	9	16	12	42	17	36	40	50	9	17	711
			<i>29.11</i>	<i>11.25</i>	<i>15.19</i>	<i>7.59</i>	<i>1.97</i>	<i>1.27</i>	<i>2.25</i>	<i>1.69</i>	<i>5.91</i>	<i>2.39</i>	<i>5.06</i>	<i>5.63</i>	<i>7.03</i>	<i>1.27</i>	<i>2.39</i>	

YLP = yellow-poplar; OAK = all oaks; HIC = hickory; BLC = black cherry; LOB = loblolly pine; SYCA = sycamore; SUMA = sumac spp.; BASS = basswood; RBUD = redbud; HOP = hophornbeam; DOG = dogwood; OTHER includes sassafras, persimmon, eastern redcedar, sugar maple, and miscellaneous species (all <1 percent of competing stem population); Density = the average number of competing stems surrounding a sample tree inside of a 5-foot radius; Samples = number of flagged/marked trees within a particular treatment; stems within the 5-foot radius were tallied around these trees.

Italicized numbers are species percentages of the total competing stem count.

Bold font is the overall combined species percentages (all treatment counts combined for individual species) for the entire population.

Stem density of competing stems around the sampled measured trees in the control and sulfometuron methyl treatments were similar at 5.23 and 5.27 stems per tree, respectively (table 3). The radial glyphosate spray treatment was substantially lower at 2.98 stems per tree. Yellow-poplar (29.1 percent) and ash (15.2 percent) were the most abundant competitors to the sample trees surveyed (table 3). Unmarked oak species comprised 11.3 percent of the competing stem population.

DISCUSSION

The lack of data in one of the control units likely did not impact analysis results for either red or white oak as sample sizes were of similar values to both the radial and sulfometuron methyl treatments. Due diligence was applied to find seedlings, but efforts were futile with dense, actively growing vegetation (July 2020). Yellow-poplar sample size was low due to difficulty determining if most of the yellow-poplars on site were previously sampled. It is possible that some tags may have grown into the trees themselves or were removed by wildlife. Flagging was evident at the base of some trees where it had become detached from tree growth, but a tag may not have been found making it unidentifiable. Future

studies will likely require biennial or annual upkeep to avoid loss of sample stems.

The findings regarding the gained absolute change in height growth for red oaks in response to the sulfometuron treatment is notable and would most likely be statistically significant at a lower level of significance, alpha level of 0.10. This herbicide treatment yielded a mean enhancement in height of 18.22 inches over the control. The suppression of herbaceous competition using sulfometuron methyl during the inchoate development of sample red oak likely accelerated early height growth (Peairs 2018). Likewise, the radial glyphosate release treatment improved height growth 10.11 inches which may also be attributed to both herbaceous and woody plant control in the immediate growing area around the crop trees. This response is especially noteworthy as sample trees within the radial glyphosate treatment appeared to have produced a “stunted” change in height growth compared to the control after the first two growing seasons (Peairs and Clatterbuck 2020). Thus, the sample trees appear to have recuperated from previous deleterious effects caused by glyphosate release during late summer of the first growing season.

The increased height growth resulting from release treatments may place red oaks in a more competitive position for maintaining dominance and higher vigor until

crown closure in the next few years as compared to the poorer performing red oaks found in the control treatment. Untreated vegetation around red oak in the control units may suppress preferred oak trees prior to crown closure potentially leading to mortality or lower vigor (Romagosa and Robison 2003). For the first few years, the presence of herbaceous vegetation may have also reduced potential growth of the oak seedlings (Romagosa and Robison 2003). Within any treatment, red oak will certainly have the advantage over white oak in this situation given the family's faster growth rate (Burns and Honkala 1990, Johnson and others 2009). Red oaks' faster growth rate has also been evident during the course of this study (Peairs 2018).

Adjacent competing woody stem density will also be a factor in determining if oak will be successful in maintaining dominance over time. The lower average density around crop trees in the radial sprays may continue to yield greater gains in subsequent years. Lower density equates to less competition for available resources including canopy/ root expansion growing space, water, and nutrients. Less competitor stems may also lead to decreased costs (labor time) should a crop tree release application be applied after crown closure. The sulfometuron methyl treatment stem density was similar to that of the control but is an anticipated response given the active ingredient, when applied at 2 ounces per acre, does not have injurious effects on oak or yellow-poplar. The abundant prevalence of competitors (especially yellow-poplar) around oak stems will likely lead to suppression of oak in the developing stand (Beck 1990, Brashears and others 2004). It will be imperative that some additional silvicultural management, such as crop tree release, be applied to the stand to continue oak prominence. Yellow-poplar will continue to dominate (Beck and Hooper 1986) and will not likely experience stagnated growth (Beck and Sims 1983).

CONCLUSIONS

Early attempts to control competing vegetation around preferred, higher-value species is common practice to establish hardwood stands. Few studies have investigated the efficacy of chemical applications to promote natural regeneration in recently disturbed stands. Though a statistical difference was not found at $\alpha=0.05$, a numerical difference appears evident to suggest that early release may promote red oak competitiveness in regard to height growth by using sulfometuron methyl and competition reduction using glyphosate applied as foliar sprays. The observance of height stunting by glyphosate after two growing seasons was previously observed, however, results from this study suggest that seedlings had recuperated and height is now greater than that of untreated seedlings.

LITERATURE CITED

- Beck, D.E. 1990. *Liriodendron tulipifera* L. Yellow-poplar. In: Burns, R.M.; B.H. Honkala, eds. *Silvics of North America*. Volume 2. Hardwoods, Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture Forest Service: 406–416.
- Beck, D.E.; Hooper, R.M. 1986. Development of a Southern Appalachian hardwood stand after clearcutting. *Southern Journal of Applied Forestry* 10(3): 168–172.
- Beck, D.E.; Sims, D.H. 1983. Yellow-poplar. In *Silvicultural systems for the major forest types of the United States*. Agric. Handb. 445. Washington, DC: U.S. Department of Agriculture Forest Service: 180–182.
- Brashears, M.B.; Fajvan, M.A.; Schular, T.M. 2004. An assessment of canopy stratification and tree species diversity following clearcutting in Central Appalachian Hardwoods. *Forest Science*, 50(1): 54–64.
- Burns, Russell M.; Honkala, B.H., tech. coords. 1990. *Silvics of North America: 1. Conifers; 2. Hardwoods*. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture Forest Service. 877 p. Vol. 2.
- Clatterbuck, W.K.; Blakley, P.; and Yielding, P. 1999. Development of oak regeneration nine years after shelterwood cutting and clearcutting on the Coastal Plain of west Tennessee. Gen. Tech. Rep. SRS-24. Proceedings of 12th central hardwood forest conference. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 189–194.
- Clatterbuck, W.K.; Schubert, M.R. 2007. Effects of pre- and post-harvest site preparation treatments on natural regeneration success in a mixed hardwood stand after 10 years. In: Stanturf, J.A., ed. *Proceedings of the 14th biennial southern silvicultural research conference*. Gen. Tech. Rep. SRS-121. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 451–454.
- Hilt, D.E.; Dale, M.E. 1987. Effects of precommercial thinning on diameter growth in young central hardwood stands. In: Hay, R.L.; Woods, F.W.; DeSelm, H., eds. *Proceedings of the 6th central hardwood forest conference*. Knoxville, TN: University of Tennessee: 179–187.
- Hopper, G.M.; Buckner, E.R.; Mullins, J.A. 1993. Effects of weed control and fertilization on plantation establishment and growth of green ash, sweet gum, and loblolly pine: four-year results. In: Brissette, J.C., ed. *Proceedings of the seventh biennial southern silvicultural research conference*. Gen. Tech. Rep. SO-93. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 357–360.
- Jensen, R.G.; Kabrick, J.M. 2008. Comparing single-tree selection, group selection and clearcutting for regenerating oaks and pines in the Missouri Ozarks. USDA General Technical Report NRS-P-24. Proceedings of the 16th central hardwood forest conference. Newtown Square, PA: U.S. Department of Agriculture Northern Research Station: 38–49.
- Johnson, P.S.; Shifley, S.R.; Rogers, R. 2009. *The ecology and silviculture of oaks*, 2nd addition. Wallingford, Oxfordshire, UK: CABI International. 580 p.
- Johnson, R.L.; Krinard, R.M. 1988. Growth and development of two sweetgum-red oak stands from origin through 29 years. *Southern Journal of Applied Forestry*. 12(2): 73–78.
- McGee, C.E.; Hooper, R.M. 1970. Regeneration after clearcutting in the Southern Appalachians. Res. Pap. SE-70. Asheville, NC: U.S. Department of Agriculture Forest Service, Southeastern Forest Experimental Station: 520–523.
- Nix, L.E. 2004. Herbicide release of 4-year-old, naturally regenerated bottomland oaks—10 year results. In: Connor, K.F., ed. *Proceedings of the 12th biennial southern silvicultural research conference*. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 520–523.
- Peairs, S.E. 2018. Oak and yellow-poplar response to pre-commercial chemical applications after clearcutting a high-graded hardwood stand on the Western Highland Rim of Tennessee. Knoxville, TN: University of Tennessee. 155 p. Ph.D. dissertation. https://trace.tennessee.edu/utk_graddiss/5083. [Date accessed: August 2018].

- Peairs, S.E.; Clatterbuck, W.K. 2020. Potential detrimental effects of using glyphosate for hardwood seedling release. In: Bragg, D.C.; Koerth, N.E.; Holley, A.G., eds. Proceedings of the 20th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 302–308.
- Romagosa, M.A.; Robison, D.J. 2003. Biological constraints on the growth of hardwood regeneration in upland Piedmont forests. *Forest Ecology and Management*. 175: 545–561.
- SAS Institute. 2013. SAS/STAT 13.1 user's guide. Version 9.4. Cary, NC: SAS Institute. [Not paged].
- Schuler, J.L.; Robison, D.J. 2006. Stand development and growth responses of 1- and 3-year-old natural upland hardwoods to silvicultural treatments. *Forest Ecology and Management*. 232(1–3): 124–134.
- Self, A.; Ezell, A.W.; Rowe, D. 2014. Performance of oak seedlings grown under different Oust® XP regimes. *Forests*. 5(6): 1331–1340. <https://doi.org/10.3390/f5061331>.
- Smalley, G.W. 1984. Classification and evaluation of forest sites on the northern Cumberland Mountains. Gen. Tech. Rep. SO-50. New Orleans: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station. 84 p.
- Smith, D.M. 1986. The practice of silviculture, eighth edition: New York: John Wiley and Sons. 527 p.
- Stringer, J. 2005. Harvest survivability of oak advanced regeneration. In: Weigel, D.R.; Van Sambeek, J.W.; Michler, C.H., eds. Ninth workshop on seedling physiology and growth problems in oak plantings. 2004 October 18–20; West Lafayette, IN. Gen. Tech. Rep. NC-262. St. Paul, MN: U.S. Department of Agriculture Forest Service, North Central Research Station: 26–27.
- Thompson, J.F., Jr.; Nix, L.E. 1993. Early release of naturally-regenerated cherrybark and shumard oak seedlings with herbicides. In: Brisette, J.C., ed. Proceedings of the seventh biennial southern silvicultural research conference. General Technical Report SO-93. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 445–451.
- Ward, J.S.; Stephens, G.R. 1994. Crown class transition rates of maturing northern red oak (*Quercus rubra* L.). *Forest Science*. 40(2): 221–237.
- Ward, J.S.; Stephens, G.R. 1999. Influence of cutting methods on 12-year-old hardwood regeneration in Connecticut. Gen. Tech. Rep. SRS-24. Proceedings, 12th central hardwood forest conference. Asheville, NC: U.S. Department of Agriculture, Southern Research Station: 204–208.
- Zedaker, S.M.; Smith, D.W.; Kreh, R.E.; Fredericksen, T.S. 1989. The development of five-year-old mixed upland hardwood-pine stands. In Proceedings of pine-hardwood mixtures: A symposium on management. Gen. Tech. Rep. SE-58. Atlanta: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station: 100–106.