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forest management

Influence of Herbicides and Improvement Cutting, Fertilization, and Prescribed Fire on Planted Longleaf Pine Development

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There is an interest in restoring longleaf pine (*Pinus palustris* Mill.) across its native range in the southeastern United States, and establishment of longleaf pine on much of its original range requires artificial regeneration and management of competing vegetation after planting. In Louisiana, two fertilization levels (No or Yes [36 kg/ha nitrogen and 40 kg/ha phosphorus]) in combination with three vegetation treatments (check, five prescribed fires [PFs], or multiyear vegetation control [IVM]) were applied to longleaf pine plantings established in a randomized complete block factorial design ($\alpha = 0.05$). After 12 years, survival averaged 61% across the six-treatment combinations. Fertilization did not affect longleaf pine growth or stand production, and thus, native fertility was not limiting pine development. Longleaf pine bolewood production was significantly greater on IVM plots (165 m^3/ha) than on check and PF plots (average of 113 m^3/ha). In the 13th growing season, IVM plots had significantly less understory tree cover (51%) than checks (80%), but PF plots had the least tree cover (16%) and the most grass (5%) and forb (10%) cover. Fertilization significantly increased understory tree cover (58%) compared with that for unfertilized plots (40%), but woody vine cover was significantly less on fertilized plots (3%) than on unfertilized plots (6%).

Keywords: diammonium phosphate; hexazinone, *Pinus palustris* Mill., triclopyr, understory cover, vegetation management

Longleaf pine (*Pinus palustris* Mill.) forests once occupied about 37 million ha in the southeastern United States, of which longleaf pine was dominant on 23 million ha and was in mixtures with other pines and hardwoods on 14 million ha (Frost 2006). Because of the many desirable commercial attributes of longleaf pine, these forests were intensively exploited since European settlement (Wahlenberg 1946, Landers 1995, Frost 2006). For a number of reasons, longleaf pine did not often naturally reestablish after logging and land clearing for pasture and cropland, and land managers had serious problems artificially regenerating longleaf pine (Wahlenberg 1946, Croker 1987, Landers 1995, Frost 2006). Thus, many managers favored loblolly (*Pinus taeda* L.) and slash (*Pinus elliottii* Engelm.) pines over longleaf pine (Croker 1987).

Presently, there are about 1.4–1.7 million ha of longleaf pine forests remaining (America's Longleaf 2009, Gaines 2012). Because of the loss of most longleaf pine forest cover, recovery of longleaf pine within its historical range is necessary to restore functional ecological processes needed to maintain many species that evolved in the longleaf pine landscape (Hoctor et al. 2006).

To reverse this situation, a sustained regional effort is underway with the goal of increasing the area of longleaf pine to between 2.4 and 3.2 million ha by 2027 (America's Longleaf 2009, Gaines 2012). Achieving this outcome will require forests, pastures, and croplands to be reforested or converted to longleaf pine, principally by planting longleaf pine seedlings (The Longleaf Alliance 2013). Of the 69–80 million longleaf pine seedlings produced annually, 70–90% were grown in containers (South et al. 2005, McNabb and Enebak 2008, Barnard and Mayfield 2009, The Longleaf Alliance 2013).

After planting, vegetation management may be necessary because hardwood brush and volunteer loblolly and slash pines can outgrow young longleaf pine seedlings (Haywood 2000, Haywood and Grelen 2000, Haywood et al. 2001). The slow growth of longleaf pine seedlings is partly attributed to its grass stage, a time in which there is little aboveground stem growth. The grass stage continues for an average of 6 years after germination as the root system develops and the stem thickens (Wahlenberg 1946). However, quality nursery-grown seedlings planted on good sites can initiate height growth before the end of the second growing season (Haywood 2005, 2007).

Prescribed fire is often used for vegetation management in longleaf plantations because seedling longleaf pines tolerate low-intensity fires better than hardwood, loblolly, and slash pine seedlings. Fire is particularly useful because it can be applied over large areas

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This article uses metric units; the applicable conversion factors are: centimeters (cm): 1 cm = 0.39 in.; meters (m): 1 m = 3.3 ft; square meters (m^2): 1 m^2 = 10.8 ft^2; cubic meters (m^3): 1 m^3 = 35.3 ft^3; millimeters (mm): 1 mm = 0.039 in.; kilograms (kg): 1 kg = 2.2 lb; hectares (ha): 1 ha = 2.47 ac.

relatively quickly and on sites not accessible with mechanical equipment. Fire consumes forest floor litter, which otherwise smothers herbaceous vegetation, and prescribed burning keeps woody understory plants in check (Haywood et al. 2001). Without some means to remove litter, herbaceous plant communities will be smothered in even young longleaf pine stands within a few years although the woody vegetation was kept in check by herbicidal applications and improvement cutting (Haywood 2009, 2011). Fortunately, where the herbaceous plant community has been nearly lost, fire can have a rejuvenating effect on the herbaceous ground layer (Brockway and Outcalt 2000, Haywood 2009, 2011). To maintain the understory condition, fire must be repeatedly applied because the benefits of a single prescribed fire can be transitory (Haywood 1995, Brockway and Outcalt 2000).

Although recommended, fire is not a panacea for managing longleaf pine stands. Fire can destroy seedlings, and the use of fire can adversely affect stand yield and soil properties (Wahlenberg 1946, Bruce 1951, Boyer 1983, Boyer and Miller 1994, Haywood 2002). If land managers are reluctant to use fire because of these or other reasons, an alternative would be postplant vegetation control by chemical or mechanical means when the landowner's primary objective is to produce commercial goods from longleaf pine stands (Nelson et al. 1985, Barnett 1989, Loveless et al. 1989, Haywood 2000, Ramsey and Jose 2004). Total competition control is not necessary (Nelson et al. 1985); reducing plant cover to about 50% is sufficient to ensure early emergence from the grass stage (Haywood 2000).

When competing vegetation was controlled, early fertilization with diammonium phosphate increased longleaf pine seedling survival and growth on a sandy loam soil (Loveless et al. 1989). Phosphorus amendment was more beneficial than nitrogen (N) or potassium (K) amendment through 15 growing seasons on loamy sand to sand soils (Lewis 1977). On a fine sandy loam, Schmidtling (1987) reported gains in growth in a 25-year-old stand of longleaf pine from N, phosphorus (P), and K fertilization at the time of planting when coupled with cultivation. Without vegetation management, Derr (1957) had poor results after applying N, P, and K fertilizer to planted seedlings on a sandy loam soil because of severe grass competition. In addition, fertilization with N, P, and K reduced longleaf pine seedling survival with or without vegetation control, and fertilization with vegetation control did not influence height growth better than vegetation control alone through two growing seasons on a sandy loam soil (Ramsey et al. 2003).

In this research, several available options for managing longleaf pine plantings were examined in a randomized complete block factorial design for comparing fertilization levels (No or Yes) in combination with three vegetation treatments (check, prescribed fire, and intensive vegetation management). Herein, longleaf pine development from the 7th through 12th growing seasons is reported as are the percent cover of forest floor litter and understory vegetation in the 13th growing season.

Study Area

The study area is within the humid, temperate, coastal plain, and flatwoods province of the West Gulf Region of the southeastern United States (McNab and Avers 1994), and the site comprises two soil complexes on the Kisatchie National Forest in central Louisiana. One complex (92°36′ W, 31°6′ N at 55 m above sea level) is Ruston fine sandy loam (fine-loamy, siliceous, semiactive, thermic Typic Paleudult), Malbis fine sandy loam (fine-loamy, siliceous, subactive, thermic Plinthic Paleudult), and Gore very fine sandy loam (fine, mixed, active, thermic Vertic Paleudalf) soils with a slope of 1–10% (Kerr et al. 1980). The other complex (92°38′ W, 31°8′ N at 66 m above sea level) is Beauregard (fine-silty, siliceous, superactive, thermic Plinthaquic Paleudult), Malbis, and Gore soils with a slope of 1–5%. A closed-canopy, loblolly pine, and hardwood forest occupied both complexes that were clearcut harvested in 1996 and were roller drum chopped and prescribed burned in August 1997. By the third growing season, the six most widely distributed arborescent competitors were eastern baccharis (*Baccharis halimifolia* L.), American beautyberry (*Callicarpa americana* L.), sweetgum (*Liquidambar styraciflua* L.), loblolly pine, winged sumac (*Rhus copallinum* L. var. *latifolia* Engl.), and blackberry (*Rubus* spp.).

The study complexes are suitable for restoring loamy dry-mesic upland longleaf pine forests (Turner et al. 1999). The Beauregard, Malbis, and Ruston soils have been reported to be deficient in P for growing pine trees (Tiarks 1983, Burton 1984, Haywood and Tiarks 1990), and P probably limits pine growth on the Gore soil as well.

Methods

Study Establishment

In October 1997, four blocks of six treatment combinations that included two fertilization levels (Fert) and three vegetation treatments (VT) were established in a randomized complete block factorial design at $\alpha = 0.05$ (Steel and Torrie 1980). The 24 research plots (4 blocks $\times$ 6 Fert-VT combinations) each measured 22 $\times$ 22 m (0.048 ha) and contained 12 rows of 12 seedlings arranged in a 1.83-m $\times$ 1.83-m spacing. The center 64 longleaf pine seedlings (8 rows of 8 seedlings each) were the measurement plot. Blocking was based on soil type (two blocks on each soil complex) and topographic location within each complex.

Longleaf pine seeds from a standard Louisiana seed source were sown in containers in May 1997 at the Alexandria Forestry Center in Pineville, LA. Container seedlings were grown because this is the most common type of longleaf pine planting stock (South et al. 2005, McNabb and Enebak 2008, Barnard and Mayfield 2009, The Longleaf Alliance 2013). The 28-week-old seedlings were planted in November 1997 using a planting dibble with a tip of the correct size and shape for the 3.8-cm wide and 14-cm deep root plug.

The two fertilization levels per block were as follows: No, no fertilizer applied; and Yes, broadcast 200 kg/ha diammonium phosphate (36 kg/ha N and 40 kg/ha P) in June 1998. The fertilizer rate was based on a preliminary nutrition trial with planted longleaf pine seedlings (Burton 1984). The three vegetation treatments per block were as follows: check, no management activities after planting; PF, prescribed fire was applied to the plots five times during the 12-year study; and IVM, intensive vegetation management in which herbicides were applied after planting for herbaceous and arborescent plant control, and arborescent regrowth was hand-felled as an improvement cut.

For the IVM treatment, hexazinone (3-cyclohexyl-6-[dimethylamino]-1-methyl-1,3,5-triazine-2,4[1*H*,3*H*]-dione) in aqueous solution was applied in 0.9-m bands over the rows of unshielded longleaf pine seedlings for general herbaceous plant control in April 1998 and 1999. Within the 0.9-m bands, the rate of hexazinone was 1.12 kg active ingredient/ha. Only hexazinone was used because not enough bluestem grasses (*Andropogon* spp. and *Schizachyrium* spp.) were present to require using an additional herbicide for their control. Triclopyr (3, 5, 6-trichloro-2-pyridinyloxyacetic acid) at 4.8 g of acid equivalent/liter was tank mixed with surfactant and water and applied as a directed foliar spray to competing arborescent vegetation in April 1998 and May 1999. Recovering brush was hand-felled in February 2001.

For all prescribed burns, firelines were installed around the PF plots. A backfire was first set on the downwind plot boundary. Once the fire had moved far enough into the plot to secure the fireline, strip headfires were set. The first prescribed fire was delayed until the third growing season (June 2000) or 31 months after planting because of a lack of grass development and subsequent poor fuel bed conditions. The June 2000 PF was low in intensity and generated a Byram's fire intensity (BFI) of 60 kJ/s/m for fire front across all PF plots (Haywood 2007). A wildfire in January 2003 burned blocks 3 and 4. The check and Fert-check plots were the only ones that had not been previously prescribed burned or weeded, and injury to the longleaf pine on those plots was the most likely. However, the longleaf pines were not seriously injured, and all survived on all of the plots because this species commonly endures even high fire intensities (Haywood 2002, 2007). Blocks 1 and 2 were prescribed burned the second time in May 2003. The fires generated an average BFI of 35 kJ/s/m of fire front (Haywood 2007). Plots were again prescribed burned in May 2005, June 2007, and May 2009. The last three fires were more intense than the previous two. The fires in 2005, 2007, and 2009 generated an average BFI of 538, 1,024, and 244 kJ/s/m of fire front, respectively.

Climatic Conditions

Mean January and July temperatures were 10 and 28° C, respectively, from 1978 through 2009 in central Louisiana (National Climatic Data Center 2013). Annual precipitation averaged 1,460 mm/year; August was the driest month (84 mm/year) and November was the wettest month (144 mm/year) during the 12-year period.

Based on Palmer Drought Severity Index (PDSI) values obtained from the National Climatic Data Center (2013), drought conditions occurred 44% of the time in central Louisiana from 1998 through 2009. The seedlings were planted in November 1997, which was a drought-free year. A severe 4-month drought occurred in 1998 and was followed by an extreme 20-month drought spanning 1999 and 2000 based on the PDSI values. Mild 1- to 6-month droughts developed in 2001 through 2004, respectively, and a moderate 17-month drought spanned 2005 and 2006. A mild 3-month drought occurred in 2007, and mild drought conditions developed intermittently in 2008 and 2009.

Measurements

Longleaf pine tree total height and dbh measurements were taken at ages 7 and 12 years. Heights were measured with a calibrated pole at age 7 and with a laser instrument (Criterion 400 Survey Laser; Laser Technology, Inc., Centennial, CO) at age 12. Tree dbh was measured with a diameter tape. Total height and dbh were used to calculate outside-bark bole volume with Baldwin and Saucier's (1983) formulas.

In September of the 13th growing season, percent cover of forest floor litter and understory vegetation was estimated as five different taxa: grasses, forbs (which included grasslike-plants and ferns), trees, shrubs (which included blackberry), and woody vines. The measurements were taken at five 1.83-m × 1.83-m squares whose corners were the original planting locations for the longleaf pine seedlings. A square was located in the middle of each plot and in the center of each quarter section of the plot. Because the five taxa were estimated separately, and plants in different taxa can overtop or overlap each other, total plant cover exceeded 100% in some squares.

Data Analysis

Number of longleaf pine per ha, average total height, basal area, volume per tree, and basal area and volume per hectare were compared with SAS Institute, Inc. (1985) software using a randomized complete block factorial design model at $\alpha = 0.05$ (Steel and Torrie 1980). Analyses compared treatments at ages 7 and 12 years and the difference in growth and production over the 5-year period. Percent cover of litter and understory plants in the 13th growing season was analyzed with an analysis of covariance model in which the covariate was longleaf pine basal area per hectare after 12 growing seasons. Other covariates were tried (number of longleaf pine trees at age 12 years and number of trees, shrubs, and woody vines per hectare in the fourth growing season), but no covariate was better than another based on the analyses of covariance at $\alpha = 0.05$. Without clear differences among possible covariates, longleaf pine basal area was used because its influence on understory plant cover has been reported in the work of others (Grelen and Enghardt 1973, Grelen and Lohrey 1978, Wolters 1982).

In all analyses, mean VT comparisons were made with Tukey's studentized range test at $\alpha = 0.05$ if there were significant differences among the three vegetation treatments in the analyses of variance or covariance. Percentages were arcsine transformed before analysis to equalize variances (Steel and Torrie 1980).

Results and Discussion

Longleaf Pine

The IVM treatment significantly increased total height and basal area per longleaf pine tree compared with those for the other two vegetation treatments at ages 7 and 12 years (Table 1). Yet, vegetation management did not significantly affect the change in height and basal area over the 5-year period. Volume per tree was significantly greater on the IVM plots than on the other two vegetation treatments after the 7th and 12th growing seasons, and volume growth over the 5-year period was also significantly greater on IVM plots. After 12 years, bole volume was 84 dm^3/tree on IVM plots and averaged 65 dm^3/tree on the check and PF plots. From the 7th through 12th growing seasons, the gain in volume was 63 dm^3/tree on the IVM plots and averaged 51 dm^3/tree on the check and PF plots. There were no significant differences between fertilization levels in longleaf pine stature.

Drought in the first growing season (1998) probably led to the deaths of the weakest newly planted seedlings, and survival averaged 68% after one growing season (Haywood 2007). Tree survival was little influenced during the extensive and severe 1999–2000 drought of the second and third growing seasons and averaged 65% after six growing seasons (Haywood 2007). Tree mortality continued at a gradual rate of about 0.7% per year, and longleaf pine survival averaged 61% after 12 growing seasons. There were no significant differences between fertilization levels or among vegetation treatments in stand stocking, with stocking ranging from 1,728 trees/ha on PF plots to 1,974 trees/ha on IVM plots after 12 years (Table 2).

The somewhat better survival and larger stature of individual trees on IVM plots resulted in significantly greater basal area and volume per hectare on IVM plots than on check or PF plots after the 7th and 12th growing seasons and over the 5-year period (Table 2).

Table 1. Longleaf pine total height, basal area, and volume per tree after the 7th and 12th growing seasons and the change in values over the 5-year period from fall 2004 to fall 2009 in central Louisiana.

Treatments and analysis of variance	*df*	Total height (m)			Basal area (dm^2)			Volume (dm^3)		
		7th g.s.	12th g.s.	Chg	7th g.s.	12th g.s.	Chg	7th g.s.	12th g.s.	Chg
Fert[a]										
No		5.3a	10.8a	5.5a	0.43a	1.21a	0.78a	16a	70a	54a
Yes		5.5a	10.9a	5.4a	0.47a	1.25a	0.79a	17a	73a	56a
VT[a]										
Check		5.3b	10.7b	5.4a	0.40b	1.13b	0.73a	15b	65b	50b
PF		5.0b	10.4b	5.4a	0.39b	1.14b	1.76a	14b	66b	52b
IVM		5.9a	11.5a	5.6a	0.56a	1.42a	0.86a	21a	84a	63a
ANOVA						$P > F$ value				
Block effect	3	0.2600	0.2489	0.4746	0.1226	0.3462	0.6271	0.1808	0.3589	0.5144
Fert	1	0.1045	0.3515	0.5428	0.1895	0.4724	0.8139	0.1552	0.3807	0.5411
VT	2	0.0003	0.0004	0.1366	<0.0001	0.0015	0.0814	<0.0001	0.0011	0.0080
Fert × VT interaction	2	0.9284	0.8420	0.7831	0.8142	0.7869	0.8533	0.8953	0.8260	0.8367
Error mean square	15	0.10364	0.17932	0.05727	0.00340	0.02115	0.01275	5.5035	85.6426	60.0769

g.s., growing season; Chg, change in variable value over the 5-year period.
[a] Within columns, Fert or VT means followed by the same letter are not significantly different based on Tukey's studentized range test at $\alpha = 0.05$.

Table 2. Longleaf pine stocking, basal area, and volume per ha after the 7th and 12th growing seasons and the change in values over the 5-year period from fall 2004 to fall 2009 in central Louisiana.

Treatments and analysis of variance	*df*	No. of pines/ha, 12th g.s.	Basal area (m^2/ha)			Volume (m^3/ha)		
			7th g.s.	12th g.s.	Chg	7th g.s.	12th g.s.	Chg
Fert[a]								
No		1,845a	8.1a	22.5a	14.4a	29.4a	129.5a	100.1a
Yes		1,783a	8.3a	22.5a	14.2a	30.7a	131.2a	100.5a
VT[a]								
Check		1,740a	7.0b	20.0b	13.0b	25.8b	114.9b	89.1b
PF		1,728a	6.6b	19.4b	12.8b	23.6b	111.0b	87.4b
IVM		1,974a	11.0a	28.0a	17.0a	40.8a	165.2a	124.4a
ANOVA					$P > F$ values			
Block effect	3	0.0023	0.0936	0.0160	0.0109	0.0859	0.0232	0.0206
Fert	1	0.4791	0.6450	0.9731	0.8098	0.5539	0.8288	0.9463
VT	2	0.0579	<0.0001	<0.0001	0.0020	<0.0001	<0.0001	0.0002
Fert × VT interaction	2	0.5873	0.7847	0.7283	0.7607	0.7853	0.6921	0.6932
Error mean square	15	44,171.28	1.8167	10.0108	4.6014	27.5718	363.9709	221.2897

g.s., growing season; Chg, change in variable value over the 5-year period.
[a] Within columns, Fert or VT means followed by the same letter are not significantly different based on Tukey's studentized range test at $\alpha = 0.05$.

The IVM plots produced 165 m^3/ha of bolewood at age 12 years and grew 124 m^3/ha of bolewood over the 5-year period compared with an average on the check and PF plots of 113 m^3/ha of bolewood at age 12 years and 88 m^3/ha of bolewood growth over the 5-year period. There were no significant differences between fertilization levels in longleaf pine stand production.

IVM was the best treatment for increasing young longleaf pine growth and yield through 12 growing seasons (Tables 1 and 2), although total plant control was never achieved (Haywood 2007). Usually, some type of vegetation management program is necessary because brush can outgrow young longleaf pine seedlings and saplings (Haywood and Grelen 2000, Haywood et al. 2001). Use of herbicides and mechanical equipment for site preparation and competition control after planting of loblolly and slash pines is a widely accepted practice in the southern United States as well (Moorhead et al. 2013).

Repeated application of prescribed fire was not beneficial in terms of increasing longleaf pine stature or stand production (Tables 1 and 2), and when fires are very intense, prescribed burning may reduce longleaf pine growth and production (Haywood 2009). However, use of prescribed fire can provide other attributes for landowners. Because longleaf pine stands can be prescribed burned even when the trees are seedlings (Haywood 2005, 2007), the maintenance of an open understory of herbaceous plants and low brush with fire can provide a forest habitat for wildlife different from that of nearby, unburned stands. This diversity in forest cover should increase hunting choices and may improve the value of a property as a hunting lease. In addition, open forest structure can be esthetically pleasing and culturally valued, and the rich understory cover provides the biological diversity sought by some landowners (North Carolina Forest Service 2012, The Longleaf Alliance 2013). As long as the longleaf pine overstory is not allowed to become too dense, these desired attributes can be maintained with fire (Wolters 1981, Haywood 2012). For example, in central Louisiana, herbage production would be about 1,000 kg/ha under an 18-m^2/ha longleaf pine overstory, but herbage production will be nil once basal area increases to 28 m^2/ha (Wolters 1981). Furthermore, the tolerance of longleaf pine to fire is the reason that it is the pine species of choice for planting in arson-prone areas in the coastal plain of the southeastern United States.

Without prescribed fire, the manager should expect eventually to lose the herbaceous and low woody shrub communities as stands mature (Wolters 1981, Haywood and Grelen 2000, Haywood et al. 2001, Haywood 2009). If pine-grassland habitat is a management

Table 3. In central Louisiana, percentages of understory ground cover under a longleaf pine overstory in September 2010 during the 13th growing season.

Treatments and analysis of variance	*df*	Percent cover of litter and understory plants by taxa: Litter	Grasses	Forbs	Trees	Shrubs	Vines	Plant total
Fert[a]								
No		82a[b]	2.5a	4.0a	40b	23a	5.5a	75a
Yes		84a	1.8a	4.2a	58a	22a	3.1b	89a
VT[a]								
Check		97a	0.8b	1.1b	80a	22a	2.8a	107a
PF		53b	5.2a	10.0a	16c	21a	3.7a	56b
VT		99a	0.5b	1.1b	51b	24a	6.5a	83a
ANOVA					$P > F$ values			
Block effect	3	0.8707	0.6217	0.1218	0.1100	0.0393	0.0404	0.1007
Fert	1	0.2243	0.3169	0.5544	0.0039	0.8043	0.0266	0.0725
VT	2	<0.0001	0.0087	<0.0001	<0.0001	0.5606	0.5765	0.0004
Fert × VT interaction	2	0.1086	0.9700	0.6274	0.1266	0.9246	0.9267	0.3695
Pine basal area as covariate	1	0.0206	0.1387	0.5766	0.2927	0.1506	0.2326	0.8432
Error mean square	14	0.00966	0.00556	0.00434	0.02625	0.02610	0.00331	0.05352

[a] Within columns, Fert or VT means followed by the same letter are not significantly different based on Tukey's studentized range test at $\alpha = 0.05$.
[b] Percentages were arcsine transformed before analysis, except for total plant cover because total plant cover on checks exceeded 100% because the five taxa were estimated separately and plants in different taxa can overtop or overlap each other; as a result, total plant estimates exceeded 100% in most squares on the check plots. However, transformation of data did not change the interpretation of results in the other analyses.

objective, fire will have to be introduced at some point (Waldrop et al. 1992) and pine overstory density controlled to arrest the decline in herbaceous cover (Wolters 1981, Haywood 2012). In central Louisiana, repeatedly burned pine stands maintained for red-cockaded woodpecker (*Picoides borealis*) habitat at a medium basal area of 15 m^2/ha could support 1,250 kg/ha of herbage (Wolters 1981, US Fish and Wildlife Service 2003). Fortunately, fire can be introduced into sapling size stands without serious longleaf pine mortality, although some loss in postburn height growth may result (Haywood 2009).

Application of fertilizer did not influence longleaf pine total height, per-tree basal area and volume, and basal area and volume per hectare (Tables 1 and 2). Based on Burton's (1984) work on soils similar to those in this study, 200 kg/ha of diammonium phosphate (36 kg/ha N and 40 kg/ha P) was broadcast in the first growing season, which was greater than the 28 kg/ha P rate recommended by Blevins et al. (1996) for longleaf pine straw management. Thus, the fertility amendments recommended in prior studies for these soils deserve reconsideration. In addition, no significant Fert-VT interactions influenced longleaf pine survival or its growth and yield.

Understory Plant Cover

Check plots had 97% litter (mostly pine straw) cover over the soil surface and 107% total plant cover in the understory in the 13th growing season (Table 3). The IVM plots had litter (99%) and total plant cover (83%) similar to those of the checks. However, herbicide application in the first two growing seasons and improvement cutting in the fourth growing season resulted in the IVM plots having significantly less understory tree cover (51%) than checks (80%) in the 13th growing season. This result demonstrated that IVM could have long-term effects on certain taxa of vegetation, although the treatments did not eliminate the target vegetation (Haywood 2007).

The repeated application of prescribed fire significantly reduced litter (53%), tree (16%), and total plant cover (56%) compared with those for the check and IVM treatments (Table 3). In addition, grass (5%) and forb (10%) cover was significantly greater on the PF plots than on the check and IVM plots, which averaged 0.6% grass and 1.1% forb cover. This result demonstrated the ability of fire to preserve herbaceous vegetation. The cover of grass and forbs 16 months after the last prescribed fire was similar to the increase in forb cover reported by Brockway and Outcalt (2000) and Haywood (2009). Waldrop et al. (1992) found that periodic summer burning increased the number of forbs per hectare compared with that for winter burning. Vegetation treatments did not significantly influence shrub or woody vine cover in the 13th growing season.

Application of diammonium phosphate in the first year resulted in significantly greater understory tree cover (58%) than in unfertilized plots (40%) in the 13th growing season (Table 3). There was significantly less vine cover on fertilized plots (3%) than on unfertilized plots (6%). Thus, although fertilization did not influence longleaf pine development, it did influence cover of certain taxa of understory vegetation. No significant Fert-VT interactions influenced understory cover.

Conclusion

If longleaf pine volume production is the primary goal of the landowner, longleaf pine can be established and managed just as loblolly or slash pine with mechanical and chemical vegetation management treatments. IVM also reduced understory tree cover compared with that for checks 9 years after the last treatment application. Because herbicides are often used in southeastern United States forestry, this management option can be viable where threatened and endangered plants are not growing. Prescribed fire and fertilization did not influence longleaf pine growth and production. However, both management options influenced understory plant cover but in different ways.

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