INTENSIVE LONGLEAF PINE MANAGEMENT FOR HURRICANE RECOVERY: FOURTH-YEAR RESULTS

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Abstract--The frequency and intensity of hurricanes affecting the United States has been projected to increase during coming decades, and this rising level of cyclonic storm activity is expected to substantially damage southeastern forests. Although hurricane damage to forests in this region is not new, recent emphasis on longleaf pine (*Pinus palustris* Mill.) restoration and the increasing number of longleaf pine plantations resulting from such efforts raise questions about both tropical storm effects on this species and suitable strategies and practices for facilitating its recovery from such storms. This study was established to evaluate different methods of quickly returning damaged stands to productive longleaf pine forests following Hurricane Ivan in 2004. After salvage operations cleared the study areas, three herbicides (hexazinone, imazapyr, triclopyr) versus an untreated control were tested for their effects on stand development using artificially regenerated longleaf pine. A fertilizer treatment was also applied on half of the plots. Four years following planting, developing trends show the possible benefits of chemical site preparation on longleaf pine seedling height and ground-line diameter, whereas fertilization has shown no significant effect.

INTRODUCTION

Hurricanes are a regular source of natural disturbance that cause both widespread and localized damage to forests on the Gulf and Atlantic Coastal Plains. Although these tropical cyclones may seem to occur irregularly during a human lifetime, if the activity from the mid-20th century is extended backwards through the Holocene, over 40,000 tropical storms are estimated to have affected the northern Gulf coast (Conner and others 1989). Furthermore, although likely due to multidecadal variability, Atlantic hurricane frequency and intensity have increased since 1995 (Pielke and others 2005); some models predict that this trend may continue because of global warming (Smith and others 2010). Thus, although southern ecosystems have developed in concert with these disturbance patterns, contemporary values and needs may not allow for the natural, unassisted rate of forest recovery or for potential increases in hurricane frequency and intensity.

Hurricanes represent a complex conundrum for southern forests, as they can both destroy and rejuvenate forests at the same time. Whereas cyclonic winds often greater than 100 miles per hour can damage or destroy hundreds or thousands of acres of forests, heavy rainfall - sometimes measured in feet - can break long-term droughts and provide immature forests the moisture needed to secure survival and establishment. Some data show that older stands are more severely damaged by hurricanes (Kush and Gilbert 2010), providing growing space for new cohorts that regenerate ecologically mature stands. By preventing succession to "climax" or steady-state conditions, hurricanes can actually increase ecosystem productivity and structural diversity (Conner and others 1989), which may benefit overall long-term ecosystem health.

In the early morning hours of September 16, 2004, Hurricane Ivan crossed Brewton, AL with winds as high as 120 miles per hour and dropped over 8 inches of rainfall. The eye-wall passed 15 miles west of the USDA Forest Service's Escambia Experimental Forest (EEF), damaging the forest to the extent that almost 700,000 cubic feet of timber were salvaged from the property during the ensuing 6 months. Within the state of Alabama, an estimated $610 million worth of timber was damaged on 2.7 million acres.

This cooperative study with Cedar Creek Land and Timber Company of Brewton, AL was initiated in 2007 to identify the most effective approaches for restoring longleaf pine (*Pinus palustris* Mill.) on sites impacted by Hurricane Ivan. Ivan caused overstory losses exceeding 90 percent on six 22-acre units at the EEF that had been recently thinned to a basal area of 25 square feet per acre for regeneration with the shelterwood method. Because of extensive damage and the disruption caused by salvage operations, artificial regeneration remained the only viable option for achieving restoration goals. The resulting restoration project provided

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an opportunity to evaluate various approaches for quickly reestablishing the longleaf pine forest and possibly decreasing rotation length for even-aged stands through intensive management practices. Given the predictions for increased frequency and intensity of disturbance in forests of the southern Coastal Plain, the objective of this operational-scale experiment is to test the effects of chemical site preparation and fertilization on reestablishment of productive longleaf pine forests.

METHODS

Study Site

This project is located at the EEF (31°N, 87°W) in Escambia County, AL. The EEF is a 3,000-acre tract owned by T.R. Miller Mill Company of Brewton, AL, that has been managed by the Forest Service since 1947 for longleaf pine management research. Timber on the property ranges from newly regenerated fourth-growth to second-growth stands (120+ years old). The EEF is a mesic upland site with rolling topography and elevations ranging between 85 and 285 feet above sea level. Soils on the study areas are all Ultisols, principally the Troup and Wagram associations. The EEF is located in the Alabama Area longleaf pine site zone (Craul and others 2005). Average rainfall is over 60 inches per year, evenly distributed throughout the year but with monthly minima in April and October. Temperatures are mild, with mean annual high and low temperatures of 79 °F and 53 °F, respectively, resulting in a growing season that typically extends from the end of March through October. The EEF contains a native bluestem (*Andropogon* and *Schizachyrium* spp.) understory with a wide variety of grasses and forbs that has been maintained for decades with dormant-season prescribed fire on a 3-year interval. This burning pattern has resulted in the development of an extensive shrub layer of clonal hardwood species and gallberry [*Ilex glabra* (L.) A. Gray] 2- to 3-feet high.

Experimental Design and Sampling

Six 22-acre stands that had been extensively damaged by Hurricane Ivan in 2004 were clearcut for artificial regeneration in 2007. Twenty-four (492 by 492 feet) experimental plots were then installed (four 5.5-acre plots per stand) in a randomized complete block design of eight treatments replicated three times. Treatments include fertilized and unfertilized combinations of: (1) control, in addition to (2) hexazinone as Velpar ULW, 33 pounds per acre [2.5 pounds of active ingredient (a.i.) per acre] applied March 2008; (3) imazapyr as Chopper EC, 48 ounces per acre (0.75 pounds a.i. per acre) plus 5 ounces methylated seed oil, applied June 2008; and (4) triclopyr as Garlon XRT, 4 quarts per acre (6 pounds. a.i. per acre) applied June 2008. During August 2008, all 24 plots were burned by prescription. Plots were hand-planted by a professional crew in February 2009 at 889 trees per acre (7- by 7-foot spacing) with container-grown longleaf pine seedlings obtained from Simmons Tree Farm in Kite, GA. An initial fertilizer treatment was applied to half of the plots in March 2009 and consisted of phosphorus (P as superphosphate, 120 pounds per acre) and potassium (K as muriate of potash, 70 pounds per acre). Measurement plots consist of n = 49 seedlings arranged in seven rows. Seedling heights and ground-line diameters (GLD) were measured annually, and the number of competing pine and hardwood stems within a 3.28-foot (1 m) radius of study seedlings was also tallied. All study plots were burned by prescription during winter of 2011, prior to the second-year data collection.

Data Analysis

Statistical analyses were conducted using NCSS version 7.1.1 software (Hintze 2007). For all tests, statistical significance was determined at $\alpha = 0.05$. Repeated measures analysis of variance (ANOVA) and Tukey-Kramer tests were used to determine differences among treatments and years for the following response variables: mean seedling survival, height, GLD, and number of competing stems.

RESULTS AND DISCUSSION

Seedling Survival

Four years after plantation establishment, there were no significant treatment differences in seedling survival. However, survival rates for years 2 through 4 (2010-2012) ranged between 60 and 85 percent and are significantly lower than survival following the first growing season, which was over 90 percent ($F = 77.32$; $p < 0.0001$) (fig. 1). Although seedlings were not graded or measured at time of planting, evaluating mean seedling diameters after one growing season and later growth rates suggest that average seedlings in all treatments exceeded the current interim guidelines for container seedlings (Dumroese and others

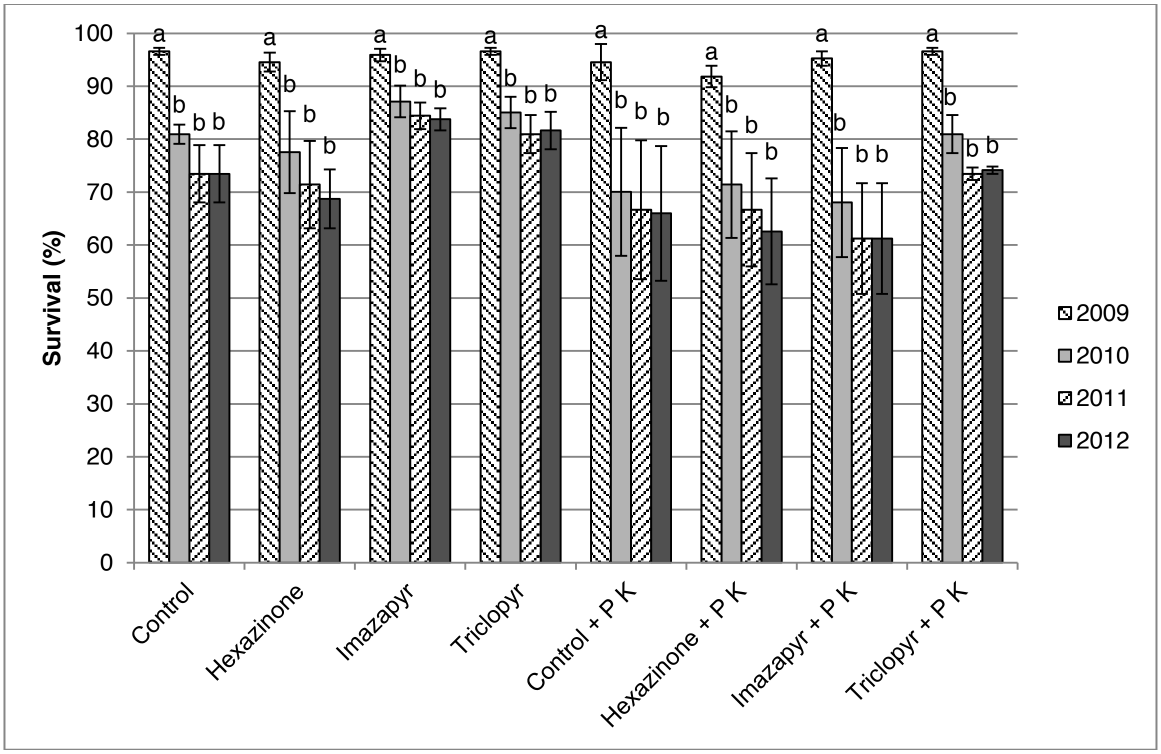

Figure 1--Mean seedling survival by treatment through four growing seasons. Bars with different letters indicate statistical significance. Winter prescribed fire occurred immediately prior to 2010 measurements.

2009). Therefore, seedling quality is unlikely to have been a factor in survival rates.

Such high initial seedling survival is not unexpected for container longleaf pine seedlings, nor is it a guarantee (Cram and others 1999; Hainds 1999; Jackson and others 2007, 2010; South and others 2005). In this case, it may be a positive result of unusually high rainfall during the year of planting (fig. 2). As expected, the survival pattern shows fewer surviving seedlings each year. The majority of the mortality occurred during the second growing season, which was an abnormally dry year that included an extended drought between August and October (fig. 2). Survival was further reduced by the 2011 prescribed fire, but this source of mortality was less than 5 percent and concentrated among smaller, lower-quality seedlings. Chemical site preparation, fertilization, and prescribed fire have been shown to produce both higher and lower survival rates 6 years after artificial regeneration (Haywood 2007) but also may not have an effect (Boyer 1988, Ramsey and Jose 2004), depending on site, climate, or other circumstances.

Seedling Height

Mean seedling heights four growing seasons after planting are presented in figure 3. Using Haywood's (2000) 4.8-inch threshold for grass stage emergence, all eight treatment means indicated active height growth. There were no significant treatment effects on seedling height, but time was again a significant factor ($F = 34.19$, $p < 0.0001$). A divergent trend is developing, however, such that the year 4 measurements were all significantly greater than the previous 3 years, whereas earlier measurements were not significantly greater than preceding ones (fig. 3). Thus, although high variation within treatments currently obscures potential differences, increasing growth rates suggest future differences in treatment effects.

Intensive vegetation management with herbicides has been documented to reduce the amount of time spent in the grass stage (Haywood 2007) and increase longleaf pine growth relative to untreated controls after 10 years (Haywood 2011). However, these effects may be transitory, as these differences can disappear over time (Boyer 1983). In one study, the level of site preparation did not affect

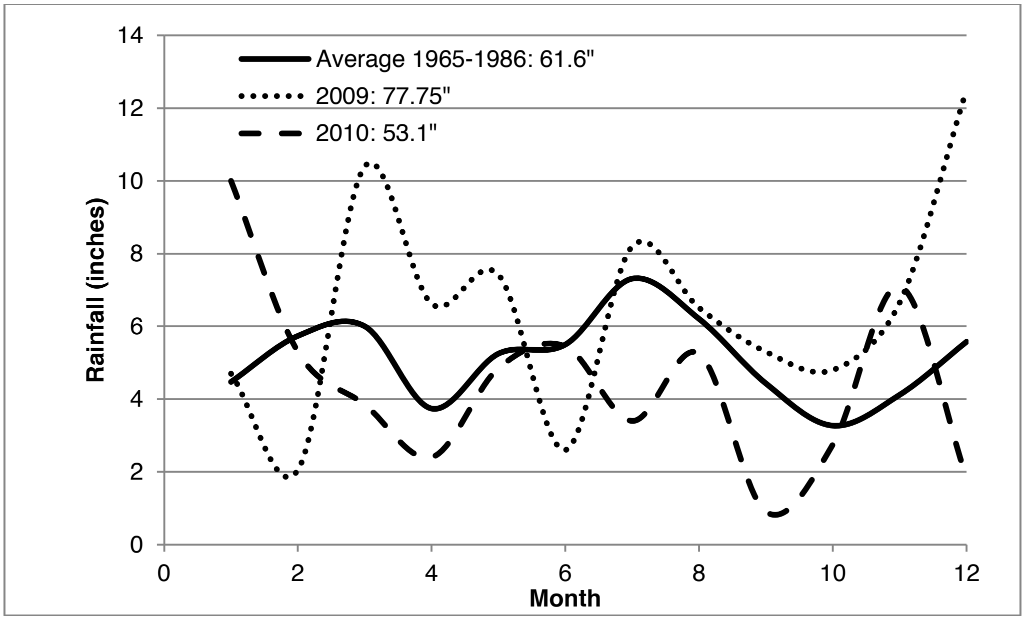

Figure 2--EEF rainfall data: long-term mean paired with totals from first (2009) and second (2010) growing seasons.

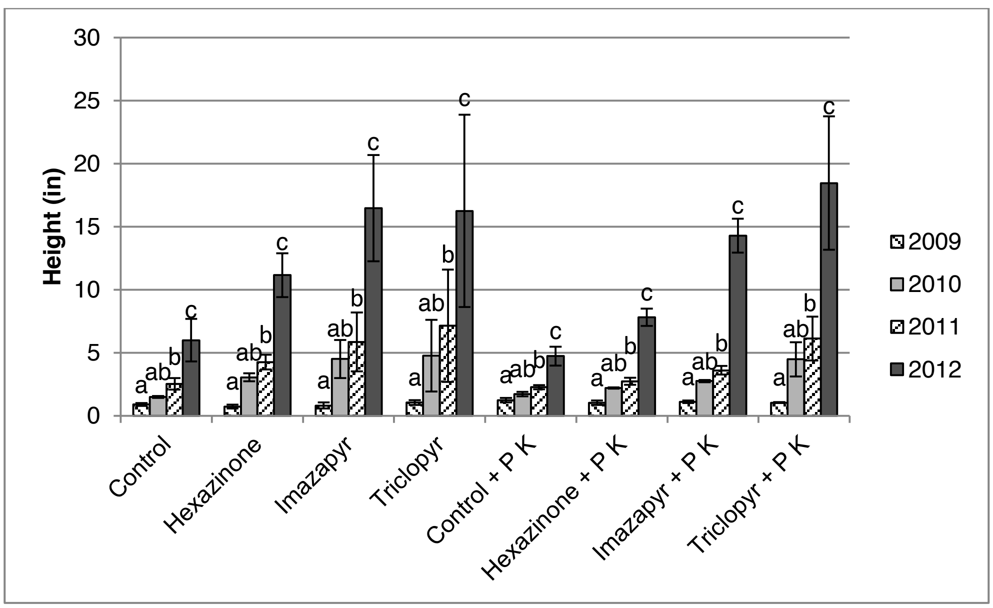

Figure 3--Mean seedling height by treatment through four growing seasons. Bars with different letters indicate statistical significance.

seedling height growth after only 3 years (Boyer 1988).

Seedling Ground-line Diameter

Seedling GLD is used as a measure of growth prior to the onset of height growth, which generally occurs as seedlings approach 1 inch (25 mm) in diameter (Boyer 1990, Wahlenberg 1946). After four growing seasons, treatment effects on mean GLD were not statistically significant (fig. 4). However, comparisons of mean seedling diameters among measurement years were significantly different in 3 of 4 years ($F = 124.42$, $p < 0.0001$). Additionally, it is worth noting that after 4 years, each treatment had surpassed or was approaching the 1-inch GLD threshold for imminent height growth. It is therefore expected that the existing numerical

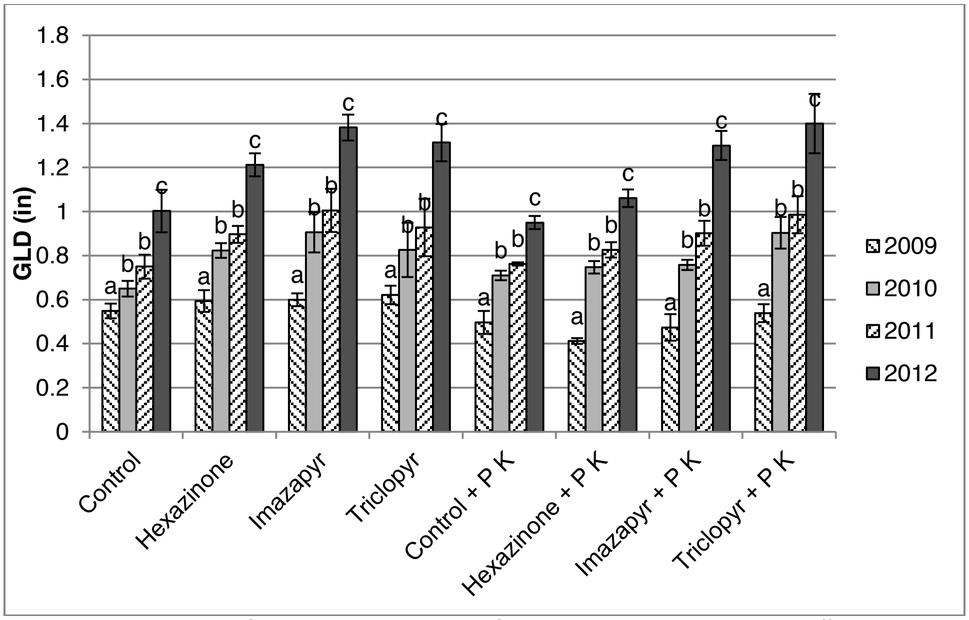

Figure 4--Mean seedling GLD by treatment through four growing seasons. Bars with different letters indicate statistical significance.

differences will be amplified and may become statistically significant in the future.

Competition

Hardwoods--Relative levels of competition were assessed annually and exhibited the same lack of significant treatment effects, but significant differences were detected among measurement years. For hardwood competition, mean number of competing stems per acre was significantly greater during the first growing season (F = 9.51, p = 0.0003) than after the following three growing seasons (table 1).

Hardwood competition data from 2009 did not show a clear pattern but suggested that the herbicide treatments were initially only marginally effective, leaving on average as few as 1,200 and as many as 22,000 stems per acre (table 1). The number of competing stems was significantly lower after the second year (2010) largely because the plots were burned by prescription following the 2010 growing season (prior to that year's measurements). In effect, fire served to remove many of the stems that had survived or only been weakened by the chemical herbicides. This indicates that herbicides alone provided a window for seedling establishment but would not generate desirable stand composition on these sites. Rather, the combination of herbicide and fire provides a longer period of reduced competition that gives artificially regenerated longleaf pine seedlings time to develop site dominance, a result similar to earlier longleaf pine restoration efforts on sandhills (Brockway and Outcalt 2000). Furthermore, the apparent "baseline" amount of hardwood competition following herbicide and fire is between 1,000 and 4,000 stems per acre, so repeated burning will be required to discourage further hardwood development. This level of remaining competition seems to support previous research showing that release treatments may be more effective in promoting height growth than intensive site preparation alone (Boyer 1988, Haywood 2007, Ramsey and others 2003).

In this study, hexazinone was relatively ineffective for hardwood control during the first growing season (table 1), which may explain why this treatment consistently showed the poorest pine growth response. Increased woody competition present in this treatment may have resulted from an application rate 20 to 40 percent lower than that commonly used on similar sites (Personal communication. 2013. W.D. Mixson, Sales and Technical Services Manager, DuPont Land Management, Pensacola, FL 32503). Other research (Haywood 2000, Ramsey and Jose 2004, Ramsey and others 2003) suggests that the rate used in this experiment is more beneficial for pine release than site preparation treatments.

Table 1--Mean number of competing hardwood and pine stems per acre through four growing seasons[a]

	Hardwood				Pine			
Treatment	2009	2010[b]	2011	2012	2009	2010*	2011	2012
Control	10,482a	2,837b	5,428b	7,401b	0c	606d	632d	629d
Hexazinone	18,309a	1,766b	1,960b	3,894b	39c	90d	142d	219d
Imazapyr	22,048a	645b	1,586b	1,702b	0c	168d	219d	232d
Triclopyr	4,165a	1,122b	2,540b	2,463b	39c	477d	593d	619d
Control + P K	16,891a	3,443b	5,854b	7,066b	90c	245d	425d	464d
Hexazinone + P K	18,696a	1,044b	632b	1,135b	168c	322d	425d	530d
Imazapyr + P K	1,251a	400b	348b	1,006b	0c	181d	232d	284d
Triclopyr + P K	1,380a	1,702b	2,514b	2,991b	0c	464d	606d	658d

[a]Values with different letters indicate statistical significance at $\alpha = 0.05$.
[b]2010 measurements occurred in winter 2011, immediately after first cycle of prescribed fire.

Similarly, the imazapyr treatment was initially ineffective at hardwood control, but its results improved with the prescribed fire after the second growing season.

Pines--Pine competition shows a pattern inverse to that of hardwood competition. The mean numbers of competing pines were significantly lower during the first growing season than in following years ($F = 27.74$, $p < 0.0001$) (table 1). The 2009 measurements show few competing pine stems, but data were collected just prior to seedfall in a “good” [> 50 cones per tree (Boyer 1996)] longleaf pine seed year at EEF (Brockway and Boyer 2010). As a result, the 2010 measurements showed a significant increase in competing pine stems. Although 2010 had a failed seed crop, 2011 produced another good seed crop at EEF (Brockway and Boyer 2011). Therefore, the net effect is a slightly positive trend in the number of competing (volunteer) longleaf pine seedlings, such that mortality among these volunteers has been more than replaced by new germinants, at levels of 200 to > 600 trees per acre (table 1). Because of the limited size of the clear-cut areas in this experiment, natural regeneration from the surrounding forest might have been adequate to restore the ecosystem without planting nursery stock. However, reliance on natural regeneration under the circumstances found in this study is risky, given the variable nature of longleaf pine seed production from year to year (Brockway and others 2006).

Effect of Fertilization

Four years after fertilizer application, there were no significant differences in mean longleaf pine height and GLD in fertilized versus unfertilized plots (figs. 3 and 4). Although fertilization can result in increased volume growth in southern pines (Dickens and others 2003), its effects on longleaf pine are not always positive (Haywood 2007). Other studies also have shown fertilizer to be an ineffective treatment in artificially-regenerated longleaf pine. In Louisiana, fertilization had no effect on longleaf pine height, basal area, or volume per tree after 10 years and even reduced stand density (Haywood 2011). Similarly, longleaf pine survival and growth were lowest on fertilized plots in a western Florida old-field study (Ramsey and others 2003).

CONCLUSIONS

Management objectives on many public and private lands now include retention of biological legacies (Franklin and others 2007) and attempt to minimize mechanical and chemical disruption of vegetation. Nevertheless, in extraordinary circumstances it may be necessary to use intensive management practices temporarily in order to rapidly restore the forest ecosystem and regain the trajectory identified in the forest management plan. Even on land managed for conservation, intensive management practices similar to those employed by production forestry can help to restore or sustain forests effectively. However, careful attention should be paid to prevent long-lasting damage from operations that disrupt ecosystem functions or impair productivity.

Prescribed fire appears vital to quickly and effectively restore damaged longleaf pine forests. Even though this experiment is located on areas burned regularly for decades, hardwood and shrub vigor exceeded the capabilities of chemical use alone, and continued burning is required for effective competition control. Given the observed importance of repeated prescribed burning in preventing hardwood succession, it is imperative that management practices be performed in a manner that does not diminish the effectiveness of surface fire. Harvest operations should be closely monitored so that equipment is either altered or relocated to prevent soil damage when necessary (Carter 2011). In this study, high-value timber was salvaged shortly after the hurricane when soils were still water-saturated, causing severe rutting in certain areas. After only 8 years, these localized microsite changes have noticeably altered understory vegetation composition, primarily by disrupting fire behavior. The impaired soil structure and altered moisture regime continue to impede the restoration process on such areas.

After four growing seasons, chemical site preparation and fertilization exhibited no significant treatment effects relative to non-treated controls. However, qualitative assessment shows that non-prepared sites result in forest structure inconsistent with both conservation and production objectives. These preliminary results suggest that some form of chemical site preparation will be required to adequately restore longleaf pine forests to full stocking and production. However, the application of phosphorus and potassium at time of planting is not justified. Rather, these results support previous findings that fertilizing longleaf pine at time of planting is either neutral or is detrimental.

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