CURRENT-YEAR FLUSH AND NEEDLE DEVELOPMENT IN LONGLEAF PINE SAPLINGS AFTER A DORMANT SEASON PRESCRIBED FIRE

Shi-Jean S. Sung, James D. Haywood, and Mary Anne S. Sayer[1]

Abstract--A longleaf pine (*Pinus palustris* Mill.) field performance study was established in central Louisiana in 2004. The study has received three prescribed burns (February 2006, May 2009, and February 2012) since establishment. In late April 2012, 35 saplings were selected and classified based on ocular estimates of needle mass scorch percentages. Mean needle scorch percentages for the lightly (LS), moderately (MS), and severely scorched (SS) saplings were 17, 50, and 99 percent, respectively. The prescribed fire did not change the temporal development of all flushes and their needles. However, the first three flushes of the SS saplings were significantly shorter than those of the LS saplings. The fourth and fifth flushes did not differ in lengths among scorch classes. Compared to flushes developed in 2011, which was a severe drought year, flush growth in the SS saplings was less in the fire year. Needles from the first SS flushes extended faster than those from the LS and MS saplings in May. Final needle lengths for the first and fourth flushes were not different among scorch classes whereas needles of the second and third SS flushes were shorter than those of less-scorched saplings. The physiological parameters, such as photosynthesis, stomatal conductance, and chlorophyll content, generally did not vary among scorch classes in August and September. However, these parameters were greater for the first SS flush needles than those of less-scorched saplings. The possibility of residual impact from prescribed fire on sapling growth in a subsequent year is discussed.

INTRODUCTION

The loss of 97 percent of the pre-European settlement longleaf pine (*Pinus palustris* Mill.) ecosystem acreage in the South was attributed to extensive harvesting of longleaf pine for timber and naval store products, conversion of lands supporting longleaf pine to croplands, pasture, or other fast growing southern pine species, and exclusion of fire from the landscape (Brockway and Outcalt 1998, Landers and others 1995, Outcalt 2000). For the last three decades, many public, industrial, and private land managers and owners have been actively restoring longleaf pine ecosystems in the southern United States (Barnett 2002, Boyer 1989, Landers and others 1995). Much of the original longleaf pine range is within 240 km of the Atlantic or Gulf coasts, a region frequented by tropical wind storms and hurricanes (Landers and others 1995). Longleaf pine trees suffered less wind damage than loblolly pine (*Pinus taeda* L.) during Hurricanes Hugo in South Carolina (Gresham and others 1991) and Katrina in Mississippi (Johnsen and others 2009). Due to longleaf pine's ability to withstand storm damage, many forest practitioners decided to restore this species to the hurricane-prone Atlantic and Gulf coast states. Another reason to restore longleaf pine is to arrest the decline of many associated plants and animals that depend on these highly biologically diverse ecosystems (Brockway and others 1998, Mitchell and others 2006). Because of the efforts to restore longleaf pine ecosystems, the Range-wide Conservation Plan for Longleaf Pine was compiled and proposed by America's Longleaf (2009). This plan has a goal of increasing longleaf acreage from 1.4 million to 3.2 million ha by 2024 (America's Longleaf 2009). To be successful in this conservation endeavor, prescribed fire regimes need to be implemented in natural and plantation longleaf pine forests.

Most longleaf pine seedlings experience delayed height growth and have been known to remain in the grass stage for up to 9 years (Wahlenberg 1946). The grass-stage seedlings are vulnerable to brown-spot needle blight fungal infection (caused by *Mycosphaerella dearnessii* Barr), vegetation competition, and smothering by dead grass and litter (Wahlenberg 1946). On the one hand, prescribed fire has been used as a management tool in longleaf pine forests to reduce brown-spot needle blight-related mortality and to relieve longleaf from vegetative competition (Grelen 1983, Haywood 2007). On the other hand, prescribed fire has negatively affected longleaf pine productivity (Boyer 1987, Boyer and Miller 1994, Haywood 2009, Haywood and Grelen 2000). Ford and others (2010) observed that adult longleaf pine tree growth was reduced during fire years, but tree

[1]Research Plant Physiologist, Supervisory Research Forester, and Research Plant Physiologist, respectively, USDA Forest Service, Southern Research Station, Pineville, LA 71360.

Citation for proceedings: Holley, A. Gordon; Connor, Kristina F.; Haywood, James D., eds. 2015. Proceedings of the 17th biennial southern silvicultural research conference. e–Gen. Tech. Rep. SRS–203. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 551 p.

growth during years between fire events did not differ significantly among fire-return intervals.

Prescribed fire regimes routinely implemented in longleaf pine forests on the Kisatchie National Forest in Louisiana have 2- to 3-year fire-return intervals. The burns are alternated between dormant and growing seasons with the first burn occurring 13 to 15 months after outplanting. In November 2004, 28-week-old longleaf pine seedlings grown in six kinds of containers were outplanted at the Kisatchie National Forest. The trial site has been prescribe burned three times since then. The objective of this study was to follow the dynamics of flush and needle development of these longleaf pine saplings with different levels of needle mass scorch after a dormant season prescribed burn in February 2012.

MATERIALS AND METHODS

Seedling Culture and Field Establishment in the Original Study

Details of seedling culture and field establishment protocols were reported by Sword Sayer and others (2009). Briefly, longleaf pine seeds were sown in containers of three cavity sizes (54, 93, and 170 mL) with two cavity types (with and without copper oxychloride lining) in April 2004. In early November 2004, 27-week-old container-grown longleaf pine seedlings were lifted and outplanted on the same day. The field experiment site is located on the Palustris Experimental Forest within the Kisatchie National Forest in Rapides Parish of central Louisiana (31°11' N, -92°41' W). The soil is a moderately well-drained, gently sloping Beauregard silt loam (fine silty, siliceous, superactive, thermic, Plinthaquic Paludults). Mima mounds of Malbis fine sandy loam (fine loamy, siliceous, subactive, thermic, Plinthic Paleudults) are scattered across the study area. The study was a 3 by 2 randomized complete block factorial design with four replications. Twenty-four (3 cavity sizes x 2 cavity types x 4 blocks) treatment plots of 0.0576 ha (24- by 24-m) each were established. Seedlings were planted at 2- by 2-m spacing. All plots were prescribed burned in February 2006, May 2009, and February 2012.

Fire Impact Study

Two months after the latest prescribed burn, a total of 35 longleaf saplings were selected based on the ocular estimates of needle mass scorch in 10 percent increments. For accessibility, only saplings shorter than 280 cm were considered, and the original treatments were disregarded for the current study. The lightly scorched (LS) class had 10 saplings with 10 to 30 percent of needle mass scorch. The moderately scorched (MS) and severely scorched (SS) classes had, respectively, 12 saplings with 40 to 70 percent and 13 saplings with 90 to 100 percent needle scorch. Means and ranges of height and breast height diameter at the end of 2011 for these saplings are presented in table 1. Individual flush development in the leader shoot of each sapling was monitored biweekly from May through September. The last measurements were made in mid-November. One fascicle was selected from the middle section of each flush and tagged with a paper clip to track needle development over time.

Table 1--Number of saplings, mean and range of 2011 height and breast height diameter of longleaf pine saplings selected for each needle mass scorch class. Only saplings shorter than 280 cm were considered

Scorched class	Sapling number	2011 height (range)	2011 breast height diameter (range)
		-------*cm*-------	----*mm*----
Lightly[a]	10	233 (183-271)	32 (28-46)
Moderately	12	220 (177-253)	32 (20-51)
Severely	13	227 (180-262)	35 (28-41)

[a] Classification was based on the percentages of needle mass scorched by a February 2012 prescribed fire: 10 to 30, 40 to 70, and 90 to 100 percent for lightly, moderately, and severely scorched classes, respectively.

In mid-August, four saplings were randomly selected from each scorch class for photosynthesis and stomatal conductance measurements with a LiCor 6400 portable, open-system infrared gas analyzer (LiCor, Lincoln, NE). Measurements were made between 9:00 and 11:00 am and again between 1:00 and 4:00 pm on the same day on fascicles from the third flushes of 2011 and the first three or four flushes of current year. Photosynthetic active radiation was set between 1400 and 1600 $\mu E\ m^{-2}\ sec^{-1}$ with a red-blue light source, and the CO_2 level for the reference chamber was 400 ppm. The middle section of one three-needle fascicle was enclosed in the measuring chamber (2- by 3-cm) within 20 seconds of detachment from the flush. After measurements, the same fascicle was stored on ice and transported to the laboratory. Needle surface area was measured with a displacement method described by Johnson (1984). Chlorophylls a and b were extracted with N,N-dimethylformamide, and the absorbance of the extract was read at 664 nm and 647 nm as described in detail by Sung and others (2010). The same saplings were measured again in mid-September following the same procedures. Number of needle fascicles in each flush of the leader shoot in these saplings was counted in mid-November.

Statistical Analysis
Using Proc GLM in SAS (2004), a one-way analysis of variance was conducted for each variable of interest against three levels of needle scorching. Means were compared using the Duncan's Multiple-Range Test at significance level 0.05. The assumptions for homogeneous variance and normality were checked using Levene's test and the Kolmogorov-Smirnov D statistic, respectively.

RESULTS

By the time the first set of measurements were made on May 1, 2012 (Julian Day, JD 122), the current-year first flushes had completed elongation (fig. 1a); the second flushes for the LS, MS, and SS saplings averaged, respectively, 10.6, 9.2, and 3.6 cm (fig. 1b); and the third flushes were about to begin elongation (fig. 1c). Monitoring the development of the third and subsequent flushes began when bud swelling was visible. The bud swelling dates for the third, fourth, and fifth flushes did not vary among scorch classes (fig. 1c, 1d, and 1e). More than half of the saplings started the elongation of the third, fourth, and fifth flushes by JD 135, 174, and 202, respectively. The linear growth rate (slope) of the third SS flushes was less than those of the LS and MS saplings (fig. 1c). Levels of needle mass scorch affected final lengths of the first three flushes with the SS flushes being shorter than the corresponding LS flushes (fig. 1a, 1b, and 1c). The first and second flushes of the MS saplings were also shorter than those of the LS saplings. Levels of needle scorch did not affect the development or final lengths of the fourth and fifth flushes (fig. 1d and 1e).

Within each scorch class, the first flush was the longest, and the subsequent four flushes were not different from each other except that in the SS saplings the second flushes were shorter than their subsequent flushes (results of statistical analysis not shown). When compared to flush growth in 2011, which had a prolonged and severe drought, the current-year first-three flushes of the SS saplings were shorter whereas the current-year first flushes of the LS saplings were longer (fig. 1f). The fourth and fifth flushes developed in 2012 were longer than those in 2011 except the fourth MS flushes.

The initial development of the first-flush needles was not monitored. The first-flush needles of the SS saplings were longer than those of the LS and MS saplings in May (JD 122, 135, and 146), although the final needle lengths were not different among scorch classes (fig. 2a). Days of year for the appearance of needle fascicles in the second and subsequent flushes were not affected by the levels of needle scorch (fig. 2b through 2e). More than half of saplings had needle fascicles emerged on JD 122, 160, 202, and 228 from the second, third, fourth, and fifth flushes, respectively. Similar to the third-flush development (fig. 1c), rates of the linear elongation by the second and third-flush needles in the SS saplings were less than those of LS and MS saplings (fig. 2b and 2c). Levels of needle scorch did not affect the fourth or the fifth-flush needle development (fig. 2d and 2e).

Mean chlorophyll a and b contents in the first-flush needles of the SS saplings sampled in August and September ranged between 21.8 and 23.8 $\mu g/cm^2$ and were greater than those (18.0 to 19.6 $\mu g/cm^2$) of the less-scorched saplings. Chlorophyll contents for the subsequent flush needles did not differ among scorch classes and ranged between 16.4 and 22.0 $\mu g/cm^2$. With one exception, the photosynthetic parameters measured were not different among scorch classes; means of all 12 saplings measured were presented in figure 3.

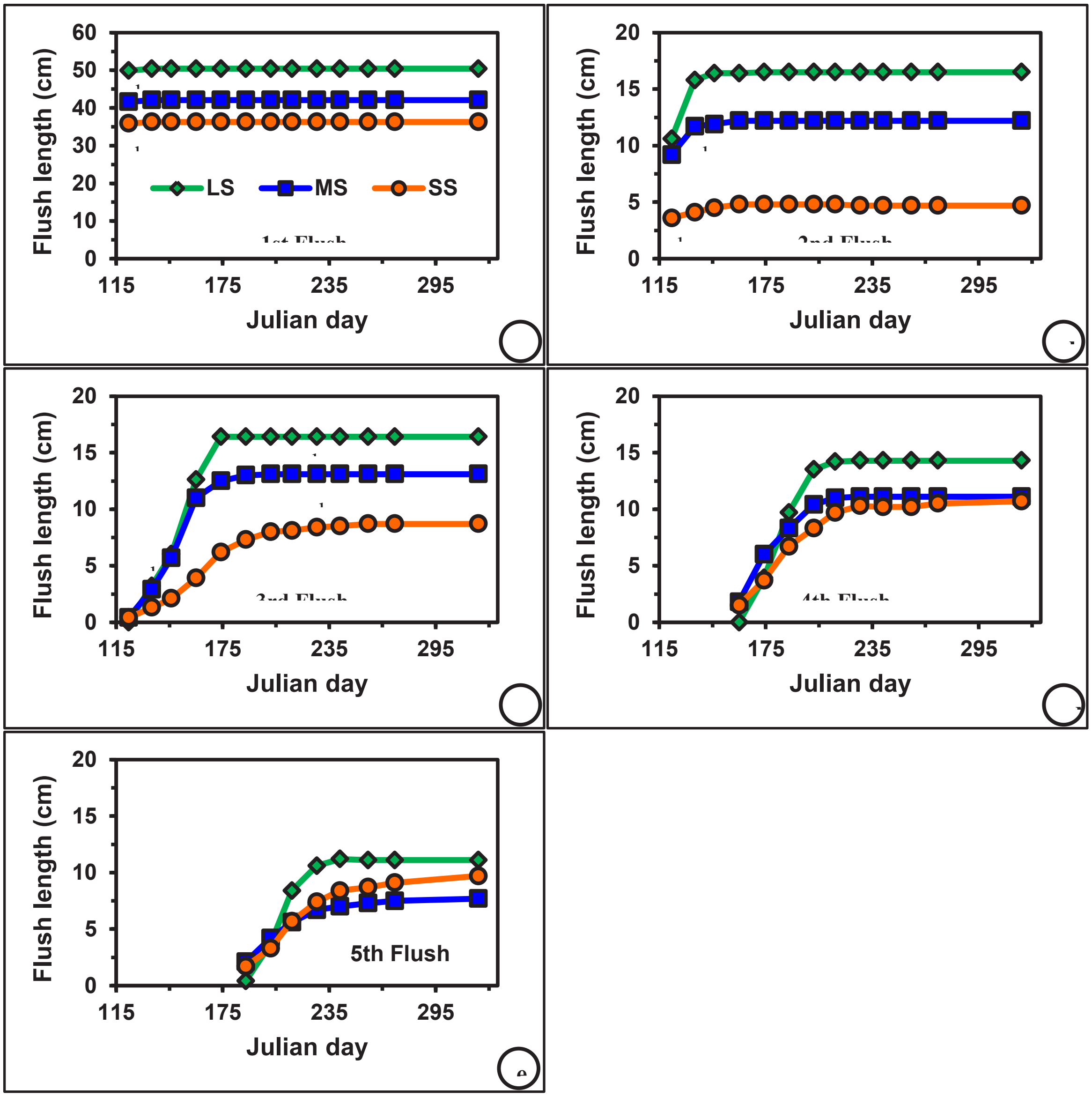

Figure 1--Temporal development patterns of current-year leader shoot flushes in longleaf pine saplings outplanted in November 2004 in central Louisiana with lightly (LS), moderately (MS), and severely (SS) needle mass scorched by a prescribed fire in February 2012. Within each flush, means with the same letter were not different at significance level of 0.05 using Duncan's Multiple-Range Test. For clarity, the same statistical test results as previous date were omitted. (a) First flush; (b) second flush; (c) third flush; (d) fourth flush; (e) fifth flush; (f) differences in final flush lengths between current year (2012) and previous year (2011).

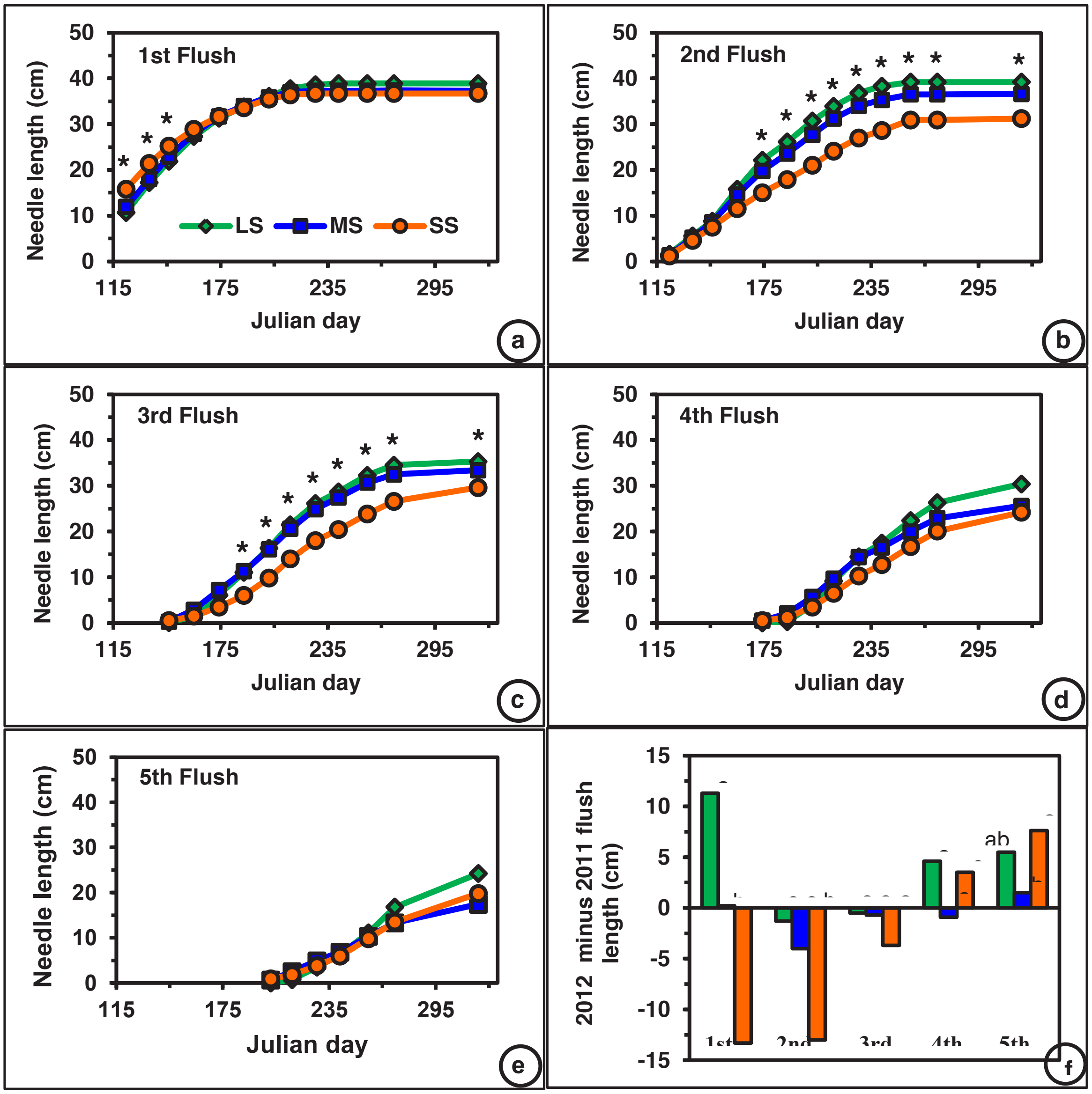

Figure 2--Temporal development patterns of needles in longleaf pine saplings outplanted in central Louisiana in November 2004 with lightly (LS), moderately (MS), and severely (SS) needle mass scorched by a prescribed fire in February 2012. Within each flush, an asterisk (*) indicates significant difference between SS saplings and the other saplings at the 0.05 level using Duncan's Multiple-Range Test; (a) first flush; (b) second flush; (c) third flush; (d) fourth flush; and (e) fifth flush.

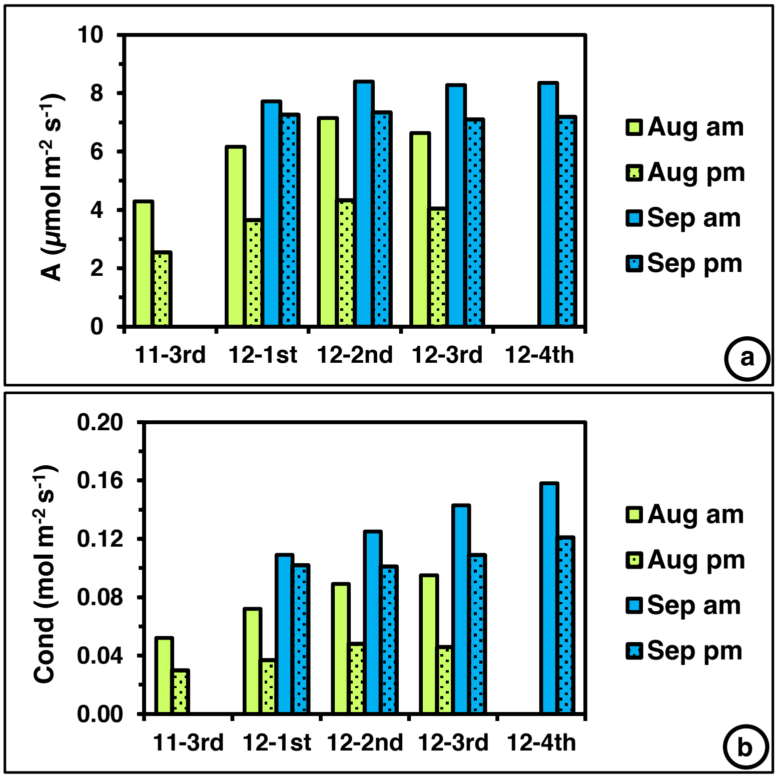

Figure 3—Means from all scorch class longleaf pine saplings for (a) photosynthetic rate and (b) stomatal conductance of needles from the third flushes of previous year (2011) and the first four current-year (2012) flushes measured in August and September. The study was prescribed burned in February 2012.

The exception is that the first SS flush needles had greater photosynthetic rate and stomatal conductance for the September morning measurements than needles of less severely scorched saplings (data not shown). In August, photosynthetic rates and stomatal conductance were lower in the afternoon than in the morning whereas no differences between morning and afternoon measurements existed in September (fig. 3). Based on the number of needle fascicles in each flush (including previous year's third flush in the LS and MS saplings), the needle surface area, and photosynthetic rate from August and September measurements, estimates of total needle surface area for the leader shoots and the amount of daily (8 hours) photosynthesis were derived (fig. 4). Compared to the LS and MS saplings, the SS saplings were more negatively impacted in their capacity to produce photosynthate by the prescribed fire (fig. 4b).

DISCUSSION

The dormant season prescribed burn did not change the temporal development patterns of flushes and needles (figs. 1 and 2) when compared to the 2007 and 2008 growth patterns reported for the same study (Sung and others 2013). Unlike the mature longleaf pine trees where there was a 30-day delay between flush elongation cessation and needle elongation (Sheffield and others 2003), needles of these young longleaf pine saplings started elongation before flush elongation was complete (figs. 1 and 2). Furthermore, the levels of needle scorch had no effects on flush or needle development patterns with two exceptions. First, both the third flushes and needles had slower linear elongation rates in the SS saplings than the other less-scorched saplings (figs. 1c and 2c). Second, the second flushes were the shortest among all flushes within the SS saplings. It was generally accepted that longleaf pine remains very susceptible to heat-related injury until the

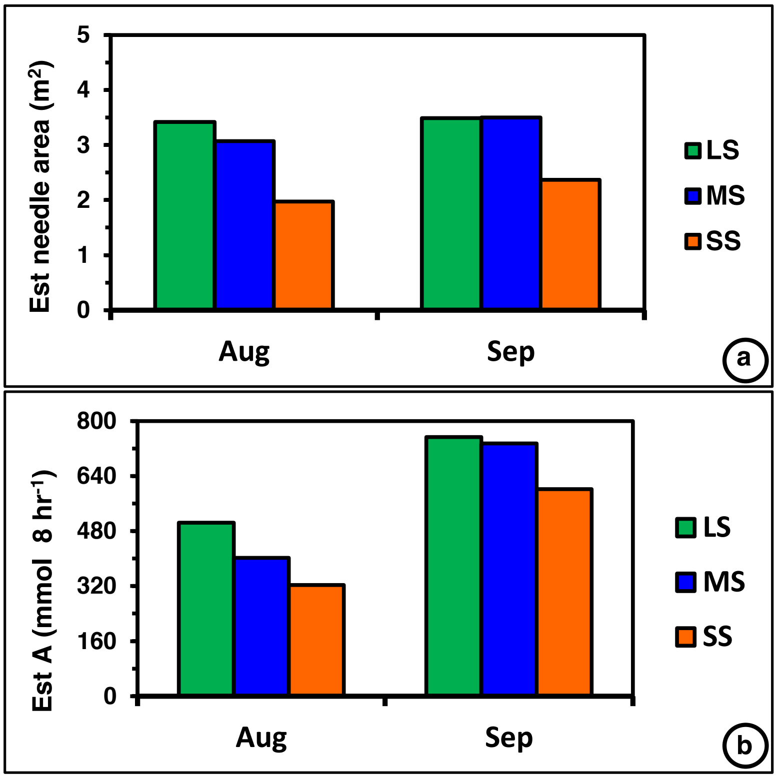

Figure 4--Estimated sums of (a) total needle surface area and (b) daily (8-hour) photosynthesis in leader shoots of longleaf pine saplings with lightly (LS), moderately (MS), and severely (SS) needle mass scorched from a February prescribed fire.

seedlings are above 1.8 m in height (Bruce 1951). However, the negative impacts of the prescribed fire on the SS saplings were readily evident with the much shorter lengths of the first three current-year flushes and of the second and third-flush needles compared to those of less severely scorched saplings. Haywood and Grelen (2000) and Haywood (2009) found that March-, May-, and July-burns reduced longleaf sapling growth with March-burn having the most negative impact. The negative impact of prescribed fire on longleaf sapling growth is also shown when growth of the first three flushes in the year with a severe drought was greater than that of the SS saplings in the subsequent fire-year that had average rainfall (fig. 1f).

Studies in loblolly pine (Chung and Barnes 1980), red pine (*P. resinosa* Ait.) (Gordon and Larson 1968), and Scots pine (*P. sylvestris* L.) (Ericsson 1978) showed that pine needles start to export photosynthate when they are almost mature. With all previous years' needles scorched by the dormant season prescribed fire, carbon needed for the growth of the first and second flushes and their needles in the SS saplings has to originate from stored reserves in stems and roots before the current year first-flush needles become a carbon source. By JD 202, the majority of first-flush needles in the SS saplings had completed elongation and were able to export photosynthate to meet the carbon demands of sinks such as needles of the third flushes and the fourth and fifth flushes and their needles as well as stem cambial tissues and fine roots (Chung and Barnes 1980, Gordon and Larson 1968, Sword Sayer and Haywood 2006, van den Driessche 1987). By JD 257, the fully extended second-flush needles joined the first-flush needles to supply carbon for growth. In less severely scorched saplings, carbon for the first flush and initial needle growth can come from current photosynthate produced by previous year's needles and from stored reserves (Dickson 1991, Kuhns and Gjerstad 1991). Shorter first flushes in the SS saplings indicate that these saplings either exhausted their reserves or stopped mobilizing more reserves before their first flushes were fully extended. Had the first flush development been monitored earlier than JD 122, we may have learned more about the rate differences of flush elongation based on possible carbon sources present (current photosynthate or reserves). Longer first-flush needles in the SS saplings observed in May resulted either from earlier appearance of needles or greater elongation rates. No conclusion can be drawn about carbon source and growth rate based on needle development.

O'Brien and others (2010) reported a negative relationship between crown scorching levels and chlorophyll contents in needles that flushed after a wildfire in a long-unburned longleaf pine stand. The current study agreed with their finding for the first-flush needles but not the needles in subsequent flushes. The estimates of daily photosynthesis in SS saplings were lower than those of LS and MS saplings. This may result in lower amounts of reserves being stored in the stems or roots of SS saplings that have used some or most of their reserves earlier in the season. Three years after a prescribed burn, the annual diameter growth of 22-year-old loblolly pine trees with complete crown scorch was still less than trees without crown scorch (Lilieholm and Hu 1987). It would be interesting to follow the development patterns of the first two flushes and their needles in the year following the prescribed fire to detect any carry-over effects of a dormant season prescribed burn as reported by Ford and others (2010).

CONCLUSIONS

Variations in needle mass scorch levels existed as a result of dormant season prescribed fire. The negative impact from fire on longleaf sapling growth persisted for the first three flushes and their needles in saplings with all their previous year's needles scorched. Although the fourth and fifth flushes of the severely scorched saplings were similar in lengths to those of less severely scorched saplings, the amounts of stored reserves in these saplings may be reduced at the end of the fire year which in turn could affect flush growth the year after fire.

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