NOTE

Survival and growth of *Pinus echinata* and Quercus seedlings in response to simulated summer and winter prescribed burns

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Abstract: First-year seedlings of shortleaf pine (*Pinus echinata* Mill.), southern red oak (Quercus *falcata* Michx.), and white oak (*Quercus alba* L.) were subjected to simulated prescribed burns during August (growing season) or January (dormant season) on an Upper Coastal Plain site in southeastern Arkansas, U.S.A. Survival and growth of resprouting rootstocks were compared with control seedlings through one growing season after burning. Although 100% of the oaks and 99% of the pines were topkilled by the fires, survival of resprouting rootstocks exceeded 95% for all three species in the year following the winter burn. No pines resprouted following the summer burn, but rootstock survival of oaks averaged >65%. Compared with controls, winter burns reduced ($P < 0.01$) mean height and groundline diameter (GLD) of shortleaf pine sprouts through the next growing season. For southern red oak, season of burning did not negatively affect ($P > 0.05$) the growth of sprouts during the year after burning. Although mean heights and GLDs of white oak sprouts versus controls were reduced ($P \le 0.04$) when means were averaged across burns, white oak sprouts on winter-burn plots were comparable in size with the control seedlings.

Résumé : Des semis de pin à courtes feuilles (*Pinus echinata* Mill.), de chêne digité (*Quercus falcata* Michx.) et de chêne blanc (*Quercus alba* L.) âgés de cinq ans ont été soumis à un brûlage dirigé simulé pendant le mois d'août (saison de croissance) ou de janvier (saison de dormance) dans une station située sur une plaine côtière surélevée dans le sud-est de l'Arkansas, aux États-Unis. La survie et la croissance des rejets produits par le système racinaire ont été comparées à des semis témoins tout au long d'une saison de croissance après le brûlage. Bien que 100% des tiges de chênes et 99% des tiges de pin aient été tuées par le feu, la survie des rejets dépassait 95% chez les trois espèces dans l'année qui a suivi le brûlage d'hiver. Aucun pin n'a produit de rejets suite au brulâge d'été mais la survie du sysrème racinaire des chênes atteignait en moyenne plus de 65%. Comparativement aux témoins, le brûlage d'hiver a entraîné une réduction ($P < 0,01$) de la hauteur moyenne et du diamètre à la base des rejets de pin à courtes feuilles au cours de la saison de croissance suivante. Dans le cas du chêne digité, le moment du brûlage n'a pas affecté négativement ($P > 0,05$) la croissance des rejets au cours de la saison de croissance qui a suivi le brûlage. Bien que la hauteur moyenne et le diamètre à la base des rejets de chêne blanc soient plus faibles ($P \le 0,04$) comparativement aux témoins lorsqu'on fait la moyenne de I'ensemble des parcelles brûlées, les rejets de chêne blanc dans les parcelles brûlées en hiver ont des dimensions semblables aux semis témoins.

[Traduit par la Rédaction]

Introduction

In the southeastern United States, shortleaf pine (*Pinus echinata* Mill.) has the widest range of any southern pine, but the regions of best development for the species are in Arkansas, northern Louisiana, and the southern Piedmont (Lawson 1990). Shortleaf pine is a major component of three forest cover types: shortleaf pine (type 75), shortleaf pine oak (*Quercus* spp.) (type 76), and loblolly pine (*Pinus taeda* L.) - shortleaf pine (type 80) (Eyre 1980). In the Upper Coastal Plain of the West Gulf Region, loblolly and shortleaf pines often dominate natural stands because of prolific seeding and rapid height growth following their establishment on disturbed sites. However, in the absence of disturbance, these shade-intolerant pines cannot regenerate beneath a closed canopy composed of midstory hardwoods (Cain and Shelton 1995). For that reason, prescribed burning is often used as a silvicultural tool to control the hardwood component when managing southern pines for timber production (Crow and Shilling 1980).

Shortleaf pine is unique among the southern pines, because seedlings have the ability to sprout prolifically when the crown is killed or badly damaged (Lawson 1990). This sprouting characteristic is attributed to dormant buds that are associated with primary needles and the formation of a sharp

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J-shaped crook in the stem at groundline (Stone and Stone 1954). The dormant buds affiliated with this crook are apparently protected from fire by the forest floor and soil surface. According to Harlow et al. (1979), shortleaf pines that are up to 10 years old retain this ability to sprout after their main stems have been destroyed by fire or cutting. Although the sprouting ability of shortleaf pine is widely recognized among foresters in the South, there have been no controlled experiments to assess the effects of growing season fires on survival and growth of shortleaf pine regeneration (Williams 1998).

Like shortleaf pines, oaks in the southeastern United States are adapted to disturbance regimes such as fire (Van Lear 1991). Their thick bark, resistance to rot, and ability to persistently resprout following top kill indicate that fire has played an important role in oak regeneration (Watt et al. 1993). When pine establishment and growth are the objectives of management, hardwoods are often categorized as competitors, because their presence can significantly reduce pine volume production (Cain 1999). Under these circumstances, growing season fires have been reported to be more effective than dormant season fires for controlling hardwood competition in pine stands (Lotti 1956; Ferguson 1957; Grano 1970).

We are aware of only one study reporting the effects of fire on oak seedlings within 1 year after their establishment from acorns, and it was conducted using white oak ***(Quercus alba*** L.) and northern red ***oak (Quercus rubra*** L.) in the Central Lowlands of Missouri, U.S.A. (Huddle and Pallardy 1999). The present investigation was conducted on the Upper Coastal Plain of southeastern Arkansas, U.S.A. Southern red ***oak (Quercus falcata*** Michx.) and white oak were chosen for this investigation, because they are common associates of shortleaf pine in natural stands on Coastal Plain sites (Lawson 1990).

The objectives of the present investigation were (i) to monitor survival and growth of l-year-old shortleaf pine, southern red oak, and white oak seedlings through a single growing season following their exposure to simulated summer and winter prescribed burns; (ii) to compare the survival and growth of burned seedlings with unburned controls; and (iii) to assess the effect of fire on competing vegetation.

Methods

Study area

The study was located on forest lands of the School of Forest Resources, University of Arkansas, Monticello. The study site is situated in the West Gulf Coastal Plain at 91°46′W and 33°37′N. Elevation of the forested area is 98 m with rolling topography. The soil is a Sacul loam (clayey, mixed, thermic, Aquic Hapludult), described as a moderately well-drained upland soil with a site index of 24 m for shortleaf pine at age 50 (USDA 1976). The growing season is about 240 days, and annual precipitation averages 134 cm with seasonal extremes being wet winters and dry autumns.

Within a pine seed-tree area, a 10 x 10 m opening was prepared for study installation by using a small tractor and push blade to remove vegetation and roots, thereby exposing mineral soil. Within the cleared area, nine 1.5 x 2.1 m beds were framed with 5 x 10 cm pine studs, and the soil in each bed was leveled with hand tools in December 1996. The leveled soil was allowed to settle 4 months before planting.

To discourage the growth of herbaceous vegetation and ensure uniform fuel conditions for burning (Hungerford et al. 1994), a forest floor was reconstructed within each bed using procedures developed by Shelton (1995). Within 100 m of the study area, undisturbed forest floor material was obtained from beneath a closed forest canopy, where pine basal area averaged 21 $m^2 \cdot ha^{-1}$. Within this forest stand, a broadcast herbicide treatment was applied 2 years earlier, eliminating competition from understory hardwoods and herbaceous vegetation. At the time of burning, litter depth averaged 23.0 mm on the summer-bum beds. Shortly before the winter burn, the litter layer on those beds was enhanced by applying additional litter that had fallen since the date of the summer burn; consequently, litter depth averaged 36.7 mm. The forest floor used in this experiment was typical of similar stand conditions found elsewhere in the South (Switzer et al. 1979).

Seedlings

Shortleaf pine seeds and southern red and white oak acorns were obtained from the 1996 seed crop from a minimum of five trees per species. Pine seeds were extracted from the cones of trees felled during a logging operation in October 1996, and acorns were collected from beneath standing oaks shortly after their dispersal in autumn. The seed sources were within a radius of 10 km of the study area. Collected pine seeds and acorns were subjected to a float test, and those that sank were considered viable and were retained for use in this study. To facilitate germination, the pine seeds and red oak acorns were stratified at 4°C on moist sterile sand for 30 days. White oak acorns do not require stratification, so they were refrigerated at 4°C until needed in this study.

Seedlings were grown in Ventblocks® (Beaver Plastics Ltd., Canada)* that contained a 1:1 peat-vermiculite mixture (Barnett and Brissette 1986). The germination process began on December 31, 1996, after seeds and acorns were placed in the growth medium. White oaks were grown in cells that measured 4.0 cm in diameter and 15.0 cm deep (≈100 cm^3). Shortleaf pines and southern red oaks were grown in cells that measured 2.8 cm in diameter and 13.3 cm deep (≈60 cm^3). During January and February 1997, seedlings were grown indoors and were exposed to 10 h of full-spectrum fluorescent light and 14 h of darkness during each 24 h. The indoor temperature ranged between 21 and 24°C. In March, seedlings were transferred outdoors during daylight hours to ensure acclimation before field planting.

Seedlings were hand planted in early April 1997. At each planting spot, litter was pushed aside by hand and a metal-tipped staff was inserted into the soil to form a depression where the extracted tubling root system and growth medium was placed. After planting, each depression was backfilled with 20 mL of dry topsoil and irrigated with water; this ensured a uniform soil surface above the peat-vermiculite growth medium. Litter was then redistributed around the planted stems to provide a uniform layer across the beds to carry a fire. Within each bed, pine and oak seedlings were randomly assigned planting locations, with 21 seedlings per species and 63 seedlings per bed. Extra seedlings were held in reserve through April to replace mortality. At the time of planting, mean seedling heights averaged 4.4 cm for pine, 11.5 cm for red oaks, and 13.9 cm for white oaks.

Prescribed burns

Each of the nine beds was assigned one of three treatments:

[2] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Table 1. Fuel and weather conditions during simulated prescribed burns in southeastern Arkansas, U.S.A.

Fuel and weather variables	Burn type	
	Summer	Winter
Date of bums	Aug. 19, 1997	Jan. 30, 1998
Days since last precipitation	3	4
Time of burning (CST)	11:00–11:30	14:00–14:15
Dry bulb temperature (“C)	29	18
Relative humidity (%)	53	43
Wind direction	South	South
Wind speed ($km \cdot h^{-1}$)[a]	6.8	6.8
Fine fuel moisture (%)	20	20
Forest floor mass ($Mg \cdot ha^{-1}$)	16.8	19.8
Litter depth before burning (mm)	23.0	36.7
Litter depth after burning (mm)	15.0	20.8
Mean fireline intensity ($kW \cdot m^{-1}$)[b]	16.3	24.2
Maximum fire temperature (“C)	400	400
Rate of spread ($m \cdot h^{-1}$)	85	57

“Wind speed generated by three electric box fans.
[b]$I = 259.8L_f^{2.174}$, where L_f is the ocular estimate of flame length in metres (Alexander 1982).
‘Based on melting point of Tempil” temperature pellets placed on the surface litter.

(i) control, where no burning was done; (ii) summer bum on August 19, 1997; and (iii) winter bum on January 30, 1998 (Table 1).

All bums were simulated headfires. Wind for these fires was provided from three 0.56-m’ electric box fans positioned side-by-side at ground level. Fan-blade rotation was varied during burning to maintain a constant wind speed at the fire front. Wind speed was determined from an electronic Turbo-Meter@ wind-speed indicator (Davis Instruments; Hayward, Calif.). While bums were in progress, flame lengths were ocularly estimated to the nearest 15 cm and recorded. Fireline intensity was calculated from flame lengths in accordance with Alexander (1982).

To accurately measure temperatures generated by the fire, Tempil® temperature indicator pellets (Big Three Industries, Inc.; South Plainfield, N.J.) with known melting points were placed atop the litter before burning. The melting temperature for these pellets ranged from 48 to 804°C in increments of ≈55°C.

To determine fuel moisture, three separate 0.1-m’ subplots containing a reconstructed forest floor were set up at the bum site. Immediately after burning, these unburned litter samples were removed and percent moisture was determined on an ovendry basis.

The depth of litter burned was assessed by using a pinning technique. On each bum bed, 20 wire pins were vertically inserted through the unburned litter and into the soil. The top of each pin was 25 mm above the unburned surface litter. After burning, the exposed length of each pin above the burned surface was measured to an accuracy of 1.0 mm, and a mean bum depth was calculated for each bed.

Measurements

Before burning, height of surviving seedlings was measured to an accuracy of 0.3 cm. After burning, crown scorch of each seedling was ocularly estimated to the nearest 10%, and total height of the dominant pine or oak sprout at each seedling cluster was measured monthly to an accuracy of 0.3 cm until September 1998, which was the end of one growing season after burning. Also at the end of the 1998 growing season, groundline diameter of the largest sprout in each seedling cluster was measured to an accuracy of 0.1 mm. Additionally, all pine sprouts, oak sprouts, and other plants were clipped at groundline, and their mass ($g \cdot m^{-2}$) was determined separately on an ovendry basis.

Experimental design and data analysis

The experiment was a 3 x 3 factorial in a split-plot design with three randomized complete blocks. Burning seasons (summer, winter, and an unburned control) were the main effects, and species (shortleaf pine, southern red oak, and white oak) were the sub-effects. The mean value for surviving seedlings of each species within a bed was considered a replicate. Blocking was based on topographic position because of a 5% slope from south to north.

Data were analyzed using analysis of variance, and orthogonal contrasts were used to partition mean differences among species by bum season. Survival percent was analyzed following arcsine square-root proportion transformation, but only nontransformed percentages are reported. Shortleaf pines were not included in the analysis for the summer burn because no resprouting occurred. Significance was accepted at the a = 0.05 probability level.

Results and discussion

Seedling and rootstock survival

There was a nonsignificant (P = 0.07) species by burn interaction for rootstock survival (Table 2). With surface temperatures up to 400°C during the burns (Table 1), crown scorch of shortleaf seedlings was 100% after the summer burn, and none of the shortleaf pine rootstocks resprouted (Fig. 1A). After the winter burn, the least crown scorch was 85% on one shortleaf seedling, but mean crown scorch averaged 99% for that species. After two growing seasons, survival of shortleaf pine seedlings averaged 91% on control plots, and survival of shortleaf pine rootstocks averaged 95% on winter burn plots, with no statistically significant difference (P = 0.07) between these two treatments.

Southern red oak seedlings had 100% survival on control plots (Fig. 1A), which was 17 percentage points higher (P < 0.01) than mean rootstock survival for the summer and winter burns combined (Table 2). Regardless of the bum season, there was 100% crown scorch of all southern red oak seedlings, yet 68% of their rootstocks survived the summer bum, 98% survived the winter bum, and the mean difference was significant (P < 0.01).

Rootstock survival of white oak seedlings was similar to the southern red oaks (Fig. 1A). While the seasonal bums resulted in 100% top kill of all white oaks, survival of rootstocks on the summer and winter burns was 75 and 98%, respectively. This compared with a 98% survival rate on control plots. Survival on control plots was 12 percentage points better (P < 0.01) than the mean of the summer and winter burns (Fig. 1A), and rootstock survival in winter bum plots was 23 percentage points higher (P < 0.01) than on summer bum plots (Table 2).

For both oak species, resprouting from top-killed rootstocks occurred several weeks after the summer bum, whereas resprouting from the winter bum occurred the following spring. Oaks that have been top-killed by fire must have sufficient starch reserves to support the growth of new shoots (Malanson and Trabaud 1988). Starch concentrations are highest during the dormant season (Huddle and Pallardy 1999), which corresponds to higher survival rates for southern red oak and white oak seedlings following the winter bums versus the summer bums in the present study.

Fig. 1. Mean (+standard error) survival (A), height (B), groundline diameter (C), and aboveground mass (D) of shortleaf pines, southern red oaks, and white oaks one growing season after simulated prescribed burns. For shortleaf pine, zero values for the summer burn indicate that no pines survived..

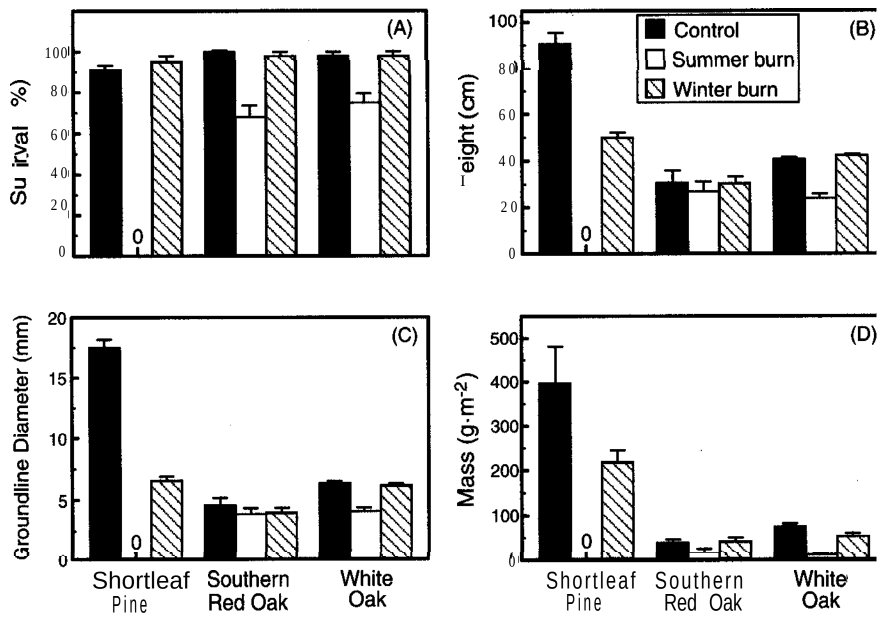


Table 2. Analysis of variance for survival, mean size, and mass of pine and oak seedlings one growing season after prescribed burns in southeastern Arkansas, U.S.A.

Source of		Survival		Height		Groundline diameter		Mass	
variation	df	MS (arcsine)	>*F*	MS (cm)	***P* >*F***	MS (mm)	***P* >*F***	MS (g·m^{-2})	***P* >*F***
Block	2	0.047	0.20	1.27	0.97	0.059	0.93	2 177	0.45
Bum	2	0.486	<0.01	613.96	0.02	37.712	x0.01	12 853	0.07
Error I	4	0.019		48.30		0.746		2 245	
Species	2	0.061	<0.01	2431.86	<0.01	96.145	<0.01	130 602	<0.01
Species x bum	3	0.014	0.07	636.26	<0.01	38.341	<0.01	9 932	0.08
Contrasts"									
Shortleaf pine									
c vs. w	1	0.018	0.07	2488.38	<0.01	180.258	<0.01	47 252	<0.01
Red oak									
c vs. s + w	1	0.232	<0.01	8.71	0.52	0.822	0.17	223	0.80
s vs. w	1	0.385	<0.01	19.64	0.34	0.028	0.79	1 187	0.56
White oak									
c vs. s + w	1	0.100	<0.01	113.30	0.04	2.988	0.02	3 778	0.31
s vs. w	1	0.280	<0.01	506.67	CO.01	6.352	4.01	3 063	0.36
Error II	10	0.004		19.76		0.372		3 335	

'Contrast abbreviations are as follows: C, control; **S**, summer bum; W, winter bum.

Seedling and sprout heights

At the time of the summer burn, mean heights averaged 19, 13, and 14 cm for shortleaf pine, southern red oak, and white oak seedlings, respectively. Just before the winter burn, seedlings were somewhat taller, averaging 25, 15, and 16 cm for shortleaf, red oaks, and white oaks, respectively. One growing season after the burns, there was a significant ($P < 0.01$) species x burn interaction for seedling heights, which was attributed to the change in the magnitude of the difference between unburned pines and oaks versus those that were top-killed by fire. By the end of the growing season, shortleaf pine seedlings on control plots averaged 90.6 cm tall (Fig. 1B) and were 82% taller ($P < 0.01$) than shortleaf sprouts on winter burn plots (Table 2). From April to June immediately following the February burn, height growth patterns for shortleaf sprouts on winter-bum plots were similar to that of seedlings on control plots during the same time period (Fig. 2A). However, height growth of shortleaf sprouts on winter-bum plots declined from June through September when compared with control seedlings, possibly as a result of their smaller root systems and the associated late-summer soil-moisture deficits.

Southern red oaks averaged 29.3 cm tall one growing season after burning (Fig. 1B), and there was no difference ($P = 0.52$) in mean height of seedlings on control plots versus sprouts on combined bum plots (Table 2). Also, heights for

Fig. 2. Periodic trends in mean height for surviving shortleaf pines (A), southern red oaks (B), and white oaks (C) from the time of simulated prescribed burning (★) through the following growing season. The *x* axis is not to scale.

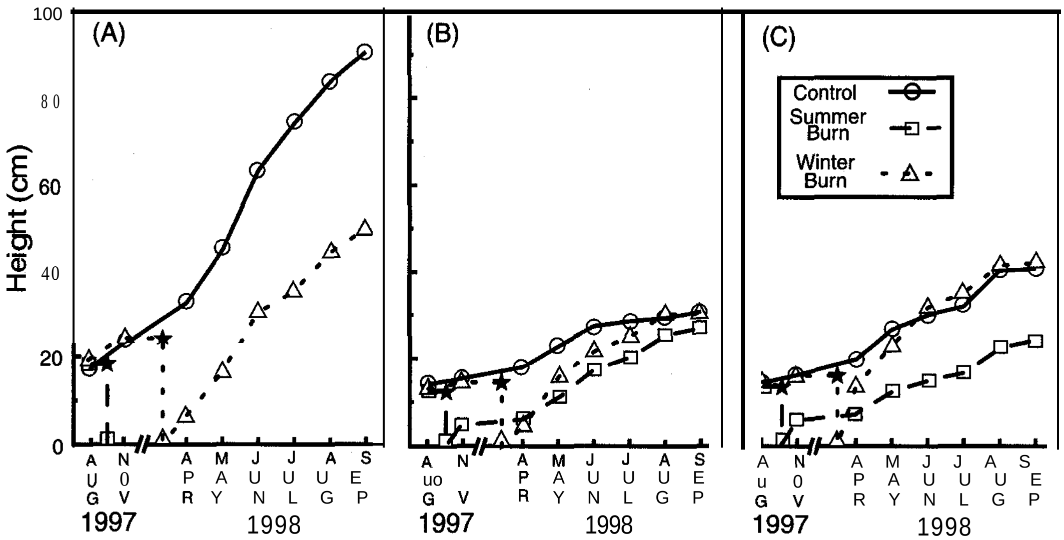
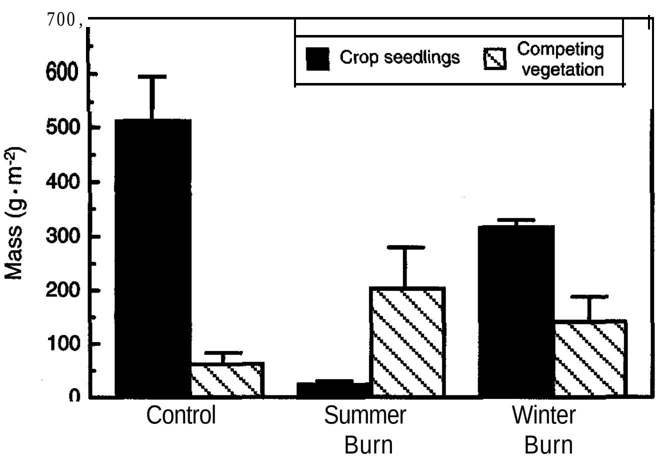


Fig. 3. Mean (+standard error) aboveground mass of crop seedlings and competing vegetation one growing season after simulated prescribed bums.



southern red oak sprouts did not differ (P = 0.34) between summer and winter burns. Sprouts from top-killed southern red oaks regained their preburn height during the growing season following both burn treatments, because periodic height growth of sprouts exceeded that of unburned control seedlings (Fig. 2B).

White oak seedlings on control plots were 23% taller (P = 0.04) than the mean height of sprouts on burned plots (Table 2). Average height of white oak sprouts on winter bum plots was 77% greater ($P < 0.01$) than those on summer burn plots. One growing season after winter burning, white oak sprouts were as tall as unburned control seedlings (Fig. 1B). That occurred because, during the growing season after burning, periodic height growth of white oak sprouts on winter-bum plots exceeded growth on control plots from April to June (Fig. 2C). Summer burning resulted in reduced height growth, which suggests that starch reserves in the root system at the time of burning are important for supporting subsequent sprout growth (Huddle and Pallardy 1999).

Seedling and sprout diameters

As with heights, there was a significant ($P < 0.01$) species x burn interaction for groundline diameters (GLDs) one growing season after burning (Table 2). This interaction was again attributed to the change in the magnitude of the difference between unburned seedlings and the sprouts that developed after burning (Fig. 1C).

One growing season after burning, shortleaf pine seedlings on control plots averaged 17.5 mm in GLD (Fig. 1C), which was 165% larger ($P < 0.01$) than shortleaf sprouts on winter-bum plots (Table 2). For southern red oaks, mean GLDs averaged 4.2 mm one growing season after burning (Fig. 1C), and there were no differences ($P > 0.05$) among the bum treatments (Table 2). At 6.4 mm, the mean GLD for white oak seedlings on control plots was 25% larger (P = 0.02) than the mean GLD of sprouts on burn plots, and mean GLD of white oak sprouts on winter-bum plots (6.2 mm) was 55% larger ($P < 0.01$) than on summer-bum plots (Fig. 1C).

Seedling and sprout biomass

Unlike mean height and GLD, the species x bum interaction for mass was nonsignificant (P = 0.08) (Table 2). Shortleaf pine seedlings on control plots averaged 397 $g \cdot m^{-2}$ after two growing seasons (Fig. 1D) and had 81% more ($P <$ 0.01) biomass than shortleaf sprouts on winter-bum plots (Table 2). Even though shortleaf pine seedlings were 65% shorter than the oaks at the time of planting, surviving shortleaf seedlings and sprouts had eight times as much biomass as surviving oak seedlings and sprouts after two growing seasons.

Biomass for southern red oak control seedlings and bum sprouts averaged 32 $g \cdot m^{-2}$ one growing season after burning (Fig. 1D), and there were no differences in mean masses between the combined bum treatments versus control (P = 0.80) or between the burn treatments (P = 0.56) (Table 2). Likewise, white oak control seedlings and bum sprouts had similar (P = 0.31) biomass, averaging 46 $g \cdot m^{-2}$, with no difference (P = 0.36) between the bum treatments (Fig. 1D).

Competing vegetation biomass

Because competing vegetation has been shown to reduce the growth of naturally regenerated shortleaf pines (Cain 1999) and upland hardwoods (Cain 1995), aboveground biomass of noncrop plants was measured. Biomass for these competitors averaged 96% from herbaceous species (i.e., grasses (18%), forbs (66%), vines (1%), and semiwoody plants (11%)) and 4% from noncrop woody species. One growing season after burning, the aboveground biomass ranking ($P < 0.05$) of all crop seedlings and sprouts by burn treatments was as follows: control (511 $g \cdot m^{-2}$) = winter burn (316 $g \cdot m^{-2}$) > summer burn (24 $g \cdot m^{-2}$) (Fig. 3). The mean mass of competing vegetation (P = 0.07) ranged from 62 $g \cdot m^{-2}$ on control plots, where there was the most shade from crop seedlings and undisturbed litter, to 203 $g \cdot m^{-2}$ on summer-bum plots, where crop seedling shade was least and litter was reduced by burning. Other investigations have shown that fire enhances seed germination of some herbaceous species (Blank and Young 1998; Brown and Van Staden 1998), and that may have contributed to the occurrence of more herbaceous biomass on burned plots versus control plots in the present study. Herbaceous vegetation tends to be shade intolerant and eventually disappears from the forest floor as the woody canopy closes (Cain 1999).

Management implications

Even though shortleaf pine seedlings were initially shorter than oak seedlings because of their smaller seed size compared with acorns, within two growing seasons pine seedlings on control plots in this study were twice as tall as the oaks and three times as large in GLD. In contrast, l-year-old shortleaf pine sprouts from the dormant-season bums grew at about the same rate as l-year-old southern red oak and white oak seedlings and sprouts, irrespective of whether the oaks were top-killed by fire or not. However, most hardwood sprouts that develop in forest conditions following disturbance on these sites come from rootstocks that are perhaps decades old (Reynolds 1956). Because of their large root systems, dominant sprouts from top-killed southern red oaks and white oaks can attain heights of 6 m within 9 years after disturbance in southeastern Arkansas (Cain 1995). Results from this study suggest that rootstocks of top-killed shortleaf seedlings may resprout following low-intensity bums that occur in the winter following seedling establishment. If the objective of management is to regenerate shortleaf pines from natural seedfall, then multiple growing-season bums in advance of pine seedfall would probably provide better control of competition from oak regeneration than would dormant-season bums.

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