New Forests 16: I-10, 1998.
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Viability of litter-stored *Pinus taeda* L. seeds after simulated prescribed winter burns

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Accepted 1 December 1997

Application. Timing of prescribed burning in the Southeastern U.S. can be critical when used to enhance seedbeds for natural regeneration of loblolly pine (*Pinus taeda* L.). Since the majority of loblolly pine seeds are disseminated before January during average seed years on Coastal Plain sites, prescribed winter burns conducted after that date are likely to destroy most pine seeds deposited in the upper litter layer of the forest floor.

Abstract. Stratified loblolly pine (*Pinus taeda* L.) seeds were placed at three depths in a reconstructed forest floor and subjected to simulated prescribed winter burns. Within the forest floor, pine seeds were placed at the L/upper-F interface, upper-F/lower-F interface, and lower-F/mineral-soil interface. Wind was generated by electric box-fans. Seeds that survived the burns were transferred to moist sand flats for 30-day germination tests. About 96% of seeds placed at the two upper layers in the forest floor were either destroyed by the fires or failed to germinate. Germinative capacity of seeds placed at the lower-F/mineral-soil interface averaged 79% as compared to 97% for unburned control seeds.

Key words: loblolly pine, natural regeneration, seed bank, southeastern Arkansas

Introduction

Since fire plays an important role in favoring natural pine regeneration over hardwoods (Brender and Cooper 1968), prescribed burning is widely used as a management tool in the loblolly-shortleaf pine (*Pinus taeda* L.-P: *echinata* Mill.) forest cover type that occurs throughout the Southeastern U.S. (Wright and Bailey 1982). Prescribed burning is most often associated with even-aged pine reproduction cutting methods, but may have application in uneven-aged silviculture of loblolly and shortleaf pines (Cain 1993). Benefits from prescribed burning include: site or seedbed preparation, control of unwanted vegetation, disease control, thinning of dense young pine stands, increased

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growth and yield of pines, and improvement of wildlife habitat (Davis 1959; Crow and Shilling 1980).

When using prescribed fire to prepare seedbeds for natural regeneration of pines, burning should be complete just before seedfall to ensure a maximum seedling catch (Davis 1959). For loblolly pine, natural seedfall begins in October and may persist into spring. However, during average seedyears, when 74,000–198,000 sound seeds are produced per ha (Baker and Langdon 1990), seedfall for loblolly pine peaks in early November (Cain 1991). Concomitantly, Grano (197 1) found that in southeastern Arkansas, loblolly-shortleaf pine seedfall was 77% complete by the end of November and 92% complete by the end of December.

Lotti et al. (1960) surmised that if a prescribed fire takes place after the main seedfall in loblolly pine, almost full dependence must be placed on the following years' seedcrop for pine regeneration. The reasoning has been that pine seed in the forest floor will be destroyed during a prescribed fire (Chaiken 1952; Smith and Bower 1961; Cain 1986). Although seed loss by fire is a reasonable assumption, such reports have been based on anecdotal observations rather than definitive research. The purpose of the present investigation was to experimentally determine if loblolly pine seeds could survive prescribed winter bums depending upon seed placement in a reconstructed forest floor.

Methods

The study was located on forest lands of the School of Forest Resources, University of Arkansas at 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 loblolly 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, we prepared a 10-m by 10-m study site by using a small tractor and push-blade to remove vegetation and roots, thereby exposing mineral soil. Within the cleared area, two 1.5-m by 2. l-m beds were framed with steel railings and the soil was leveled using hand tools. The leveled soil was allowed to settle two weeks at which time we reconstructed a forest floor within each bed using procedures developed by Shelton (1995). A reconstructed forest floor was desirable to ensure uniform fuel conditions for burning (Hungerford et al. 1994) as well as uniform litter layers for seed placement.

In late-January 1996, 5 days after a rain event, we obtained undisturbed forest floor material from beneath a closed forest canopy, 100 m from the burn site, where pine basal area averaged 21 m^2/ha. A broadcast herbicide treatment, applied 2 yr earlier, eliminated competition from understory hardwoods and herbaceous vegetation. Therefore, no hardwood leaves were incorporated in the litter layer. The forest floor was typical of similar stand conditions found elsewhere in the South (Switzer et al. 1979). To facilitate reconstruction on the bum beds, we collected the forest floor in three layers – L, upper F, and lower F – using 0.12 m^2 sampling frames. The L layer refers to the litter layer consisting of unaltered dead remains of plants (Pritchett 1979). The fermentation (F) layer was immediately below the L layer and consisted of fragmented, partly decomposed organic materials that were sufficiently preserved to permit identification as to origin (Pritchett 1979). For this experiment, we subdivided the F layer into upper and lower zones based on visual evidence of decay. The undisturbed L layer averaged 9 mm in thickness, the upper F layer averaged 5 mm, and the lower F layer averaged 17 mm. Each layer was removed separately; then layers were transferred from the undisturbed forest floor in paper bags and reconstructed on the two burn beds during the day of removal, which was 24 hours before the bums.

Within each bed, a 0.95-m by 1.50-m interior plot was subdivided into twelve 0.12 m^2 cells (subsamples) for placement of the reconstructed forest floor and pine seeds. Wind for the simulated fires was provided from two 0.56-m^2 electric box-fans positioned side-by-side. Fan-blade rotation was varied during burning to maintain a constant wind speed at the fire front. The experiment was a randomized complete block design with four subsamples of the three litter depths within each bum bed (block).

Seeds for the study were extracted from loblolly pine cones that were collected in mid-October 1993 from a naturally established stand in southeastern Arkansas. Cones came from four felled trees of sawlog size (>30 cm in diameter at 1.37 m above ground). Once collected, all cones were pooled and were placed in a forced-draft oven at 38 °C until fully open (24 hours). Seeds were dewinged by hand and filled seeds were separated from empty seeds by floating in a water bath for 30 minutes. Seeds that did not float were considered sound, were dried to 10% moisture, and stored in a laboratory freezer at – 18 “C. To facilitate germination, seeds were removed from the freezer and stratified in moist sand at 4 °C for 2 weeks before being used in the present study.

For each subsample cell in the burn beds, we used 30 loblolly pine seeds. In order to relocate all seeds per treatment cell after burning, we glued them at l-cm intervals onto fiberglass cord (fiberglass gasketing from Worcester Brush, Worcester, MA) with Permatex® high-temperature silicone. At this

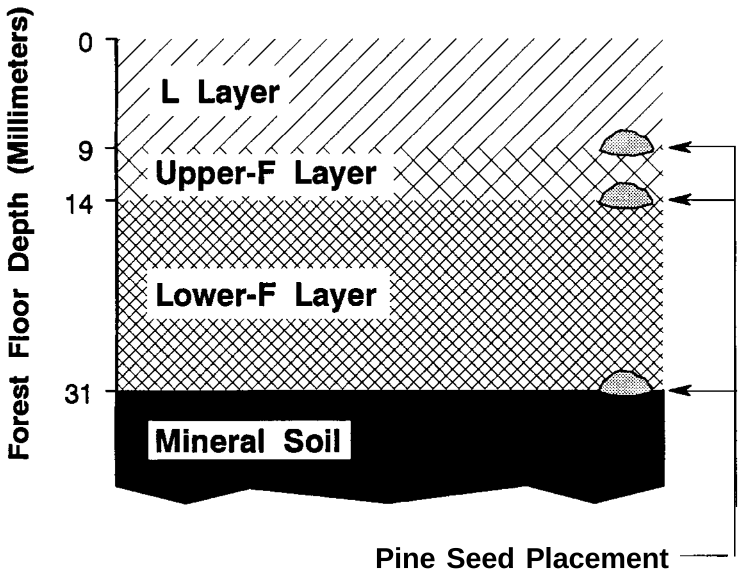

Figure I. Before prescribed burning, loblolly pine seeds were placed at three depths within the forest floor – at the L and upper-F interface, the upper-F and lower-F interface, and the lower-F and mineral-soil interface.

time, seed moisture content was 24% (oven-dry basis). This process was done 24 hours before the scheduled burn to permit the glue to cure. Volatilization around the seeds was minimized by air-drying the glued seeds outdoors in a National Weather Service instrument shelter until the time of burning. Just before fire ignition, seeded cords containing 30 pine seeds each were transferred to the center of each burn cell and placed at one of three layers within the reconstructed forest floor – L and upper-F interface, upper-F and lower-F interface, lower-F and mineral-soil interface (Figure 1).

Prescribed burns were conducted on January 29, 1996 (Table 1). Wind speed generated by the box fans was determined from an electronic Turbo-Meter@ wind speed indicator. While burns 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 Byram (1959).

For fuel moisture determination, we set up a separate 0.3-m^2 subplot containing a reconstructed forest floor at the burn site. Immediately after burning, we took three unburned litter samples from this subplot within each of the three litter layers in proportion to the weight of each layer. Moisture determination was on an oven-dry basis (105 °C for 24 hours). From within each burn bed, we also took four 0.1-m^2 samples of residual litter after the burns and determined weight of this unburned material on an oven-dry basis.

Table *1*. Fuel and weather conditions during simulated prescribed winter burns in southern Arkansas, USA.

Fuel and weather variables	
Date of burns	January 29, 1996
Days since last precipitation	6
Time of burning (hours CST)	1400–1430
Dry bulb temperature (°C)	14
Relative humidity (%)	69
Wind direction	South
Wind speed' (km/hour)	6.4
Forest floor moisture (%)	
L layer[2]	19
Upper F	23
Lower F	59
Forest floor weight (Mg/ha)	
L layer	2.5
Upper F	1.8
Lower F	14.7
Mean fireline intensity' (kW/m)	33
Rate of spread (m/hour)	22

[1] Wind speed generated by two electric box-fans.
[2] Fine-fuel moisture.
[3] $I = 5.67L_f^{2.17}$, where L_f = Ocular estimates of flame length.

Immediately after the bums, we removed the seeded cords from the burn beds and transferred the seeds to moist, sterile-sand flats for germination. Severely charred seeds were counted and discarded. Two groups of unburned seeds (glued and not glued) were used as controls, each consisting of four subsamples of 30 stratified seeds. The germination test ran for 30 days during which seeds were exposed to 10 hours of full-spectrum fluorescent light and 14 hours of darkness during each 24 hours. Temperature in the germination room was maintained at 21 "C. Germination was considered complete when the pine seedcoat had lifted from the sand.

Analysis of variance with subsamples (Steel and Torrie 1980) was used to compare germinative capacity of seeds relative to their location within the forest floor (SAS Institute, Inc. 1989). Germination percent was analyzed following arcsine square-root proportion transformation, but only nontransformed percentages are reported. Orthogonal contrasts were used to partition mean differences among seed locations within the forest floor as follows: LF_U versus $F_UF_L + F_LS$, and F_UF_L versus F_LS (*L* is the L layer, F_U is the upper-

Table **2.** Proportion of loblolly pine seeds destroyed by simulated prescribed burns and the germinative capacity of residual pine seeds at three depths within the forest floor.

Seed location during prescribed burns	Visibly destroyed seeds[1]	Seed germination
	(percent)[2]	
L/Upper-F interface	82.0	0.0
Upper-F/Lower-F interface	30.0	2.1
Lower-F/Mineral-soil interface	0.0	19.2

[1] Seeds that were consumed by the fire or were so charred that there was no likelihood of germination.
[2] Germination for unburned control seeds averaged 96.7%.

F layer, F_L is the lower-F layer, and S is mineral soil). A second analysis of variance was used to compare the germinative capacity of seeds from the F_LS interface to that of unburned control seeds.

Results and discussion

After the 30-day germination test, germinative capacity for the two control groups (glued and not glued) was identical (96.7%). These results suggested that the glue had no detrimental effect on seed germination during the course of this study.

Once burning was complete, it was obvious from the charred litter that both fires completely traversed the burn beds, leaving no unburned gaps. At the L/upper-F interface and a depth of 9 mm within the forest floor (Figure 1), 82% of pine seeds were visibly destroyed by the fires (Table 2). Also, none of the residual seeds taken from that depth germinated during the 30-day test that followed.

The proportion of seeds visibly destroyed within the upper-F/lower-F interface, at 14 mm within the forest floor, averaged 30% (Table 2). At that depth, only 2% of pine seeds proved to be viable during germination.

In these simulated prescribed burns, the only location within the forest floor where no pine seeds were visibly destroyed by fire was at the lower-F/mineral-soil interface (Table 2), which occurred at a depth of 31 mm in the forest floor (Figure 1). For pine seeds placed at this location, germinative capacity averaged 79% (Table 2). Survival of pine seeds at this depth was mainly attributed to high moisture content (59%) of the lower-F layer (Table 1) which prevented consumption of the detritus by the fires and moderated their heat. Hartford and Frandsen (1992) reported that moist duff (60% to

Table **3.** Analysis of variance for germinative capacity of loblolly pine seeds by simulated burn type and seed location within the forest floor.

Source of variation	Degrees of freedom	Mean square	$P > F$
Block	1	0.0401	0.19
Seed location in forest floor[1]	2	3.1919	<0.01
(LF_U vs $F_UF_L + F_LS$)	1	1.9101	to.01
(F_UF_L vs F_LS)	1	4.4131	<0.01
Experimental Error	2	0.0106	
Sampling Error	18	0.0220	

[1] LF_U is the Litter/Upper-F interface, F_UF_L is the Upper-F/Lower-F interface, and F_LS is the Lower-F/Mineral-Soil interface.

80% moisture content) gave considerable protection from mineral soil heating in surface fires.

Fireline intensity averaged 33 kW/m (Table 1), with fuel consumption averaging 8.0 Mg/ha. After burning, residual litter weight averaged 11.0 Mg/ha, which might represent an effective heatshield for pine seeds located at the lower-F/mineral-soil interface. The germinative capacity of pine seeds placed at this lower depth in the forest floor averaged 77 percentage points higher ($P < 0.01$) than pine seeds that survived at the upper-F/lower-F interface (Tables 2 and 3).

In a separate statistical analysis, germinative capacity of seeds at the lower-F/mineral-soil interface was compared to the germinative capacity of unburned control seeds. At that depth, germination of pine seeds averaged 17.5 percentage points less than unburned controls ($P = 0.11$, MSE = 0.0112).

Clearly, this study has demonstrated that loblolly pine seeds are not likely to survive prescribed winter burns if they are located within the upper litter layer of the forest floor. Although killing of plant tissue has been reported to occur at about 49 °C (Davis 1959), both temperature and its duration are important. On these 1.5-m by 2.1 -m beds, we conducted followup test burns using Tempil® temperature indicator pellets (Big Three Industries, Inc.; South Plainfield, NJ) placed on a reconstructed forest floor that consisted mainly of pine litter. In these burns, temperatures up to 400 °C were indicated, but temperatures of 300 °C were most common. Regardless of lethal temperature, virtually all pine seeds were consumed by the fires to a depth of 9 mm, and some were consumed at a depth of 14 mm within the forest floor.

Loblolly pine seeds were more likely to survive prescribed winter burns when they were located at the forest-floor/mineral-soil interface, as long as moisture content at that depth was ≥60%, which would prevent complete consumption by fire. Shelton (1995) found that loblolly pine seeds placed on the forest floor and separated from the soil surface had the same probability to develop into established seedlings as seeds placed on the soil surface and covered by forest-floor material.

How might pine seeds attain a depth within the forest floor comparable to the lower-F/mineral-soil interface that was tested in the present study? Our experience has shown that there are three probable scenarios that may account for seed placement deep within the forest floor. In the first, tree harvesting with heavy mechanical equipment in autumn or early winter months can turn up the forest-floor layers, thereby depositing recently dispersed pine seeds under the litter and near the mineral soil. In the second, foraging activity of birds and woodlot mammals might cause pine seeds to be dispersed deep within the forest floor. Lastly, mature pine and hardwood trees can be windthrown during thunderstorms or winter ice storms, thereby disrupting the forest-floor layers within the rooting zone as the trees collapse. Nevertheless, such events would probably account for only a small fraction of pine seed placement. In the absence of site disturbances, recently disseminated pine seeds will most likely occur at or near the L/upper-F interface in the forest floor.

Operational prescribed winter burns have been conducted on sites with fuel and weather conditions similar to those described in this paper (Cain 1993). In operational burns, fireline intensities were greater (163-464 kW/m), fine-fuel moisture was lower (6-15%) and wind speeds were higher (5-21 km/h) than reported in the present experimental burns (Table 1). Under those burning conditions, it is unlikely that loblolly pine seeds would survive in the forest floor.

The consequence of a one-year delay in natural pine regeneration depends on two factors – site quality and future seed crops. When site index is >26 m at 50 years for loblolly and shortleaf pines, ground cover from herbaceous vegetation and resprouting hardwoods can approach 100% within one growing season after a pine harvest with hardwood control (Cain in press). This ground cover can preclude successful establishment of natural pine regeneration following the next seed crop. If seedbeds are not receptive, then less-than-average pine seed crops are not likely to result in adequate numbers of pine seedlings. Depending on seedbed condition, between 100,000 and 2,000,000 sound seeds/ha are needed to successfully regenerate loblolly and shortleaf pines (Cain and Shelton 1996).

Results of the present investigation tend to substantiate past recommendations regarding the use of prescribed fire in southern pine management (Cain 1986). When the objective is the establishment of natural loblolly and shortleaf pine regeneration using seed-tree, shelterwood, patch-clearcut, or selection (uneven-aged) cutting methods, timing of seedbed preparation can be a critical consideration. Late-winter (i.e., January-February) prescribed burning for seedbed preparation may result in an insufficient supply of viable seeds for regeneration purposes if done in poor to average seed years. That is because most pine seeds will have been disseminated from cone-bearing pines by the end of December, and those seeds will most likely be destroyed by prescribed fires.

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