PLANTING SHORTLEAF PINES DEEPER INCREASES RESPROUTING AFTER FIRE

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Abstract—Unlike loblolly pine (*Pinus taeda* L.), shortleaf pine (*Pinus echinata* Mill.) seedlings often resprout following topkill from fire because the basal crook their stem produces places dormant buds at the soil surface which insulates them. The primary goal of our study was to compare resprouting following fire of shortleaf pine and loblolly pine with dormant buds placed at three depths: 2 cm above soil surface, at soil surface, and 2 cm below soil surface. We also compared resprouting of containerized versus bare-root shortleaf pine. Seedlings were planted near Idabel, OK, and burned after 1 year. Regardless of planting depth, none of the loblolly pine seedlings resprouted. For shortleaf pine, 8 percent resprouted when planted above the soil surface, 36 percent resprouted when planted at the soil surface, and 53 percent resprouted when planted below the soil surface. Bare-root seedlings resprouted at greater frequency than containerized seedlings. Therefore, planting shortleaf pine seedlings deeper should increase resprouting following fire.

INTRODUCTION

Loblolly pine (*Pinus taeda* L.) is the main commercial species in the Southeastern United States. When compared to shortleaf pine (*Pinus echinata* Mill.), loblolly pine grows faster on all but the driest sites (Branan and Porterfield 1971, Dipesh and others 2015, Schultz 1997). Even though it is slower growing than loblolly pine, shortleaf pine has the widest distribution of southern pines and plays an important role in many natural ecosystems. Some nonindustrial private forest landowners, State and Federal agencies, and nongovernmental organizations plant shortleaf, and this is especially important in areas with insufficient natural seed supplies. Additionally, shortleaf pine is often the species of choice for planting when the primary goal is wildlife or ecosystem restoration. Shortleaf pine is also less susceptible to fire and drought (Schultz 1997, Williams 1998) and has greater tolerance to cold, ice, and fusiform rust (Hepting 1971, Mattoon 1915). Given shortleaf pine's greater tolerance, it can serve as a buffer against climate change and disturbance.

Both loblolly pine and shortleaf pine will resprout when top-clipped above the dormant buds, which develop in the axils of the primary needles, but shortleaf pine is a much more aggressive resprouter (Lilly and other 2012a, Will and others 2013). In regard to fire, shortleaf pine seedling and sapling resprouting after topkill is facilitated by a morphological adaptation, i.e., basal crook, which insulates dormant buds during fires (Mattoon 1915, Bradley and others 2016). The basal crook forms when the seedling bends just below the hypocotyl region for a brief period and then resumes upright growth just above the hypocotyl region. This process results in a horizontal section 2.5-7.5 cm long (Mattoon 1915) that places the dormant buds at the soil surface where fire is cooler, and the accumulation of soil and duff may further protect and insulate. While open-grown seedlings develop this crook in the first year, development may be delayed several years in shaded individuals.

Our overall goal was to determine if planting depth of loblolly pine and shortleaf pine seedlings influenced survival after fire. We hypothesized that planting seedlings deeper would facilitate resprouting of loblolly pine by protecting their dormant buds from fire and increase resprouting of shortleaf pine by providing further protection of the basal crook region. We also evaluated whether resprouting after fire would be different between containerized and bare-root shortleaf pines seedlings. A final objective was to determine if bare-root shortleaf pine without basal crooks resprout after fire. Often nursery-grown shortleaf pine seedlings do not develop a basal crook until after planting.

METHODS

Loblolly pine bare-root and containerized seedlings and shortleaf pine containerized seedlings were obtained from Oklahoma Forestry Services. Shortleaf pine bare-root seedlings were obtained from Arkansas Forestry Commission. All seedlings were 1-0. Seedlings were planted in the field in March 2016 in Idabel, OK. Burning to cause topkill was conducted in March 2017 and seedlings were monitored for resprouting for the 2017

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growing season. Diameter of each seedling at root collar was measured with calipers at time of planting and again just prior to burn. Height was also measured just prior to burning. Replanting to replace dead seedlings was conducted 14 days after the initial planting. Planting depths (see below) were initially established at time of planting, but depth to the hypocotyl region was reestablished just prior to burn in cases where there was soil movement or settling.

Fresh, air-dried pine litter (0.6-0.8 kg) was piled in a 5- to 7-cm-deep, 0.5-m^2 circle at the base of each seedling to serve as fuel. A handheld Fluke 51-II thermometer (Fluke, Raleigh, NC, USA) recorder with type k thermocouples positioned next to seedling stem at ground level was used to measure temperature during the burn. Most temperatures exceeded 450 °C and all seedlings sustained topkill. Ambient air temperature ranged from 4.4 to 18.3 °C and relative humidity ranged from 44 to 74 percent during the burning.

Primary Study

The objectives of the primary study were to compare resprouting following fire of containerized and bare-root shortleaf pine and loblolly pine with dormant buds at different depths. Both containerized and bare-root shortleaf pine were planted at three depths: 1) dormant bud 2 cm above soil surface, 2) dormant bud at soil surface, and 3) dormant bud 2 cm below soil surface. Only seedlings with a basal crook were used. Both containerized and bare-root loblolly pine were planted at four depths: 1) root collar 2 cm above soil surface, 2) root collar at soil surface, 3) dormant buds at soil surface, and 4) dormant buds 2 cm below soil surface. The primary study contained 15 replications at time of planting and 14 treatments (shortleaf: 2 (containerized, bare-root) x 3 depths; loblolly: 2 (containerized, bare-root) x 4 depths) for a total of 210 seedlings. Fisher's exact test was used to test for differences in proportion of seedlings resprouting between planting depths, taken two at a time (shortleaf: 3 tests, loblolly: 6 tests). Differences in seedling size among species and planting stock (4 treatments: shortleaf—containerized, shortleaf—bare-root, loblolly—containerized, and loblolly—bare-root) were tested using one-way analysis of variance both at time of planting and immediately before burning.

Secondary Study

The secondary study consisted of bare-root shortleaf pine with and without crooks. Seedlings were planted at three depths: 1) dormant buds 2 cm above soil surface, 2) dormant buds at soil surface, and 3) dormant buds 2 cm below soil surface. The secondary study contained 10 replications and 6 treatments (2 (with and without basal crook) x 3 depths) for a total of 60 seedlings. Fisher's exact test was used to test for differences in proportion of seedlings resprouting between planting depths, taken two at a time (3 tests).

RESULTS

Primary Study

In March 2016, at time of planting, average root collar diameters of bare-root loblolly pine (8.0 ± 0.2 mm; mean ± standard error) and shortleaf pine seedlings (6.7 ± 0.2 mm) were larger ($p < 0.05$) than diameters of the containerized loblolly pine (5.6 ± 0.1 mm) and shortleaf pine seedlings (5.2 ± 0.1 mm).

In March 2017, just prior to burning, average root collar diameters of loblolly pine containerized (10.8 ± 0.3 mm) and bare-root (11.9 ± 0.4 mm) seedlings were larger ($p < 0.05$) compared to shortleaf pine containerized (9.8 ± 0.2 mm) and bare-root (8.3 ± 0.2 mm) seedlings. Loblolly pine containerized (59.4 ± 1.4 cm) and bare-root seedlings (56.8 ± 2.2 cm) were taller ($p < 0.05$) compared to containerized (53.5 ± 1.5 cm) and bare-root (41.6 ± 2.3 cm) shortleaf pine seedlings.

No loblolly pine resprouted following topkill regardless of planting depth or seedling type and loblolly pine was excluded from analyses. There was significant mortality of shortleaf pine during the initial growing season due to herbivory and water stress. At the time of burning in March 2017, there were 94 live seedlings out of the 150 initial shortleaf pine planted. Therefore, for shortleaf pine, data from the primary and secondary studies were pooled to test for planting depth effects as both contained the same treatments.

Overall (containerized and bare-root treatments combined), only 35 percent (33 of 94 burned seedlings) of shortleaf pine seedlings resprouted

Table 1—Number and percent of total burned shortleaf pine seedlings resprouting at three planting depths

Dormant bud placement	Total burned	Dead	Resprouted Number	Resprouted Percent
Above (shallow)	25	23	2	8.0
At (buds at soil surface)	33	21	12	36.4
Below (deep)	36	17	19	52.8

Bare-root and containerized seedlings are combined from the primary and secondary studies. No loblolly pine resprouted.

(table 1). Seedlings with dormant buds at the soil surface (p = 0.01) and 2 cm below the soil surface (p = 0.0002) had significantly greater resprouting than the seedlings with dormant buds 2 cm above the soil surface. Seedlings with dormant buds 2 cm below the soil surface tended to have greater resprouting than seedlings with dormant buds at the soil surface, but this difference was not statistically significant (p = 0.13).

The comparison of containerized vs. bare-root seedling survival was restricted to the primary study (60 of each type planted, 26 bare-root and 30 containerized survived to be burned). Half of the burned bare-root shortleaf pine seedlings resprouted, which was significantly greater (p = 0.01) than the percent of containerized shortleaf pine seedlings that resprouted (table 2). While resprouting was lower in containerized seedlings than bare-root seedlings, both types of seedlings exhibited the same trend in sprouting with planting depth. Containerized seedlings resprouted at rates of 0, 8.3, and 40.0 percent for seedlings with dormant buds above, at, and below soil surface. Bare-root seedlings resprouted at rates of 16.6, 44.4, and 72.3 percent for seedlings with dormant buds above, at, and below soil surface.

Secondary Study

When comparing resprouting of shortleaf pine with and without the basal crook at time of planting (30 of each type planted with only 19 surviving to be burned), no significant differences were observed. Shortleaf pine seedlings with a crook at time of planting resprouted at a rate of 42 percent (8 of 19) compared to 52 percent (10 of 19) of shortleaf pine seedlings with no crook at time of planting (p = 0.75).

DISCUSSION

Shortleaf pine resprouts after fire while loblolly pine generally does not (Bradley and others 2016, Williams 1998). In this study, fire killed every loblolly pine seedling regardless of planting depth. Loblolly pine can resprout when topclipped (Lilly and others 2012a, Will and others 2013) or if the dormant buds are protected during the fire (Bradley and others 2016). Bradley and others (2016) mounded soil around the base of loblolly pine to protect dormant buds during fire, but then removed the soil within several hours after burning. In the current study, soil was not removed from around the base of the loblolly pine seedlings and likely hindered resprouting. From this result, it appears that operationally planting loblolly pine deeper will not increase its ability to resprout after fire.

Planting shortleaf pine seedlings deeper increased resprouting. Two seedlings resprouted even when the dormant buds were exposed to fire. This was somewhat surprising and likely due to the aggressive resprouting capacity of shortleaf pine combined with the heterogeneity of fire such that the exposed dormant buds of these two trees were not exposed to temperature high enough to kill them. Seedlings planted with dormant buds at the soil surface resprouted at a rate of around 36 percent which was lower than the 71 percent reported by Bradley and others (2016). The difference could be due to factors such as genetics, fuel conditions, ambient conditions during fire, etc.

Bare-root shortleaf pine seedlings resprouted significantly more than containerized. Although not significant, the root collar diameters of bare-root shortleaf pine seedlings (8.3 mm) tended to be smaller just prior to burn compared to the containerized shortleaf pine seedlings (9.8 mm). Lilly and others (2012b) found that smaller seedlings exhibited greater resprouting, but did not see a reduction in sprouting capacity until root collar diameters approached 20 mm. Only one seed source for each seedling type was compared after a single growing season, so it is possible that genetics or other factors related to seedling type influenced resprouting.

Based on our study, presence of a basal crook at time of planting does not affect ability to resprout after fire. Crook formation often occurs after field planting, and we observed this also, but did not quantify. From an operational standpoint, the presence of crook at time of planting is not crucial to resprouting after fire. Planting deeper, however, will afford protection of the dormant bud, regardless of presence or absence of crook.

Table 2—Number and percent of total burned bare-root and containerized shortleaf pine seedlings resprouting

			Resprouted	
Seedling	Total burned	Dead	Number	Percent
Containerized	30	25	5	16.7
Bare-root	26	13	13	50.0

Management Implications

In our study, none of the loblolly pine seedlings resprouted after fire, supporting that fire is effective in eliminating loblolly pine seedlings. Planting shortleaf pine seedlings deeper increased their ability to resprout after fire and should be considered. Presence of a basal crook at time of planting had no effect on shortleaf pine resprouting success after fire. Seedlings without crooks often form one when planted in the field. Alternatively, placing the hypocotyl region just below the soil surface at time of planting will protect the dormant buds regardless of whether a basal crook eventually forms or not. When planting shortleaf pine seedlings, establishment of unwanted loblolly pine or shortleaf x loblolly pine hybrids can pose a major challenge. However, fire kills most hybrids and loblolly seedlings (Bradley and others 2016) and fosters shortleaf pine-dominated stands (Stewart and others 2015).

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