EFFECTS OF SITE PREPARATION SUBSOILING AND PRESCRIBED BURNING ON SURVIVAL AND GROWTH OF SHORTLEAF PINE IN THE MARK TWAIN NATIONAL FOREST: RESULTS AFTER 20 GROWING SEASONS

David Gwaze, Ross Melick, Lynn McClure, Charly Studyvin, and David Massengele[1]

ABSTRACT.—The objective of this study was to evaluate the effect of subsoiling (ripping) and prescribed burning on height, survival, diameter, volume, and competition of planted shortleaf pine (*Pinus echinata* Mill.). The study was established at the Salem Ranger District, Mark Twain National Forest. The treatments were subsoil/burn, burn, and control with no site preparation. Height was assessed at 5 and 20 years; survival, diameter, volume, and competition were assessed at 20 years. Survival rate was only 469 trees/ha in the control treatment, while the survival rate was 1680 trees/ha in the burn treatment and 1600 stems/ha in the subsoil/burn treatment. Subsoil/burn treatment improved height growth by 55.8 percent at 5 years, and 32.3 percent at 20 years over the control treatment. Although, subsoil/burn treatment improved volume by 46.5 percent over the control, and burn treatment improved volume by 30.6 percent at age 20 over the control, these improvements were not statistically significant. Twenty years after planting, these results suggest that site preparation is critical for regenerating shortleaf pine and that subsoiling after burning does not provide additional growth responses or increased survival to that attributed to burning.

INTRODUCTION

Shortleaf pine forests in Missouri have been severely altered by logging, grazing and fire suppression, prompting restoration efforts within the state. The future success of these restoration efforts requires a better understanding of site preparation methods. Many of the shortleaf pine sites being restored have a dense soil layer (fragipan) at soil depths near 18 inches, and hardwoods present serious competition problems for the planted shortleaf pine seedlings. Subsoiling (ripping) the soil may provide openings in the fragipan that allow root growth into and below this dense layer. In addition, subsoiling may reduce soil bulk density, improve overall root development, and increase nutrient uptake. Subsoiling reduces hardwood competition around the seedling during the first few years after planting, eliminating the need for follow-up release treatment from competing hardwoods (Wittwer et al. 1986). Subsoiling can be done alone, but is usually easier, safer, and more uniform if preceded by a slash-reduction treatment such as prescribed burning. Burning prior to subsoiling reduces slash, improves the visibility of stumps and other obstacles, reduces equipment wear and tear, and reduces the time spent freeing ripper teeth of accumulated slash, which hinders and reduces subsoiling depth (Fryar 1984). Burning reduces competition from grass, forbs and hardwoods. Few reports quantify benefits of subsoiling on shortleaf pine in the USA. In Georgia, subsoiling increased height growth by 17 percent, root-collar diameter by 15 percent and tree volume by 38 percent five years after planting compared to the control (Berry 1979). In Arkansas, subsoiling improved survival by 20-25 percent and competition from weeds and other vegetation was reduced (McClure 1984). In Missouri, subsoiling improved volume by 41.2 percent after two growing seasons, but reduced it by 10.2 percent at 16 years (Gwaze et al. 2006).

Prescribed burning is used for regenerating southern pines by direct seeding, planting, or natural regeneration (Pritchett 1979). It is probably the most economical site preparation tool (KcKee 1982). Fire alone can control competing vegetation until seedlings become established. Prescribed fire has an advantage over mechanical site preparation methods such as subsoiling in that less accessible sites (e.g., steep slopes) can easily be prepared using burning. Although site preparation burning is used in Missouri, there is no existing documentation of its effect on survival and growth of planted shortleaf pine. In Florida, burning improved neither survival nor growth of slash pine 10 years after planting (Outcalt 1982). Generally, prescribed burning is believed to be most effective when used in conjunction with chemical or mechanical site preparation methods (Frey 1984).

[1]Resource Scientist (DG), Missouri Department of Conservation, 1110 S. College Avenue, Columbia, MO 65201; Former Silviculturist (RM) and Silviculturist (CS), Mark Twain National Forest, 401 Fairgrounds Road, Rolla, MO 65401, Former Silviculturist (LM) and Silviculturist (DM), Mark Twain National Forest, 1301 South Main, Salem, MO 65560. DG is corresponding author: to contact call (573)882-9909 ext. 3320 or email at David.Gwaze@mdc.mo.gov

The objective of the study is to quantify the long-term effects of subsoiling and prescribed burning on survival and growth of planted shortleaf pine seedlings at Mark Twain National Forest.

MATERIALS AND METHODS

Study Site

The study is located in stand 15, compartment 169, on the Salem Ranger District, Mark Twain National Forest. The compartment is located in SE of SW 1/4 Section 23, T32N, R3W in Reynolds County, southeast Missouri. The stand is 17 acres, has a SW aspect, and runs from a gentle ridgetop on the NE to a drainage on the SW. Slopes exceed 35 percent on spots, but the slope average is 20 to 25 percent. Soils on the ridge tops are Captina series, which characteristically have a fragipan at a depth around 18 inches. Clarksville soils are generally found on the side slopes, and these soils are excessively drained and lack fragipans. The original stand was a 60-year-old oak-pine stand, dominated by black oak (*Quercus velutina*), scarlet oak (*Q. coccinea*), post oak (*Q. stellata*), white oak (*Q. alba*), hickory (*Carya* spp.) and some scattered shortleaf pine (*Pinus echinata*). The overall site index for the stand is 60 based on black oak. The stand was clearcut in 1983.

Site Preparation, Planting, and Assessment

The southeast 6 acres of the stand (control) received no site preparation. In June 1984, the northwest 11 acres received a good, hot burn. Approximately half of the burned area was subsoiled to a depth of 20 inches in fall 1984. The other half of the burned area was not subsoiled. The subsoiling was done using a single-toothed 25-inch ripper with furrows spaced 8 feet apart. Unimproved 1-0 shortleaf pine seedlings were planted on a spacing of 8 x 8 feet in spring 1985.

In June 1989, "V"- shaped transects, with the point of the "V" down hill, were established in the burned plus subsoiled area and the control area. Transects in both areas ran from the ridge on the NE side at an azimuth of 2700 and returned at an azimuth of 300. The point of the "V" was located on about the same contour line in both treatments. Transects were designed to sample across possible variation in slope position. A total of 44 trees and 27 trees located along the transect were measured for height in subsoil/burn and control treatments, respectively. In July 2004 approximately the same trees were assessed for height. Because the "V" transects did not allow assessment of survival and competition, five random plots in each treatment (subsoil/burn, burn, and control) were established to assess survival and hardwood competition in July 2004. Each plot was 100 square meters (10 m x 10 m). The number, species, height, and diameter at breast height of all trees in a plot were measured. Height was measured using a height pole and diameter at breast height (DBH, cm) using a diameter tape.

Conical volume (V, dm^3 per tree) was calculated for all trees using the following equation:

$$V = \frac{1}{3}\pi\left(\frac{D}{2}\right)^2 H$$

where D = diameter at breast height (cm), and H = height (m).

Statistical Analysis

Analyses were carried out for survival, height, diameter, and volume for each age separately. Survival and stocking were analyzed using chi-squared tests. Growth data from the "V" transects were analyzed using pooled T-tests. The assumptions of equal variances and normality were tested prior to the pooled T-tests, and were accepted. Growth data from plots were analyzed using the PROC GLM procedure in SAS Version 9.1 (SAS Institute Inc., Cary, NC). The following linear model was used for analyzing the data from plots:

$$Y_{ij} = \mu + T_i + e_{ij}$$

where Y_{ij} is the j^{th} observation on the i^{th} treatment, μ is the population mean, T_i is the fixed effect of treatment, and e_{ij} is the error term. All analyses were carried out at the $P \leq 0.05$ probability level.

RESULTS

Survival

After 20 growing seasons, planted shortleaf pine had an average density of only 469 stems/ha in the control treatment, a significantly lower density ($P < 0.001$) than in the burn treatment (1680 stems/ha) and in the subsoil/burn treatment (1600 stems/ha) (Fig. 1). Survival in the areas that were prepared (burn and subsoil/burn treatments) was not significantly different, suggesting that subsoiling after burning does not provide additional increase in survival to that attributed to just burning. Pine stocking in the control treatment was 469 trees per ha (190 trees per acre), a

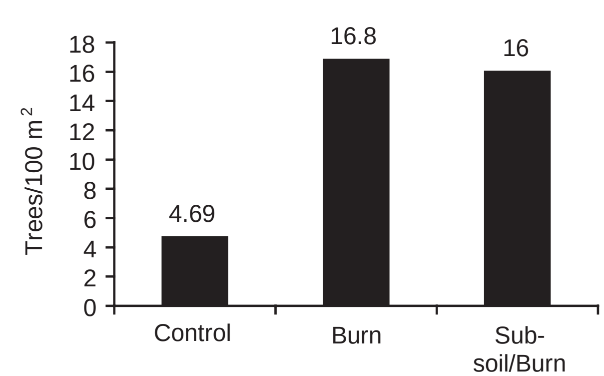

Figure 1.—Survival of shortleaf pine trees after 20 growing seasons.

stocking below the minimum required for a fully stocked shortleaf pine stand in Missouri.

Growth

Transects

Trees in the subsoil/burn treatment had significantly greater height growth ($P < 0.001$) than those in the control treatment at 5 and 20 years (Fig. 2). Subsoiling after burning increased height growth by 55.8 percent and 32.3 percent at age 5 and 20, respectively. The increased height advantage of subsoiling appears to decline with age.

Random Plots

Trees in the subsoil/burn and burn treatments had significantly greater height growth than those in the control treatment at 20 years (Table 1). However, no significant improvement in height growth was attributable to subsoiling over that obtained from burning alone. Burning alone increased height by 23.4 percent, while burning plus subsoiling increased height by 24.2 percent (Table 1). Although subsoiling after burning increased diameter and volume over the control treatment by 17.2 percent and 46.5 percent, respectively, these improvements were not statistically significant because of a large variation in diameter measurements in the control treatment.

Hardwood Competition

Twenty years after planting, naturally regenerated hardwood species had an average density of 1988 stems/ha in the control treatment, a much higher number than in the burn treatment (1422 stems/ha) and in the subsoil/burn treatment (1244 stems/ha) (Table 2). The differences between treatments were not statistically significant ($P = 0.100$).

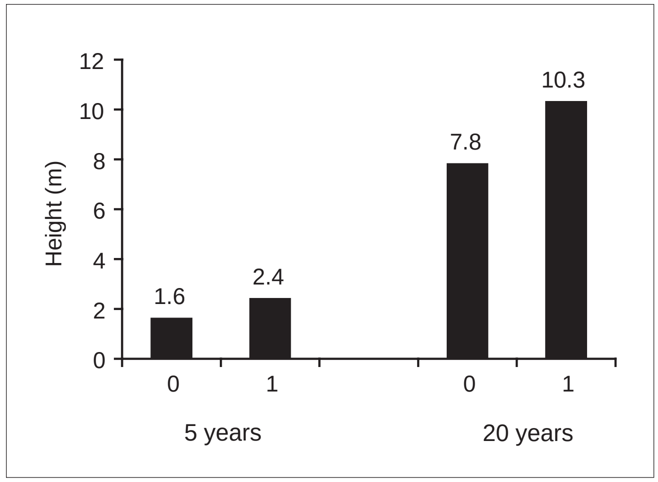

Figure 2.—Treatment effects (0 = control, 1 = subsoil/burn) on height growth at 5 and 20 years estimated from "V" transects.

Hardwoods were significantly taller in the burn treatment than in the control and subsoil/burn treatments ($P = 0.03$). Hardwoods in the subsoil/burn treatment were smaller in diameter compared to those in the burn and control treatments ($P < 0.001$).

DISCUSSION

Twenty years after field establishment, subsoiling improved survival compared to the control. Results from this study are consistent with other studies in Georgia (Berry 1979) and Missouri (Gwaze et al. 2006) which showed that subsoiling improved survival of shortleaf pine. The improvement in survival in this study was much higher than that reported by

Table 1.—Treatment effects on height, diameter, and volume at 20 years estimated from square plots. Standard errors of the means are in parentheses.

Trait	Subsoil/Burn	Increase (percent)	Burn	Increase (percent)	Control	P-value
Height (m)	9.76 (0.22)	24.2	9.69 (0.23)	23.4	7.86 (0.47)	< 0.001
Diameter (cm)	11.83 (0.47)	17.2	11.38 (0.39)	12.8	10.09 (0.92)	0.174
Volume (dm^3)	46.04 (3.48)	46.5	41.05 (2.83)	30.6	31.43 (5.51)	0.088

Table 2.—Status of naturally regenerated hardwood vegetation 20 years after planting.

	Subsoil/burn	Burn	Control	P-value
Stocking (trees/ha)	1244	1422	1988	0.100
Height (m)	6.32	7.09	6.45	0.03
Diameter (cm)	4.79	6.38	6.56	< 0.001

Gwaze et al. (2006) partly because the control was treated differently in the two studies. In Gwaze et al.'s study, the control treatment was bulldozed, while in this study the control treatment did not receive any site preparation. Because of the more intensive site preparation method in the control treatment in their study, the improvement in survival due to subsoiling was unimportant 16 years after planting. Despite the low survival in the control treatment in this study, the stocking of pine (190 stems per acre) may be acceptable given Mark Twain National Forest's current emphasis on pine-oak mixtures rather than pine plantations. Subsoiling did not provide benefits in survival beyond those provided by burning alone. Because the number of trees in the burn and subsoil/burn was more than 1500 trees per hectare (607 trees per acre), fewer seedlings need to be planted in both treatments to achieve a stocking of 400 seedlings at 5 years. In Missouri, a pine stand is considered fully stocked if it has 400 shortleaf pine seedlings per acre at 3-5 years (Gwaze et al. 2006).

When compared to the control, height growth was significantly improved by subsoiling at 5 and 20 years, a result consistent with other studies in the United States. Berry (1979) reported that height of shortleaf pine was improved by 17 percent by subsoiling at 5 years of age in a Piedmont site in Georgia. In Oklahoma, subsoiling increased height of loblolly pine by 10 percent after two growing seasons (Wittwer et al. 1986). In contrast, long-term results from studies in Missouri revealed that subsoiling at 16 years had no significant effect on height of shortleaf pine (Gwaze et al. 2006). Burning alone improved growth equally as well as subsoiling and burning. The increased growth in the burn/subsoil treatment in this study resulted from improved soil physical properties, improved short-term nutrient availability, improved soil-water extraction, and/or reduced hardwood competition. The increased growth in the burn treatment the result of improved short-term nutrient availability and reduced hardwood competition. Because productivity on the two prepared treatments was similar, the increased height growth on prepared treatments compared to the control treatment is likely to be the result of reduced hardwood competition.

Hardwood competitors reinvaded regardless of the site preparation treatment. However, competing hardwoods were fewer and smaller when the site was prepared by burning or burning and subsoiling. Burning is likely to have killed many hardwoods, and subsoiling damaged root systems, which probably reduced the vigor of subsequent hardwood sprouts. Survival of trees planted in the control treatment (unprepared site) could have been improved by follow-up release to control the hardwood competition a few years after planting. However, follow-up release may not be necessary when the site is prepared using burning or subsoiling after burning.

Our results are not consistent with other studies in Florida where burning did not improve survival or growth of slash pine 10 years after planting (Outcalt 1982). The relative effectiveness of prescribed burning depends on site characteristics and burn conditions. It is not clear why subsoiling after burning provided no benefit in survival, growth and hardwood competition beyond what was provided by burning in our study. It may be that the subsoiling depth was not sufficient to break the fragipan or that there are other limiting factors below the fragipan that restrict tree growth in the subsoiling treatment. It is difficult to relate the results to soil properties because information on soil properties is absent. Results from this study suggest that burning can be an effective site preparation method. Burning as a site preparation technique also can be unpredictable, however, due to varying amounts and types of fuel, variations in slope and aspect, and unstable weather conditions. Subsoiling might provide additional benefits on poorer sites which are either severely compacted or rocky.

CONCLUSION

This study demonstrated that site preparation is an important factor in regenerating shortleaf pine successfully. Without site preparation, high mortality and poor growth can be expected from the planted shortleaf pine. The study suggests that at 20 years after planting, subsoiling after burning does not provide additional growth responses or increased survival over that attributed to burning alone. Thus, burning might be the preferred site preparation method because the extra cost of subsoiling may not be justified.

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