ARTIFICIALLY REGENERATING LONGLEAF PINE ON WET SITES: PRELIMINARY ANALYSIS OF EFFECTS OF SITE PREPARATION TREATMENTS ON EARLY SURVIVAL AND GROWTH

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Abstract—Our study, conducted over two years on poorly drained, sandy sites in Onslow County, NC, compared the effects of eight common site preparation treatments on early survival and growth of planted longleaf pine seedlings. Through two growing seasons, we found survival to be similar across all treatments ($p = 0.8806$), but root collar diameter was greatest with combinations of mounding and herbicides or bedding and herbicides ($p < 0.0001$). After the first growing season, treatments that included herbicides resulted in the greatest reduction in abundance of surrounding vegetation ($p < 0.0001$), but by the second growing season mounding treatments provided the best vegetation control ($p < 0.0001$). Mounding and bedding treatments reduced soil moisture when compared to flat planting in both growing seasons ($p < 0.0001$). When used properly, site preparation treatments that reduce competition from surrounding vegetation and relieve excess soil moisture will help improve early growth rates of artificially regenerated longleaf pine on wet sites.

INTRODUCTION

Restoration of the longleaf pine (*Pinus palustris*) ecosystem is an important topic for landowners within the Southeastern United States. The natural range of longleaf pine once dominated the Atlantic coastal plain and included sites that ranged from well drained sandhills to poorly drained flatwoods (Boyer 1990). However, historic land use and forest management practices that included fire exclusion have resulted in widespread conversion of longleaf pine sites to other forest types. Many landowners now interested in restoring longleaf pine are faced with the problem of successful seedling establishment, especially on wet sites that support an abundance of competing vegetation.

Although longleaf pine may be established using natural regeneration methods (Croker and Boyer 1975), artificial regeneration must be used in areas that no longer contain mature pines in the overstory to provide seed (Barnett 1999). Longleaf pine is considered intolerant of competition for available resources (Boyer 1990, Wahlenburg 1946) and therefore thrives in the absence of canopy trees. Following conventional southern silviculture, regeneration protocols would include removal of canopy trees and implementation of site preparation techniques to improve growing conditions for planted longleaf pine seedlings.

Common site preparation techniques of this region include mechanical treatments, chemical applications, and prescribed fire. Of these, prescribed fire is considered an essential ecological process shaping the structure and function of the longleaf pine ecosystem (Landers and others 1995), and periodic fire is a necessary occurrence for good seedling establishment. However, mechanical or chemical treatments may also be used to promote early seedling growth or survival by reducing competing vegetation and alleviating limiting growth conditions (Boyer 1988, Croker and Boyer 1975), and the use of mechanical treatments has been shown to be critical in the absence of prescribed fire (Croker 1975).

Poorly drained sites of the coastal plain present unique problems for land owners regenerating longleaf pine. First, because wet sites are typically highly productive, competitive pressures are high. The development of effective herbicides has provided opportunities for competition control through chemical application, and previous work has found herbicides to benefit longleaf pine seedling establishment when used alone (Nelson and others 1982) or in combination with mechanical treatments (Boyer 1988). Second, excess moisture has been reported as a limiting factor in southern pine seedling growth. Previous studies on loblolly pine (*Pinus taeda*) and slash pine (Pinus elliottii) suggest that mechanical treatments such as bedding and mounding result in greater seedling growth by increasing soil drainage and raising the root zone above the water table (Haywood 1987, Outcalt 1984, Pritchett 1979). However, it is not clear whether longleaf pine seedlings will exhibit a similar response to mechanical treatments on wet sites.

This study was designed to evaluate the effectiveness of various site preparation treatments used for regenerating longleaf pine seedlings on wet sites. We attempted to explore the influence of surrounding vegetation abundance and soil moisture on seedling response. Our specific objectives were to: 1) determine the effects of site preparation treatments on longleaf pine seedlings survival and growth and 2) quantify effects of site preparation treatments on surrounding vegetation and soil moisture. To fully understand the mechanisms behind seedling response to site-preparation, a more complete analysis of the effects of site preparation on resource availability is planned.

METHODS AND MATERIALS

Study Site

This study was conducted on Marine Corps Base Camp Lejeune, in Onslow County, NC, within the Atlantic Coastal Flatlands Section of the Outer Coastal Plains Mixed Forest Province (Bailey 1995). All study sites are on Leon fine sand,

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a Spodosols with light gray to white sand in the first 30 to 60 cm and a dark B horizon of organic accumulation. A hardpan beneath the surface impedes internal drainage and creates poorly to very poorly drained conditions. Historically, these sites were wet longleaf pine savannas and consisted of longleaf pine overstories with herbaceous ground layers dominated by grasses (e.g. Aristida spp., Andropogon spp., Schizachyrium spp.), sedges, and a diverse mix of forbs.

Experimental Design

The study was a randomized complete block design, with eight treatments replicated on five blocks. Each experimental unit was 0.6-ha and included a 0.4-ha measurement unit. Treatment application included two types of site preparation: treatments designed to control competing vegetation (chopping or herbicides) and treatments that impact soil drainage (flat planting [no treatment], mounding, or bedding). The eight treatments of this study were various combinations of these site preparations, and included a check (F), chopping and flat planting (CF), herbicide and flat planting (HF), chopping and mounding (CM), herbicide and mounding (HM), chopping and bedding (CB), herbicide and bedding (HB), and chopping, herbicide, and bedding (CHB).

Prior to treatment application, all canopy trees were removed and remaining vegetation was sheared. Vegetation control treatments (chopping or herbicides) were applied to each experimental unit first, followed by the appropriate planting-site treatment. Chopping was done with a 2.4-m drum chopper pulled by a crawler tractor (Cohen and Walker 2005). The herbicide treatment, made up of 0.70 kg/ha of imazapyr and 0.56 kg/ha triclopyr, was broadcast at a rate of 280 L/ha. Mounds approximately 1.2-m-wide were created with an excavator and placed in rows as opposed to random distribution typically associated with mounding preparation. We used a 6-disc bedding harrow to create 2.1- to 2.4-m-wide beds. Treatment application was complete in August 2003. All study sites were burned following treatment application to further prepare them for planting. In December 2003, container-grown seedlings from locally collected seed were hand planted at 4.5 m by 2 m spacing.

Data Collection

A sub-sample of 45 seedlings was randomly selected and permanently marked for measurement on each experimental unit. Seedling growth was monitored by measuring the diameter of the root collar with digital calipers. Survival was determined by monitoring mortality within the subsample of seedlings.

Of the 45 seedlings measured for seedling response data, we randomly selected 15 to determine abundance of surrounding vegetation. An approximately 1 m2 circular plot was centered at each selected seedling, and an ocular estimate of the percentage of the ground surface covered by vegetation was recorded. Cover classes were modified from the North Carolina Vegetation Survey (Peet and others 1998), as follows: (1) < 1, (2) 1 to 2, (3) 3 to 5, (4) 6 to 10, (5) 11 to 25, (6) 26 to 50, (7) 51 to 75, (8) 76 to 90, (9) 91 to 100 percent.

Percent soil moisture was measured at a 6-cm depth using a Theta Probe Moisture Meter (Delta-T Devices, Ltd.). Measurements were taken adjacent to 10 seedlings from each sub-sample per experimental unit. To reduce variability from weather conditions, all measurements within a single block were taken from 13:00 to 15:00. No measurements were taken within 24 hours of a precipitation event.

Data Analysis

We used one-way analysis of variance (ANOVA) to determine differences among the treatments for the seedling response variables (survival, growth), total vegetation abundance, and soil moisture. Significant differences among the treatments were determined using Tukey's LSD post-hoc test. Transformations were used to normalize data if necessary, and we used a level of significance of $\alpha = 0.05$.

RESULTS

Seedling Response

Seedling survival at the end of the first and second growing seasons was not affected by the site preparations (p = 0.5557, p = 0.8806, respectively) (fig 1). In 2004, survival ranged from 67.7 to 76.8 percent, with a mean of 72.5 percent. By the end of the second growing season, mean survival dropped to 59.1 percent and ranged from 57.1 to 64.5 percent. We found significant differences in root collar diameter among the various site preparation treatments in both 2004 (p = 0.0032) and 2005 (p < 0.0001) (fig 2). In 2004, there was a relatively narrow range of diameters, from 11.7 mm on CF to 13.4 mm on CHB. The check (F) and the chop treatment (CF) were significantly smaller than all other treatments. In 2005, growth differences were more pronounced. The check and CF remained the smallest among the treatments, with the greatest growth on CHB, HB, and HM. A more complete analysis of the effect of site preparation treatments on seedling response is presented in Knapp and others (2006).

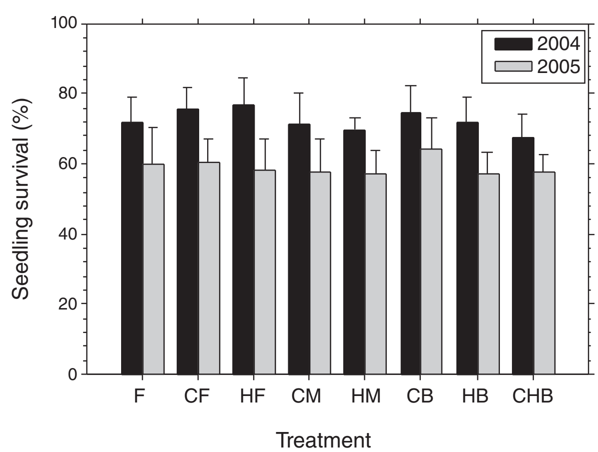

Figure 1—Seedling survival (%) through August 2004 and August 2005 for each treatment. Survival was not significantly different by treatment for either year (p = 0.5557, p = 0.8806, respectively). Error bars are one standard error. F = flat (check), CF = chop/flat, HF = herbicide/flat, CM = chop/mound, HM = herbicide/mound, CB = chop/bed, HB = herbicide/bed, CHB = chop/herbicide/bed.

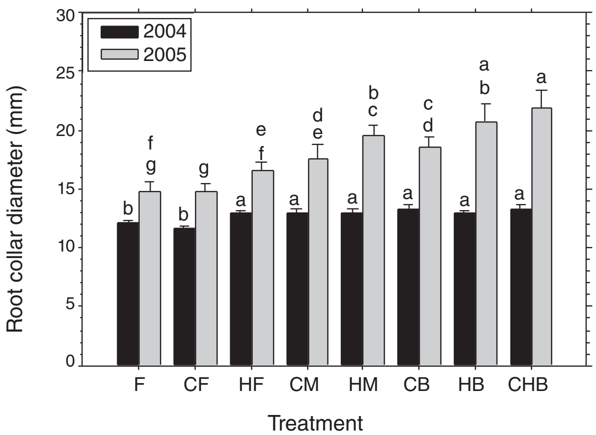

Figure 2—Mean root collar diameter (mm) in August 2004 and August 2005 for each treatment. Similar letters within a year indicate no significant difference. Error bars are one standard error. F = flat (check), CF = chop/flat, HF = herbicide/flat, CM = chop/mound, HM = herbicide/mound, CB = chop/bed, HB = herbicide/bed, CHB = chop/herbicide/bed.

Vegetation Cover

The treatments used in the study significantly affected the abundance of surrounding vegetation in both growing seasons (2004: $p < 0.0001$, 2005: $p < 0.0001$) (fig 3). In 2004, percent cover was highest on F, although not significantly different from CF. All other treatments reduced vegetation abundance to below 30 percent cover, although treatments with the least vegetation present included HM, HB, and CHB. Cover on F and CF remained the highest in 2005, followed by HF, CB, HB, and CHB. The lowest abundance of surrounding vegetation two years after treatment application was on HM and CM.

Soil Moisture

In 2004, there was significantly more soil moisture ($p < 0.0001$) present on HF (34 percent soil moisture) than any other treatment (fig 4). F and CF were not significantly different (28 percent), and all treatments including either mounding or bedding lowered moisture levels to around 20 percent. In 2005 ($p < 0.0001$), soil moisture on the three flat planted treatments was not significantly different and averaged 32 percent. Of the remaining treatments, soil moisture was lowest on HM (17 percent), although moisture levels only ranged from 17 to 22 percent for treatments including mounding or bedding.

DISCUSSION

The site preparation treatments used in this study did not significantly affect survival rates during the first two growing seasons following treatment application. In a study on well-drained sites of FL, bedding reduced survival of planted longleaf pine seedlings by 11 percent when compared to a shear and rake treatment (Loveless and others 1989). Additionally, Boyer (1988) found that container-grown seedlings planted on sites treated with herbicides had lower survival rates (71 percent) than those receiving no treatment (87 percent) three years after planting. Early longleaf pine survival has been reported to vary by site (Boyer 1988, Rodriguez-Trejo and others 2003) and the impact of site preparation is also likely to be dependent on site conditions. However, our results suggest that container-grown seedlings planted on poorly drained coastal plain sites have fairly good survival regardless of site preparation.

All of the treatments used in our study, with the exception of chopping alone, resulted in greater root collar growth than the untreated check. In the first growing season, the differences in root collar diameter among the treatments were small; by the next year, however, the differences were quite pronounced. Grass stage emergence, a critical event in the establishment of a longleaf pine stand, typically occurs when seedling root collar diameter approaches 25 mm (Boyer 1990). Under unfavorable conditions, seedlings have

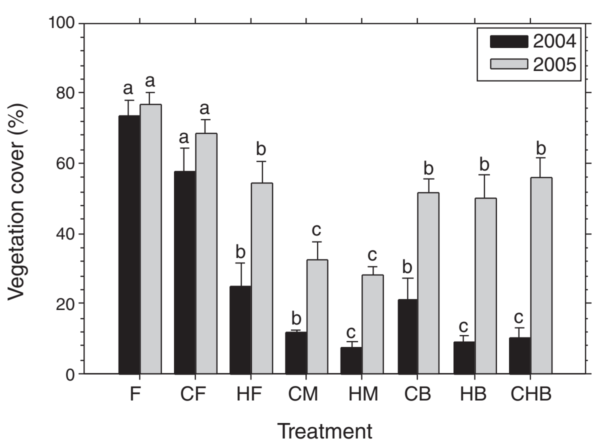

Figure 3—Percent cover of surrounding vegetation in August 2004 and August 2005 for each treatment. Similar letters within a year indicate no significant difference. Error bars are one standard error. F = flat (check), CF = chop/flat, HF = herbicide/flat, CM = chop/mound, HM = herbicide/mound, CB = chop/bed, HB = herbicide/bed, CHB = chop/herbicide/bed.

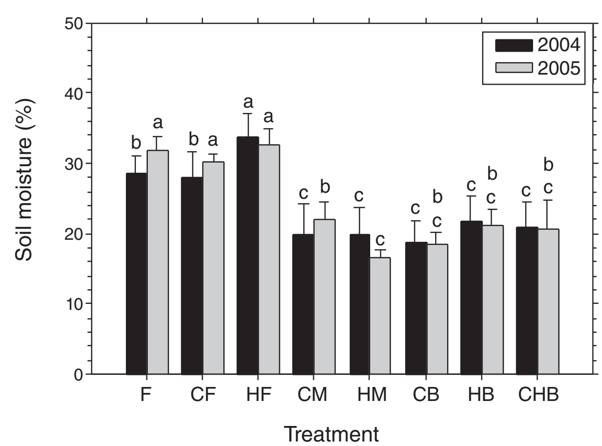

Figure 4—Percent soil moisture in 2004 and 2005 growing seasons for each treatment. Similar letters within a year indicate no significant difference. Error bars are one standard error. F = flat (check), CF = chop/flat, HF = herbicide/flat, CM = chop/mound, HM = herbicide/mound, CB = chop/bed, HB = herbicide/bed, CHB = chop/herbicide/bed.

the potential to remain in the grass stage for up to 10 years (Pessin 1944). In 2005, seedlings on F and CF averaged 14.8 mm while those on HM, HB, and CHB averaged 20.8 mm. We can expect seedlings on HM, HB, and CHB to emerge from the grass stage much earlier than those on CF and F, potentially resulting in long-term differences in stand production.

Our results are consistent with previous work suggesting that excess soil moisture on wet sites limits pine seedling growth. Flat planted sites had both the smallest seedlings and highest soil moisture contents, and treatments that reduced soil moisture coincided with large seedlings. Mounding was developed in wetlands of northern latitudes with a primary purpose of improving the drainage of planting sites (Londo and Mroz 2001, Sutton 1993) and has been shown to increase early growth of planted slash pine when applied in LA (Haywood 1987). Similarly, bedding is commonly used in the southeastern Unites States on poorly drained sites where moisture levels limit seedling growth (Miwa and others 2004). Treatments in our study that included either mounding or bedding reduced soil moisture by around 10 percent compared to those that were flat planted. Consequently, all treatments including mounding or bedding increased mean seedling growth over the check.

In our study, all treatments were expected to provide some degree of vegetation control; however, the abundance of surrounding vegetation was not significantly different between the chop-only treatment (CF) and the check in either growing season. Chopping, a site preparation designed to reduce competition by crushing standing vegetation, was apparently ineffective in decreasing abundance of surrounding vegetation. However, mechanical treatments often alter the structure and composition of ground layer vegetation (Conde and others 1983, Swindel and others 1986), and although chopping did not decrease percent cover of vegetation it may have changed the composition.

The effectiveness of vegetation control in this study appeared to change over time. In the first year, treatments that included herbicides and mechanical control had the lowest vegetation abundance; the next year, mounding treatments had significantly less vegetation cover than any other treatment. Mounding inhibits growth of vegetation by inverting the soil and providing a “cap” of mineral soil at the surface that creates a barrier to returning vegetation (Sutton 1993). Herbicides are often quite effective in the first year following application, but may not provide long term competition control without reapplication (Zutter and Zedaker 1987). As these stands continue to develop and surrounding vegetation returns, treatments that provide lasting competition control may become more important for seedling growth.

CONCLUSION

Artificial regeneration of southern pine species often includes the use of site preparation treatments that change growing conditions and increase seedling survival and growth. We found that increased growth of longleaf pine, like other southern pines planted on poorly drained sites, coincided with site preparations that improved soil drainage and reduced competing vegetation. Treatments resulting in the greatest seedling growth in this study included either bedding or mounding combined with herbicides. We found these treatments to be effective for rapidly increasing seedling growth, but recognize that they likely have other effects on the ecosystem. The objectives of the land manager will dictate whether these treatments are appropriate, and future research will help determine the effects of site preparation on other aspects of the ecosystem.

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