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Effects of site preparation treatments on early growth and survival of planted longleaf pine (*Pinus palustris* Mill.) seedlings in North Carolina

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Abstract

We tested the effects of eight site preparation treatments on early growth and survival of container-grown longleaf pine (*Pinus palustris* Mill.) seedlings. Treatments included an untreated check, six combinations of two initial vegetation control treatments (chopping or herbicide) with three planting site conditions (flat [no additional treatment], mounding, or bedding), and a more intense treatment consisting of chopping, herbicide, and bedding. All plots were prescribed burned after site preparation and before planting. Seedling survival was not significantly different among treatments at either 12 ($p = 0.768$) or 20 ($p = 0.881$) months after planting. Both bedding and mounding increased root collar diameter after 20 months when compared to flat treatments ($p \leq 0.002$). Between the vegetation control treatments, herbicides increased root collar diameter growth over chopping ($p = 0.002$) while chopping did not significantly differ from the check. The most root collar growth occurred on the chopping/herbicide/bedding and herbicide/bedding treatments, with the least on the flat (check) and chopping/flat treatments. The percentage of seedlings in height growth 20 months after planting was higher on bedding and mounding treatments when compared to flat treatments ($p \leq 0.003$). Herbicide was also significantly better than chopping with respect to the percentage of seedlings in height growth ($p = 0.016$). The treatments with the most seedlings in height growth were chopping/herbicide/bedding followed by herbicide/bedding and herbicide/mounding.

Keywords: Grass stage; Height growth; Longleaf pine; *Pinus palustris* Mill.; Root collar diameter; Site preparation treatments; Vegetation control

1. Introduction

Longleaf pine (*Pinus palustris* Mill.) restoration is a primary management goal of landowners throughout the southeastern United States. Due to the extensive decline of longleaf pine within its historical range, many areas no longer contain overstory trees to provide seed for natural regeneration and therefore require artificial regeneration for seedling establishment (Barnett, 1999). The development of container-grown seedlings has helped to make artificial regeneration practical (Barnett and McGilvary, 1997; Barnett, 2002; Hainds, 2002) by improving early survival and increasing growth rates when compared to bare root seedlings (Boyer, 1988). However, longleaf pine establishment is by no means guaranteed as long as seedlings remain in the grass stage. Under adverse conditions, seedlings may remain stemless for over 10 years (Pessin, 1944) and eventually be crowded out altogether. Rapid growth is the key to timely grass stage emergence, and site preparation treatments are a tool foresters have to increase early growth rates.

Preparing a site prior to planting is a common practice for the regeneration of southern pines. Previous studies have shown that mechanical site preparation treatments increase the survival and growth of planted longleaf pine seedlings and are essential in the absence of prescribed fire (Croker, 1975; Croker and Boyer, 1975; Boyer, 1988). However, these studies were conducted on well-drained sites, and the question remains as to how site preparation treatments affect growth and survival of longleaf pine seedlings planted on poorly drained sites. Past studies on other southern pines suggest that mechanical treatments such as bedding and mounding may increase seedling survival and growth by improving soil drainage, raising the root zone above the water table, and increasing aeration (e.g., Prichett, 1979; Outcalt, 1984; Haywood, 1987).

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McKee and Wilhite (1986) studied the effects of bedding on loblolly pine growth on sites ranging from poorly drained to moderately drained. Bedding improved growth on poorly drained sites but had no impact on sites with better drainage, indicating that the importance of using this treatment for seedling establishment increases as soil drainage decreases.

Because of longleaf pine's lack of tolerance for competition (Boyer, 1990), vegetative control is critical for seedling establishment. Vegetative control can be achieved mechanically or chemically. Bedding and mounding reduce competition by disturbing the soil surface while other treatments, such as chopping and shearing, are applied directly to competing vegetation (Miller, 1980; Miyata et al., 1982). Boyer (1988) found seedling survival significantly increased with the intensity of a chop treatment. Chemical treatments (i.e., herbicide applications) have also consistently improved the early survival and/or growth of planted longleaf pine seedlings, resulting in earlier emergence from the grass stage (e.g., Nelson et al., 1982, 1985; Creighton et al., 1987; Ramsey et al., 2003; Ramsey and Jose, 2004). However, studies on growth and survival response of longleaf pine seedlings have rarely involved combinations of mechanical and chemical treatments.

The overall objective of this study was to determine the effects of site preparation treatments on early survival and growth of longleaf pine seedlings planted on poorly drained sites. We addressed three specific questions: (1) Did planting site manipulation affect survival and growth? (2) Did vegetation control affect survival and growth? (3) Did application of both mechanical and chemical vegetation control provide added benefit to the survival and growth of planted longleaf pine seedlings?

2. Methods and materials

2.1. Study site

This study was conducted on Marine Corps Base Camp Lejeune, in Onslow County, NC. The area is located within the Atlantic Coastal Flatlands Section of the Outer Coastal Plains Mixed Forest Province (Bailey, 1995). The sites are on Leon fine sand (sandy, siliceous, thermic, Aeric Alaquod), which is characterized by light-gray to white sand within the first 30–60 cm, underlain by a dark B horizon of organic accumulation. A hardpan, cemented by organic and iron compounds, is present beneath the surface, with varying thickness of 15–25 cm. The soil is poorly to very poorly drained, with internal drainage impeded by the hardpan layer (Jurney et al., 1923; NRCS, 2005). Typical natural forests on Leon sand in this area are wet longleaf pine savannas and consist of longleaf pine overstories with predominantly wiregrass (*Aristida stricta* Michx.) and bluestem (*Andropogon* spp. and *Schizachyrium* spp.) ground layers (Frost, 2001). Additionally, the ground layer vegetation is made up of a diverse array of graminoids and forbs, and with frequent fire this site type is favorable for rare species such as roughleaf loosestrife (*Lysimachia asperulifolia* Poir.) and Venus flytrap (*Dionaea muscipula* Ellis). Other common species include *Ilex glabra* (L.) Gray, *Gaylussacia frondosa* (L.), and *Vaccinium* spp.

Areas selected for the study were previously dominated by mature stands of second growth longleaf pine. Overstories were harvested within two years prior to treatment application and any remaining vegetation was removed by shearing the sites.

2.2. Experimental design

The study was a randomized complete block design, with location as the blocking factor, and consisted of 8 treatments replicated on 5 blocks, for a total of 40 experimental units. Study treatments were randomly assigned to experimental units, which were approximately 0.4 ha in size and had 15 m buffers between plots to reduce treatment overlap. Eight site preparation treatments were applied in the summer of 2003, consisting of a check (no treatment applied), six combinations of two initial vegetation control treatments (chopping or herbicide) with three planting site conditions (flat [no additional treatment], mounding, or bedding), and a more intense treatment of chopping, herbicide, and bedding (Table 1). Within this paper, we refer to the treatments as follows: flat or check (F), chopping and flat (CF), herbicide and flat (HF), chopping and mounding (CM), herbicide and mounding (HM), chopping and bedding (CB), herbicide and bedding (HB), and chopping, herbicide, and bedding (CHB).

Vegetation control treatments were applied to the study sites first, followed by the planting site condition treatments. Treatment application was completed in August 2003. The chop treatment was done with a 2.4 m Lucas Drum Chopper, pulled by a TD15 Dresser crawler tractor (Cohen and Walker, 2005). The herbicide treatment, made up of 1.54 lb/ha of imazapyr (2-(4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl)-3-pyridinecarboxylic acid) and 1.24 lb/ha of triclopyr (3,5,6-trichloro-2-pyridinyloxyacetic acid), was mixed and broadcast at a rate of 280 l/ha. Mounds approximately 1.2 m wide were created with a New Forest Technology™ custom mounding bucket on a Caterpillar 320BL excavator. The mounds were placed in rows as opposed to the random distribution that is often associated with mounding site preparation. A Rome 6 disc Bedding Harrow, with three discs on each side, was used for the bedding treatment to create beds

Table 1
Summary of site preparation treatments implemented in the study

Treatment	Chopping	Herbicide	Flat	Mounding	Bedding
Flat (F)[a]			X		
Chopping/flat (CF)	X		X		
Herbicide/flat (HF)		X	X		
Chopping/mounding (CM)	X			X	
Herbicide/mounding (HM)		X		X	
Chopping/bedding (CB)	X				X
Herbicide/bedding (HB)		X			X
Chopping/herbicide/ bedding (CHB)	X	X			X

[a] Check.

2.1–2.4 m wide. A prescribed burn in October/November 2003, following treatment application, removed remaining vegetation on all plots, which further prepared the sites for planting.

Study plots were hand planted in December 2003 with container-grown seedlings grown from locally collected seed. Average root collar diameter of planted seedlings was 6.6 mm with a standard deviation of 1.2 mm. Planting was done by contracted crews who exhibited a wide range of planting skill, occasionally leaving plugs exposed or buried too deep in the soil. To avoid confounding planting quality with treatment effects, only seedlings planted with the root collar from 1 cm above the soil to 3 cm beneath the soil (i.e., terminal bud exposed and plug buried) were considered for repeated growth measurements in this study.

2.3. Data collection

In May 2004, a census of all seedlings was used to determine survival rates for each measurement plot after six months of growth. Seedlings were classified as 'alive' if any of the foliage was green. Additionally, a sub-sample of 45 seedlings was randomly selected and permanently marked for repeated measurement on each experimental unit. Seedlings were selected by randomly determining a seedling within the first planted row and selecting the other seedlings at a set interval to evenly distribute them throughout the plot, based on the number of rows per plot and approximate number of seedlings per row. Survival through August 2005 was monitored on the sub-sample of 45 seedlings per experimental unit during every subsequent growth measurement period.

Growth measurements were repeated for each sub-sampled seedling in May, June, July, August, and December 2004, and May and August 2005. Root collar diameter, considered the best way to monitor growth while the seedling remains in the grass stage, was measured using digital calipers. Care was taken not to cut the cambium of the seedlings. The distance from the soil surface to the base of the terminal bud was measured, and seedlings were considered to be in height growth when the terminal bud reached a height of 15 cm (Nelson et al., 1985; Boyer, 1988).

2.4. Data analysis

Seedling survival from May 2004 to August 2005 was monitored for only the 45 sub-sampled seedlings during each of the growth measurement periods. Overall seedling survivorship was calculated for each measurement period by applying the survival rates from the sub-sampled seedlings to the number of living seedlings at the start of May 2004, as determined by the complete census. Because the sub-sampled seedlings were randomly selected from only those seedlings with proper planting depth, our survival rates would likely be an overestimation of the actual survival rates for the entire population. However, a complete survey of seedling survivorship after one year (Cohen and Walker, 2005) found survival to differ from our estimate by only 1.2%. A paired *t*-test, by matching experimental units, indicated there was no significant difference in survival rates from the two estimates ($p = 0.402$). Therefore, we feel confident in using the survival rates calculated from the sub-sampled seedlings in the analysis.

Repeated measures analysis of variance was used to examine the treatment effects on seedling survival and root collar diameter, and changes in seedling survival and root collar diameter over time (from May 2004 to August 2005). Seedling survival and root collar diameter at 12 and 20 months after planting were also analyzed using analysis of variance, with the eight treatment combinations as factors, and a 3×2 factorial analysis of variance without the intense treatment (CHB) and check (F). The first factor in the factorial analysis (planting site condition) had three levels: flat (i.e., no treatment), mounding, and bedding. The second factor (vegetation control) had two levels: chopping and herbicide. We used analysis of variance, followed by pairwise comparisons, to draw conclusions about each treatment combination and specific site preparation factor (planting site condition or vegetation control).

After 20 months of growth, the number of seedlings in height growth (i.e., emerged from the grass stage) per sub-sample was calculated as a percentage of live seedlings measured. The data were log-transformed to improve normality (Krebs, 1999):

$$Y = \log(X + 1)$$

where Y is the transformed data and X is the original percentage. Analysis of variance followed by pairwise comparisons was used to determine differences among the eight treatments. A 3×2 factorial analysis of variance was also conducted to determine the effect of each specific factor. Additionally, the root collar diameter of each seedling in height growth was noted one measurement period prior to emergence from the grass stage. Treatment differences in root collar diameter prior to emergence were determined using analysis of variance. We used SAS (SAS Institute, 2003) and SYSTAT (SYSTAT Software Inc., 2002) software for the analysis. Unless otherwise stated, the level of statistical significance was set at $\alpha = 0.05$.

3. Results

3.1. Seedling survival

Although seedling survival significantly decreased over time ($p < 0.001$), no differences in survival were detected among the eight treatments ($p = 0.566$). There was no interaction between treatment and time ($p = 0.753$). First-year survival (through December 2004) ranged from 68% on HM to 75% on CB, with an overall mean of 70% (Fig. 1). At 20 months after planting (August 2005), seedling survival averaged 59%, with the lowest survival on HB (57%) and the highest survival on CB (65%). Based on factorial analysis of variance, there was no interaction between planting site condition and competition control treatment at either 12 ($p = 0.559$) or 20 months ($p = 0.645$). Neither planting site condition nor vegetation control treatment affected seedling survival at 12 or 20 months after planting ($p \geq 0.280$) (Table 2).

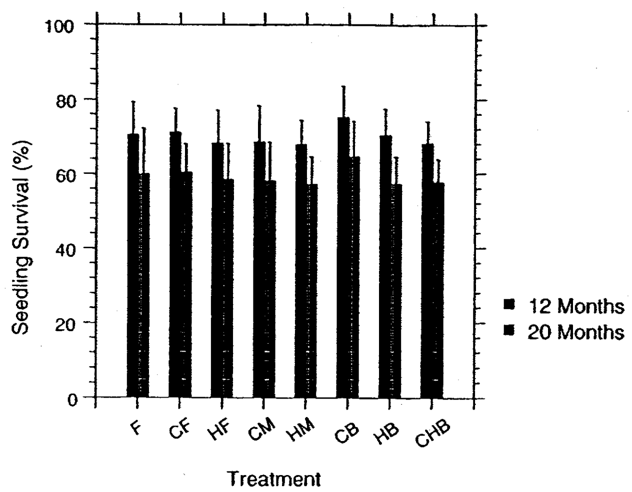

Fig. 1. Survival rates of planted longleaf pine seedlings by treatment at 12 and 20 months after planting. Error bars are standard errors. Treatments are defined in Table 1.

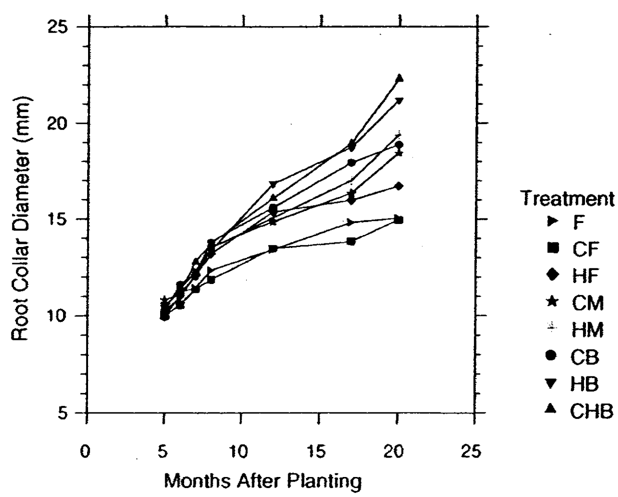

Fig. 2. Root collar diameter (mm) by treatment during each measurement period from 5 months after planting (May 2004) to 20 months after planting (August 2005). Treatments are defined in Table 1.

3.2. Root collar diameter growth

Root collar diameters increased over time ($p < 0.001$) and differed among treatments ($p < 0.001$). There was an interaction between treatment and time ($p < 0.001$) (Fig. 2). When analyzed for each measurement period, treatment differences were detected only eight (August 2004) or more (December 2004, May 2005, and August 2005) months after planting ($p \leq 0.003$). After 12 months of growth, HB and CHB resulted in similar root collar diameters and were both greater than F, CF, and CM (Fig. 2; Table 3). Additionally, HB increased root collar growth when compared to HM and HF. The least amount of growth was on CF, which was lower than all other treatments besides F. After 20 months of growth, CHB resulted in greater root collar diameter growth than all other treatments except HB; the least amount of growth was once again on F and CF.

Based on factorial analysis of variance, both planting site condition and vegetation control treatment affected root collar diameter ($p \leq 0.002$), and there was no significant interaction between them at 12 ($p = 0.169$) or 20 months ($p = 0.983$) after planting. After 12 months of growth, bedding resulted in greater root collar diameter than either mounding ($p = 0.004$) or flat treatments ($p < 0.001$), and no difference ($p = 0.214$) was found between mounding and flat treatments (Table 4). The herbicide treatment resulted in greater growth than chopping ($p < 0.001$). At 20 months of growth, bedding and mounding were similar ($p = 0.194$), and both resulted in more growth than the flat treatment ($p \leq 0.002$). The herbicide treatment yielded more growth than the chop treatment ($p = 0.002$).

Table 2
Factorial analysis of mean seedling survival rates at 12 and 20 months after planting

Treatment	Mean survival percentage at 12 months	Mean survival percentage at 20 months
Flat	69.6^a	59.4^a
Mounding	68.2^a	57.6^a
Bedding	72.7^a	60.8^a
p-Value	0.431	0.689
Chopping	71.6^a	60.9^a
Herbicide	68.8^a	57.6^a
p-Value	0.332	0.280

Means with the same superscript letter indicate no significant difference ($\alpha = 0.05$).

3.3. Height growth

After 20 months, the percentage of seedlings in height growth (i.e., terminal bud at least 15 cm above soil surface) differed among the eight treatments ($p < 0.001$). CHB had more seedlings in height growth than CB, HF, CF, and F (Table 3). Additionally, HB and HM had significantly more seedlings in height growth than F and CF, in which no seedlings had yet emerged from the grass stage.

Table 3
Root collar diameter means for each treatment through 12 and 20 months after planting and percentage of seedlings in height growth for each treatment at 20 months after planting

Treatment[1]	Root collar diameter (mm)		Percentage in height growth[2]
	12 months	20 months	20 months
F	13.2 de (2.7)	15.1 fg (3.8)	0.0 c (0.0)
CF	13.0 e (2.8)	15.0 g (3.8)	0.0 c (0.0)
HF	14.9 bc (3.5)	16.6 ef (4.9)	4.3 bc (7.2)
CM	14.1 cd (3.4)	17.8 de (5.7)	5.9 abc (5.2)
HM	14.9 bc (3.8)	19.8 bc (6.2)	11.4 ab (8.0)
CB	15.2 abc (3.8)	18.6 cd (5.4)	5.0 bc (8.2)
HB	16.1 a (4.3)	21.2 ab (6.8)	11.3 ab (13.0)
CHB	15.6 ab (4.1)	22.1 a (7.4)	19.0 a (10.2)

Means are followed by standard deviation in parenthesis. Means with the same letter indicate no significant difference ($\alpha = 0.05$).
[1] Treatments are defined in Table 1.
[2] Analysis was conducted based on log-transformation.

Table 4
Factorial analysis of least square means of root collar diameter at 12 months and 20 months after planting and percentage of seedlings in height growth 20 months after planting

Treatment	Root collar diameter (mm)		Percentage in height growth[1]
	12 months	20 months	20 months
Flat	14.0 b	15.7 b	2.2 b
Mounding	14.5 b	18.6 a	8.6 a
Bedding	15.6 a	19.8 a	8.1 a
p-Value	<0.001	<0.001	0.003
Chopping	14.1 b	17.0 b	3.6 b
Herbicide	15.3 a	19.0 a	9.0 a
p-Value	<0.001	0.002	0.016

Means with the same letter indicate no significant difference ($\alpha = 0.05$).
[1] Analysis was conducted based on log-transformation.

Based on the factorial analysis of variance, both planting site condition and vegetation control treatment affected the number of seedlings in height growth ($p < 0.016$), although no interaction was found between them ($p = 0.972$). Bedding and mounding were similar ($p = 0.565$) and were both greater than the flat treatments ($p \leq 0.030$) with respect to the percentage of seedlings in height growth. The herbicide treatment resulted in a higher percentage of seedlings in height growth than the chop treatment ($p = 0.016$) (Table 4).

For seedlings emerged from the grass stage, there were no treatment differences in root collar diameter measured prior to height growth initiation ($p = 0.348$). The root collar diameters of these seedlings ranged from 22.4 mm (HM) to 24.8 mm (HF), with a mean of 23.3 mm and standard deviation of 2.8 mm across all treatments.

4. Discussion

We did not find any treatment effects on seedling survival. The overall mean survival rates of 70% after 1 year and 59% after 20 months found in our study are within the range of survival rates previously reported. For example, Loveless et al. (1989) reported average first-year survival at 56%, Ramsey et al. (2003) reported a first-year survival rate of 75% on a well-drained site in Florida, and Boyer (1988) reported a survival rate of 67% on a poorly drained site after three years of growth. Barnett et al. (1990) recommended a minimum of 300 seedlings per acre after the first year. Our study sites were planted at a density of approximately 550 seedlings per acre, which would leave 373–413 seedlings per acre (depending on treatment) after the first year of growth. Therefore, all site preparation treatments resulted in satisfactory survival for longleaf pine regeneration on these poorly drained, sandy sites.

Although site preparation treatments tested in our study did not affect seedling survival up to 20 months after planting, these treatments had significant effects on seedling growth. Among the three planting site conditions, bedding and mounding positively affected root collar diameter and percentage of seedlings in height growth after 20 months of growth. Compared to flat sites, bedding and mounding improve growing conditions, perhaps resulting from increased soil aeration and improved surface drainage as others have suggested (Prichett, 1979; McKee and Wilhite, 1986; Haywood, 1987; Sutton, 1993). Additionally, the disturbance created by the treatments appears to reduce competing vegetation, which has long been considered important for improving longleaf pine growth (Wahlenburg, 1946).

Previous studies have demonstrated the potential of herbicide use for increasing growth of longleaf pine seedlings (Nelson et al., 1985; Haywood, 2000; Ramsey et al., 2003). For example, herbicide use resulted in as many as twice the number of seedlings in height growth after two years when compared to a check (Nelson et al., 1982). In our study, the herbicide-only treatment (HF) resulted in greater root collar growth than CF or the check (F), although there were no significant differences in the percentage of seedlings in height growth. However, seedlings had begun height growth on HF, indicating that the treatment is superior to CF and F, in which neither had any seedlings in height growth.

Overall, the chop treatment used in this study appeared to be essentially ineffective for increasing growth. Studies on the effect of chopping on longleaf pine are limited to Boyer (1988), in which multiple passes of a chopper increased growth after two years when compared to a single pass. A single pass, as seen in the current study, may not provide adequate competition control to improve seedling growth. Previous studies have also found chopping to be inferior for competition control when compared to other mechanical treatments. For example, Miller (1980) found shearing and windrowing caused a 55% reduction in standing vegetation after two years when compared to chopping. Although chopping initially reduces competing vegetation, its benefit is usually short-lived due to rapid vegetation regrowth. For example, in the Boyer study (1988), the effects of chopping on seedling growth were no longer significant after the third year of growth.

Our results indicated that the effects of planting site condition and competition control were additive. We found that CHB, HB, and HM were the treatment combinations that most benefited seedling growth. The CHB treatment included both types of competition control and was the most intense treatment used in the study. Site preparation intensity is considered to be positively correlated with longleaf pine growth, especially when used for competition control (Boyer, 1983). However, because HB was similar to CHB in root collar diameter growth and percentage of seedlings in height growth, the addition of the chop treatment to HB may not be necessary for maximizing longleaf pine growth.

We also investigated the idea that different treatments may influence the timing of height growth initiation. Among the seedlings that had begun height growth, we found that root collar diameters prior to emergence were confined to a narrow range (22.4–24.8 mm, mean of 23.6 mm). This result supports the idea that longleaf pine seedlings begin height growth when the root collar approaches 25 mm (Boyer, 1990). The treatments used in this study affected the root collar diameter, which in turn affected grass stage emergence. However, the treatments did not appear to have any other influence on height growth initiation other than that associated with effects on root collar diameter.

5. Management implications

Site preparation treatments appear to be an appropriate technique for land managers who wish to rapidly establish planted longleaf pine seedlings on poorly drained, sandy sites in the southeastern United States. Because the treatments used in this study had no impact on early seedling survival of planted longleaf pine seedlings, decisions on treatment application should be based on the effects of site preparation treatments on seedling growth. We found that root collar diameter was directly related to height growth initiation, and therefore treatments maximizing root collar diameter growth would also shorten time in the grass stage. Based on seedling growth at 20 months after planting, we found bedding and mounding to be the best planting site conditions and herbicide to be the best vegetation control treatment. To improve early seedling growth, bedding or mounding in combination with herbicide treatments should be applied when planting longleaf pine seedlings. Chopping may also be used in combination with bedding and herbicide to provide the maximum benefit. These recommended site preparation treatments, if in accordance with other management objectives, can be a valuable tool for forest managers interested in artificially regenerating longleaf pine on poorly drained sites within the coastal plain of the southeastern United States.

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