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# Site Establishment Practices Influence Loblolly Pine Mortality Throughout the Stand Rotation

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Cover photo: A long term soil productivity study installation on the Croatan National Forest, New Bern, NC.

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# Site Establishment Practices Influence Loblolly Pine Mortality Throughout the Stand Rotation

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**Abstract**

During a rotation, land managers need to estimate yields, update inventories, and evaluate stand dynamics. All of these factors in land management are heavily influenced by tree mortality. Tree mortality can, in turn, be influenced by land management practices from the inception of the stand and throughout the rotation. We describe the impact of organic matter removal and soil compaction during stand establishment on loblolly pine *(Pinus taeda* L.*)* mortality over the course of 15 years. We also describe the impact of understory control throughout the study on tree mortality. In this study, soil compaction did not impact tree mortality at any time. Removal of surface organic matter impacted tree mortality, with the least intensive practices (bole only removal) resulting in the greatest tree mortality. This effect, observed very early in the rotation, was probably due to immobilization of essential nutrients. Control of the understory became a significant factor to tree mortality late in the rotation as intraspecific competition for light became an important consideration. Site amelioration, via regional Best Management Practices, negated the impact of competition control on mortality.

**Keywords:** Compaction, loblolly pine, mortality, organic matter.

## Introduction

The long-term soil productivity (LTSP) experiment was designed to investigate the impact of soil compaction and surface organic matter removal during a harvest on net ecosystem productivity (NPP). The core experiment was installed on more than 140 sites across the United States and Canada, making it the world's largest coordinated effort to examine the relationship between soil processes and NPP. Since the establishment of the first LTSP installations in 1991 and over the course of the experiment, cooperators from the Forest Service, U.S. Department of Agriculture, National Forest System, Forest Service Research and Development, British Columbia Ministry of Forests, Canadian Forest Service, and various university and private industry cooperators have published more than 300 manuscripts that describe various aspects of the experiment, including soil processes, soil macro- and micro-fauna, and above- and belowground biomass.

The information gained from the LTSP experiment has been invaluable in advancing understanding of the soil processes that impact stand productivity. However, a critical piece of information that has not received as much attention is the treatment impacts on tree survival. Understanding treatment impacts on tree survival is a complicated matter because of multiple factors that can directly or, in combination with other factors, indirectly impact survival. For example, trees weakened by one stressor, such as insects or disease, may be susceptible to additional stressors, such as drought and storm damage, resulting in tree mortality. Neither stressor in isolation directly led to tree mortality but the combination of stressors was instrumental in the death of the tree. Researchers have linked management practices, such as soil compaction (Lockaby and Vitrine 1984) and herbicide application (Edwards 1994, Lauer and others 1993, Wittwer and others 1986), to tree mortality. But linking specific treatments to mortality over the duration of a study is not always straightforward. Nevertheless, land managers need to predict tree survival throughout a rotation in order to estimate yields, update inventories, and evaluate stand dynamics (Amateis and others 1997).

The LTSP installations in North Carolina utilize loblolly pine *(Pinus taeda* L.*)* plantations. Loblolly pine is an important tree species in the Southeastern United States, covering, together with shortleaf pine *(Pinus echinata* Mill.*)*, more than 20 million ha, approximately a quarter of the South's total timberland area (Conner and Hartsell 2002). Research from the North Carolina LTSP installations has yielded information on loblolly pine tree growth (Sanchez and others 2006a, Scott and others 2004), root development (Ludovici 2008), soil nutrient contents and cycling (Butnor and others 2006, Li and others 2003, Sanchez and others 2006a, 2006b, Scott and others 2004), soil fauna (Eaton 2006, Eaton and others 2004), and fusiform rust incidence (Eaton and others 2006). The objectives of this manuscript are to describe the general treatment impacts on loblolly pine survival throughout the life of the Croatan LTSP installations and to identify potential contributing factors. This information will help land managers understand the interrelationship of factors that affect their yields.

## Materials and Methods

### Study Site

The LTSP installations are located in the Croatan National Forest in Craven County, NC, in the Atlantic Coastal Plain. The study site has a mean annual temperature of 16 ºC and receives 1360 mm of precipitation. The installations were established in 1991 as a component of the LTSP cooperative. Prior to study installation, the site was occupied by a 60-year-old pine-hardwood forest.

### Treatments

Prior to harvesting the existing stand, three replicated blocks were established. Block 1 was located in the Goldsboro soil series (fine-loamy, siliceous, thermic Aquic Paleudults), while blocks 2 and 3 were in the Lynchburg series (fine-loamy, siliceous, thermic aeric Paleudults). Within each block, nine experimental plots (0.4 ha) were established representing a 3 x 3 factorial of organic matter removal and compaction treatments. Three levels of organic matter removal were applied: merchantable bole removal ($OM_0$), whole-tree removal ($OM_1$), and whole-tree plus forest floor removal ($OM_2$). Additionally, three levels of soil compaction were applied: no compaction ($C_0$), moderate compaction ($C_1$), and severe compaction ($C_2$). The $C_2$ treatment was intended to approximate 80 percent of growth limiting bulk density in the upper 0 to10 cm of the mineral soil (Daddrow and Warrington 1983). The $C_1$ treatment was intended to be mid-range between the $C_0$ and $C_2$ treatments. To achieve the desired compaction levels, plots were either not compacted ($C_0$ treatment); compacted with one pass of a smooth drum vibrator roller without vibration ($C_1$ treatment); or compacted with two passes of a smooth drum vibrator roller with full vibration ($C_2$ treatment). The plots were then planted with loblolly pine bare-root seedlings on a 3 x 3 m spacing, and half of each plot was maintained with native understory ($U_+$) while the other half had complete understory control ($U_-$) where the understory was controlled by mechanical and chemical means.

One of the hypotheses of the LTSP experiment is that any negative effects due to the main treatments could be ameliorated by the Best Management Practices (BMPs) of the region (Powers and others 1990). To test this hypothesis, an additional plot, referred herein as the ameliorated plot, was installed in each block. The ameliorated plot replicated the $OM_1C_1$ experimental treatment followed by bedding and a one-time fertilization application of 224 kg $ha^{-1}$ of triple superphosphate, which supplied 45 kg P. The split-plot subtreatment of understory control was applied as in the core LTSP experimental design. Over the course of the study, inventories of tree mortality have been documented for each plot.

### Statistical Analysis

Analysis of variance (ANOVA) using the GLM procedure for split-plot design (SAS 9.2 2002) was used to test for treatment effects on tree mortality. Soil compaction and organic matter removal treatments were the main effects while the understory control treatments were the split plot effects. Differences between treatments were determined significant at $\alpha \leq 0.05$ level using the Tukey's Paired Comparison Procedure. Student's t-test comparison was used to detect differences in the ameliorated plots and the $OM_1C_1$ experimental plots for each understory control split plot subtreatment.

## Results

Soil compaction did not impact tree survival in any of the years measured (fig. 1); however, significant impacts were detected for the organic matter removal and understory control treatments. Since the significance levels for the compaction treatments (or any compaction interaction) were not significant (no value was lower than $p = 0.53$) for any year, the compaction values were pooled to increase the power of the statistical tests for the organic matter removal and understory

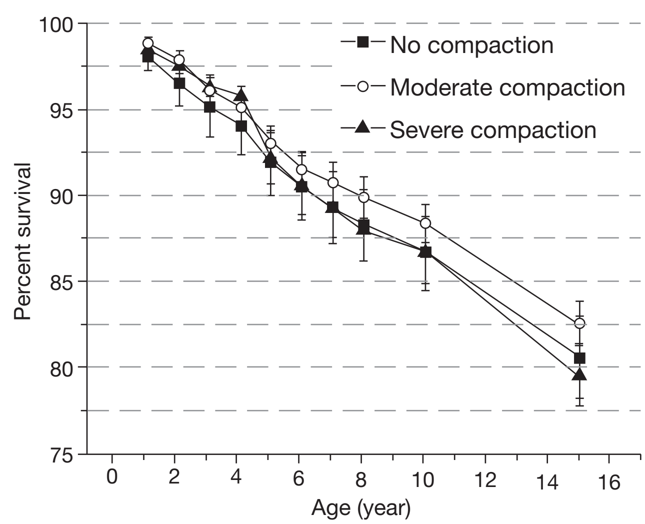


Figure 1—Percent survival of loblolly pine trees over 15 years for soils with three levels of compaction.

control treatments. Using the pooled data, the $OM_0$ plots had significantly lower survival than the $OM_1$ and $OM_2$ treatment plots early in the rotation but percent survival between the treatments was not significantly different after 5 years (fig. 2) (table 1). The presence of an understory ($U_+$ plots) resulted in lower survival than plots without an understory ($U_-$ plots); however, this effect was significant only in two years of the study (fig. 3) (table 1). The interaction between organic matter removal and understory control treatments was nearly, but not quite, significant at the $p \leq 0.05$ level after 6 years (table 1).

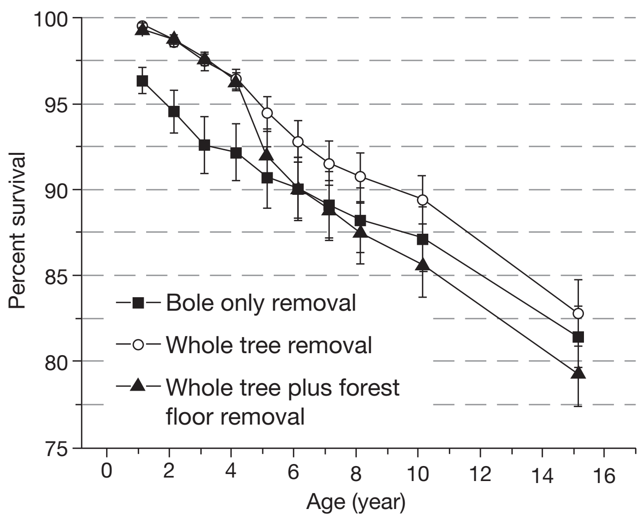


Figure 2—Percent survival of loblolly pine trees over 15 years for soils with three levels of surface organic matter levels.

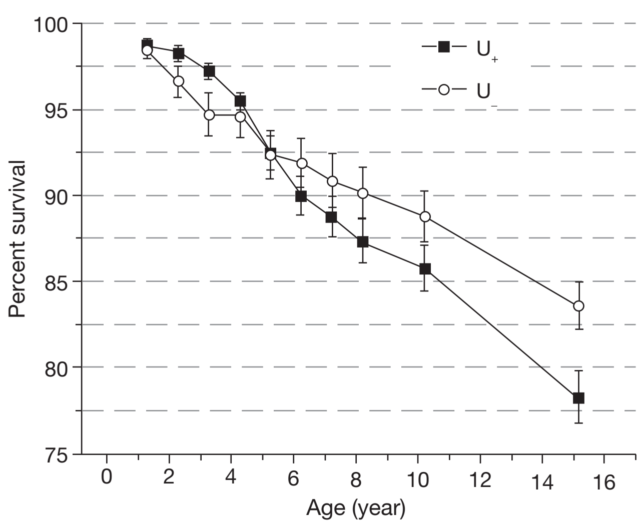


Figure 3—Percent survival of loblolly pine trees over 15 years for plots with no or complete understory control, $U_+$ and $U_-$, respectively.

**Table 1—Significance levels (p values) for the organic matter (OM) removal and understory control (U) treatments and their interaction (OM x U) for each year**

| Year | OM | U | OM x U |
|---|---|---|---|
| 1 | <0.0001 | 0.67 | 0.89 |
| 2 | 0.00017 | 0.061 | 0.56 |
| 3 | 0.00085 | 0.033 | 0.34 |
| 4 | 0.008 | 0.47 | 0.25 |
| 5 | 0.17 | 0.96 | 0.14 |
| 6 | 0.33 | 0.29 | 0.075 |
| 7 | 0.43 | 0.27 | 0.054 |
| 8 | 0.35 | 0.14 | 0.05 |
| 10 | 0.27 | 0.12 | 0.066 |
| 15 | 0.36 | 0.011 | 0.15 |

For the comparison between the ameliorated and experimental ($OM_1C_1$) treatment plots, tree survival was profoundly impacted by the understory. When the understory was present, the ameliorated plots had significantly ($p \leq 0.05$) greater survival than the experimental plots for the majority of the time (fig. 4a). However, when the understory was absent, there was no significant difference in survival between the ameliorated and experimental plots for any of the years measured (fig. 4b).

## Discussion

### Soil Compaction

The lack of significant compaction effects on tree mortality (fig. 1) (table 1) is not surprising since compaction did not impact tree growth (Sanchez and others 2006a), insect and disease incidence (Eaton and others 2006), and soil nutrients (Powers and others 2005, Sanchez and others 2006a, 2006b). The reason for the lack of a compaction effect is because soil bulk density on these plots recovered rapidly (Page-Dumroese and others 2006). The only exception to this general trend was the observation that compaction decreased root biomass and increased the ratio of aboveground to belowground biomass (Ludovici 2008). While the decreased root biomass may lead to future productivity declines, it did not impact tree mortality to date. Since soil bulk density recovered rapidly and survival of loblolly pine, after crown closure, is determined primarily by intraspecific competition (Amateis and others 1997), it is unlikely that soil compaction (or its interaction) during stand establishment will become a factor later in the rotation.

### Organic Matter Removal

With a lack of any significant or nearly significant compaction effect (table 1), we decided to pool the compaction plots in the

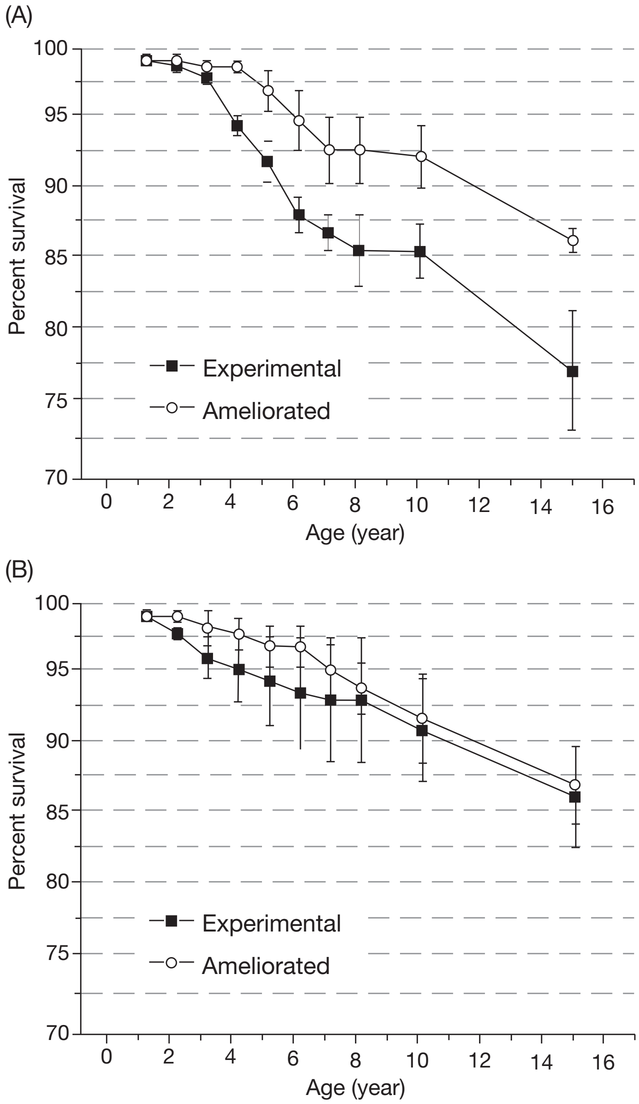


Figure 4—Percent survival of loblolly pine trees over 15 years for ameliorated and experimental plots when (A) the understory was present and (B) the understory was absent.

examination of the effects of organic matter removal and understory control on tree mortality. Analysis of the pooled data showed that early in the rotation, the $OM_0$ plots had the greatest mortality with no difference in tree mortality between the $OM_1$ and $OM_2$ plots; however, there was no significant difference ($p > 0.05$) between the organic matter removal treatments after year 4 (fig. 2). Assuming minimal between-plot variation in planting stock or planting efficiency, early rotation mortality is primarily determined by competition for site resources, e.g., nutrients and water (Amateis and others 1997, Haywood and others 1997). The $OM_0$ treatment plot is the least invasive organic matter removal treatment and should result in a condition favoring soil moisture retention. Additionally, removal of the bole results in relatively little nutrient loss from the forest floor as compared with the more intensive organic matter removal treatments (Powers and others 2003). With little soil moisture or nutrients loss in the $OM_0$ treatment, then why was early rotation mortality greatest on these treatment plots? The answer may lie in the availability of nutrients. Although most of the nutrients are contained in the limbs and foliage (Powers and others 1990), these nutrients are sequestered in the forest floor and are essentially unavailable until the forest floor decomposes (Gholz and Fisher 1982). Nutrient immobilization would be the greatest on the least disruptive plots ($OM_0$ treatments). The more intensive practice of removing parts or the entire forest floor ($OM_1$ and $OM_2$ treatments, respectively) would create conditions (increased soil temperature and mineral soil disruption) that would result in increased carbon and nutrient mineralization (Jenkinson 1990). Thus the $OM_1$ and $OM_2$ treatments provided the highest level of soil nutrients to young seedlings despite the fact that they contained the lowest absolute amount of nutrients (Sanchez and others 2006a, 2006b). By the time the forest floor decomposed and the nutrients contained in it were made available, the trees had developed enough that nutrient availability had a small impact on mortality.

### Understory

The presence or absence of an understory did not significantly impact tree survival for the majority of the study and was only significant in the $3^{rd}$ and $15^{th}$ year (fig. 3) (table 1). In the third year of the study, the trees were damaged by the herbicide application that was exasperated by below-average growing season precipitation (Goodwin 1989). This damage was also exhibited in stunted tree growth on the $U_-$ plots during that year. In the $15^{th}$ year, tree mortality was higher in the $U_+$ plots. After crown closure, tree mortality is primarily influenced by intraspecific competition (Amateis and others 1997). Consequently, the understory is now becoming an important factor for tree mortality at these installations.

### Ameliorated Plots

Soils on the Atlantic Coastal Plain are historically nutrient deficient and often times poorly drained. Thus, the silvicultural practices for this region generally call for bedding and phosphorus fertilization as a means of achieving high loblolly pine productivity. Bedding increases soil aeration and soil macropore space, and lowers soil moisture, thus creating an environment for favorable root development for the newly planted seedlings (Will and others 2002). Additionally, the soil disruption of the bedding results in increased mineralization of soil organic matter and consequently nutrient release (Edwards 1994). This coupled with inorganic fertilization should provide optimal conditions for seedling establishment. The availability of essential nutrients limits growth of pine forests in the Southern United States (Allen 1987, Gurlevik and others 2003) and maintaining adequate levels of soil nutrients is the dominant factor for maintaining high productivity within the natural range of loblolly pine (Jokela and Long 2004).

For the first 3 years of the study, amelioration of the experimental plots ($OM_1C_1$) by bedding and fertilization did not impact tree survival, suggesting that the conditions on the experimental plots were sufficient for seedling establishment. However, after the third year, amelioration did result in lower tree mortality but the effect was dependent on the presence (fig. 4a) or absence (fig. 4b) of an understory. Competition for site resources is the primary factor for tree mortality before crown closure (Amateis and others 1997) and this effect is manifested early (fig. 4a) in this study. As the tree developed larger and deeper root systems, this intraspecific competition became less of a factor and is demonstrated by the parallel path of tree mortality for the ameliorated and experimental plots (fig. 4a). The abrupt increase in tree mortality in the experimental plots compared with the ameliorated plots may be a response to the drought that occurred at these sites in year 3. Bedding and fertilization increase root development (Haywood and others 1997, Will and others 2002) making the trees on the ameliorated plots better equipped to survive the drought.

## Conclusion

The site preparation methods employed at the Croatan National Forest LTSP installations impacted loblolly pine mortality throughout the life of the study. Soil compaction was the only treatment that did not impact tree mortality. This is consistent with the observed lack of a significant treatment effect on the majority of the metrics, i.e., tree growth and soil nutrient status, at the installations. Although the forest floor regulates soil moisture and temperature levels and contains considerable amounts of essential nutrients, its retention actually increased tree mortality during the first few years of the study. This can be attributed to nutrient immobilization within the forest floor prior to its decomposition. Finally, the presence of an understory also impacted tree mortality because of competition for site resources such as water and nutrients (early in the study) or light (after crown closure). Regional BMPs negated the negative effect of understory on tree mortality. Consequently, land managers should be cognizant that the silvicultural practices during stand establishment can have long-term consequences on yield estimates, annual tree inventories, and stand dynamics.

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