

PROJECTED GROWTH AND YIELD AND CHANGES IN SOIL SITE PRODUCTIVITY FOR LOBLOLLY PINE STANDS 10 YEARS AFTER VARYING DEGREES OF HARVESTING DISTURBANCE

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Abstract—Southern industrial pine plantations are intensively managed. Shortened rotations and wet season trafficking can result in significant soil disturbances. This study investigated the effects of wet and dry weather harvesting, the ameliorative effect of bedding on soil site productivity on a rotation-length study, and compared the cost benefit of several site preparation treatments. Loblolly pine plantations were subjected to combinations of wet- and dry-weather harvesting and mechanical site preparation. Sites that were bedded had significantly more wood production at age 10 than non-bedded sites: approximately 60 and 45 tons/acre green-weight respectively. There were no significant differences between wet- and dry-weather harvested sites that were not bedded. Dry-weather harvested sites had the least production among the bedded sites, but there were few significant differences. Projected growth using the model FASTLOB2 suggests that flat-planted sites may be more profitable, but only if survival can be assured. This study also indicates that an experimental mole plow treatment can be productive and profitable, but requires further investigation on a wider variety of sites.

INTRODUCTION

Southern pine plantations are among the most intensively managed forests in the country (Allen and Campbell 1988). Forests in this region produce up to 400 cubic feet/acre annually (Borders and Bailey 2001), and due to limitations with mill inventories, they are harvested year-round. As a result, harvests during winter months, when evapotranspiration is minimal and soils are wet, results in soil impacts. Studies of trafficking disturbance have shown negative effects on soil properties and reductions in tree growth and survival (Aust and others 1995, Hatchell and others 1970, Lockaby and Vidrine 1984, Moehring and Rawls 1970, Scheerer 1994, Shoulders and Terry 1978, Youngberg 1959). Harvesting traffic during wet weather may cause rutting and compaction, erosion, nutrient loss, and organic matter disturbance (Greacen and Sands 1980, Kozlowski 1999, Miller and others 2004, Miwa and others 2004, Powers and others 1990, Sheriff and Nambiar 1995). In spite of literature that shows how forest practices can negatively affect soil chemical and physical properties related to tree growth, the direct link between forest operations and reduced productivity has been difficult to establish (Burger 1996, Morris and Miller 1994, Worrell and Hampson 1997).

Potential site impacts due to trafficking and biomass removal may be mediated both naturally and artificially (Cairns 1989, Vorhees 1983). The presence of shrink-swell clays can allow compacted soils to achieve lower bulk densities after multiple cycles of wetting and drying (McGowan and others 1983, Sarmah and others 1996). Soil biological activity, such as soil organisms or root systems, can benefit soil properties by contributing to the formation and stabilization of soil aggregates, alter soil structure, incorporate organic matter, and decrease bulk density (Jastrow and Miller 1991, Larson and Allmaras 1971, Oades 1993, Perfect and others 1990).

Intensive management practices may enhance site conditions, increase growth and yield, and improve economic

return. Site preparation may also be used to ameliorate harvesting impacts. Bedding is a common site preparation practice on intensively managed plantations of the coastal plain recognized for its benefits for drainage, competition control, and nutrient allocation (Aust and others 1995, Coile 1952, Gent and others 1983, McKee and others 1985, Morris and Lowery 1988, Schultz and Wilhite 1974). Other types of mechanical site preparation include chopping, harrowing, disking, shearing, ripping, etc. (Smith 1986). Additional goals might include improving site drainage, as with drainage (Smith 1986) or mole plowing (Spoor and Fry 1983, Spoor and others 1982, Weil and others 1991). The main limitations of mechanical site preparation methods include the expense and potential impacts of repeated trafficking (Walstad and Kuch 1987).

The long-term goal of this study is to evaluate (1) whether logging disturbances affect soil quality and loblolly pine (*Pinus taeda* L.) productivity on wet pine flats, and (2) can forestry practices mitigate disturbance effects if they exist? A specific objective of this paper is to evaluate the cost-benefit of an experimental mole plow treatment relative to more common site preparations.

METHODS

The study site is located on wet pine flats (Messina and Conner 1998) on the Atlantic Coastal Plain in Colleton County, SC. Three, 50-acre, bedded, loblolly pine plantations were selected as blocks in 1992 based on similar age (20–25 years), soil, and hydrologic conditions. The topography is flat to gently rolling marine terraces dissected by drainages. Soil parent materials consist of marine and fluvial sediments and feature the phosphatic Cooper Marl (Stuck 1982). Soils are poorly to somewhat poorly drained, and have an aquic moisture regime. Regionally, these sites are considered highly productive and are often intensively managed for the production of loblolly pine (*Pinus taeda* L.).

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Soils primarily consist of the Argent (fine, mixed, thermic, Typic Ochraqualfs) (57 percent), Coosaw (Loamy, siliceous, thermic Arenic Hapludults) (15 percent), Santee (Fine, mixed, thermic, Typic Argiaqualfs) (13 percent), and Yemassee (Fine-loamy, siliceous, thermic Aeric Ochraqualfs) (14 percent) series. However, the sites are similar enough that they managed as a single unit. Surface drainage is largely controlled by microtopography and subsurface drainage by thick argillic horizons of low permeability that cause perched water tables (Xu and others 2002).

Five approximately 8-acre treatment areas were laid out as individual harvest units within each block including separate decks and skid trails (fig. 1). A sixth area in each block consisted of a no-harvest control, and was not used in this portion of the experiment. Prior to harvest each treatment area was overlain with a 66 by 66 feet grid. Within each of the 1170 1/10th-acre cells, a circular 1/50th-acre measurement subplot was permanently established.

In the fall of 1993, two randomly selected plots on each block were dry-weather harvested. In the spring of 1994, the remaining three plots on each block were harvested in wet conditions with the goal of maximizing soil disturbance. Harvesting was performed by conventional commercial logging operations using mechanized fellers and wide tired buncher/grapple skidders. The logger was instructed to treat the individual sites as they normally would for the site conditions that were encountered. Specifically, no effort was made to alter logger behavior. Disturbances were applied in this manner to ensure that the degree and distribution of both soil physical and harvesting residue disturbances would be operationally realistic.

Three levels of mechanical site preparation were applied in 1995: no mechanical site preparation (flat planting), conventional bedding, and an experimental mole plow

treatment. The purpose of the mole plow treatment was to facilitate water table equilibration via subsurface drainage in the argillic horizon for areas where rutting and churning may have disrupted normal drainage. Bedded sites were sheared and drum chopped prior to bed installation. Mole plowing was performed in October 1995 using a mole-shank and modified bedding plow, and then bedded in November 1995. Thus there were five treatments at the operational level: dry-harvested and flat-planted (DF), wet-harvested and flat-planted (WF), dry-harvested and bedded (DB), wet-harvested and bedded (WB), and wet-harvested, mole plowed and bedded (WMB).

All sites received chemical weed control in the form of Imazapyr (16 ounces/acre) and Glyphosate (76 ounces/acre) in July 1995. The sites were hand planted in February 1996 with best first generation, open-pollinated family, loblolly pine seedlings. As a precaution, non-bedded stands were double planted to emphasize treatment effects on productivity over that of stocking and survival effects. Extra seedlings were culled from double plantings that remained after the first year of growth.

Height and diameter breast height (d.b.h.) of all trees within the 1/10-acre subplots were measured prior to harvesting. Inventories of height and d.b.h. in the current rotation were conducted at ages two, five, and ten for the same 1/10-acre subplots across the entire study area. Site indexes (base age 25) were calculated at age 10 based on the height of a dominant or codominant tree nearest each 1/10-acre subplot center using equations developed for a range of loblolly pine site types (Amateis and Burkhart 1985). Green weight biomass was calculated as a function of height and d.b.h. (Bullock and Burkhart 2003, Phillips and McNab 1982).

An economic analysis was conducted by projecting growth and yield to the end of the rotation using the FASTLOB2 stand development model (Amateis and others 2005). Rotation lengths were optimized for individual treatment plots based on maximum net present value (NPV) at interest rates of 8 and 12 percent. The expressed site index and stocking at age 10 were used as surrogates for treatment effects in FASTLOB2. Biomass was assumed to be sold as pulpwood (4 inch d.b.h., \$6 per ton), chip and saw (9 inch d.b.h., \$21 per ton), or sawtimber (12 inch d.b.h., \$38 per ton) using Southwide average prices obtained from Timber Mart South (University of GA) in February 2007. Treatment costs were estimated using regional trends (Dubois and others 2003). The assumed costs for flat-planted sites included hand planting (\$48 per acre), fertilization (\$65 per acre), chop and shear (\$100 per acre), and herbicides (\$52 per acre). The assumed costs for bedded sites included the additional costs of bedding (\$135 per acre). The cost of the experimental mole plow treatment was estimated to be approximately \$100 per acre. Cost and benefits associated with taxes, hunting leases, and other sources of revenue were not considered.

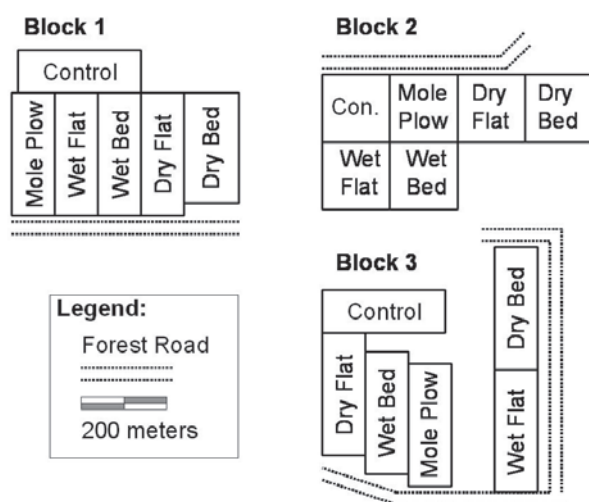


Figure 1—Block layout of individual harvesting units and corresponding treatments.

Maximum NPV, stand age, and biomass were evaluated at the operational scale using the general linear model at the alpha = 0.05 level (Hicks and Turner 1999). Means separations were conducted using Fishers' protected least significant difference. The covariates prior stand production

and site index were considered, but not found to be significant.

RESULTS AND DISCUSSION

Disturbance Response

In a review of harvesting disturbance from the 1960s to the 1980s, Reisinger and others (1988) reported that greater than 63 percent of logging areas remain undisturbed after harvesting operations. At the time of treatment installation, deep rutting was considered excessive in SC when 20 to 25 percent of the site is affected (Tim Adams, SC Forestry Commission, Personal Communication, 1994). The wet-weather harvesting treatments were designed to maximize soil disturbance. While soil compaction occurred on less than 10 percent of dry-weather harvested sites, wet-weather harvested sites were over 60 percent disturbed including compaction, rutting, and churning (Eisenbies and others 2006). Between 26 and 44 tons per acre of harvesting residues were distributed across the sites with greater quantities found on wet-harvested sites (Eisenbies and others 2002). Loggers topped trees where they were felled on wet-harvested sites in order to increase tire floatation and reduce drag on wet harvested sites. On dry harvested sites whole trees were skidded to delimbing gates near the landings.

Production was greatest on bedded sites, but no significant differences were found between wet- and dry-harvested sites (Eisenbies and others 2007). The benefits of bedding loblolly pine stands are already well established (Aust and others 1995, Gent and others 1983, McKee and others 1985, Miller and others 2004, Miwa and others 2004, Morris and Lowery 1988, Schultz and Wilhite 1974, Terry and Hughes 1975). However, no changes in soil-site productivity were detected among non-bedded (DF and WF) and bedded (DB, WB, and WMB) sites except with regards to height growth on flat-planted sites. Eisenbies and others (2007) noted that survival was very high on flat-planted sites due to relatively dry conditions for the first few years of growth. They also observed that localized areas where moderate amounts of disturbance occurred appeared to perform better than less

disturbed areas, and that soil bulk density and porosity were also improve over time due to bedding and natural processes.

Simulation Results

These sites are projected to produce between 134 and 260 tons/acre when their net present values are maximized at 8 and 12 percent (table 1). The wet-harvested, mole plowed and bedded sites are projected to have the highest production of the five treatments. There is some evidence that the MP sites may have had slightly higher initial site quality (Eisenbies and others 2006). Optimized rotations lengths based on cost estimates and current estimates for timber prices are between 16 and 33 years. Higher costs and higher interest rates logically result in the maximum NPV being attained earlier in the rotation. Simulated mortality on flat-planted sites only resulted in 2 year delay in rotation age, but there was no change in actual yield.

Although the WMB treatment had significantly higher simulated production, it did not generate significantly higher income than the other bedded sites in most cases (table 2). The flat-planted sites were the most profitable within blocks, but rarely significantly so and not when a planting failure was simulated. One limitation is that the simulations do assume that current separation between treatments will be maintained for another 10 years; however, apparent changes in soil-site productivity have been converging with time (Eisenbies and others 2007). Additionally, FASTLOB2 seems to predict slightly high yields from age 10 data. These sites were unusually productive for coastal plain plantations due to the parent material and have high site indexes. Thus, either the model's capacity to accurately simulate these sites may be impaired, or the site index curves utilized are too general and overestimate some stands.

The comparatively high costs of operating heavy machinery may favor flat-planting economically, especially if interest rates rise; however, site-preparation may remain the best choice in order to ensure proper stocking. It is also difficult to recommend the WMB treatment despite its higher predicted

Table 1—Predicted age and yield where net present value is maximized based on FASTLOB2 simulations from age 10 for five harvesting/site preparation treatments

Treatment	----- 8 percent -----		----- 12 percent -----	
	Harvest Age	Yield	Harvest Age	Yield
	<i>years</i>	<i>tons/acre</i>	<i>years</i>	<i>tons/acre</i>
DF	30.0 bc	200 c	18.3 ab	134 c
WF	33.3 a	230 b	19.0 a	147 bc
DB	32.3 ab	240 b	18.3 ab	156 b
WB	30.7 bc	240 b	17.3 bc	156 b
WMB	29.0 c	260 a	16.0 b	179 a

Table 2—Comparison of maximum net present value (in dollars) predicted using four FASTLOB2 simulations for five combinations of harvesting treatments

Treatment	Maximum Net Present Value			
	Block 1	Block 2	Block 3	Total
----- 8 percent IR without Mortality -----				
DF	145	244	18	135 a
WF	107	178	46	110 a
DB	74	104	-97	27 b
WB	-18	150	39	57 ab
WMB	114	162	-101	58 ab
----- 8 percent IR with Mortality -----				
DF	31	115	-78	16 a
WF	13	74	-39	22 a
DB	74	104	-97	27 a
WB	-18	150	39	57 a
WMB	114	162	-101	58 a
----- 12 percent IR without Mortality -----				
DF	-89	-36	-163	-96 a
WF	-122	-85	-157	-121 a
DB	-195	-181	-291	-223 b
WB	-247	-146	-220	-204 b
WMB	-201	-163	-345	-236 b
----- 12 percent IR with Mortality -----				
DF	-185	-143	-244	-191 a
WF	-189	-160	-217	-189 a
DB	-195	-181	-291	-223 a
WB	-247	-146	-220	-204 a
WMB	-201	-163	-345	-236 a

yield without more replication on a wider variety of sites. Although few clear economic decisions can be drawn from this study, the opportunity to compare the experimental site preparation against more common practices is valuable.

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