# Slash and Loblolly Pine Productivity on Reclaimed Titanium Mined Lands in Northeast Florida

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Abstract:--Titanium mining often occurs on forestlands that previously supported productive pine plantations. The productivity of reclaimed mined lands is uncertain, based on observations that tree height on reclaimed lands is less, perhaps due to compaction. This paper summarizes early results from field studies initiated in December 1999 on unmined and reclaimed mined lands near Green Cove Springs, Florida, using two slash (*Pinus elliottii var. elliottii)* and loblolly (*Pinus taeda*) pine progenies, three fertilizers (granulite, diammonium phosphate, and a 16-4-8 blend at 36lbs N/acre (40.3 kg N/ha)) each, one herbicide (glyphosate), one dry humate addition, one mycorrhizal inoculation, subsoiling, and various combinations thereof to determine silvicultural treatments that optimize pine productivity on reclaimed mined lands. Mined sites had significantly higher survival but shorter trees than the unmined lands. A combination of treatments, including pines genetically superior for growth and disease resistance, may afford the opportunity for sustaining pine productivity on titanium mined lands.

Keywords: *Pinus elliottii var. elliottii*, *Pinus taeda*, fertilization, subsoiling, pest incidence, humate

## INTRODUCTION

Titanium mining is a major industry in Florida, but its impact on site productivity is difficult to assess (Poulin and Sinding, 1993). Current extraction techniques include dredge and satellite mining that removes existing vegetation and pushes approximately 25 cm of topsoil into berms. The dredge or other heavy equipment removes the underlying 1.5 to 4.5 m of soil. The material is macerated into a homogenized slurry mix containing humic matter, soil residuals, humates, water, and the titanium ore and other select minerals. This process generates tailings that are used to partially backfill the excavation site and a black turbid wastewater created when the organically rich spodic (Bh) horizon is masticated prior to the separation process. The water is pumped into treatment ponds where the suspended solids often form a very stable colloidal suspension. Carefully monitored additions of $H_2SO_4$ or $FeCl_2$ lower the pH of these waters to 4.5 whereupon the humates precipitate allowing the purified water to be returned to the mining operation or discharged into steams if it conforms to state standards. The humate material is allowed to dry before the previously removed topsoil is redeposited over the dried pond prior to its reclamation with trees or other suitable vegetation.

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Mined soils are problematic for companies reclaiming mined lands. These soils are typically homogenized by the mining and retain virtually none of the soil structure that benefits vegetation through favorable bulk density, soil strength, and porosity. Competition for water and nutrients is especially critical on reclaimed sites due to the upheaval of the spodic horizon and the degradation of the stored topsoil. For reclamation practices to be effective, water and nutrients must be available in the soil, and roots must be able to penetrate the soil.

Current reclamation policy includes the redeposition of topsoil to the mined area. Unfortunately the bermed topsoil is often degraded due to the effects of long-term storage. Additionally, soil compaction by heavy equipment has detrimental effects on the soil (Zabowski et al., 1996). Topsoil amendments can effectively enhance the productivity of these sites.

Silvicultural practices can assuage some of these limitations. Controlled drainage reduces the nitrogen and phosphorus export as well as the total suspended solids lost from a watershed (Amatya et al., 1998). Conserving the total organic carbon concentration in the soil preserves electrical conductivity levels. Bedding improves survival by increasing root zone aeration, reducing compaction, and prolonging water availability. Trees grown on infertile soils respond prominently to fertilization and to increased nutrient allocation afforded by weed control. The enhanced growth potential and disease resistance of genetically superior stock may augment the productivity of reclaimed lands.

Mathey (2001) evaluated the productivity of slash pine as old as 16 years on reclaimed titanium mined lands. Tree heights were significantly higher on unmined sites, although there was a high degree of variability. While nutrients were not significantly different between unmined and reclaimed sites, pH was slightly higher on reclaimed sites (5.1 vs. 4.6). Furthermore, compaction was greater on the reclaimed sites and was suspected as the primary reason for reduced height. Subsoiling is positively related to the growth of pines in the southeastern United States (Slay et al., 1987). The cost of subsoiling reclaimed mined sites would be minimal since mining companies are typically replete with the necessary equipment.

The purpose of the field studies reported here was to determine the silvicultural and genetic treatments, or combination of treatments, that optimize the productivity of pine planted on reclaimed mined lands in northeast Florida.

## MATERIALS AND METHODS

Approximately 13km south of Green Cove Springs, Florida, unmined and reclaimed sites in close proximity were paired to minimize topographic variations. Unmined sites were not disturbed by any mining activity or affected by additional humate. All reclaimed sites had undergone reclamation at roughly the same time interval prior to planting and did not have any wetland inclusions.

Studies 1 and 2 were planted on reclaimed satellite mined and unmined lands on poorly drained, low nutrient spodosols (Hurricane and Leon series, CRIFF group D) endemic to the flatwoods of northeast Florida. Study 1 involved three treatments (C, G2, and D2 in Table 1) replicated three times on paired unmined and mined sites according to a randomized complete block design, with six more treatments in one replication. In Study 2, four of the same nine treatments were replicated three times in a randomized complete block design on an unmined site and twice on a paired mined site with adjacent non-subsoiled and subsoiled blocks, five of the nine treatments were only in one replication, and three humate treatments were also included in one replication in the subsoiled block. Study 1 was planted in mid-December 1999 on beds prepared up to three months earlier, Study 2 in mid-January 2001 on beds that had settled for 4 to 6 months. Loblolly progeny 1-1313 was planted after the slash pine progeny 164-58 (selected for fast growth and resistance to fusiform rust). Each gross treatment plot had 6 beds at 11 feet (3.4m) by 11 trees at 5 feet (1.5m), for a planting density of 792 trees/acre (1,955 trees/ha). Three fertilizers were evaluated: granulite, a 5-3-0 organic derived from anaerobically digested sewage sludge, diammonium phospate (DAP, 18-46-0), and a 16-4-8 blend with balanced micronutrients (Mg, Mn, Cu, and S). The fertilizers were manually broadcast over the beds eight weeks after planting in amounts calculated to provide 36lbs/acre of nitrogen (40.3kg/ha). Weed control using 4% glyphosate (Roundup ) was implemented in May 2000 and 2001. The second year fertilizer treatments for Study 1 were broadcast in March 2002. A 0.35% aluminum humate amendment was also broadcast. The mycorrhizae treatment was three ectomycorrhiza (*Pisolithus tinctorius*) tablets per planting hole prior to closure.

Treatments **CHP** and **CHHP** (Table 1) were established in dredge mined areas to determine any significant difference with satellite mining. Dredge mining techniques had exclusively been performed until recently when satellite mining became more efficacious. The **CHP** site is identical to the control plots installed over the satellite-mined areas. The **CHHP** site had a preponderance of humate material close to the surface of the topsoil.

Tree height and survival were measured annually in June. Pitch canker, fusiform rust, and insect incidences were also noted. In July 2001 and 2002, several additional measurements were performed. Topsoil depth (horizons A and E) above the spodic horizon or reclaimed humate layer was measured at 15 random locations on each unmined and reclaimed site with a trenching shovel and meter stick. Soil strength was measured with a soil penetrometer at 10 random samples from a spot located between beds in each location. Groundcover was assessed as vegetation type and percentage cover at 10 one square meter plots randomly located between beds for each location and year. Height, survival, and soil data including topsoil depth, soil strength, and percent vegetative cover were subjected to ANOVA using GLM and Duncan's tests in SAS to determine significant treatment differences. Pearson's correlations were also calculated.

| Treatment | Study 1 | | Study 2 | | |
|---|---|---|---|---|---|
| | Unmined\No | Mined\No | Unmined\No | Mined\No | Mined\Sub |
| **C** | 3 | 3 | 3 | 2 | 2 |
| **G0R** | 1, *1* | 1, *1* | 1, *1* | 1, *1* | 1, *1* |
| **G0H** | | | | | 1 |
| **G2** | 3 | 3 | 3 | 2 | 2 |
| **D0R** | 1 | 1 | 1 | 1 | 1 |
| **D0H** | | | | | 1 |
| **D2** | 3 | 3 | 3 | 2 | 2 |
| **B0R** | 1 | 1 | 1 | 1 | 1 |
| **B0H** | | | | | 1 |
| **B2** | 1 | 1 | 1 | 1 | 1 |
| **H0** | | 1 | | 1 | 1 |
| **M0** | 1 | 2 | 1 | 1 | 1 |
| **CHP** | | | | 1 | |
| **CHHP** | | | | 1 | |

**Table 1.** Number of replications (66 tree gross plot, 36 tree net) of silvicultural treatments (C= bedding only, **G** = bedding + granulite, **D** = bedding + DAP, **B** = bedding + blend with micronutrients, **M** = bedding + mycorrhizae, **H** = bedding + humate, **CHP** = bedding + humate pond, **CHHP** = bedding + humate pond with extra humate; **R** = herbicide; **0** = broadcast at planting, **2** = rebroadcast in year 2) applied to slash (loblolly in italics) pine in the unmined and mined components of Studies 1 and 2 with (Sub) and without (No) subsoiling.

## RESULTS AND DISCUSSION

Tree height was greater on unmined sites than on reclaimed locations in both studies (Table 2). In Study 1, land types, treatments, and land type*treatment interaction were significant (Type and Treatment $p<.0001$ at $\alpha=.05$, Type*Treatment $p<.0010$ at $\alpha=.05$). In Study 2, no differences were detected between subsoiled and non-subsoiled sites, but significant effects of land types, treatments, subsoiling*treatment, type*treatment, and type*treatment*subsoiling were observed ($p<.0001$ at $\alpha=.05$).

Conversely, survival was higher on mined sites (Table 2). In Study 1, spring drought stress and probably J-rooted seedlings reduced survival at the unmined site. Much mortality occurred before May 2000, and entire rows within treatment plots were dead by the end of the first year. There were significant effects due to land types, treatments, and land type*treatment interaction ($p<.0001$ at $\alpha=.05$).

Survival in Study 2, reflecting the influence of another spring drought following planting, was more varied than in Study 1, but still higher in the reclaimed sites (Table 2). Not surprisingly, the subsoiled site had the best survival by alleviating the detrimental effects of soil compaction on early establishment. Future survival trends should be more revealing. Roots elongate through the soil by growing through larger pore spaces or enlarging pores smaller than their own diameter. Land types, subsoiling, treatments, subsoiling*treatment, type*treatment, and land type*treatment*subsoiling were significant ($p<.0001$ at $\alpha=.05$).

| Treatment | Study 1 – 3 years | | | | Study 2 – 2 years | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Unmined\No | | Mined\No | | Unmined\No | | Mined\No | | Mined\Sub | |
| | H | S | H | S | H | S | H | S | H | S |
| **C** | 3.71 | 48.1 | 2.47 | 82.4 | 1.15 | 80.5 | 1.15 | 80.5 | 1.77 | 93.1 |
| **G0R** | 3.05 | 30.6 | 2.76 | 80.6 | 1.75 | 66.7 | 1.04 | 75.0 | .88 | 91.7 |
| | *3.93* | *86.1* | *2.34* | *97.2* | *1.85* | *80.6* | *1.46* | *97.2* | *.99* | *94.4* |
| **G0H** | | | | | | | | | 1.24 | 97.2 |
| **G2** | 4.03 | 66.7 | 3.15 | 92.6 | 2.25 | 72.2 | 1.18 | 81.9 | 1.04 | 93.1 |
| **D0R** | 3.76 | 30.6 | 2.41 | 91.7 | 2.19 | 61.1 | 1.20 | 66.6 | 1.64 | 91.7 |
| **D0H** | | | | | | | | | 1.60 | 83.3 |
| **D2** | 3.81 | 61.1 | 2.81 | 79.6 | 2.14 | 50.0 | 1.36 | 54.2 | 1.36 | 76.4 |
| **B0R** | 3.90 | 8.3 | 2.69 | 91.7 | 2.47 | 22.2 | 1.45 | 55.6 | 1.53 | 80.8 |
| **B0H** | | | | | | | | | 1.24 | 86.1 |
| **B2** | 3.41 | 58.3 | 3.00 | 83.3 | 1.80 | 36.1 | 1.23 | 50.7 | 1.36 | 54.2 |
| **H0** | | | 2.72 | 91.7 | | | .96 | 88.9 | 1.10 | 97.2 |
| **M0** | 3.40 | 16.7 | 2.69 | 87.0 | 1.48 | 63.9 | 1.38 | 81.9 | 1.62 | 75.0 |
| **CHP** | | | | | | | NA | | | |
| **CHHP** | | | | | | | NA | | | |
| Mean | 3.79 A | 50.6B | 2.76B | 86.4 A | 1.93A | 60.9B | 1.26B | 73.3A | 1.36B | 83.6A |

**Table 2.** Height (H in m) and survival (S in %) by silvicultural treatment and species (loblolly in italics) in Studies 1 and 2.

Pest incidences were relatively unimportant in both studies. Virtually no pitch canker was noted, fusiform rust was evident only in Study 1, and insect incidence, primarily tip moth, tended to be higher on mined sites. Fusiform rust in Study 1 at three years exceeded 10% in only the **C**, **G2**, and **D2** treatments on the unmined site. Insect damage was notably higher on the non-subsoiled mined site, with average incidence still less than 20%, but surpassing 60% in the **G0R** treatment at three years.

All treatments except **C** and **M0** included fertilizer. The generally poor soils associated with pine flatwoods negatively influence the allocation of biomass and the aboveground net primary production (ANPP) (Gower et al. 1994). The redistribution or addition of available nutrients on the unmined sites through weed control and/or fertilization should increase the ANPP and LAI due to the increase in biomass or a shift in the present biomass from belowground to aboveground. The diminished growth seen on the reclaimed site is likely caused by an externality, such as compaction, not present on the unmined site.

Where nutrient resources are likely to become limiting to growth, fertilizers and vegetative control are often complementary (Goncalves, 1997). The availability of such nutrients is critical to the productivity of pine trees in north central Florida (Polglase et al., 1992). The initial effectiveness of fertilizer treatments can be reduced by the presence of weeds and hardwoods, and weed control measures may be required to ensure successful pine seedling establishment. Future measures may not be necessary as the crown coverage begins to shade out and suppress competition (Goncalves, 1997). Fertilization prior to canopy closure is most likely to increase future volume because trees in the early stages of development depend on the soils where nutrients are limiting (Miller, 1981).

Penetrometer measurements confirmed suspicions about the reclaimed sites, as soil strength increased with soil depth (Figure 1). Soil strengths also differed significantly between unmined and reclaimed sites in Studies 1 and 2 ($p<.0001$ at $\alpha=.05$). Root elongation decreases as soil strength increases. Compaction usually increases both bulk density and soil strength. Root growth in moist soils is generally limited by bulk densities ranging from 1.45kg/cm$^3$ in clays to 1.85kg/cm$^3$ in loamy sands (Brady and Weil, 1999). The effects of tractors and other heavy equipment are especially damaging if the soil is wet when trafficked. Subsoiling can reduce the soil strength and density as related to resistance to penetration, but the effects typically last less than 18 months on sandy soils.

Vegetative cover was significantly less on reclaimed sites in both studies ($p<.0001$ at $\alpha=.05$). Presumably, the storage of the topsoil in berms decreased viability of autochthonous plant life. Plant species on the unmined sites included saw palmetto, gallberry, blackberry (*Rubus spp.*), grasses (various *Poaceae* genera), and various berries (*Vaccinium spp.*). Patchy outcroppings of grasses, etc., only appeared on the reclaimed sites after the wind had dispersed seeds from neighboring unmined tracts This effect made the application of herbicide less problematic, if not unnecessary. Furthermore, correlations between the percentage of cover and soil strength (Table 3) support assertions regarding survival of seedlings on the reclaimed sites and compaction.

The depth of the topsoil layer in Study 2 varied from 24 to 49cm on the unmined to 25 to 49cm on the reclaimed sites (Figure 2). Study 1 had slightly more variation with the unmined site ranging from 20 to 45cm, but the reclaimed depths were from 13 to 49cm. The topsoil harbors most of the biological activity. For reclaimed sites to equal unmined sites in productivity, at least 30cm of topsoil should be redistributed over the area after mining.

The pedigrees of the slash and loblolly progenies used in these studies provide some opportunity to speculate about how genetic variability in these species may influence productivity. Slash progeny 164-58 has breeding values of 23 and 25 for volume and fusiform rust resistance, respectively. As these breeding values are exceeded by only some 20 other open-pollinated progenies that may be publicly available for northeast Florida, use of less superior planting stock for replanting mined lands could result in less growth and more fusiform rust (Vergara et al., 2003) by slash pine than what has thus far been observed in these two studies. Loblolly pine progeny 1-1313 has a Piedmont origin, however, and may consequently underestimate loblolly productivity, especially when intensive silviculture is practiced. Open-pollinated progenies of Gulf Coast or Florida origin have the potential to increase loblolly productivity by up to 15 and 30%, respectively, in northeast Florida (D. Huber, personal communication).

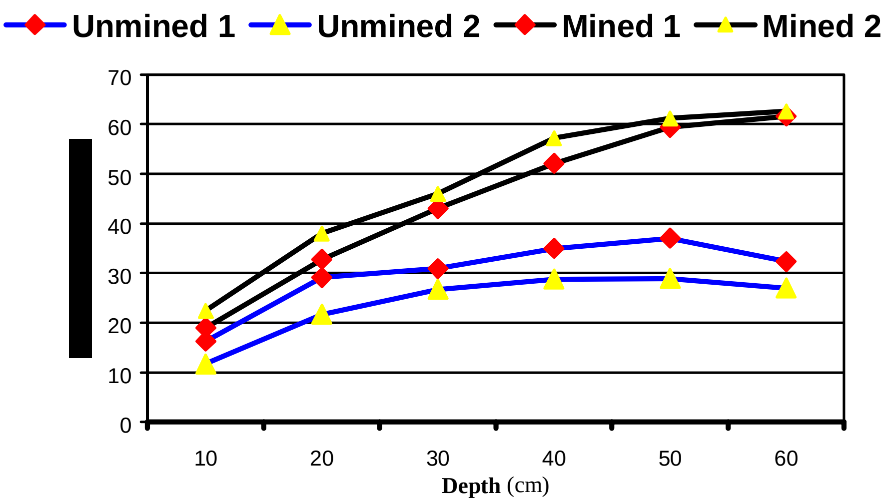


**Figure 1.** Soil strength with depth for Studies 1 and 2 unmined and reclaimed sites.

| Study | Soil Depth (cm.) | | | | | |
|---|---|---|---|---|---|---|
| | 10 | 20 | 30 | 40 | 50 | 60 |
| 1 | -.44* | -.44* | -.64* | -.67* | -.67* | -.65* |
| 2 | -.12 | -.18 | -.72* | -.62* | -.64* | -.52* |

**Table 3.** Pearson correlations between percent cover and soil strength at six soil depths in Studies 1 and 2. (*significant at $\alpha$=.05)

## CONCLUSION

Current recommendations derived from Studies 1 and 2 are preliminary. Reclaimed sites had higher survival but shorter trees. Subsoiling increased survival and should be considered for reclaimed lands. Nutrient deficiencies common to the flatwoods may be overcome through proper site and species selection, appropriate fertilization, and/or reallocating existing nutrients through the application of herbicides. Clearly, compaction limits the productivity of reclaimed sites, although there is no way currently to reclaim these areas without the use of heavy machinery. Reclaimed sites have the potential for productive forestry through the application of these methods over time.

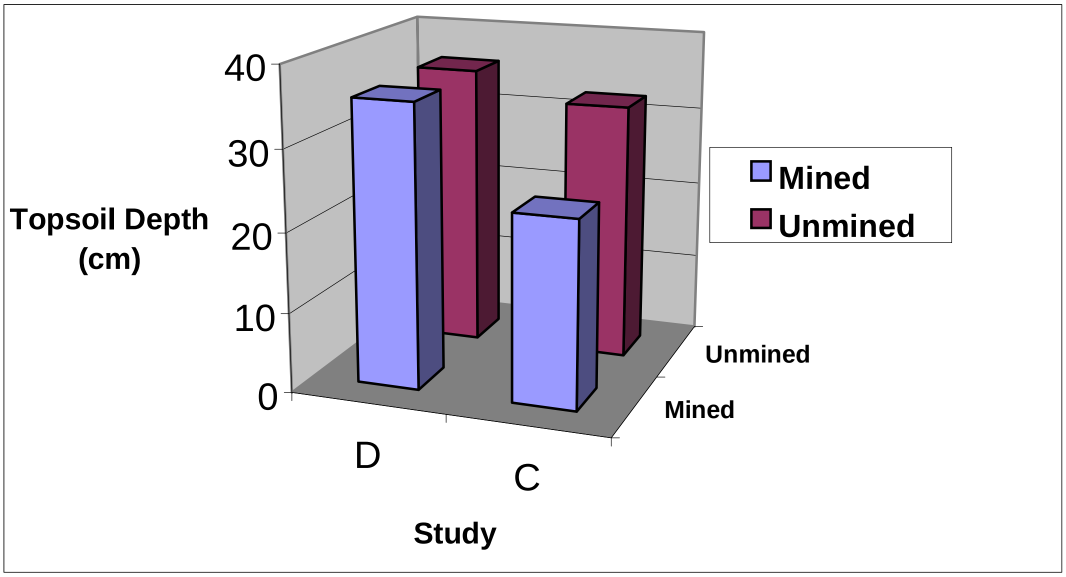


**Figure 2.** Topsoil depths for Studies 1 and 2 unmined and reclaimed sites.

## ACKNOWLEDGMENTS

We acknowledge general assistance and support from Iluka Resources Inc., assistance and materials by Rayonier Forest Research Center, significant participations by Ted Goodman of Iluka and Tom Fox of Rayonier, reviews of slash and loblolly pine breeding values by Early McCall and Dudley Huber, and assistance with study establishment from Mark Torok and Richard Cardellino.

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