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THE DEVELOPMENT OF TECHNIQUES FOR THE USE OF TREES IN THE RECLAMATION OF PHOSPHATE LANDS

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FLORIDA INSTITUTE OF PHOSPHATE RESEARCH

THE DEVELOPMENT OF TECHNIQUES FOR THE USE OF TREES IN THE RECLAMATION OF PHOSPHATE LANDS

FINAL REPORT

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June 1987

DISCLAIMER

PERSPECTIVE

David J. Robertson

Florida Institute of Phosphate Research

This report is the culmination of the first reclamation research program to receive support from the Institute. Even though the investigation got underway in 1980, many years were required to develop reliable data on survival and growth.

Success criteria for phosphate mine reclamation are embodied in rules promulgated by the Florida Department of Natural Resources, Bureau of Mine Reclamation (Chapter 16-C-16) which have been in effect since the year this project began. These rules contain criteria for tree plantings on upland and wetland sites. At a minimum, 10% of uplands must be revegetated as forested areas with a variety of indigenous hardwoods and conifers. The Department requires a stand density of 200 trees/acre at the end of one growing season. Forested wetlands must also achieve a stand density of 200 trees/acre. All plants used in revegetation must be indigenous native species and the Department normally requires that at least three species be incorporated into plantings. The Department grants an exception for trees that could be considered silvicultural crops.

Planting trees is usually the last in a long series of tasks that comprise the rehabilitation of a mine site. Given reasonable survival rates, tree planting is often the least expensive component of the entire reclamation budget, the vast majority of which goes toward restoring topographic integrity. Nonetheless, trees are the most prominent feature of the reclaimed landscape and the lack of trees is often singled out as the greatest failing in successful reclamation.

Planting trees was not always essential for restoring land to a semblance of the landscape that existed before mining. Prior to the central Florida phosphate industry's widespread acceptance of mineral flotation technology and electric draglines, mined areas were small and isolated. The waste was a mixture of sand and clay which served as a foundation for development of a soil that would hold nutrients and moisture. In addition, mines were usually adjacent to undisturbed forested lands or stream floodplains which provided a source of tree seeds. This combination of characteristics produced revegetated landscapes much like those the area supported before mining occurred, with most of the same tree species dominating the canopy.

With the modernization of the industry, though, mining began to encompass vast acreages and processing operations segregated the individual components of the waste stream into droughty sand-filled mining cuts, elevated clay settling ponds, and overburden areas. The remnants of undisturbed land, located principally along stream courses, in wetlands, and overlying uneconomic deposits, became too distant from most areas of the mine to provide reliable seed sources for revegetation. When reclamation became mandatory in 1975, tree planting became essential.

Although active reclamation activities prior to the mid-1970's produced several successfully reforested areas, the phosphate industry in general was not accustomed to planting trees. Central Florida is not a traditional timber producing area: the nearest pulp plants are in north Florida and because of transportation costs, timber prices in central Florida are typically lower than further north. Therefore, it was necessary to develop the experience necessary to plant trees on the reclaimed landscape in order to meet the letter of the law.

The results of this project were generated from 18 field sites scattered-throughout the central Florida phosphate mining area. A total of 29 tree species were tested for survival and growth in four reclaimed landform and soil types: overburden, phosphatic clay, sand tailings, and a mixture of clay and tailings commonly known as sand-clay mix. Some plots were established during the first year, while others were not established until 1983 so that the results are based on variable growing periods. From these plantings the Division has produced a summary of trees recommended for use on reclaimed land.

Since this project was funded, the Institute and several of the mining companies have supported other studies which have focused on the reestablishment of a balanced ecosystem dominated by trees, although none have had the specific goal of identifying the best-performing trees on a given soil type. These projects have tended to address the two extremes of the hydrologic spectrum, forested wetlands and sand pine scrub, but other recent projects have attempted to integrate the knowledge gained from these areas into a unified understanding of ecosystem-level organization.

Forested Wetlands. The phosphate industry's initial attempt to reclaim a forested swamp took place on the shore of Altman Bay Lake at Occidental Chemical Company's Suwannee River Mine. Occidental planted 500 cypress and 1000 loblolly pine seedlings on two acres of the tract and reported excellent survival for both species.

One of the most ambitious forested wetland reclamation projects to date was undertaken by International Minerals and Chemical Corporation (IMC), the Florida Game and Fresh Water Fish Commission, and the U.S. Fish and Wildlife Service in 1978 on the Peace River floodplain. This project, known to reclamation planners as "Parcel B," involved extensive plantings of 27 species of native Florida trees., The participants planted 10,400 seedlings and over 100 tree-spaded trees onto the site in carefully designed plots that allowed the investigators to test the effect of slope, inundation and soil moisture on tree survival. Parcel B is one of the phosphate industry's most carefully documented wetland reclamation projects, and progress and results of the first several years of succession have been reported in numerous publications.

At Brewster Phosphates, small plots were planted in 1980 with bare-root seedlings representing eight species. Preferred hydric tree species were not available, so Brewster used transitional zone species such as sweetgum, red maple and slash pine with generally good success (91%, 85% and 46% survival, respectively).

In 1982, Agrico began to reclaim a portion of the floodplain of Little Payne Creek to hardwood swamp and marsh. This large area (300, acres) was planted with sweetgum and ash seedlings. IMC plans two floodplain hardwood swamps, one on a small tributary of the Peace River, the other in the upper watershed of Lake Branch of the South Prong Alafia River.

The Institute awarded a grant to Dr. Mark Brown of the Center for Wetlands at the University of Florida to test the efficacy of spreading organic wetland mulch for-hardwood swamp reclamation. Dr. Brown's project, "Studies of a Method of Wetland Reconstruction after Phosphate Mining" (FIPR Publication #03-022-032), involved spreading mulch in two different configurations along the edge of a reclaimed lake at Occidental Chemical Company in north Florida, then planting seedlings of three tree species in the mulch. Unfortunately, vagaries in the weather and in water requirements in Occidental's recirculation system disrupted Dr. Brown's planned research, limiting the amount of information that the project provided.

Reclamation of streams and floodplain forest is becoming increasingly important. Stream relocation to allow mining is particularly controversial because virtually no data have been collected to demonstrate or refute that a stream and its environs can be reclaimed.

Industry-wide, there are only a handful of stream relocation and reclamation projects that have been completed. In 1979, Mobil Mining and Minerals diverted 1000 feet of Sink Branch, a tributary of the Peace River northeast of Ft. Meade, from its original unmined channel into a parallel channel excavated on mined land to the north. Nine species of native trees were tree-spaded or hand planted as bareroot or potted seedlings, 700 per acre. Mobil monitored tree survival for 14 months, but made no provisions for evaluating the success of the project after February 1981. The Institute of Phosphate Research took the initiative to supplement the data through an in-house research effort, "Sink Branch: Stream Relocation and Reclamation by the Florida Phosphate Industry" (FIPR #82-03-033). The findings of the Institute's study are being readied for publication.

Mobil also recently graded and revegetated a small tributary of Guy Branch of the North Prong Alafia River named George Allen Creek. The site was heavily planted with a variety of tree species and herbaceous vegetation. Unfortunately, severe erosion problems that developed almost immediately after contouring was completed dictated that the site be entirely regraded. This rehabilitation has been completed and the channel has been replanted.

Mobil has begun work on three additional stream projects. The headwaters of McCullough Creek lie partially within the boundary of Mobil's Ft. Meade Mine. The total wetland area in the completed project will be 21 acres consisting of two acres of marsh and 19 acres of floodplain hardwood swamp. Myers Branch, a tributary of the Peace River parallel to Sink Branch is also being reclaimed. The project involves the reforestation of eight acres of hardwood swamp along 1400 feet of stream channel. Rocky Branch, formerly a direct tributary of the Peace River northeast of Ft. Meade now diverted into Sink Branch, will be returned to approximately its original location and will serve as the main channel collecting drainage from a number of bayhead swamps established on reclaimed settling areas.

Brewster Phosphates relocated three small tributaries of the South Prong Alafia River at the Fort Lonesome Mine: Lizard, Dogleg, and Hall Branches. Brewster is monitoring the success of the project, concentrating on tree survival and growth.

Since May 1982, The Institute has been working with the U.S. Bureau of Mines, the U.S. Geological Survey and the U.S. Fish and Wildlife Service on a stream reclamation project at AMAX Chemicals' Big Four Mine. The "Wetlands Reclamation Research Project" is unique in that the stream, its associated riparian forest and the area's hydrology were all evaluated before the 16 acre tributary of Lake Branch of the South Prong Alafia River was mined in 1984. This pre-disturbance data will provide a basis for comparison once reclamation is complete.

Forested wetland reclamation is not restricted to stream channels and excavated basins. Evidence is accumulating that clay settling areas can support more natural wetlands than the willow thickets that are normally associated with old abandoned ponds. In a few old locations, hardwood species have invaded relatively dry, consolidated settling areas indicating that improved seeding and hydroperiod control may provide a means for establishing a variety of wetland forests as reclamation alternatives. The Institute of Phosphate Research is actively supporting research to try to determine how reforestation could be encouraged on settling areas in an award to the Center for Wetlands at the University of Florida entitled "Interactions Between the Phosphate Industry and Wetlands" (FIPR Publication #03-007-025). Promising results during the first two years led to support for a supplemental project, "Interactions between Wetlands and Phosphate Mining" (FIPR #83-03-041R).

Xeric and Mesic Uplands. One particular upland community that has been singled out for special attention is the sand pine scrub. Most of the scrub and other xeric communities in west and central Florida have been destroyed by urban development or citrus groves. An opportunity exists to reestablish scrub on well-drained mined uplands. Sand pine scrub experiments are underway at three separate mine sites, all of which have incorporated topsoil from native xeric communities. A project recently funded by the Institute, "Restoration Techniques for

Sand Scrub" (FIPR #85-03-066R), is also attempting to reestablish scrub habitat on reclaimed land by planting sand pine seedlings, scrub live oak, and a variety of understory species. No mulching with scrub topsoil is involved in this investigation, under the direction of Florida Southern College in Lakeland.

Reclamation on moister sites is often more easily accomplished than on droughty areas, but the range of tree species that can be introduced is largely restricted by availability. Two Institute projects sponsoring investigators from the University of Florida have sought to overcome this shortcoming in different ways.

In a series of experiments conducted in microplots and in full-scale field plots, Dr. G. Ronnie Best and several graduate researchers tested direct seeding as an option for planting. This project, "Enhancing Ecological Succession Following Phosphate Mining" (FIPR #81-03-008), incorporated 60 different species commonly encountered in central Florida landscapes including 40 arboreal and woody plants. The microplot studies tested the efficacy of various surface mulches and soil amendments for improving the germination and survival of seeds planted in overburden soil. Using the results of these experiments, the project's staff members prepared full-scale field plots. In the course of the experiment, Dr. Best modified a commercial agricultural seed drill to accept a wide variety of seed sizes so that a mixture of species could be planted in a single pass during field operations. The results of the experiments, as well as tests of mycorrhizal fungal innoculation, are being prepared for publication.

Drs. Bijan Dehgan and Tom Sheehan of the Department of Ornamental Horticulture at the University of Florida have taken a different approach to introducing trees and shrub vegetation onto reclaimed minesites. The investigators have identified species that are important components of their respective ecosystems in phosphate mineralized areas, but are not commercially available. These plants are being propagated by techniques requiring the least intensive effort, whether that be by seed, stem cutting, or in the case of plants very difficult to reproduce such as scrub rosemary, by tissue culture techniques. The research plants are being inoculated with native mycorrhizal fungi species to improve their chances for survival and growth once they are planted on reclamation sites. Nursery and field trials are being established to evaluate the success of these efforts.

With the increasing awareness that the most successful reclamation will ultimately involve landscape design and restoration of regional hydrology, the phosphate industry and the Institute have recently undertaken sophisticated reclamation projects designed to replace functional hydrologic units. Wetlands and forested uplands are integrated into watersheds that frequently also include streams and lakes, producing a unified reclaimed landscape.

In 1982, Agrico Chemical Company began reclamation of a 366 acre watershed restoration project at its Fort Green Mine known as Morrow Swamp. The original project was designed to monitor tree planting, effect of mulching, natural invasion and colonization. Morrow Swamp includes 240 acres of upland with two lakes spilling over into a 126 acre wetland. The wetland consists of 75 acres of marsh, one acre of bayhead swamp and 50 acres of floodplain hardwoods on the western side of Payne Creek. Agrico reported moderate to high survival rates for most of the tree species planted on the site. The apparent success of the Morrow Swamp project encouraged Agrico to pursue an even larger and more ambitious watershed reclamation project on the opposite bank of Payne Creek.

Although not the largest, one of the best integrated of the watershed reclamation projects was recently completed at Gardinier's Fort Meade Mine. This wetland project was designed by the Center for Wetlands at the University of Florida in cooperation with Gardinier, Inc. Two reclaimed bayheads in the upper watersheds were sealed with phosphatic clays topped with organic muck soils. These wetlands drain through a series of swales through an herbaceous wetland and into a small lake. Eventually, the water finds its way through a forested channel into Whidden Creek. The total wetland area on the site is about 10.5 acres with a watershed of 153 acres.

The Institute is in the midst of one of its longest and most costly reclamation research commitments, "Development of Techniques and Guidelines for Reclamation of Phosphate Mined Lands as Diverse Landscapes and Complete Hydrologic Units" (FIPR #83-03-044). This five-year project with the Center for Wetlands at the University of Florida is designed to (1) document the physical and biological organization of relatively undisturbed Florida plant communities, (2) develop reclamation plans with the goal of producing diverse yet integrated landscapes based on "templates" offered by the natural communities, and (3) prepare a manual setting forth guidelines for reclamation planning and implementation. Rather than planning reclamation from a "techniques" standpoint or from a piecemeal, parcel-by-parcel approach, these investigators are attempting to consider reclamation systematically by developing an understanding of how individual reclaimed parcels can be fit together into complete hydrologic and landscape systems.

Research Needs. Despite the considerable progress that has been made on incorporating trees into the reclaimed landscape, additional research is needed to improve survival, reduce cost, enhance growth, and increase variety. Specifically, research is needed:

To increase the speed at which bare-root and "tubeling" trees can be planted;

To improve the success and germination of direct seeded trees to reduce the cost of introducing trees and expand the variety of species on reclaimed land;

To reduce competition from weeds that can overwhelm or stunt the growth of newly planted seedlings;

To test culture techniques such as soil amendments, mycorrhizal inoculation, and greenhouse soil mixtures for tubeling trees; and

To expand the availability of trees that are available through seed collection and greenhouse growing programs.

Other research may prove to be profitable as well, such as the use of some plants to act as "nurse" vegetation to ameliorate microclimate or soil conditions. The Institute's history of support for research dedicated to the reintroduction of trees on reclaimed land has been broad and substantial, and we look forward to continuing this commitment in the future.

ACKNOWLEDGEMENTS

The Principal Investigator wishes to express his appreciation to District Forester Mark E. Hebb and Reclamation Research Foresters: Richard A. Bailey, Cherry A. Wadsworth and D. Gary Zipprer, for their hard work and their contributions toward the completion of this study. The assistance of Florida phosphate industry and the staff of the Florida Institute of Phosphate Research is also gratefully acknowledged.

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EXECUTIVE SUMMARY

Tree seedlings have been planted by Florida's phosphate industry on surface-mined land for many years, however, success has been disappointing for the industry as a whole. Tree planting studies by the phosphate companies have typically lacked documentation, or have been done "in-house" and not made available to the rest of the industry. As a result, the industry continues to experience tree planting failures and individual companies must frequently replant specific sites two or three times to achieve the minimum stocking level required by the Florida Department of Natural Resources.

This study addressed the problem of reforestation on reclaimed land. Part I involved the selection of tree species for planting on specific post-mining soils (sand-clay mix, overburden, sand tailings and phosphatic clay), and Part II evaluated the feasibility of direct seeding sand pine (Pinus clausa) and slash pine (Pinus elliotii var. elliottii) on sand tailings. Funding was provided through a five-year contract with the Florida Institute of Phosphate Research (Contract Number: F.I.P.R. 80-03-001).

Part I of this research project (tree species selection) required the establishment of fourteen (14) species selection plots over a four-year period on four different post-mining soil types: sand-clay mix (3), overburden (5), sand tailings (3) and phosphatic clay (3). Thirteen tree species selection plots were located in Polk County, Florida, and one was located in Hamilton County, Florida. Trees were measured annually, and parameters monitored included: total height, tree diameter at ground level and percent survival.

Survival at the end of one growing season was the principal criterion used in tree species selection. "Recommended" species were defined as those species which demonstrated a first-year survival rate in excess of 50 percent. This was determined to be more than adequate to meet the reclamation requirements of the Florida Department of Natural Resources; i.e., 200 trees per acre surviving at the end of one growing season.

Mean height, diameter and survival percentages are given in this study for each tree species tested. Based upon that data, twenty native tree species were classified as "Recommended" species for outplanting on post-mining soils (sand-clay mix, overburden, sand tailings and phosphatic clay). Thirteen tree species were classified as undesirable ("Not Recommended") for outplanting on reclaimed land.

In Part II of this research project (direct seeding of sand pine and slash pine on sand tailings), four four-acre study plots were established on contoured stockpiles of sand tailings on land belonging to the Estech Corporation and the International Minerals and Chemicals Corporation in Polk County, Florida. Each plot was divided into eight subplots and the following treatments were applied: (1) harrowing followed by direct seeding, (2) harrowing followed by direct seeding and compaction with a cultipacker, (3) direct seeding followed by compaction with a cultipacker and (4) direct seeding only.

Two of the four plots (IMC II and Estech II) were direct seeded in February of 1982. One half of each plot was direct seeded with sand pine seed and one half was direct seeded with slash pine seed. The repellant-treated seed was dispersed with a hand-cranked mechanical seeder at a rate of 0.7 pounds per acre for sand pine and 1.0 pound per acre for slash pine. Both plots failed to yield any germinating seedlings. Plot failure was primarily attributed to the time of year in which direct seeding occurred.

The two remaining plots (IMC III and Estech III) were direct seeded in November of 1982. Again, one-half of each plot was direct seeded with sand pine seed and the other one-half was direct seeded with slash pine seed. The repellant-treated seed was dispersed with a hand-cranked mechanical seeder at a rate of 0.7 pounds per acre for sand pine and 1.0 pound per acre for slash pine.

In May following seed dispersal, an inventory of IMC III and Estech III indicated that varying amounts of germination had occurred on one of the plots (Estech III). Sand pine germination occurred on treatments: #1, #2 and #3; while slash pine germination was present on treatments: #2 and #3, only. The most successful treatment for both species was treatment #2 (harrowing followed by direct seeding and compaction with a cultipacker). This treatment resulted in a germination rate of 680 seedlings per acre for sand pine and 100 seedlings per acre for slash pine.

In November of 1983 (one year following direct seeding), a second seedling inventory was made on Estech III. It was found that the number of surviving seedlings had been drastically reduced during their first summer. Mortality was attributed to: high summer temperatures and the abrasive action of the wind blown sand.

A final seedling inventory in November of 1984 (two years following direct seeding) indicated that all seedlings on Estech III had died. The seedlings were apparently unable to overcome the harshness of a dry environment of unstable, eroding sands.

Based upon the results of this study, direct seeding does not, at this time, appear to be a realistic regeneration alternative for the stabilization and reforestation of sand tailings soils.

Trees should be viewed as an integral part of phosphate mine reclamation programs. They have both economic and aesthetic value in the post-mining landscape and their successful establishment is the single most significant aspect of reclamation faced by Florida's phosphate industry. The objective of this study was to provide the phosphate industry with information which would increase the success of reforestation programs on reclaimed land.

1. INTRODUCTION

Florida has been a leading producer of phosphate during the twentieth century. In 1984, Florida produced 37.9 million metric tons of phosphate, which represented eighty percent of the U.S. production and one-fourth of the world's total production (B. Congleton, personal communication). Florida, the U.S.S.R., and Morocco account for more than 70 percent of the total world production (McClellan, undated).

Phosphate mining began in Florida in the 1880's with the mining of river pebbles from the Peace River (Polk County) and the discovery of land pebbles in 1888 near Ft. Meade (Polk County). By 1908, stripmining of land pebble phosphate by steam shovels and hydraulic pumps had become the dominant mining process.

Prior to 1929, phosphate pebbles were extracted by wet screening while the overburden and ore matrix were discarded into debris piles which were deposited to the side of dragline cuts with the mineral content more or less intact. Since forests at this time seemed inexhaustible, no thought was given to reclamation of the site or reforestation of the resulting spoils. Many of these original debris piles now support stands of mature live oak (Quercus virginiana) or north Florida slash pine (Pinus elliottii var. elliottii) which have seeded-in from nearby forests.

In 1929, a newly developed "flotation process" began to significantly alter the mineral composition of post-mining soils. This process was introduced industry-wide in the 1940's and allowed the industry to recover the smaller sand-size phosphate particles in addition to the pebble phosphate. The flotation process resulted in the separation of the ore matrix into the post-mining waste products of siliceous sands and phosphatic clays, making reclamation a much more challenging process.

The residual siliceous sands have generally been used to partially refill mining cuts which are then capped with overburden prior to reclamation. Disposal of the clays, however, has become a significant environmental problem. Normal procedure is for the clays, when separated from the sands, to be pumped in a watery slurry into huge diked clay settling ponds, up to several hundred acres in size. Because of the water retaining characteristics of the clays, settling ponds may take as long as 20 years to stabilize sufficiently to allow for reclamation.

Tree seedlings have been planted by phosphate companies on mined land for many years (Figure 1), however, success has been disappointing for the

Figure 1. Planted Pines on Reclaimed Land, Central Florida Mining District

industry as a whole. Tree planting studies by the companies have typically lacked documentation, or have been done "in-house" and not made available to the rest of the industry. As a result, the industry continues to experience tree planting failures and individual companies must frequently replant specific sites two or three times to achieve the minimum stocking level required by the Florida Department of Natural Resources.

The purpose of this study was to assist the phosphate companies with the use of trees in reclamation by testing tree species' suitability to post-mining soils and by evaluating techniques for the direct seeding of pines on sand tailing soils.

2. THE STUDY AREA

LOCATION

Although Florida has several different types of phosphate deposits, the major producing deposit is the land pebble type which underlies about 2,600 square miles in Polk, Hillsborough, Hardee, Manatee and DeSoto Counties in Central Florida (Moudgil, 1976). Phosphate is also mined in parts of Hamilton and Columbia Counties in northern Florida (Figure 1). The central Florida land pebble deposit contains abundant vertebrate fossils, and has, for this reason, become known as the Bone Valley Formation. The Bone Valley Formation is the most prolific phosphate-producing region of the world (McClellan, undated).

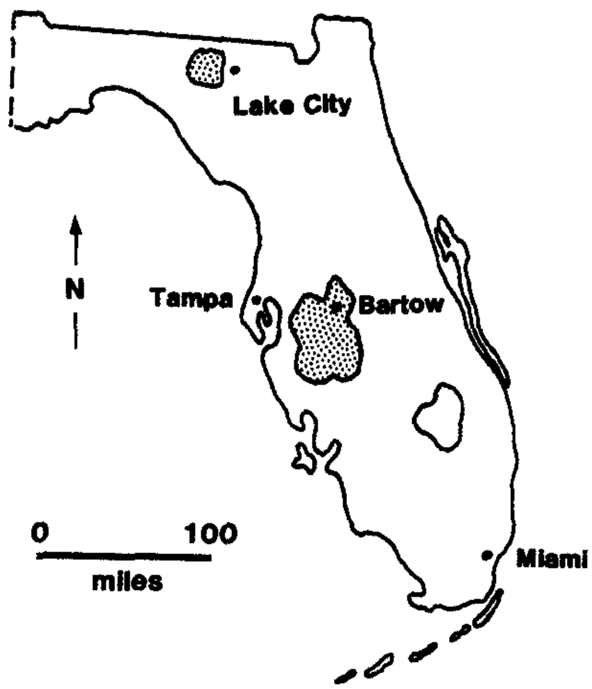

Figure 2. The North Florida and Central Florida Mining Districts

Although the major portion of this study was completed in the central Florida mining districts, the north Florida mining district was included in the study. One of the study's fourteen species selection plots was located on reclaimed land in Hamilton County, the remainder of the plots were located in Polk and Hillsborough Counties.

CLIMATE

The climate of the north Florida mining district is considered temperate. The average annual temperature ranges from 65 to 69 degrees Fahrenheit (18.3 to 20.6 degrees Celsius). Average annual rainfall is 55 inches, ranging from an average monthly low of 4.5 inches during the winter months to an average monthly high of 7.0 inches during the summer months. There are approximately 250 frost free days each year. The percentage of possible sunshine for an average year is 58 to 68 percent (Fernald, 1981).

The climate of the south Florida mining district is classified as subtropical. The average annual temperature ranges from 69 to 73 degrees Fahrenheit (20.6 to 22.8 degrees Celsius). Average annual rainfall is 50 to 55 inches, ranging from an average monthly low of 2.0 inches during the winter months to an average monthly high of 8.0 inches during the summer months. There are 300 to 325 frost free days each year. The percent of possible sunshine for an average year is 58 to 68 percent (Fernald, 1981).

GEOLOGY AND SOILS

The Florida peninsula was repeatedly submerged as sea levels rose during the warmer periods of earth's prehistory. As a result, the geologic and soil features of Florida have been shaped by the seas and are primarily of marine origin.

The terrain of both the northern and central Florida mining districts is nearly level or gently sloping. Native soils are very sandy, highly permeable and low in clay, organic matter and plant nutrients.

The subsoil typically is described as consisting of an overburden of unconsolidated sand, clay and gravel lying immediately beneath the topsoil and varying in thickness from 10 to 50 feet. Underlying the overburden is a leached zone up to 10 feet thick which is characterized by a higher uranium content than other zones. Beneath the leached zone is a 5 to 50 foot thick matrix or ore layer, and below this can be found bedclay and the limestone bedrock of the Floridian Aquifer (Fountain and Zellars, 1972).

PLANT COMMUNITIES

Principal plant communities of the north and central Florida mining districts include: pine flatwoods, cypress swamps and mixed hardwood hammocks. The majority of the area is pine flatwoods interspersed with

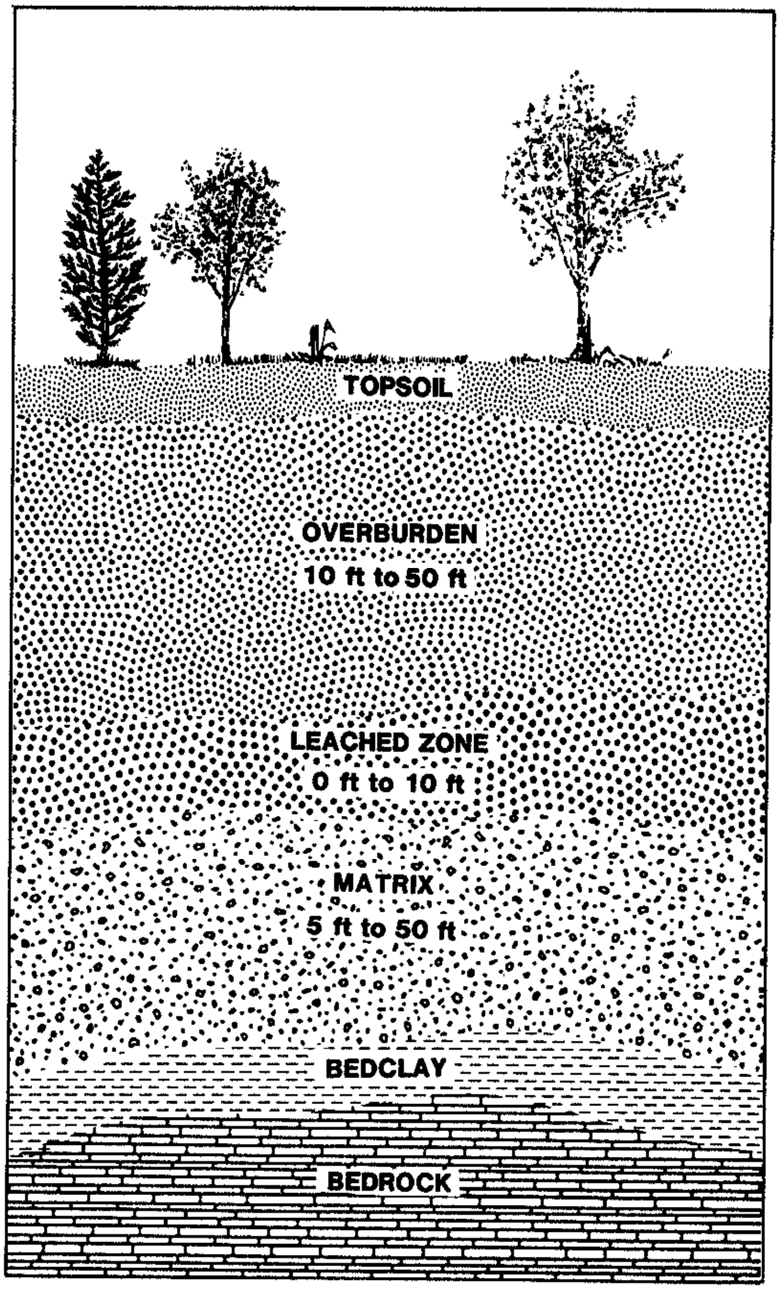

Figure 3. Profile of the Phosphate Ore Body and Overburden

cypress ponds. Mixed hardwood hammocks occur along the streams and rivers transversing the areas. A small percentage of the area is occupied by sandhills, a longleaf pine (Pinus palustris) and turkey oak (Quercus laevis) association; and sand pine (Pinus clausa) scrub, a sand pine dominated community which has as common associates myrtle oak (Quercus myrtifolia), Chapman's oak (Quercus chapmanii) and rosemary (Ceratiola ercoides). Both of these plant communities are found on excessively drained soils.

Pine flatwoods are dominated by longleaf pine, north Florida slash pine or south Florida slash pine (Pinus elliottii var. densa). Understory associates commonly include saw palmetto (Serenoa repens), gallberry (Ilex glabra), fetterbush (Lyonia lucida), wiregrass (Aristida stricta) and bluestem grasses (Andropogon spp.). Typical soil series of the pine flatwoods include the Myakka, Ona and Immokalee series. These are acidic, poorly drained soils of inherent low fertility.

Cypress swamps are composed almost entirely of either pond cypress or bald cypress (both now believed to be varieties of Taxodium distichum). Bald cypress is more commonly found along streams and sloughs where there is some water flow. Pond cypress occurs in isolated depressions known as cypress domes within pine flatwoods.

The hardwood swamps which border the numerous streams and rivers in the two areas contains a variety of broad-leaved deciduous hardwoods. Commonly found are: red maple (Acer rubrum), black gum (Nyssa biflora), water hickory (Carya aquatica), pop ash (Fraxinus caroliniana , water oak (Quercus nigra) and sweetgum (Liquidambar styraciflua).

3. TREE SPECIES SELECTION

OBJECTIVE

Statement of Problem and Goals

The north and central Florida mining districts were historically heavily forested with stands of longleaf pine, slash pine, oak (*Quercus* spp.), gum (*Nyssa* spp.) and cypress (*Taxodium* spp.). Stripmining for phosphate, however, has significantly altered the post-mining landscape. Although the north Florida mining area has been impacted to a lesser degree, by 1980, only nineteen percent of the central Florida mining district was classified as forestland (USDA, Forest Service, 1981).

Prior to 1971, the phosphate industry had placed little emphasis on the reclamation of post-mining spoils. In that year, Florida's legislature imposed a severance tax on phosphate rock and provided for a portion of the taxes received to be refunded to the phosphate companies for reclaiming mined lands under a voluntary reclamation program.

In 1975, the severance tax law was amended to make the reclamation of lands mined after July, 1975, mandatory and to also allow the Florida Department of Natural Resources to develop rules regulating reclamation. Rules developed by the Department of Natural Resources now require that a minimum of ten percent of the upland area be revegetated as upland forest areas with a variety of indigenous hardwoods and conifers. An upland area is considered to be satisfactorily reforested if a stand density of 200 trees per acre is achieved at the end of one growing season. A wooded wetland must achieve a minimum stand density of 200 trees per acre at the end of one growing season and must be protected from grazing, mowing or other adverse land uses for five years or until such time as the trees are ten feet tall (DNR, 1981). The above rules have resulted in extensive plantings of trees (typically one-year-old bareroot seedlings) on reclaimed lands.

Since 1975, millions of tree seedlings have been planted on reclaimed lands by the phosphate industry with varying degrees of success. A short planting season (December through February) with frequent droughts, extremely harsh physical soil conditions, improper species selection and poor planting techniques have, in many instances, resulted in unacceptable first-year survival rates. This has often necessitated the replanting of the same site two or three times at considerable expense to the phosphate companies, and has frequently delayed the release of reclamation program areas by the Department of Natural Resources.

One of the goals of this research project was to provide the phosphate companies with a list of recommended tree species for planting on specific sites (overburden, sand tailings, sand-clay mix and phosphatic clay areas). This required the establishment of fourteen (14) species selection plots over a four-year period on four different post-mining soil types: sand-clay mix (3) overburden (5), sand tailings (3) and phosphatic clay (3). Trees were measured annually and parameters monitored included: total height, tree diameter at ground level and percent survival.

Previous Work by Others

Relatively little information has been available to guide the phosphate companies' efforts in tree planting on post-mining sites. The companies themselves have experimented with the outplanting of a variety of one-year-old bareroot seedlings available from the Florida Division of Forestry and private nurseries, and the transplanting of larger tree specimens with tree spades. Typically, however, records of height growth, diameter growth and survival either have not been kept or are not sufficiently accurate to allow reliable conclusions to be drawn. Of thirty-five wetland reclamation projects cited in a study by Dames and Moore (1983) approximately one-third of the projects had no monitoring program for the wetland vegetation. Only three projects (Farmland-Hickory Creek Sand/Clay Mix Area, Farmland-Oak Creek Overburden and Mobil-McCullough Creek) indicated an intent to monitor tree height and diameter growth.

Best and Erwin (1984) planted approximately 55,000 bareroot tree seedlings of ten different species on 366 acres of phosphate mined land. Intensive monitoring was conducted to evaluate seedling survival which was found to average 72 percent at the end of the first growing season.

Clewell (1983) attempted to grow bareroot seedlings of five hardwood species on three plots on reclaimed mine sites at Brewster Phosphates. The plots were grazed by cattle from 1975 until 1979 when the study began. The bahia grass (Paspalpum notatum) turf was removed from two of the plots and the third plot was burned only prior to machine planting of the seedlings in January, 1980. The soil was about 92 percent sand and 8 percent clay with no significant amount of organic matter. Depth to a water table was 1-4 feet depending on seasonal rainfall.

After three full years, survival varied from 37 percent for live oak to 71 percent for laurel oak (Quercus laurifolia). Mean heights varied from 0.8 feet for dogwood (Cornus florida) to 4.2 feet for laurel oak. Survival and growth were found to be lowest on the plot on which the bahia grass turf was burned only (not removed).

The Agrico Chemical Company compared survival, height, and diameter of eighteen-year-old north Florida slash pine on native flatwoods to the same age trees on a hydraulic mine dump which was disturbed about 1926 (Hawkins, 1983). They found that the trees on the mined site outperformed trees on the native flatwoods soils in all three categories. This was attributed to: the lack of a hardpan, higher phosphorus levels in the mined soil and less competition from competing vegetation. Wallace and Best (1983), however, concluded that these older sites cannot be compared to sites mined using the technology of the present day because they were mined at a time when the scale of disturbance was small.

The Florida Game and Fresh Water Fish Commission completed one of the more comprehensive investigations of tree survival at International Minerals and Chemical Corporation's Clear Springs Mine in 1981 (Gilbert, et. al., 1981). In this 1979 study for the U.S. Fish and Wildlife Service, 12,820 bareroot seedlings of sixteen different species and 104 saplings of thirteen different species were planted on a 49-acre wetland area. Vegetation survival was monitored monthly and ranged from a low of 2.0 percent for longleaf pine to a high of 82.4 percent for bald cypress. Of the seedlings planted for follow-up monitoring, 50.6 percent survived into their second summer (1980). In a ranking of their relative performance (growth and survival), bald cypress ranked first. The fastest grower was found to be cottonwood (Populus deltoides); however, it ranked eighth because of poor survival. The poorest performers were found to be longleaf pine, south Florida slash pine, live oak and red maple, four of the most prevalent species in central Florida.

Clewell (1981) summarized four methods of swamp restoration. These included: (1) the planting of bareroot seedlings, (2) the transplanting of saplings from natural swamps with a tree spade, (3) mulching, using topsoil from natural swamps and (4) natural colonization. He reported that a combination of planting tree seedlings and mulching might be most successful.

In a detailed report on the growth of north Florida slash pine on mined spoil landscapes (Fisher, et. al., 1980), slash pine growth on reclaimed land was compared with that of pine plantations on native soils. This study was, however, completed in north Florida (Clay County) on land which had been mined for heavy minerals. The results cannot be directly applied to trees planted on phosphate mined land because of the obvious differences in soils and hydrology.

Clewell and Poppleton (1983), in a study of sand pine scrub restoration at a reclaimed phosphate mine, attempted to recreate a sand pine habitat on sand tailings by planting bareroot sand pine seedlings and mulching with topsoil from a nearby natural sand pine scrub community as a seed source. Of the 219 bareroot seedlings planted in January, 1980, only 32 percent were alive in November, 1982. Mean height of the seedlings was found to be 0.9 feet. Sand pine seedlings growing from seed on the mulched plots averaged 5.0 feet tall at the end of the same time period. No explanation for the difference in height growth was given; however, a possible explanation may have been the natural inoculation of the sand pine seed with mycorrhiza found in the mulch.

They concluded that sand pines need not be planted on sand tailings, that scrub communities can be restored using the mulching technique. In addition, they recommended that no bahia grass or other perennial cover crop be planted on the site and that no amendments of fertilizer be made because of the resulting increased competition for moisture and nutrients.

Sandrik and Crabill (1983) presented information on a two-acre project involving the transplanting of sapling-sized trees with a tree spade, a 31-acre hardwood reforestation project involving bareroot seedlings and a 130-acre sand pine scrub habitat, also using bareroot seedlings. Survival of trees transplanted with the tree spade was high (90 percent), bareroot seedling survival varied in the floodplain hardwood forest recreation and was low (5.0-6.5 percent) in the sand pine scrub reclamation project.

Best and Erwin (1983), in a study of tree seedling growth and survival, planted over 55,000 seedlings of ten (10) different species on reclaimed phosphate mined land in central Florida during the summer and late fall of 1982. Overall survival for all species remained relatively constant during the first year, ranging from 72 percent for the summer of 1982 to 77 percent by the summer of 1983 (there was some resprouting of seedlings thought to be dead). At the end of the 1983 growing season, green ash (Fraxinus pennsylvanica) had the highest net survival rate (98 percent). Several other species had survival rates in excess of 80 percent: red bay (Persea borbonia), 90 percent; sycamore (Platanus occidentalis), 90 percent; red maple, 83 percent and sweetgum percent. Holly (Ilex spp.) and loblolly bay (Gordonia lasianthus) had poor first year survival rates of 56 percent and 44 percent respectively.

METHODS

Soil

Sites chosen for the species selection plots varied considerably in the physical makeup of the soil profiles. Although an effort was made to select study lots that were as similar as possible, there still existed a considerable amount of variability in soils both among plots and within particular plots. A brief description of each of the four soil types

Overburden. The overburden species selection plots (5) consisted of mine cuts which had been filled with tailing sands hydraulically transported from the flotation plant or stockpile and subsequently capped with several feet of overburden to improve soil fertility, structure, and moisture retention.

The soil consists of the material originally overlying the leached zone and the matrix and includes the two feet or less of topsoil and the underlying material. The soil is brown to yellowish brown in color with a dominant texture of sandy clay loam; however, textures vary from sand to sandy clay. Natural fertility is medium and organic matter is low. Overburden sites are generally well drained with moderate permeability. Moisture holding capacity is moderate. The nutrient retention capacity is medium, tillage characteristics are poor, and aeration is fair (Hawkins, 1983).

Where there is a large proportion of clay particles in what might be classified as the A horizon, the soil surface frequently dries to a concrete-like hardness which is difficult to penetrate with the tree planting machine or dibble bar.

Sand-Clay Mix. The sand-clay mix plots (3) were located on land owned by Brewster Phosphates, Inc. which was reclaimed using the sand-spray method developed by that company. The sand-spray method involves partially filling mine cuts with a clay slurry from the plant for initial settling. When the clay slurry has reached a solids content of 12-15 percent (which takes a period of several months) tailing sands are sprayed over the pre-thickened clay from floating pipelines fitted with spray nozzles. After a predetermined amount of sand is applied, additional clay is added and allowed to thicken. This is then followed by another spray application of tailing sands and the process is repeated. Typically, the sand-clay mix sites are then capped with a final layer of sand (Leitzman, 1982).

This process does not produce a true homogeneous mixing of the sand and clay, but tends to allow some mixing while leaving internal lenses or layers of clay within a mostly sandy substrate. This, of course, creates a significant amount of variability in physical soil characteristics within a short distance on individual plots (USDA, Forest Service, 1981).

The estimated permeability of the upper five feet of soil material is rapid to very rapid. The available water holding capacity can vary widely. Depths to soil water vary considerably over short distances and depend on the occurrence of perched water tables over submerged clay lenses.

The soil is typically high in phosphorus (P) and calcium (Ca), but low in other plant nutrients (magnesium [Mg], potassium [K], nitrogen [N], and iron [Fe]). The upper soil horizons are low in organic matter and the soil reaction (pH) is neutral to alkaline.

Vegetative cover on the four plots at the time of tree planting consisted of a ground cover principally of bahia grass (Paspalum notatum), broomsedge (Andropogon virginicus), dog fennel (Eupatorium capillifolum), crabgrass (Digitaria ciliarsis , Cassia fasiculata, Crotalaria spectabilis and browntop millet (Brachiaria ramosa).

Sand Tailings. The sand tailings sites utilized for the three (3) tree species selection plots in this study consisted of contoured stockpiles or deposits of white quartz sand which were transported from the benefication plant as a by-product of the mining process. The topography of the sand tailings is typically gently rolling and could be described as resembling "artificial sand dunes". The sparse vegetation that occurs is typified by Poor Joe (Diodia teres), crabgrass, peppergrass (Lepidium spp.), and camphor weed (Heterotheca subaxillaris). Low, damp spots, if occurring, may support stands of broomsedge and vasey grass (Paspalum urvillei).

Soil composition is 97 to 99 percent quartz sand with the remainder being composed of small amounts of silt and clay. Permeability is very rapid and water holding capacity is very low. Organic matter and fertility are very low. Nutrient retention capacity is very low. Tillage characteristics are very good and aeration is very good (Hawkins, 1983).

Phosphatic Clay. Three (3) stabilized clay storage areas were selected as sites for the species selection plots. Each of these had been dewatering for a period of time in excess of fifteen years, and natural succession had established dense communities of coastal plains willow (Salix caroliniana), wax myrtle (Myrica cerifera), saltbush (Baccharis hamlimifolia) and numerous other shrubs and vines (e.g. species of Vitis, Smilax, and Rubus).

These were above ground settling ponds that had dried to an estimated 25-40 percent solids and had a hard, gray colored surface crust. The substrate is highly variable in chemical and mineralogical composition. However, generally the soil is 85 to 90 percent clay, and the remainder mostly silt with some sand. The clay minerals represented typically include montmorillonite, kaolinite, illite and attapulgite, with proportions varying widely. The soil reaction (pH) is neutral to moderately alkaline. Drainage is very poor and moisture holding capacity very high. Nutrient retention capacity is very high resulting in natural fertility that is higher than overburden, sand tailings, sand-clay mix, and most native soils (EcoImpact, 1980). Organic matter is low and permeability very slow. Soil strength is low. Tillage characteristics and aeration are very poor (Hawkins, 1983).

The shrink-swell characteristics of the smectite (montmorillonite clay) gives the soil a gummy texture when wet and causes the soil surface to exhibit severe cracking during dry weather (Barwood, 1982).

Plot Design

In order to test tree species for their suitability for outplanting on reclaimed land, fourteen (14) species selection plots were established between December 1980, and March 1984, on land that had been reclaimed or was in the process of being reclaimed by the phosphate industry. Individual plots varied in size from 0.71 acres to 1.40 acres and were located on overburden (5 plots), sand tailings (3 plots), phosphatic clay (3 plots) and sand-clay mix sites (3 plots). The fourteen plots were established on phosphate company lands in Polk County (10), Hillsborough County (3), and Hamilton County (1).

The first set of four plots were planted in the spring of 1981 on three overburden sites and one sand-clay mix site. These plots had one replication of each species per plot and tested sixteen different tree species. The seedlings were planted on a 6 ft. x 8 ft. spacing with 30 seedlings in each replication. The effective planting density was 908 seedlings per acre.

During the next planting season (1981-1982), seedlings of sixteen tree species were planted (one replication of each species) on three plots at a 6 ft. x 8 ft. spacing. Two plots were located on overburden sites and one was located on a sand-clay mix site. The effective planting density was 908 seedlings per acre with 30 seedlings per replication. In addition, one plot was established on phosphatic clay by planting seedlings of eight different species in three replications of sixteen seedlings each. These tree seedlings were planted on a 5 ft. x 5 ft. spacing (effective planting density was 1,742 seedlings per acre).

In February and March of 1983, three additional plots were established: one sand tailings plot, one sand-clay mix plot, and one phosphatic clay plot. The seedlings were planted on a 5 ft. x 5 ft. spacing resulting in an effective planting density of 1,742 tree Seedlings per acre. Within the plots, each species was replicated three times, and twenty-five seedlings were planted in each replication.

During year four of the project (1983-1984 planting season), the three remaining plots were established as follows: two on sand tailings (7 and 9 species tested, respectively) and one on phosphatic clay (10 species tested). Each plot was planted on a 5 ft. x 5 ft. spacing creating an effective planting density of 1,742 seedlings per acre. There were three replications of each species within the phosphatic clay plot. One of the sand tailings plots had one replication of each species and one plot had two replications of each tree species. Twenty-five tree seedlings were planted in each replication.

Plot Establishment

All tree seedlings were planted by hand using a tree planting bar (dibble bar). This was deemed necessary because of the experimental design and the small number of seedlings per replication. The typical phosphate company planting tree seedlings on reclaimed land would probably not hand plant tree seedlings, but instead would use a mechanical tree planter pulled by a rubber-tired tractor. Any experimental bias resulting from hand planting versus mechanical tree planting was assumed to be insignificant.

Overburden and sand-clay mix plots (with the exception of the sand-clay mix plot Brewster III) were planted with one replication of each tree species at a spacing of 6 ft. x 8 ft. The 6 ft. x 8 ft. spacing yielded an effective density of 908 trees per acre which is a tree density currently in common use by phosphate companies.

Three sand tailings species selection plots (Gardinier III-ST, Estech IV, and IMC IV), three phosphatic clay species selection plots (Mobil II, Gardinier III-PC and Mobile IV) and one sand-clay mix plot (Brewster III) were planted at a 5 ft. x 5 ft. spacing. This spacing resulted in an effective density of 1,742 trees per acre.

Trees were planted at a 5 ft. x 5 ft. spacing (1,742 trees per acre) on the above plots because high mortality was anticipated due to the harsh site conditions of the sand tailings and clay storage areas. Foresters commonly plant tree seedlings at a higher density if heavy mortality is expected. Because this study evaluated seedling performance prior to any competition from crowding, any experimental bias from spacing was regarded as insignificant.

Once the tree seedlings were planted, no cultural treatments followed. The trees were not fertilized, mulched or watered at any time during this research project. The intent of this was to, as much as possible, simulate the environmental conditions which seedlings would have to endure in actual outplantings on reclaimed land. It was, however, necessary to fence three of the species selection plots to prevent destructive grazing by cattle from adjacent leased pasture.

Data Collection

Trees were measured at the end of each growing season when the trees were dormant. Height measurements recorded represent the height to the tree's terminal bud (to the nearest tenth of an inch). Diameter measurements represent the average caliper of the seedling at ground level (to the nearest hundredth of an inch). To obtain the diameter measurement, two measurements were made at right angles to each other and these were then averaged. As the trees were measured, mortality in each plot replication was recorded and this yielded the mean annual survival percentages.

During the four year period from December 1980 to January 1985, over 20,000 measurements were taken on twenty-seven (27) different indigenous and exotic tree species (both hardwood and softwood species). The raw data was analyzed using the Statistical Analytical System (S.A.S.) at the Northeast Regional Data Center (N.E.R.D.C.), in Gainesville, Florida.

Although several tree species were tested on all four, types of reclaimed soil, (overburden, sand-clay mix; sand tailings and phosphatic clay), no one tree species was represented on all fourteen plots. Tree species which did well during the first years of the project were replanted in subsequent years along with some newly developed candidates (e.g., north Florida slash pine tubelings and longleaf pine tubelings). As a result, for certain species, three or four years of data were recorded, while for other tree species (those planted in 1983 and 1984), data is available for one or two years only.

RESULTS

The Florida Department of Natural Resources relies on first-year survival to determine the success of tree planting as a part of a phosphate mine reclamation program. For this reason, tree survival at the end of the first growing season was used as the basis for tree species selection in this study. A ranking of tree species survival at the end of one growing season, by soil type, is given in Tables 1 through 4.

The tree species (10) with the highest survival rates at the end of one growing season on the sand-clay mix plots were: sabal palm (100 percent), loblolly pine-tubelings (98 percent), sycamore (97 percent), magnolia (97 percent), bald cypress (95 percent), north Florida slash pine-tubelings (95 percent), spruce pine (90 percent), south Florida slash pine-tubelings (89 percent), longleaf pine (84 percent) and live oak (84 percent).

The tree species (10) with the highest survival rates at the end of one growing season on the overburden plots included: spruce pine (100 percent), loblolly pine-tubelings (97 percent), red cedar (93 percent), sabal palm (92 percent), loblolly pine (92 percent) north Florida slash pine-tubelings (85 percent), bald cypress (82 percent), sand pine (77 percent), north Florida slash pine (75 percent) and sweetgum (73 percent).

The tree species (5) with the highest survival rates at the end of one growing season on the sand tailings plots included: north Florida slash pine-genetically improved (79 percent), sand pine (74 percent), longleaf pine-tubelings (62 percent), north Florida slash pine (56 percent) and loblolly pine (56 percent).

The tree species (5) with the highest survival rates at the end of one growing season on the phosphatic clay plots were: sweetgum (66 percent), tupelo gum (64 percent), loblolly pine-tubelings (63 percent), bald cypress (60 percent) and north Florida slash pine (58 percent).

The above results for the sand-clay mix and overburden soils compare favorably with the findings of a wetland study completed by the Florida Game and Fresh Water Fish Commission (Gilbert, et. al., 1981). In the Game Commission study, the tree species (10) exhibiting the best survival at the end of their second summer (1980) were: bald cypress (82.4 percent), red cedar (72.1 percent), green ash 69.3 percent), Catalpa bignonioides (69.1 percent), sycamore (63.8 percent), spruce pine (59.2 percent), sweetgum (56.8 percent), north Florida slash pine (65.8

Table 1

Tree species survival on sand-clay mix plots at the end of one growing season

Species*	Mean Survival	C.V.**	Ranking
Sabal palm, P	100%	-	1
Loblolly pine, TU	98%	2.8	2
Sycamore, BR	97%	4.9	3
Magnolia, P	97%	-	3
Bald cypress, BR	95%	2.8	4
North Florida slash pine, TU	95%	2.8	4
Spruce pine, BR	90%	-	5
South Florida slash pine, TU	89%	-	6
Longleaf pine, BR	84%	23.3	7
Live oak, BR	84%	5.0	7
Laurel oak, BR	83%	-	8
Red cedar, BR	83%	-	8
Loblolly pine, BR	81%	15.6	9
Sweetgum, BR	81%	14.8	9
Black cherry, BR	80%	-	10
Turkey oak, BR	80%	-	10
Red maple, BR	72%	39.6	11
North Florida slash pine, BR	66%	20.3	12
Loblolly bay, P	63%	-	13
South Florida slash pine, BR	46%	38.0	14
Cottonwood, C	0%	-	15

* BR = bareroot, TU = tubeling, P = potted and C = cutting

** Coefficient of variation between plot means

Table 2

Tree species survival on overburden plots at the end of one growing season

Species*	Mean Survival	C.V.**	Ranking,
Spruce pine, BR	100%	-	1
Loblolly pine, TU	97%	-	2
Red cedar, BR	93%	10.6	3
Sabal palm, P	92%	7.1	4
Loblolly pine, BR	92%	12.6	4
North Florida slash pine, TU	85%	21:2	5
Bald cypress, BR	82%	16.6	6
Sand pine, BR	17%	25.7	7
North Florida slash pine, BR	75%	21.6	8
Sweetgum, BR	73%	-	9
Black cherry, BR	72%	30.4	10
Sycamore, BR	64%	12.1	11
Loblolly bay, P	63%	-	12
Magnolia, P	63%	14.1	12
Longleaf pine, BR	60%	18.7	13
South Florida slash pine, BR	58%	42.4	14
Live oak, BR	57%	-	15
Virginia pine, BR	52%	21.5	16
Laurel oak, BR	28%	21.6	17
Turkey oak, BR	27%	10.0	18
Red maple, BR	26%	25.2	19
Cottonwood, C	20%	24.3	20

* BR = bareroot, TU = tubeling, P = potted and C = cutting

** Coefficient of variation between plot means

Table 3

Tree species survival on sand tailings plots at the end of one growing season

Species*	Mean Survival	C.V.**	Ranking
North Florida slash pine IMP/BR	79%	8.7	1
Sand pine, BR	74%	44.5	2
Longleaf pine, TU	62%	48.8	3
North Florida slash pine, BR	56%	13.9	4
Loblolly pine, BR	56%	-	4
Laurel oak, BR	55%	24.04	5
Red cedar, BR	42%	33.6	6
Live oak, BR	41%	-	7
Longleaf pine, BR	31%	-	8
South Florida slash pine, BR	28%	-	9
North Florida slash pine, TU	21%	-	10
South Florida slash pine, TU	8%	-	11

* BR = bareroot, TU = tubeling, P = potted, C = cutting and IMP/BR = genetically improved bareroot

** Coefficient of variation between plot means

Table 4

Tree species survival on phosphatic clay plots at the end of one growing season

Species*	Mean Survival	C.V.**	Ranking
Sweetgum, BR	66%	46.5	1
Tupelo gum, P	64%	-	2
Loblolly pine, TU	63%	-	3
Bald cypress, BR	60%	47.9	4
North Florida slash pine, BR	58%	9%. 1	5
North Florida slash pine, IMP/BR	57%	-	6
Loblolly bay, P	54%	92.6	7
Red maple, BR	46%	59.1	8
Red cedar, BR	45%	-	9
Laurel oak, BR	45%	-	9
River birch, P	43%	-	10
Sycamore, BR	43%	21.9	10
Cottonwood, C	33%	-	11
Loblolly pine, BR	33%	73.4	11

* BR = bareroot, TU = tubeling, P = potted, C = cutting and IMP/BR = genetically improved bareroot

**Coefficient of variation between plot means percent), red maple (51.8 percent) and sand pine (48.7 percent). As in this study, cottonwood cuttings exhibited very poor survival (7.8 percent). Differences in survival rates between species common to both studies could probably be attributed to the skill of the individual tree planters, differences in soil moisture and the general weather conditions at the time of planting.

Figure 4. Four-Year-Old North Florida Slash Pine,
Plot: AGRICO I (Overburden)

In addition, the findings of Sandrik and Crabill (1983) on a floodplain hardwood forest project were similar to the results obtained from the overburden plots for bareroot north Florida slash pine seedlings and bareroot laurel oak seedlings at the end of one year. Sandrik and Crabill (1983) also noted "low" first year survival for bareroot sweetgum seedlings. There was no obvious explanation for the poor survival of the sweetgum seedlings. First year survival in this study was 73 percent for sweetgum.

In similar studies on sand tailings, both Sandrik and Crabill (1983) and Clewell and Poppleton (1983) reported poor first year survival rates for sand pine. Sandrik and Crabill found survival of bareroot sand pine seedlings to be 6.5 percent at the end of one year, while Clewell and Poppleton reported a survival rate of only 19 percent. These figures are probably not representative of this species' ability to survive on these droughty sands, and may, instead, reflect the sensitivity of this species to seedling care prior to planting and planting technique. In this study, a very satisfactory average survival rate of 74 percent was found for bareroot sand pine seedlings planted on sand tailings at the end of one growing season.

Hawkins (1983) summarized a study by the Agrico Chemical Company in which the growth of north Florida slash pine and loblolly pine were compared on both native flatwoods and reclaimed sites. The Agrico study found that loblolly pine (a tree species not native to Polk County) was better suited to the higher clay content of soils of reclaimed sites than north Florida slash pine. This compares favorably with the one-year survival results of the overburden sites in this study in which both bareroot loblolly pine and loblolly pine tubelings outperformed bareroot north Florida slash pine and north Florida slash pine tubelings.

An interesting observation in this study was the apparent vigor of tree species which are normally associated with soils which have a higher pH. Loblolly pine, spruce pine, red cedar and sabal palm are all known to do well on "sweeter" soils, and were among the top performers of trees planted on the sand-clay and overburden plots. This was reported by Clewell (1981) who described the vigor of red cedar and loblolly pine, species which he termed "calcium loving". He attributed the exceptional performance of these tree species to the calcium-rich soils of reclaimed lands which have higher pH levels than native Florida soils.

Figure 5. Four-Year-Old Sycamore, Plot: Agrico I (Overburden)

Figure 6. Four-Year-Old Red Cedar, Plot: Agrico I (Overburden)

CONCLUSIONS AND RECOMMENDATIONS

Recommended lists of tree species for planting on reclaimed land, by soil type, are given in Tables 5 through 8. These recommended lists of tree species are based upon a minimum survival rate of 50 percent at the end of the first growing season. This is more than adequate to meet the requirements of the Florida Department of Natural Resources; i.e., 200 trees per acre surviving at the end of one growing season.

Mine reclamation rules of the Florida Department of Natural Resources (DNR, 1981) state that "all species used in revegetation shall be indigenous species except for agricultural crops, grasses and temporary ground cover vegetation". For this reason, growth and survival data is included for those non-native species studied; however, they have been purposely excluded from the recommended species lists.

Tree species in this study which had survival rates (at the end of one growing season) of less than 50 percent are not recommended for planting on reclaimed land. These tree species are listed, by soil type, in Table 9. Thirteen different tree species had unacceptable survival rates on at least one soil type. Cottonwood had unacceptable survival rates on all soil types on which it was tested. South Florida slash pine and red maple had unacceptable survival rates on two of the three soil types on which they were tested. Laurel oak and red cedar had unacceptable survival rates on two of the four soil types on which they were tested.

Mean height, mean diameter and mean survival percentages for each species tested are listed, by soil type and age; in the Appendix. This data may be used as an indication of growth and survival that might be expected on these four soil types during the years immediately following outplanting.

Variations in annual rainfall from year to year undoubtedly influenced height and diameter growth as well as the mean survival percentage. Rainfall for the central Florida mining district in 1981, for example, was 13 to 18 inches below normal (see Table 10). From another standpoint, however, this resulted in a stronger test of the ability of these tree species to withstand the harsh environment of reclaimed sites. The sequential planting of large numbers of tree seedlings was intended to, in part, mitigate the influence of fluctuations in annual rainfall.

The survival and growth rates contained herein can be of significant value to the reclamation manager in the selection of the most appropriate tree species for planting on specific sites. It should be noted, however, that these recommendations are based entirely upon first-year survival, and inferences of later performance should be made with caution. The objectives of this study will have been fulfilled if this study provides Florida phosphate companies with guidance in the selection of tree species for planting on reclaimed land and results in increased seedling survival and more successful reclamation programs.

Table 5

Recommended tree species for planting on sand-clay mix soils*

Sabal palm, P	Laurel oak, BR
Loblolly pine, TU**	Red cedar, BR
Sycamore, BR**	Loblolly pine, BR**
Magnolia, P	Sweetgum, BR
Bald cypress, BR	Black cherry, BR
North Florida slash pine, TU	Turkey oak, BR
Spruce pine, BR**	Red maple, BR
South Florida slash pine, TU#	North Florida slash pine, BR
Longleaf pine, BR	Loblolly bay, P
Live oak, BR	

* BR = bareroot, TU = tubeling and P = potted

** Not indigenous to the Central Florida Mining District

Not indigenous to the North Florida Mining District

Table 6

Recommended tree species for planting on overburden soils*

Spruce pine, BR**	Black cherry, BR
Loblolly pine, TU**	Sycamore, BR**
Red cedar, BR	Loblolly bay, P
Sabal palm, P	Magnolia, P
Loblolly pine, BR**	Longleaf pine, BR
North Florida slash pine, TU	South Florida slash pine, BR#
Bald cypress, BR	Live oak, BR
Sand pine, BR	
North Florida slash pine, BR	
Sweetgum, BR	

* BR = bareroot, TU = tubeling and P = potted

** Not indigenous to the Central Florida Mining District

Not indigenous to the North Florida Mining District

Table 7

Recommended tree species for planting on sand tailings soils*

North Florida slash pine, IMP/BR
Sand pine, BR
Longleaf pine, TU
North Florida slash pine, BR
Loblolly pine, BR**
Laurel oak, BR

* BR = bareroot, TU = tubelings, IMP/BR = genetically improved bareroot

** Not indigenous to the Central Florida Mining District

Table 8

Recommended tree species for planting on phosphatic clay soils*

Sweetgum, BR
Tupelo gum, P
Loblolly pine, TU**
Bald cypress, BR
North Florida slash pine, BR
North Florida slash pine, IMP/BR
Loblolly bay, P

* BR = bareroot, TU = tubelings, P = potted and IMP/BR = genetically improved bareroot

** Not indigenous to the Central Florida Mining District

Table 9

Tree species not recommended for planting on reclaimed land*

Sand-Clay Mix	Overburden
South Florida slash pine, BR	Laurel oak, BR
Cottonwood, C	Turkey oak, BR
	Red maple, BR
	Cottonwood, C

Sand Tailings	Phosphatic Clay
Red cedar, BR	Red maple, BR
Live oak, BR	Red cedar, BR
Longleaf pine, BR	Laurel oak, BR
South Florida slash pine, BR	River birch, P
North Florida slash pine, TU	Sycamore, BR
South Florida slash pine, TU	Cottonwood, C
	Loblolly pine, BR

* BR = bareroot, TU = tubelings, P = potted and C = cutting

Table 10

Average annual rainfall, 1981 - 1984

Pembroke Fire Tower (Polk County)	
1981	36.68 inches
1982	62.69 inches
1983	56.31 inches
1984	41.75 inches

White Springs Fire Tower (Hamilton County)	
1981	66.36 inches
1982	66.22 inches
1983	80.20 inches
1984	64.22 inches

4. DIRECT SEEDING ON SAND TAILINGS

OBJECTIVE

Statement of Problem and Goals

The flotation process, used by the phosphate industry since 1929, results in the separation of the ore matrix into the post-mining waste products of siliceous sands and phosphatic clays. The quartz sands have generally been used to partially refill mining cuts; however, over the years a substantial amount of sand has been simply stockpiled. This has resulted in the creation of many hundreds of acres of relatively sterile terrain which is frequently described as "artificial sand dunes". A method to economically revegetate and stabilize these areas would be of significant benefit to the phosphate industry.

Both north Florida slash pine and sand pine have been successfully direct seeded on native Florida soils. Furthermore, bareroot. seedlings of both species have performed well when planted on sand tailings soils. The objective of this study was the evaluation of techniques for the direct seeding of north Florida slash pine and sand pine on sand tailings soils to revegetate and stabilize these areas.

Previous Work by Others

McReynolds and Burns (1973) reported that sand pine can be successfully established on sandhill sites by broadcasting seed and covering the seed with soil, as with a cultipacker. Success, they found, requires that seeding be done during the months of November, December and the first half of January. They estimate that fully 40 percent of the planted seed can be expected to produce seedlings within one year. High daily temperatures were found to be more of a controlling influence than rainfall.

Zarger (1973) reported moderate success when loblolly pine, shortleaf pine (*Pinus echinata*), Virginia pine (*Pinus virginiana*), and white pine (*Pinus strobus*) were broadcast by hand and helicopter on coal mine spoils in Tennessee.

Other authors have reported successful reforestation of mined sites by natural reseeding. Humphrey (1979) and Kangas (1983) described the oak-pine forests that had developed on old post-mining sites that were simply abandoned after mining. In the 50-60 years following mining, the sites had reseeded into an aesthetically pleasing landscape of large live oaks and slash pine trees with a supplemental understory of minor vegetation. Reforestation was, however, attributed to natural reseeding from adjacent parent trees at a time when the scale of disturbance from mining was not as extensive as it is with today's technology (Best, et.al., 1983).

EcoImpact (1981) indicated, in a summary of natural succession on sand tailings, that where sand tailings are surrounded by unmined woodlands, invading woody plants commonly include black cherry (Prunus serotina), slash pine and sand-live oak (Quercus geminata). They also describe woody shrubs and trees as being slow invade tailings unless the sands are kept moist by contact with ground water. The most important limiting factor to natural revegetation on sand tailings was the proximity of the site to an adjacent seed source.

Brown (1973) and Davidson (1980) have suggested direct seeding as an alternative to planting bareroot tree seedlings on surface mined lands. Successful direct seeding offers distinct advantages over the planting of seedlings in that it is applicable to large-scale reclamation at a lower per acre cost (Vogel, 1980).

Lohrey and Jones (1983) summarized the benefits of direct seeding by stating that "Direct seeding is a versatile reforestation technique that may be used on most sites and in some situations where natural regeneration or planting cannot be applied. It is applicable where a suitable natural seed source is not available and where access, terrain or soil conditions make planting difficult, expensive or impossible. Direct seeding is especially advantageous in economically regenerating very large or inaccessible areas that lack a natural slash pine seed source".

Poppleton, Clewell and Shuey (1983), in a sand pine scrub restoration study on phosphate mined land, seeded a sand tailings study plot with mulch from a natural sand pine scrub community. The researchers successfully regenerated sand pine from seed and, in fact, found that the sand pine germinating from seed on the mulched sites outgrew bareroot sand pine seedlings planted on similar soils.

METHODS

Soils

The sand tailings soils in this study consisted of contoured stockpiles or deposits of white quartz sands which were transported from the beneficiation plant as a by-product of the mining process. The sparse vegetation that occurs is typified by Diodia teres, crabgrass, Lepidium spp. and Heterotheca subaxillaris. Low damp spots, if occurring, may support stands of broomsedge and Paspalum urvillei. The study area was characterized by exposed mineral soil with less than ten percent of the area covered by vegetation.

Soil composition was estimated to be over 90 percent quartz sand with the remainder being composed of small amounts of silt and clay. Permeability is very rapid, and water holding capacity, organic matter, fertility and nutrient retention capacity are very low. Tillage characteristics are very good and aeration is very good (Hawkins, 1983).

Plot Design and Establishment

In December of 1981, two four-acre direct seeding plots (Estech II and IMC II) were established in Polk County on sand tailings sites belonging to the Estech Corporation and International Minerals and Chemicals Corporation. Two additional four-acre plots (Estech III and IMC III) were established adjacent to the above sites in September of 1982. Each site was divided into eight subplots and the following treatments were applied: (1) harrowing followed by direct seeding, (2) harrowing followed by direct seeding and compaction with a cultipacker, (3) direct seeding followed by compaction with a cultipacker and (4) direct seeding only. A grove harrow was used for treatments # 1 and # 2. The harrow and cultipacker were pulled by a Division of Forestry crawler tractor.

One-half of each plot was direct seeded with north Florida slash pine seed and the remaining one-half acre was seeded with sand pine seed (Ocala variety). See Figure 7 for the plot design of the four direct seeding plots.

The slash pine seed was obtained from the Florida Division of Forestry's Andrews Nursery at Chiefland. Sand pine seed was obtained from the U. S. Forest Service's Ocala National Forest. All seed was stratified and chemically treated to control predation by birds and rodents. In addition, the seed was de-winged and coated with aluminum powder as a lubricant for the mechanical seeder.

The first two direct seeding plots (Estech II and IMC II) were direct seeded with north Florida slash pine and sand pine seed in February of 1982 at a rate of 1.0 pound per acre for slash pine and 0.7 pounds per acre for sand pine. The second two plots (Estech III and IMC III) were direct seeded with north Florida slash pine seed and sand pine seed in November of 1982 at a rate of 1.0 pound per acre for slash pine and 0.7 pounds per acre for sand pine.

Assuming 13,500 slash pine seed (de-winged) per pound and 35,000 sand pine seed (de-winged) per pound (R. Schroeder, personal communication), this represents a dispersal rate of approximately 13,500 slash pine seed per acre and 24,500 sand pine seed per acre.

The seed was broadcast with a hand-cranked mechanical seeder. These seeders, which broadcast seed to the front and both sides of the operator, have a simple but effective method of regulating seedflow and thus the seeding rate. Approximately 15 acres can be seeded per day.

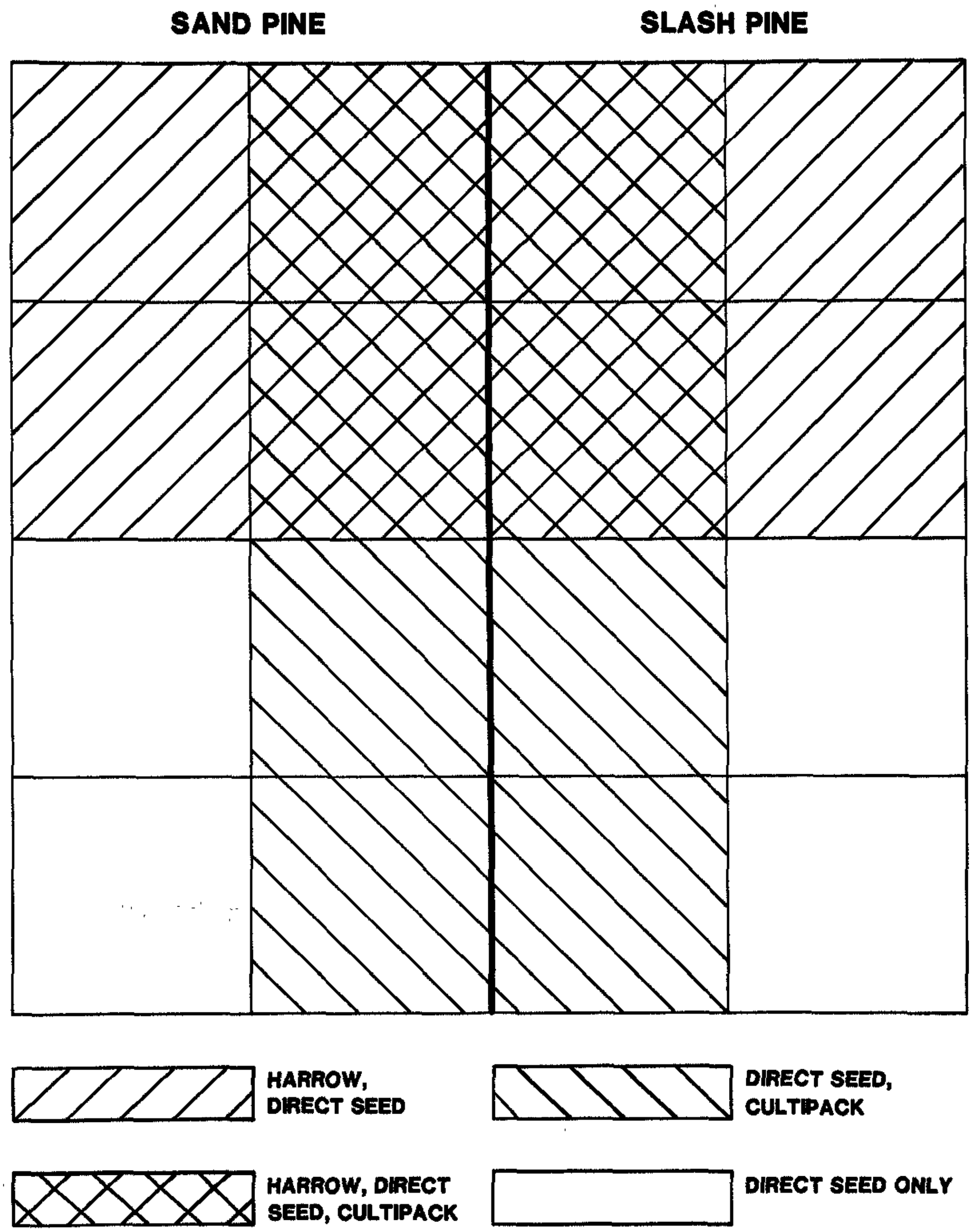

Figure 7. Plot Design of the Direct Seeding Plots

Prior to seeding, the mechanical seeder was calibrated by distributing a predetermined quantity of seed on an area of known size. Frequent rechecking of the distribution rate insured the accurate dispersal of seed.

Following broadcast of the slash pine and sand pine seed, no additional plot treatments were applied. The sites were not fertilized or watered at any time during the study. The intent of this was to, as much as possible, simulate natural conditions.

Data Collection

According to Lohrey and Jones (1983), two seedling inventories should be made the first year to evaluate success of the overall seeding operation. The first should be in the spring after germination is complete and the second in the fall. The difference between the two inventories indicate losses during the critical first summer. Losses after this period are usually low.

In this study, seedling germination was monitored by the establishment of ten circular 1/100-acre sample plots (plot radius of 11.78 feet) on each one-acre treatment area. This allowed for ten percent of each treatment area to be sampled.

Sample plots were inventoried for germinated seedlings in the spring (May) following broadcast of the seed and again in the fall (September) of the same calendar year.

RESULTS

Results of the direct seeding study are shown in Table 11. Three of the four plots (Estech II, IMC II and IMC III) were total failures; i.e., no germination of seed. For Estech II and IMC II, this may to a large extent, be attributed to the time of sowing. These two plots were direct seeded in February of 1982. Lohrey and Jones (1983) and McReynolds and Burns (1973) recommend direct seeding in the fall and winter in the lower coastal plain. They cite dry spring weather as a cause of heavy losses in stands established in February. There was no obvious explanation for the failure of IMC III.

Predation may have been a factor with all three plot failures. In some instances weathering has reportedly caused seed to lose its repellant coat, subjecting the seed to predation by birds and rodents (Lohrey and Jones, 1983).

Rainfall during February and March of 1982 was 1.35 and 6.65 inches respectively, as recorded at Pembroke fire tower, Polk County. This should have been adequate for seed germination, however, the lesser amount of rainfall occurring in February of 1982 may have contributed to plot failure.

Table 11

Slash pine and sand pine germination on Estech III

Treatment	Sand Pine	Slash Pine
May, 1983		
1. Harrow/Direct Seed	20	0
2. Harrow/Direct Seed/Cultipacker	680	100
3. Direct Seed/Cultipacker	60	10
4. Direct Seed Only	0	0
November, 1983		
1. Harrow/Direct Seed	0	10
2. Harrow/Direct Seed/Cultipacker	40	60
3. Direct Seed/Cultipacker	0	10
4. Direct Seed Only	0	0
November, 1984		
1. Harrow/Direct Seed	0	0
2. Harrow/Direct Seed/Cultipacker	0	0
3. Direct Seed/Cultipacker	0	0
4. Direct Seed Only	0	0

The only plot where germination of seed was observed was Estech III. In May of 1983 (following seed dispersal in November of 1982), germinating seedlings of both species were observed (Figures 8 and 9).

For slash pine, initial germination was observed for treatments: #2, harrowing followed by direct seeding and compaction with a cultipacker (100 seedlings per acre), and #3, direct seeding followed by compaction with a cultipacker (10 seedlings per acre).

Better results were observed on Estech III for sand pine. Initial germination (May, 1983) was observed on three of the four subplots. Treatment #1 (harrowing followed by direct seeding) resulted in the germination of 20 seedlings per acre. Treatment #2 (harrowing followed direct seeding and compaction with a cultipacker) resulted in an initial germination rate of 680 seedlings per acre. Treatment #3 (direct seeding followed by compaction with a cultipacker) resulted in an initial germination rate of 60 seedlings per acre.

A statistical analysis of the May, 1983, sampling of seedlings on the 1/100 acre plots on Estech III (treatment #2 only) is as follows:

	SAND PINE	SLASH PINE
Mean	6.8	1.0
Standard Deviation	0.96	0.84
Standard Error	0.30	0.26
Limit of Error	75%	43%
Coefficient of Variation	240%	140%

According to Lohrey and Jones (1983), tree percent, the ratio of the number of seedlings present to the number of seeds sown, is a measure of direct seeding success. It should average about 25 percent in early summer. For the dispersal rates used in this study, this would mean a minimum initial germination rate of 3,375 seedlings per acre for slash pine and 8,750 seedlings per acre for sand pine. Obviously, germination on the sand tailings soils in this study was exceptionally low.

In November, 1983, a second inventory of Estech III indicated a significant drop in seedling numbers. For slash pine, treatment #2 showed a decline in numbers of surviving seedlings to 60 seedlings per acre. Treatment #3 still had a survival rate of 10 seedlings per acre.

A similar inventory of the area seeded with sand pine seed yielded the following results: Treatment #1 - 0 seedlings per acre, Treatment #2 - 40 seedlings per acre, and Treatment #3 - 60 seedlings per acre.

Seedling mortality between the initial inventory (May) and fall inventory (September) can probably be attributed to heat stress during the summer of 1983 and the drying and abrasive effect of the wind-blown sand.

Figure 8. Sand Pine Seedling on Direct Seeding Plot: Estech III

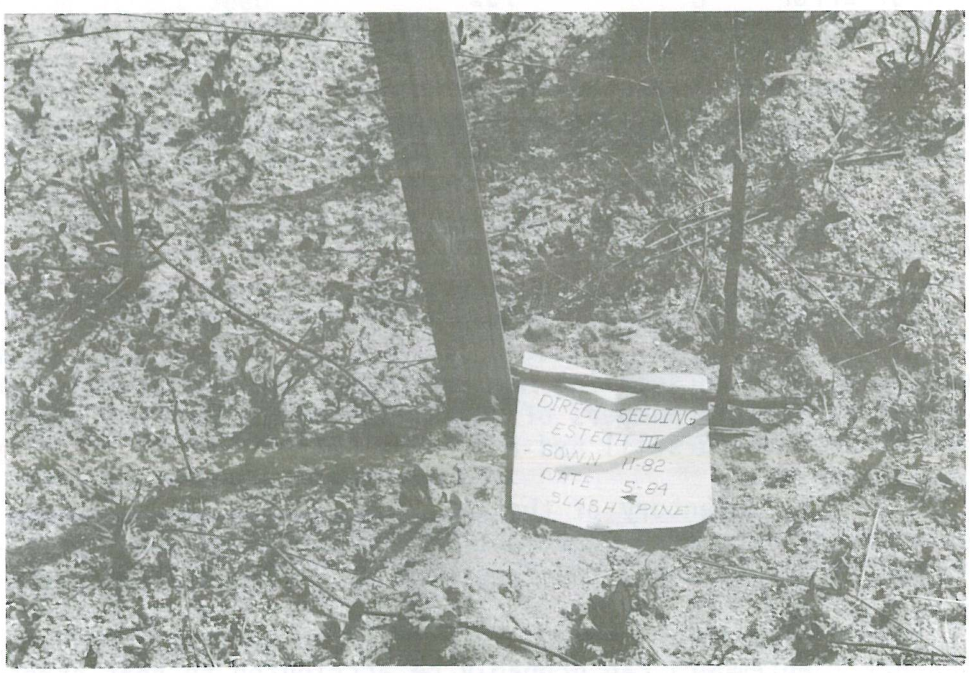

Figure 9. Slash Pine Seedling on Direct Seeding Plot: Estech III

This was noted in an EcoImpact study (1980) of natural regeneration on sand tailings where it was stated that "field observations clearly demonstrate that unstable, wind-blown sands inhibit establishment of vegetation". They concluded that bareroot sand pine seedlings could not tolerate wind erosion and sand abrasion as observed in their study. Some of the newly germinated pine seedlings in this study may also have been buried by the wind-blown sand.

A final seedling inventory in November, 1984 (two years following direct seeding) indicated that all seedlings on Estech III had died. The seedlings were apparently unable to overcome the harshness of a dry environment of unstable eroding sands.

CONCLUSIONS AND RECOMMENDATIONS

The failure of direct seeding on three of the four study plots (IMC II, Estech II and IMC III), and the low germination and eventual failure of Estech III clearly indicate that direct seeding on sand tailings is an unrealiable regeneration technique with small chance of success. There are obviously too many environmental factors working against the survival of the pine seedlings during their first critical year.

The most promising site treatment appears to also be the most intensive treatment; i.e., treatment #2 - harrowing followed by direct seeding and compaction with a cultipacker. On Estech III this treatment yielded an initial germination of 680 trees per acre for sand pine and 100 seedlings per acre for slash pine. This germination rate, although low, was in itself, a significant achievement considering the harshness of the sand tailings site.

Additional research is needed, however, to supplement the findings of this study. Based upon these results, reclamation managers wishing to experiment with the direct seeding of sand tailings sites should consider that:

1. Direct seeding probably stands the best chance of success if done in the fall of the year.

2. An intensive site preparation treatment should be selected which controls competing vegetation and covers the dispersed seeds with mineral soil.

3. A treatment should be considered which will reduce the "sand blasting" effect of wind blown sand (perhaps covering the seeded area with a mulch of some kind).

4. The simultaneous planting of one-year old sand pine or slash pine seedlings may be desirable to increase the chance of successful reforestation.

That all of the sand pine and slash pine seedlings in this study died was, of course, disappointing, however, supplemental work may eventually result in the development of direct seeding techniques which can successfully be used to reforest sand tailings.

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6. APPENDIX

MEAN HEIGHT (IN INCHES) ACROSS
ALL SAND-CLAY MIX PLOTS

Species	@ 1 Year	@ 2 Years	@ 3 Years	@ 4 Years
Eucalyptus tereticornus, P	25.0	68.7	112.3	103.4
Quercus laurifolia (Laurel oak), BR	6.8	15.4	37.6	57.7
Quercus acutissima (Sawtooth oak), BR	15.8	20.6	39.2	49.3
Platanus occidentalis (Sycamore), BR	25.6	29.1	29.6	28.4
Juniperus silicicola (Red cedar), BR	10.2	37.4	66.4	98.6
Pinus elliottii var. densa (South Fla. slash pine), BR	4.7	15.2	29.6	52.5
Pinus palustris (Longleaf pine), BR	2.3	3.8	2.05	23.5
Eucalyptus camaldulensis, P	38.8	117.9	181.6	119.6
Pinus elliottii var. elliottii (North Fla. slash pine), BR	10.2	35.6	71.1	123.8
Taxodium distichum (Bald cypress), BR	20.7	23.2	24.6	28.0
Acer rubrum (Red maple), BR	13.7	17.0	17.7	17.8
Elaeagnus angustifolia (Autumn olive), BR	42.7	64.1	59.5	70.9
Quercus laevis (Turkey oak), BR	6.3	6.1	7.1	8.1
Pinus taeda (Loblolly pine), BR	12.4	26.7	49.5	63.8
Gordonia lasianthus (Loblolly bay), P	4.4	7.0	-	-
Cupressus arizonica (Arizona cypress), BR	16.9	27.5	40.4	-
Pinus elliottii var. elliottii (North Fla. slash pine), TU	13.9	28.7	53.7	-

MEAN HEIGHT (IN INCHES) ACROSS
ALL SAND-CLAY MIX PLOTS

Species	@ 1 Year	@ 2 Years	@ 3 Years	@ 4 Years
Sabal palmetto (Sabal palm), P	0.0	0.0	0.0	-
Liquidambar styraciflua (Sweetgum), BR	16.2	18.3	28.4	-
Quercus virginiana (Live oak), BR	9.0	16.7	30.0	-
Magnolia grandiflora (Magnolia), P	4.8	5.7	6.9	-
Dalbergia sissoo (India rosewood), P	15.3	29.6	34.5	-
Pinus taeda (Loblolly pine), TU	12.8	21.0	54.2	-
Pinus glabra (Spruce pine), BR	12.1	22.9	45.1	-
Prunus serotina (Black cherry), BR	11.2	-	-	-

MEAN DIAMETER (IN INCHES) ACROSS
ALL SAND-CLAY MIX PLOTS

Species	@ 1 Year	@ 2 Years	@ 3 Years	@ 4 Years
Eucalyptus tereticornus, P	0.24	1.16	1.95	2.25
Quercus laurifolia (Laurel oak), BR	0.15	0.23	0.40	0.72
Quercus acutissima (Sawtooth oak), BR	0.24	0.29	0.56	0.85
Platanus occidentalis (Sycamore), BR	0.32	0.48	0.53	0.54
Juniperus silicicola (Red cedar), BR	0.16	0.58	0.96	1.50
Pinus elliottii var. densa (South Fla. slash pine), BR	0.44	0.64	0.94	1.97
Pinus palustris (Longleaf pine), BR	0.06	0.12	0.25	1.19
Eucalyptus camaldulensis, P	0.36	1.64	3.09	2.71
Pinus elliottii var. elliottii (North Fla. slash pine), BR	0.26	1.02	1.85	3.25
Taxodium distichum (Bald cypress), BR	0.28	0.42	0.45	0.54
Acer rubrum (Red maple), BR	0.26	0.34	0.36	0.43
Elaeagnus angustifolia (Autumn olive), BR	0.78	0.00	0.00	0.10
Quercus laevis (Turkey oak), BR	0.11	0.13	0.13	0.09
Pinus taeda (Loblolly pine), BR	0.22	0.71	1.25	1.61
Gordonia lasianthus (Loblolly bay), P	0.15	0.19	-	-
Cupressus arizonica (Arizona cypress), BR	0.29	0.37	0.56	-
Pinus elliottii var. elliottii (North Fla. slash pine), TU	0.28	0.57	1.22	-

MEAN DIAMETER (IN INCHES) ACROSS
ALL SAND-CLAY MIX PLOTS

Species	@ 1 Year	@ 2 Years	@ 3 Years	@ 4 Years
Sabal palmetto (Sabal palm), P	0.00	0.00	0.00	-
Liquidambar styraciflua (Sweetgum), BR	0.26	4.29	0.52	-
Quercus virginiana (Live oak), BR	0.23	0.31	0.43	-
Magnolia grandiflora (Magnolia), P	0.26	0.25	0.29	-
Dalbergia sissoo (India rosewood), P	0.27	0.42	0.47	-
Pinus taeda (Loblolly pine), TU	0.27	0.47	1.10	-
Pinus glabra (Spruce pine), BR	0.22	0.50	1.03	-
Prunus serotina (Black cherry), BR	0.18	-	-	-

MEAN SURVIVAL PERCENTAGE ACROSS
ALL SAND-CLAY MIX PLOTS

Species	@ 1 Year	@ 2 Years	@ 3 Years	@ 4 Years
Eucalyptus tereticornus, P	97	93	93	93
Quercus laurifolia (Laurel oak), BR	83	83	83	83
Quercus acutissima (Sawtooth oak), BR	97	90	90	90
Platanus occidentalis (Sycamore), BR	100	97	97	50
Juniperus silicicola (Red cedar), BR	83	80	80	80
Pinus elliottii var. densa (South Fla. slash pine), BR	46	37	35	63
Pinus palustris (Longleaf pine), BR	84	52	23	27
Eucalyptus camaldulensis, P	97	97	90	97
Pinus elliottii var. elliottii (North Fla. slash pine), BR	66	55	55	40
Taxodium distichum (Bald cypress), BR	95	95	95	95
Acer rubrum (Red maple), BR	72	72	72	72
Elaeagnus angustifolia (Autumn olive), BR	100	97	87	77
Quercus laevis (Turkey oak), BR	80	77	60	50
Pinus taeda (Loblolly pine), BR	81	82	80	73
Gordonia lasianthus (Loblolly bay), P	63	3	0	-
Cupressus arizonica (Arizona cypress), BR	100	73	70	-
Pinus elliottii var. elliottii (North Fla. slash pine), TU	95	90	90	-

MEAN SURVIVAL PERCENTAGE ACROSS
ALL SAND-CLAY MIX PLOTS

Species	@ 1 Year	@ 2 Years	@ 3 Years	@ 4 Years
Sabal palmetto (Sabal palm), P	100	100	100	-
Liquidambar styraciflua (Sweetgum), BR	81	70	70	-
Quercus virginiana (Live oak), BR	84	84	80	-
Magnolia grandiflora (Magnolia), P	97	90	80	-
Dalbergia sissoo (India rosewood), P	53	43	37	-
Pinus taeda (Loblolly pine), TU	98	93	93	-
Pinus glabra (Spruce pine), BR	90	90	90	-
Prunus serotina (Black cherry), BR	80	0	0	-

MEAN HEIGHT (IN INCHES) ACROSS ALL OVERBURDEN PLOTS

Species	@ 1 Year	@ 2 Years	@ 3 Years	@ 4 Years
Eucalyptus tereticornus, P	26.6	46.1	82.8	84.0
Quercus laurifolia (Laurel oak), BR	5.3	16.7	43.0	66.1
Quercus acutissima (Sawtooth oak), BR	14.7	17.0	24.8	35.4
Platanus occidentalis (Sycamore), BR	22.0	30.0	43.6	61.5
Juniperus silicicola (Red cedar), BR	9.7	17.8	27.7	43.7
Pinus elliottii var. densa (South Fla. slash pine), BR	6.6	21.8	45.4	84.7
Pinus clausa (Sand pine), BR	12.6	33.2	56.3	81.6
Pinus palustris (Longleaf pine), BR	0.0	0.4	10.4	27.1
Eucalyptus camaldulensis, P	36.4	55.1	107.1	91.8
Populus deltoides (Cottonwood), C	13.3	23.7	41.4	53.1
Pinus elliottii var. elliottii (North Fla. slash pine), BR	12.2	27.37	47.8	92.1
Taxodium distichum (Bald cypress), BR	19.7	21.2	19.2	21.6
Acer rubrum (Red maple), BR	8.4	20.2	23.1	30.5
Elaeagnus angustifolia (Autumn olive), BR	19.9	31.5	41.4	50.5
Quercus laevis (Turkey oak), BR	7.5	7.2	6.4	7.1
Pinus taeda (Loblolly pine), BR	13.3	30.6	47.4	71.0
Pinus virginiana (Virginia pine), BR	10.0	18.7	32.3	-

MEAN HEIGHT (IN INCHES) ACROSS
ALL OVERBURDEN PLOTS

Species	@ 1 Year	@ 2 Years	@ 3 Years	@ 4 Years
Gordonia lasianthus (Loblolly bay), P	4.7	*	-	-
Cupressus arizonica (Arizona cypress), BR	14.4	18.9	26.2	-
Pinus elliottii var. elliottii (North Fla. slash pine), TU	13.1	24.1	40.0	-
Sabal palmetto (Sabal palm), P	0.0	0.0	0.0	-
Liquidambar styraciflua (Sweetgum), BR	16.2	17.8	16.4	-
Prunus serotina (Black cherry), BR	13.4	6.4	5.2	-
Quercus virginiana (Live oak), BR	6.2	12.1	16.3	-
Magnolia grandiflora (Magnolia), P	4.4	4.6	4.6	-
Dalbergia sissoo (India rosewood), P	13.4	28.8	40.0	-
Pinus taeda (Loblolly pine), TU	7.6	18.2	29.4	-
Pinus glabra (Spruce pine), BR	13.6	30.5	34.5	-

MEAN DIAMETER (IN INCHES) ACROSS
ALL OVERBURDEN PLOTS

Species	@ 1 Year	@ 2 Years	@ 3 Years	@ 4 Years
Eucalyptus tereticornus, P	0.27	0.75	1.78	2.06
Quercus laurifolia (Laurel oak), BR	0.11	0.24	0.61	1.23
Quercus acutissima (Sawtooth oak), BR	0.21	0.29	0.43	0.63
Platanus occidentalis (Sycamore), BR	0.25	0.51	0.79	1.24
Juniperus silicicola (Red cedar), BR	0.13	0.31	0.41	0.74
Pinus elliottii var. densa (South Fla. slash pine), BR	0.47	1.07	1.86	2.95
Pinus clausa (Sand pine), BR	0.21	0.79	1.53	2.40
Pinus palustris (Longleaf pine), BR	0.00	0.07	0.97	1.56
Eucalyptus camaldulensis, P	0.36	0.87	1.91	2.25
Populus deltoides (Cottonwood), C	0.58	0.49	0.71	1.20
Pinus elliottii var. elliottii (North Fla. slash pine), BR	0.32	0.95	1.53	2.70
Taxodium distichum (Bald cypress), BR	0.25	0.42	0.37	0.40
Acer rubrum (Red maple), BR	0.12	0.38	0.45	0.60
Elaeagnus angustifolia (Autumn olive), BR	0.26	0.32	1.01	1.01
Quercus laevis (Turkey oak), BR	0.11	0.15	0.19	0.26
Pinus taeda (Loblolly pine), BR	0.28	0.89	1.54	2.37
Pinus virginiana (Virginia pine), BR	0.20	0.50	0.93	-

MEAN DIAMETER (IN INCHES) ACROSS
ALL OVERBURDEN PLOTS

Species	@ 1 Year	@ 2 Years	@ 3 Years	@ 4 Years
Gordonia lasianthus (Loblolly bay), P	0.15	-	-	-
Cupressus arizonica (Arizona cypress), BR	0.23	0.29	0.38	-
Pinus elliottii var. elliottii (North Fla. slash pine), TU	0.30	0.91	1.28	-
Sabal palmetto (Sabal palm) , P	0.00	0.00	0.00	-
Liquidambar styraciflua (Sweetgum), BR	0.28	0.36	0.36	-
Prunus serotina (Black cherry), BR	0.20	0.24	0.19	-
Quercus virginiana (Live oak), BR	0.14	0.28	0.28	-
Magnolia grandiflora (Magnolia), P	0.19	0.26	0.26	-
Dalbergia sissoo (India rosewood), P	0.22	1.01	0.79	-
Pinus taeda (Loblolly pine), TU	0.20	0.50	0.89	-
Pinus glabra (Spruce pine), BR	0.26	0.93	1.06	-

MEAN SURVIVAL (IN INCHES) ACROSS
ALL OVERBURDEN PLOTS

Species	@ 1 Year	@ 2 Years	@ 3 Years	@ 4 Years
Eucalyptus tereticornus, P	89	87	81	80
Quercus laurifolia (Laurel oak), BR	28	22	23	27
Quercus acutissima (Sawtooth oak), BR	74	65	61	63
Platanus occidentalis (Sycamore), BR	64	42	31	33
Juniperus silicicola (Red cedar), BR	93	89	89	89
Pinus elliottii var. densa (South Fla. slash pine), BR	58	55	63	79
Pinus clausa (Sand pine), BR	77	64	73	73
Pinus palustris (Longleaf pine), BR	60	43	40	37
Eucalyptus camaldulensis, P	94	92	92	90
Populus deltoides (Cottonwood), C	20	25	22	25
Pinus elliottii var. elliottii (North Fla. slash pine), BR	75	64	70	81
Taxodium distichum (Bald cypress), BR	82	81	66	56
Acer rubrum (Red maple), BR	26	53	53	73
Elaeagnus angustifolia (Autumn olive), BR	66	34	40	35
Quercus laevis (Turkey oak), BR	27	23	17	17
Pinus taeda (Loblolly pine), BR	92	69	88	97
Pinus virginiana (Virginia pine), BR	52	49	48	

MEAN SURVIVAL (IN INCHES) ACROSS
ALL OVERBURDEN PLOTS

Species	@ 1 Year	@ 2 Years	@ 3 Years	@ 4 Years
Gordonia lasianthus (Loblolly bay), P	63	-	-	-
Cupressus arizonica (Arizona cypress), BR	88	82	82	-
Pinus elliottii var. elliottii (North Fla. slash pine), TU	85	83	82	-
Sabal palmetto (Sabal palm), P	92	66	90	-
Liquidambar styraciflua (Sweetgum), BR	73	70	73	-
Prunus serotina (Black cherry), BR	72	12	17	-
Quercus virginiana (Live oak), BR	57	40	63	-
Magnolia grandiflora (Magnolia), P	63	17	17	-
Dalbergia sissoo (India rosewood), P	43	18	17	-
Pinus taeda (Loblolly pine), TU	97	65	85	-
Pinus glabra (Spruce pine), BR	100	53	53	-

MEAN HEIGHT (IN INCHES) ACROSS
ALL SAND TAILINGS PLOTS

Species	@ 1 Year	@ 2 Years
Quercus laurifolia (Laurel oak), BR	11.0	-
Juniperus silicicola (Red cedar), BR	8.5	17.8
Pinus elliottii var. densa (South Fla. slash pine), BR	3.3	13.8
Pinus clausa (Sand pine), BR	8.3	12.9
Pinus palustris (Longleaf pine) , BR	1.0	8.0
Pinus elliottii var. elliottii (North Fla. slash pine), BR	11.2	16.4
Pinus taeda (Loblolly pine), BR	9.9	-
Cupressus arizonica (Arizona cypress), BR	12.4	-
Pinus elliottii var. elliottii (North Fla. slash pine), TU	10.5	19.5
Quercus virginica (Live oak), BR	1.3	8.3
Pinus palustris (Longleaf pine), TU	0.0	0.0
Pinus elliottii var. elliottii (North Fla. slash pine), IMP/BR	10.7	21.6
Pinus elliottii var. densa (South Fla. slash pine), TU	2.0	10.3

MEAN DIAMETER (IN INCHES) ACROSS
ALL SAND TAILINGS PLOTS

Species	@ 1 Year	@ 2 Years
Quercus laurifolia (Laurel oak), BR	0.24	-
Juniperus silicicola (Red cedar), BR	0.21	0.37
Pinus elliottii var. densa (South Fla. slash pine), BR	0.19	0.96
Pinus clausa (Sand pine), BR	0.19	4.98
Pinus palustris (Longleaf pine), BR	0.07	0.58
Pinus elliottii var. elliottii (North Fla. slash pine), BR	0.26	0.48
Pinus taeda (Loblolly pine), BR	0.22	-
Cupressus arizonica (Arizona cypress), BR	0.20	-
Pinus elliottii var. elliottii (North Fla. slash pine), TU	0.27	0.59
Quercus virginica (Live oak), BR	0.17	0.24
Pinus palustris (Longleaf pine), TU	0.00	0.00
Pinus elliottii var. elliottii (North Fla. slash pine), IMP/BR	0.23	0.63
Pinus elliottii var. densa (South Fla. slash pine), TU	0.15	0.99

MEAN SURVIVAL PERCENTAGE ACROSS
ALL SAND TAILINGS PLOTS

Species	@ 1 Year	@ 2 Years
Quercus laurifolia (Laurel oak), BR	55	-
Juniperus silicicola (Red cedar), BR	42	81
Pinus elliottii var. densa (South Fla. slash pine), BR	28	28
Pinus clausa (Sand pine), BR	74	23
Pinus palustris (Longleaf pine), BR	31	31
Pinus elliottii var. elliottii (North Fla. slash pine), BR	56	40
Pinus taeda (Loblolly pine), BR	22	-
Cupressus arizonica (Arizona cypress), BR	20	-
Pinus elliottii var. elliottii (North Fla. slash pine), TU	21	21
Quercus virginica (Live oak), BR	41	39
Pinus palustris (Longleaf pine), TU	62	25
Pinus elliottii var. elliottii (North Fla. slash pine), IMP/BR	79	65
Pinus elliottii var. densa (South Fla. slash pine), TU	08	08

MEAN HEIGHT (IN INCHES) ACROSS ALL PHOSPHATIC CLAY PLOTS

Species	@ 1 Year	@ 2 Years
Quercus laurifolia (Laurel oak), BR	11.6	-
Platanus occidentalis (Sycamore), BR	28.9	14.3
Juniperus silicicola (Red cedar), BR	12.7	-
Populus deltoides (Cottonwood), C	20.2	-
Pinus elliottii var. elliottii (North Fla. slash pine), BR	10.4	10.0
Taxodium distichum (Bald cypress), BR	17.2	13.9
Acre rubrum (Red Maple), BR	13.9	8
Pinus taeda (Loblolly pine), BR	14.5	22
Gordonia lasianthus (Loblolly bay), P	7.1	-
Cupressus arizonica (Arizona cypress), BR	20.4	-
Liquidambar styraciflua (Sweetgum), BR	17.1	10.9
Pinus taeda (Loblolly pine), TU	10.8	17.0
Nyssa biflora (Tupelo), P	24.1	27.5
Pinus elliottii var. elliottii (North Fla. slash pine), IMP/BR	15.5	-
Betula nigra (River birch), P	14.9	21.9
Eucalyptus viminalis, P	12.5	-

MEAN DIAMETER (IN INCHES) ACROSS
ALL PHOSPHATIC CLAY PLOTS

Species	@ 1 Year	@ 2 Years
Quercus laurifolia (Laurel oak), BR	0.27	-
Platanus occidentalis (Sycamore), BR	0.47	0.32
Juniperus silicicola (Red cedar), BR	0.26	-
Populus deltoides (Cottonwood), C	0.84	-
Pinus elliottii var. elliottii (North Fla. slash pine), BR	0.24	0.25
Taxodium distichum (Bald cypress), BR	0.28	0.27
Acre rubrum (Red maple), BR	0.21	0.19
Pinus taeda (Loblolly pine), BR	0.23	0.33
Gordonia lasianthus (Loblolly bay), P	0.19	-
Cupressus arizonica (Arizona cypress), BR	0.27	-
Liquidambar styraciflua (Sweetgum), BR	0.23	0.19
Pinus taeda (Loblolly pine), TU	0.25	0.28
Nyssa biflora (Tupelo), P	0.40	-
Pinus elliottii var. elliottii (North Fla. slash pine), IMP/BR	0.32	-
Betula nigra (River birch), P	0.20	0.28
Eucalyptus viminalis, P	0.14	-

MEAN SURVIVAL PERCENTAGE ACROSS
ALL PHOSPHATIC CLAY PLOTS

Species	@ 1 Year	@ 2 Years
Quercus laurifolia (Laurel oak), BR	45	-
Platanus occidentalis (Sycamore), BR	43	20
Juniperus silicicola (Red cedar), BR	45	-
Populus deltoides (Cottonwood), C	17	-
Pinus elliottii var. elliottii (North Fla. slash pine), BR	58	58
Taxodium distichum (Bald cypress), BR	60	75
Acre rubrum (Red maple), BR	46	67
Pinus taeda (Loblolly pine), BR	33	56
Gordonia lasianthus (Loblolly bay), P	54	-
Cupressus arizonica (Arizona cypress), BR	41	-
Liquidambar styraciflua (Sweetgum), BR	66	53
Pinus taeda (Loblolly pine), TU	63	56
Nyssa biflora (Tupelo), P	64	-
Pinus elliottii var. elliottii (North Fla. slash pine), IMP/BR	57	-
Betula nigra (River birch), P	43	15
Eucalyptus viminalis, P	36	0