Taxodium ROOT GROWTH ON PHOSPHATIC CLAYS AMENDED WITH MUNICIPAL SOLID WASTE COMPOST

By

WILLIAM VICTOR MCKINSTRY

A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE

UNIVERSITY OF FLORIDA

2008

ACKNOWLEDGMENTS

I want to thank my parents who have provided guidance and encouragement throughout my life and also spent countless hours helping me with root extraction and analysis. To my wife for your countless days spent reviewing documents, extracting roots, analyzing roots, and providing emotional support when things got bad; I am forever indebted to you. To Bijay Tamang, Brian Becker, and Paul Proctor, for all the days we worked together doing field work for and with Dr. Rockwood in sometimes intolerable weather and for your assistances helping me complete the research and thesis. To Wri Irby and Wade Warren who no matter how down I was and unmotivated about my research, talking to you always provided me with a second wind.

I also thank Mosaic, Inc. and College of Agriculture and Life Sciences (CALS)/University of Florida (UF) for financial assistance and support to complete this research. To Tom Pospichal of Mosaic, Inc., thank you for all your help with obtaining equipment, labor, and historical background information about Site D in an unbelievably quick manner. My supervisory committee, Dr. D.L. Rockwood, Dr. N.B. Comerford, and Dr. T.A. Martin, provided guidance that sustained the research from inception to completion. Dr. Rockwood for all of the positive influence and extraordinary guidance throughout my undergraduate and graduate degrees; I appreciate everything you have provided me including an education, undergraduate employment, and research support. Dr. Comerford for allowing me the opportunity to use the Forest Soils Laboratory and equipment. Aja Stoppe and Kye Epps for your patience and countless hours helping me obtain and understand soil characteristics at the Forest Soils Laboratory. Chris Dervinis, thank you for all your help at the Forest Genomics Laboratory and allowing me to use the lab to scan roots and analyze them with the WinRhizo program

.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Abstract of Thesis Presented to the Graduate School
of the University of Florida in Partial Fullfillment of the
Requirements of the Degree of Master of Science

Taxodium ROOT GROWTH ON PHOSPHATIC CLAYS AMENDED WITH MUNICIPAL SOLID WASTE COMPOST

By

William V. McKinstry

December 2008

Chair: Donald L. Rockwood
Major: Forest Resources and Conservation

Taxodium species are relatively tolerant of alternating saturated/drought conditions. These conditions are common on Clay Settling Areas (CSA), which are generally considered poor agricultural lands because of many undesirable characteristics including 100% heavy clay, high pH, nitrogen deficiency, negligible amounts of organic matter, and general presence of cogongrass (*Imperata cylindrica*). CSAs may also have ample water holding capacity, substantial levels of available phosphorus and potassium, and can have improved soil characteristics by incorporating organics such as compost.

This research examined *Taxodium* root growth on CSAs amended with municipal solid waste (MSW) compost into the phosphatic clays to a depth of 30.5 centimeters at 0, 25, 50, 75, and 100% compost rates. Fifty bald cypress (*Taxodium distichum*) seedlings were planted in 2 latin square designs on CSA Site D. Of these, 30 were later extracted for root analysis. The results from Site D were compared with a Nanjing beauty (*T. distichum* x *T. mucronatum* hybrid) seedling study with the same treatment rates at a University of Florida Study on the UF campus and a mature root growth study with the same treatment rates in a bald cypress plantation at Austin Cary Memorial Forest (ACMF). Soil and compost analyses were only obtained from Site

D. As the rates of compost added to the phosphatic clays increased, soil bulk density significantly decreased and soil porosity in the upper 30.5 centimeters of the soil profile increased, but pH did not decrease. MSW compost should not be used as a controlled source of fertilization for phosphatic clays. The root results indicate that 100% compost was not the best treatment for seedling survival and root growth. Even more noticeable, 0% compost negatively affected root growth in almost every case. Incorporation of 50% compost into phosphatic clays most greatly improved *Taxodium* seedling and tree root growth and survival. It is uncertain if 75% compost could be a successful field treatment, but in the UF study, 75% compost improved root growth. Because the CSA research was conducted without irrigation, bedding, mulch, and fertilizer, a wide range of management alternatives should be studied before undertaking large scale *Taxodium* planting on CSAs.

CHAPTER 1
INTRODUCTION

Phosphate mining is a major industry in Florida and for the past 60 years has been a major industry in Polk County, Florida. About 2,023 hectares are mined every year (Richardson 2005). CSAs comprise approximately 64,750 hectares of the mined lands (Harrell 1987), approximately 40% of the total post mined areas. CSAs are a dominant feature on post mined landscapes and unfortunately have limited uses for agriculture or development due to the unstable soils of the consolidating ground surface (Ingwersen 2006). Due to the rate of consolidation of clays and the patterns of the mined cuts, the landscape is uneven. CSA soils are almost 100% heavy clay, have a high pH, are deficient in nitrogen, and contain negligible amounts of organic matter (CPI 2003). CSAs soils generally retain water, but they do not contribute to the groundwater. Furthermore, they act more as basins for nuisance or exotic species, but where exotic species can be controlled, CSAs are converted into pasture for limited cattle production.

As the human population continues to increase in the southeastern United States, the demand for viable agricultural CSAs is increasing. In Polk County, Florida, large tracts of potentially productive lands are unfeasible for urbanization and at times require substantial land management for economically viable agricultural lands. CSAs are a product of past mining operations that extracted phosphate ore for commercial and residential consumption. The effect on terrestrial and aquatic environments from the extraction of mineral resources is severe and usually irreversible (Rybicka 1996).

Although phosphatic clays have a number of unwanted characteristics in terms of agriculture and forest management, they also have the potential of having ample water holding capacity and substantial levels of available phosphorus and potassium. Incorporating organics, such as compost, in the phosphatic clay can improve soil characteristics closer to natural conditions that can benefit wetland species (Nair et al. 2001).

Generally, when any soil is prepared for planting, either with fertilizer, organic matter, lime, etc., the preparation is a onetime occurrence during establishment of the crop. As crops such as tree plantations age, subsequent additions to the soil may be needed in future years, but when the establishment of a crop is the issue, introducing the soil amendments prior to planting is important (Bilerback et al. 2008, Wong 2005). Furthermore, roots require amendments to significantly improve structure and nutrient levels within the first growing season (Ferrini et al. 2005).

In Florida, *Taxodium* is one of the most common wetland tree species (Ewel 1990). Although *Taxodium* species have many commercial values, the majority of the trees are harvested for mulch. Harvesting cypress mulch from Florida's wetlands is jeopardizing the native cypress resources and associated industries (Dicke and Toliver 1988). From 1987 – 1994, approximately 1.2 million cubic meters of cypress were harvested in Florida. This exceeded the net annual growth of cypress in Florida (approximately 1.1 million cubic meters). During this time, approximately 116,120 metric tons of cypress mulch was produced annually (Brown 1995). Thus, swamps that once were dominated by cypress now are a variety of second growth hardwoods (Rockwood et al. 2006). In addition, stands of pure second growth cypress may be overstocked and stagnating (Dicke et al. 1988).

To help alleviate these unsustainable forestry practices, many studies throughout Florida are being conducted to improve this species genetically and to determine what silvicultural techniques are best suited for potential plantation stock. Although, superior provenances for cypress have not been found, family variation in height and diameter growth suggests the potential for genetic gain (Faulkner et al. 1983). In 1990, Liu et al. noted that bald cypress exhibited 95 percent of its genetic variability within populations with a high number of alleles per locus. Rockwood and Geary (1991) determined that at one meter by one meter spacing on south Florida muck, bald cypress coppiced consistently from three to seven years of age. Gaviria (1998) reported encouraging results from studies of approximately 30 seedlots and various cultures on a wide range of sites in Florida. Lastly, cypress is one of the few native species of Florida that have exhibited tolerance to the saturated and/or dry conditions that are common on CSAs (Harrell 1987).

In an effort to utilize CSAs for commercial tree crops, bald cypress was planted on a 12-hectare CSA in 2007. Of the 12 hectares, approximately 0.04 hectares was a MSW compost amendment study to evaluate growth potential of bald cypress roots. This research determined if amending MSW compost into CSA soils improves root volumes and diameters of *Taxodium* seedlings, thereby, improving seedling survival. This was done by determining which compost rate most greatly improves soil characteristics at a CSA and produces the largest root volumes and diameters for seedlings and mature *Taxodium* species.

Bald cypress was used because it can tolerate the alternately saturated/drought conditions that frequently occur on CSAs in Florida (Rockwood et al. 2001). In 2006, Rockwood et al. determined that bedding, watering at the initial planting, continued vegetation control, good site preparation, and nutrition amendments (i.e., compost or mulch) appear to help in the successful establishment of cypress species on CSAs.

The objective of the study was to examine *Taxodium* seedling root growth on a CSA soil amended with MSW compost to determine if MSW compost can improve *Taxodium* seedling survival on a CSA and if the soil morphology and soil chemistry of a CSA is the cause of limited root growth. The specific research questions were;

How do the soil amendment treatments affect the soil characteristics?
How does the CSA soil affect *Taxodium* root growth?
How does MSW affect *Taxodium* root growth?

The primary hypothesis was that increasing compost rates in the phosphatic clays increases root growth until too much compost hinders root growth. Other general sub-hypotheses were;

Sub-Hyp. 1: Compost treatments will not significantly affect pH.
Sub-Hyp. 2: Root growth will be greatest at 75% compost.
Sub-Hyp. 3: Root growth will be lowest at 0% compost.

The soil study only showed the changes that occurred in the soil due to the addition of MSW compost after 7 to 8 months. This can be considered the first growing season which is the most critical for survival of tree seedlings (McTague and Tinus 1996). We hypothesized that the addition of the compost to the phosphatic clays at different rates will improve soil bulk density, lower the soil pH, and change nutrient levels in a controllable manner. Finally, this study benefits land managers that are establishing *Taxodium* plantations on CSAs.

CHAPTER 2
LITERATURE REVIEW

Agriculture and forestry in the southeastern United States are facing new challenges in land management practices, including changes in land use, urbanization, climate change, and timber markets. These challenges have been especially felt in Florida's forestry industry, where the timber market was relatively flat for many years and until recently the value of land had been increasing making once rural agricultural land far more valuable for urbanization than for agriculture. This view may be short-sighted, especially when one takes into account the critical changes in public and private demands for agricultural properties and rural land potential associated with global warming and climate change.

Global energy demand is expected to increase substantially in the coming years. The United States "is stepping up its bio-energy agendas at an unprecedented pace" (Marinescu 2007) in the hopes of reducing greenhouse gases, creating new markets for biomass, and improving overall bio-energy research. This new market may allow landowners and land managers to begin producing sustainable agricultural crops and forest products for fuel, energy, or carbon storage. Either way, there is a good chance that agricultural lands will benefit monetarily from the changes in the market.

In Florida, there are CSAs that are currently agricultural or unmanaged and will not be urbanized in the near future. The majority of CSAs have potential for producing market viable crops such as turf grass, vegetable crops, grain crops, citrus corps, and tree crops (Stricker 2000).

CSAs are a by-product of phosphate mining in Florida. Phosphate mining extracts phosphate ore for commercial and residential consumption. Typical phosphate ore is 4.5 to 15 meters below the soil surface and is generally 3 to 6 meters thick. The soil matrix containing phosphate ore consists of equal parts of sand, clay, and phosphate (Tamang 2006). During the mining process, residual clays or slurries are separated from the phosphate ore. In the past, these slurries were pumped back into the mining cuts. There, the clay particles settle to the bottom, and surface water is slowly discharged by outfall structures (Ingwersen 2006). In approximately 3 to 5 years, the surface of the slurry becomes solid (Richardson 2005), while the underlining clays stay in suspension for decades (Ingwersen 2006). Due to the rate of consolidation of clays and the patterns of the mined cuts, the landscape becomes uneven. The soils are generally considered to be clayey Haplaquents that are highly compacted, lack oxygen, have a relatively high pH, contain negligible amounts of organic matter, are nitrogen deficient, sometimes have a soil structure that is unstable, and extreme seasonal variations in top soil moisture (CPI 2003, Stricker 2000, Mislevy et al. 1989). Due to the mining, CSAs do not have a native seedbank and generally are covered by exotic vegetation, such as cogongrass (Tamang 2006). In general, the effect on terrestrial and aquatic environments from the extraction of mineral resources is severe and usually irreversible (Rybicka 1996).

Although the soils in a CSA appear to be unsuitable for many agricultural practices, past forestry research indicates that the CSAs may be able to support certain types of trees. Trees in this research will be considered woody vegetation with a single stem (Raven et al 1999). There are a number of reasons why forestry is considered a reasonable industry to attempt on these lands. Forestry is one of the major agricultural industries in the southeastern U.S. and has annual forest products sales exceeding $16.6 billion and generating more than $581 million in local, state, and federal taxes (Hodges et al. 2005).

Additionally, viable timber resources can be produced on CSAs. Mislevy et al. (1989) reported that CSAs can be a valuable resource for biomass production. Langholtz (2005) determined that initial results indicate cottonwood (*Populus deltoides*), *Eucalyptus grandis*, and

E. amplifolia are suited for conditions on CSAs in central Florida. Ingwersen (2006) found that species such as bald cypress and willow (*Salix caroliniana*) survived better than other wetland species. Other trees such as red maple (*Acer rubrum*), live oak (*Quercus virginiana*), laurel oak (*Q. laurifolia*), wax myrtle (*Myrica cerifera*), southern magnolia (*Magnolia grandiflora*), slash pine (*Pinus elliottii*), and other ornamental tree species can be successfully grown on CSAs with growth rates comparable to "field-production nurseries in Florida" (Jerez et al. 1996). Rockwood et al. (2004) found that with good silvicultural site preparation, cottonwood and a variety of slash pine hybrids can have high survival. Furthermore, Rockwood et al. (2004) concluded that there is a potential for commercial cypress plantations as long as significant silvicultural enhancement is completed prior to planting.

Taxodium species appear to survive relatively well in the CSAs. Historically, bald cypress has been popular for phosphate mining reclamation and can be found in plantations on portions of CSAs all across central Florida. Eucalyptus and cottonwood have also been planted on CSAs and generally have had very acceptable results as viable biomass crops. For example, eucalyptus can potentially grow 6.1 meter per year in height. The downside of planting eucalyptus in Florida is that it is an exotic species. In recent years, public and private organizations are trying to control or eradicate exotics species in Florida. In 1999-2000, the State of Florida spent a total of $90.8 million on exotic plant and animal and insect control (Torres et al. 2002). Langholtz (2005) also found that using non-native or potentially invasive species for forestry practices can be a "politically charged issue in Florida."

To utilize the CSAs and create a feasible commercial tree crop, *Taxodium* species are considered viable tree species, but negative characteristics associated with the CSA soil can hinder seedling survival after planting. As previously mentioned, CSA soils are highly compacted, lack oxygen, have a high pH, contain negligible amounts of organic matter in the soil profile, are nitrogen deficient, can have an unstable soil structure, and have extreme seasonal variations in top soil moisture (CPI 2003, Stricker 2000, Mislevy et al. 1989). In two reports published in 1996, Rockwood found that bedding, watering at the initial planting, continued vegetation control, good site preparation, and nutrition amendments (mulch or compost) appear to help in the successful establishment of cypress on CSAs (Rockwood 1996a, 1996b). Other research has shown that in order for CSA soils to become productive for sustainable agriculture use, organic matter (OM) must be amended into the heavy clay soils, thus initiating physical, biological, and chemical processes in soil creation (Wullschleger et al. 2004).

For healthy tree growth and optimum elongation and distribution of the root system, the soil must have adequate water, oxygen, and nutrients (Bengough et al. 2006). One of the critical restrictions of oxygen and water in a soil profile is compaction. Rendig and Taylor (1989) and Coder (2000) found that root elongation is correlated to soil compaction. As soil resistance increases, root elongation decreases. Furthermore, CSAs tend to be highly compacted when dry and when moist tend to retain moisture for longer periods of time than natural clayey or sandy soils (CPI 2003, Stricker 2000, Mislevy et al. 1989). Therefore, phosphatic clays generally restrict water movement and oxygen availability required for root elongation due to soil compaction during droughts, but when ample moisture is added phosphatic clays will hold water for long periods of time, which in turn, will limit oxygen availability in the soil. To help improve soil moisture and soil structure, the addition of OM is an excellent soil amendment (Harris et al. 2004).

MSW compost is increasingly utilized as an OM option for a soil amendment and a potential fertilizer (Raven et al. 1999). Composts containing manures or biosolids tend to contain more nutrients than pure green waste composts. Although composts are relatively low in macronutrients (nitrogen, phosphorous, and potassium), they generally are an excellent source of micronutrients (such as iron, zinc, and magnesium), especially composts made from biosolids. Introducing MSW compost into the soil reduces bulk density, improves moisture retention capacity, allows for added oxygen transfer, and improves the water infiltration rate (Molla et al. 2005, Shelton 1991). Dickson et al. (1991) found that compost binds clay and creates a granular soil structure. This will improve water retention and infiltration. Furthermore, the rate of compost added to the soil will reduce the bulk density proportionally (Shelton 1991). Another potential soil improvement is the reduction of soil surface crusting which specifically occurs in phosphatic clays during periods of drought.

To incorporate the compost into the soil, common tillage practices can be utilized on a CSA. If properly timed, tillage can be and is utilized on CSAs in central Florida. Tilling OM, such as compost, into the soil also stimulates microbial supply that helps stabilize soil aggregates (Brady et al. 2000). Other advantages of tilling are that it initially controls competing vegetation, integrates OM into the soil, reduces large soil clods, and potentially prepares a favorable seedbed (Brady et al. 2000).

In Citrus County, FL, on a very well drained site that received adequate rainfall but was generally considered to be infertile for most agriculture practices, a slash pine plantation and MSW compost experiment was conducted. The site also had increased levels of P in the soil because of “nearby phosphate ore outcrops” (Bengtson and Cornette 1973). The MSW compost was spread on the surface and tilled into the soil. The slash pine was allowed to grow for 2 years. The surface application showed modest affects on the soil plant ecosystem and slash pine height growth. The disking after compost application increased tree height growth more than any other treatment in the experiment. Disking only showed short-term benefits to the trees, which probably was due to the enhanced soil moisture retention from the compost and lack of understory competition because of the disking (Bengtson and Cornette 1973).

Sanderson and Martin (1974) found that Atlantic white cedar and Chinese holly grew significantly more when planted in a media of 33% MSW compost when compared to the control (0% compost). Furthermore, burkwood viburnum on 33% MSW compost grew equal as the control (0% compost). Fitzpatrick and Verkade (1991) found that *Viburnum suspensum* had equal growth when planted in a media of 0%, 40% and 100% MSW compost. Therefore, past research indicates that amending soil with MSW compost may improve tree and shrub growth.

Other horticultural studies have shown positive growth due to the amendment of compost. Wilson and Stoffella (2006) found that seven Florida native plant species grew as well in MSW compost or compost-based media as in peat-based media. In Maine, apple trees planted in compost (mixture of leaf litter, apple pomace, and chicken manure) amended soils grew more quickly and yielded greater amounts of fruit (Moran and Schupp 2005). Molla et al. (2005) found soils mixed with biosolid compost and rice straw increased corn plant height, shoot, and dry weight compared to treatments of biosolid compost with sawdust and no treatment. Four evergreen cuttings (*Juniperus horizontalis* Moench, *Juniperus horizontalis*, *Juniperus sabina* L, and *Thuja occidentalis*) all had enhanced root growth due to a MSW planting media or at least showed no significant adverse affects (Chong 2000). In a tomato growth study, Herrera et al. (2008) found that a mixture of 30% peat (white peat preferred) and 65% MSW compost media supported the greatest growth for rate of emergence, emergence, height, stem diameter, height and diameter ratio, and height of the first node.

The addition of compost may improve the compacted conditions that occur on CSA (Segrest 2008). It has been observed that as a CSA dries, the upper 15.2 to 30.5 centimeters of the soil can become hard and compacted. This may be especially true in the first 8 centimeters of the soil. During periods of extended drought, the soil will dry and crack; and the surface will crust over making water infiltration difficult (Segrest 2008). Conversely, when a CSA receives average or above average rainfall, the phosphatic clay can become unconsolidated and tacky. In an online report reviewed in 2008, Segrest referred to the phosphatic clay as “modeling clay” during periods of saturation that can develop surface crusting during spring and can become “brick-hard” during the summer. By decreasing the bulk density, the soil can become less compacted, develop improved soil moisture retention, improve water infiltration, and improve aerobic conditions.

Another major issue with phosphatic clays is available nutrients. Stricker (2000) found that phosphatic clays have large amounts of total phosphorus (P), potassium (K), magnesium (Mg), and calcium (Ca). Phosphatic clays also have high pH levels which may restrict the extractable amounts of nutrients available to plant roots. When soil pH level exceeds 7.3, the extractable P and other micronutrients, except molybdenum and chloride, are limited (Harris et al. 2004, Evans 2000, and Stricker 2000). A soil pH between 6.0 and 6.5 is excellent for soil nutrient availability (Harris et al. 2004). Furthermore, Wahid et al. (1998) documented that OM, such as compost, effectively lowers soil pH.

pH and the rate of compost are negatively correlated. Optimal pH range for plant growth is generally considered to be from 5.5 to 7.0. Therefore, if adding compost can lower the high pH, it may improve crop growth (Phillips and Eneritus 2006).

Nutrient levels may be improved if high quantities of compost are used because generally, compost contains low qualities of nutrients and "should be considered soil amendments, not fertilizers" (Smith 1996). Nutrient levels (macronutrients and micronutrients) in compost are often low, released very slowly, and will often initially have high organic carbon content. If the compost is allowed to decompose in the soil, over time, the compost may become an efficient fertilizer for plant uptake (MU 2008).

MSW compost also has additional benefits for the environment. "The average American generates approximately 2 kg of garbage per day, for a total of 196 million tons of trash per year, most of which ends up in landfills" (Dickerson 2006). This garbage accumulates in landfills, utilizes large amounts of rural property, produces environmentally harmful methane gas and leachates, and is becoming more financially detrimental due to rising land cost and fuel cost, especially in Florida.

To address growing landfill issues, Sumter County, Florida, created the Florida Organics Recycling Center for Excellence (FORCE). FORCE researched and produced high quality Class A compost from solid waste. According to Environmental Protection Agency, Class A compost must be biosolids, static pile aerated; conventional windrowed and in-vessel composting methods must meet the Process to Further Reduce Pathogens (PFRP) requirements, including temperature and time requirements (EPA 2003). Class A compost is considered an excellent growing medium for farms, greenhouse, gardens, or nurseries (MU 2008). All compost utilized in the study was created at FORCE.

Species Description

There are three species of cypress in the United States (US): Bald cypress (T. *distichum*), pond cypress (T. *ascendens*), and Mexican cypress (T. *distichum* var. *mucronatum*) (Brown and

Montz 1986). Bald cypress and pond cypress commonly grow in wetlands throughout the southeastern US. These species can be deciduous or evergreen. Cypress have lateral roots commonly producing erect, irregularly conic to rounded "knees" in periodically flooded habitats (Brown and Montz 1986). Their leaves are generally alternating, and adult leaves are commonly divergent to strongly appressed, flattened, and linear or linear-lanceolate to deltate. The pollen cones have 10-20 sporophylls, and each sporophyll has 2-10 pollen sacs. The pollen cones are usually borne at the base of alternate leaves, forming pendent axillary panicles. The seed cones are thin woody cones that are globose, valvate, peltate, and generally 5-10 mm in size (Brown and Montz 1986). The seed cones generally mature in one season, and the scales commonly fall early. The seed are contained within the scales, and there are generally 1-2 seeds per scale. The seeds are irregularly 3-angled and wingless (Watson 1993). In Florida, bald cypress commonly exist in poorly drained soils or inundated soils, and are typically associated with canopy species such as blackgum (*Nyssa sylvatica* var. *sylvatica*), sweetgum (*Liquidambar styraciflua*), sweet bay (*Magnolia virginiana*), swamp bay (*Persea palustris*), red maple, and swamp tupelo (*Nyssa sylvatica* var. *biflora*).

Mexican cypress occurs on a variety of soil types that include well drained, poorly drained soils, and inundated in Mexico and South America, “mostly in mountainous areas” (Brown and Montz 1986). Mexican cypress differs from bald cypress because of stomata placement on leaves and cone sizes. Bald cypress generally has leaf stomata on the abaxial side of the leaf, and its cones are generally 20 to 35 mm long. Mexican cypress has leaf stomata in equal abundance on both sides of the leaf, and its cones are 14 to 25 mm long (Farjon 2005). In spite of these differences and their native ranges, these two species are very similar.

CHAPTER 3
METHODS

Three separate studies evaluated *Taxodium* root growth in phosphatic clays amended with MSW compost. The main study assessed seedling root growth and soil characteristics at CSA Site D. Site D results were compared with a seedling study in a shadehouse on the University of Florida (UF) campus and a mature root growth study in a bald cypress plantation at Austin Cary Memorial Forest (ACMF). Soil and compost analyses were only conducted at Site D.

Site D

Site D is approximately 8.2 km southwest of Fort Meade, Florida and 10 km northwest of Bowling Green, Florida, at latitude 27.7255 N and longitude -81.8733 W. The study area is an approximately 25-year-old CSA. The CSA has had multiple owners; in 2004, Mosaic Fertilizer Company formed after the Cargill Crop Nutrition and IMC Global merger and took over ownership and management of the CSA (Pospichal 2008).

In 1993, Site D was converted from an overgrown, unsightly CSA into an agricultural field by removing thick, unwanted brush such as willow, cogongrass, elderberry (*Sambucus canadensis*), and pokeweed (*Phytolacca americana*), conducting soil excavations to improve drainage, and creating macro beds (Pospichal 2008). The first crop to be established on the new converted agricultural field, alfalfa (*Medicago sativa*) was grown for approximately 3 years, but then the site was abandoned until 2001. By this time, the unwanted vegetation had grown back and the macro beds had vanished. The area was cleared again and vegetable crops such as squash (*Cucurbita* spp.), peppers (*Capsicum* spp.), and corn (*Zea mays* spp.) were established with drip irrigation. The vegetable crops were grown for approximately 2 years and were very productive. After the vegetable crops, a variety of forage crops such as alfalfa and sorghum (*Sorghum* spp.)

were established. In addition, approximately 2.0 hectares of Site D was seeded with St. Augustine grass (*Stenotaphrum secundatum*) sod. All the grasses did very well (Pospichal 2008).

Tom Pospichal also noticed that the only unproductive crops and grasses were ones not irrigated. Alfalfa was the "best all around crop" at Site D (Pospichal 2008) because it could survive droughts and its root system seemed to gather moisture very well. "The primary problem with Alfalfa is that we cannot harvest it during the summer rainy season because we cannot get the equipment on the field. Without cutting at the proper time, the alfalfa lodges and then we get more competition with weeds and the alfalfa stand becomes weak" (Pospichal 2008).

In the winter 2006 - 2007, Mosaic and University of Florida established a tree plantation on approximately 12 hectares of Site D. Of the 12 hectares, approximately 0.04 hectares was utilized for this specific phosphatic clay and compost study (Figure A-15). The 0.04 hectares is relatively level, with a slope of approximately 1% or less, and is located approximately at latitude 27.7241944 N and longitude -81.8735833 W. In central Florida, the winter months are the driest months (Figure 3-1) and, for CSAs, the best time of the year for tilling, bedding, and tree planting (Segrest 2008). This is also the most opportune time to add soil amendments such as compost to the soil profile. Figure 3-1 presents data collected in Lakeland, Florida, at the Lakeland Linder Regional Airport, approximately 32.1 km northwest of Site D. The average annual rainfall in Lakeland is approximately 126.2 centimeters. In 2007, the annual rainfall was 118.9 centimeters, but between January 2007 and May 2007 (winter through spring), there was a significant drought. Average rainfall during these 5 months was approximately 23.3 centimeters, which is almost 15.2 centimeters below average.

At Site D, the compost was mixed into study plots to depths of 30.5 cm. The diameter of each plot was 30.5 cm (Table 3-1). A total of 50 plots were established on Site D in two latin

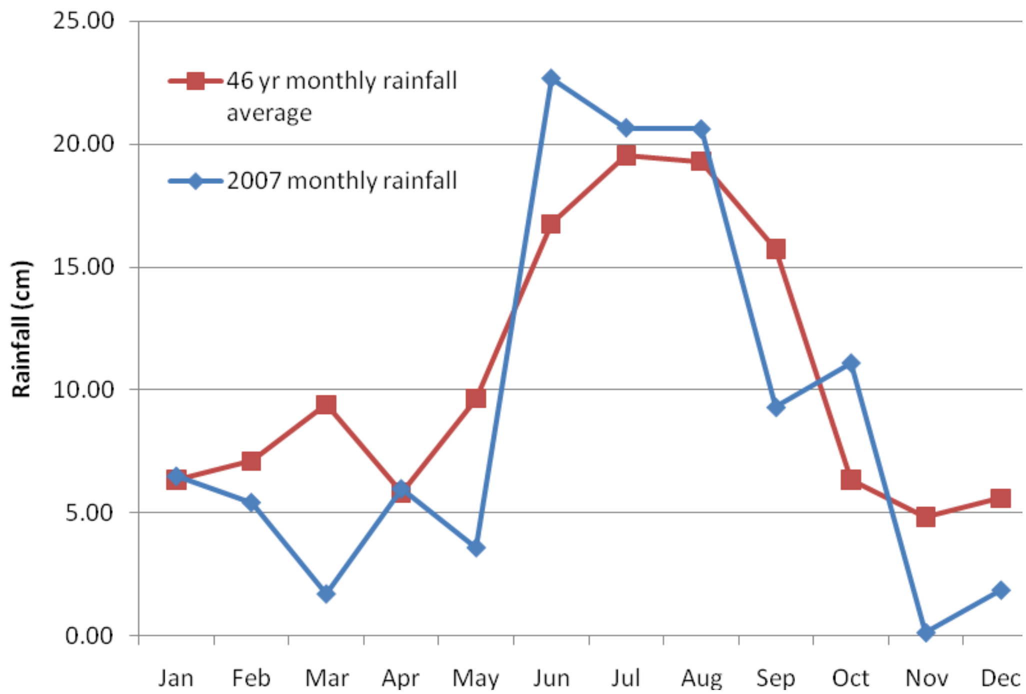

Figure 3-1. Average rainfall in Lakeland, Florida (Lakeland Linder Airport 2005)

square designs (Figure 3-2). Plots were 3 m apart with a 6.1 m buffer between Replication 1, the southern 25 plots, and Replication 2, the northern 25 plots. Each replication had 5 repetitions of the treatments aligned from west to east (East-1, East-2, East-3, East-4, and East-5) and north to south. This adjusted for potential topographic changes on the site. The compost was mixed into the phosphatic clays at 5 different percentages (0, 25, 50, 75, and 100%) systematically located throughout the study site.

All plots were excavated manually with a round pointed shovel. The holes were measured with Keson® open reel measuring tape for depths and diameters during excavation to approximately 30.5 x 30.5 cm. The MSW compost was added to the holes first. The compost was scooped and measured with a standard volume measuring cup. The holes were also measured for compost depth during filling. The holes were backfilled with the phosphatic clay removed during

Table 3-1. Plot description by study site and compost treatment

	Site														
	Site D					ACMF					UF Study				
	0%	**25%**	**50%**	**75%**	**100%**	**0%**	**25%**	**50%**	**75%**	**100%**	**0%**	**25%**	**50%**	**75%**	**100%**
Plot Depth (cm)	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5
Plot Width (cm)	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5	T=25.4 B=21.6	T=25.4 B=21.6	T=25.4 B=21.6	T=25.4 B=21.6	T=25.4 B=21.6
Total Volume of Treatment (cm^3)	22237	22237	22237	22237	22237	22237	22237	22237	22237	22237	10766	10766	10766	10766	10766
Volume of Compost Amendment (cm^3)	0	5559	11119	16678	22237	0	5559	11119	16678	22237	0	2733	5383	8198	10766
Volume of P. Clay Amendment (cm^3)	22237	16678	11119	5559	0	22237	16678	11119	5559	0	10766	8198	5383	2733	0
Volume Extracted for Root Analysis (cm^3)	22237	22237	22237	22237	22237	4636	4636	4636	4636	4636	10766	10766	10766	10766	10766
Dry Tons per hectare of Compost	0	75.1	150.2	225.4	300.5	0	75.1	150.2	225.4	300.5	0	75.1	150.2	225.4	300.5

P. Clay = Phosphatic Clay

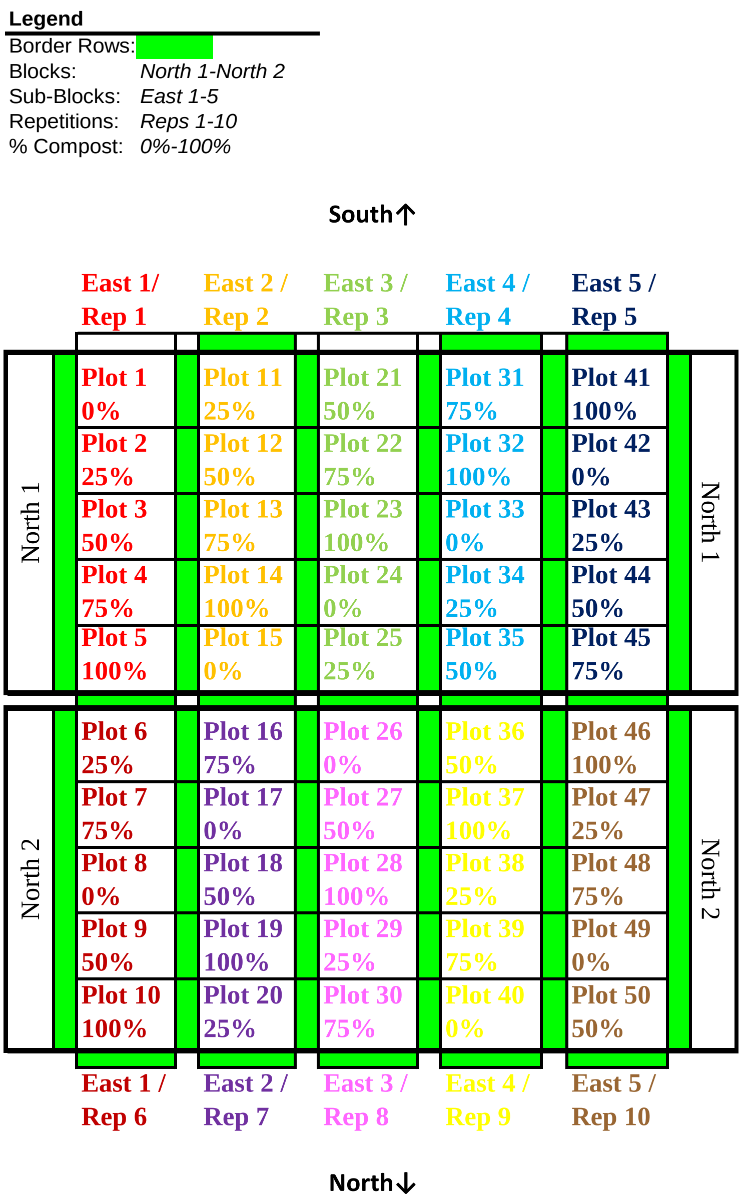

Figure 3-2. Site D plot layout

plot excavation. The compost and clay were effectively and efficiently hand mixed inside the hole. A bareroot bald cypress seedling was planted into each plot. The seedlings came from Central Florida Lands and Timber Nursery, LLC, but the exact genotype of the cypress seedlings was unknown. To reduce bias during the planting, the seedlings were randomly picked from a large quantity of bald cypress between 30.5 to 71.1 centimeters tall, and all seedlings planted had moisture retention root coating. All lateral roots were field pruned approximately 5.1 centimeters from the main stem to allow for an approximate equal starting root size. Each tree also received approximately 453.6 g of water at planting. After the planting, no irrigation or hand watering was conducted.

The plots were established on the 13th and 14th of February 2007. The site was mowed by Mosaic, Inc. employees, and the individual plots were weeded multiple times. On the 17th and 18th of July 2007, DuPont® Landscaping Fabric was installed on plots to further control weeds. The fabrics allowed for significant water penetration and reduced sunlight to the surface of the soil. It contained no harmful substances nor decomposed in a way that released addition substances that could skew the final soil data. The tree samples were collected on September 21, 2007, approximately 32 weeks after planting.

Austin Cary Memorial Forest

To investigate mature root growth in the phosphatic clay and compost mixtures, plots were established in a 7-year-old bald cypress plantation on ACMF, near Gainesville, Florida, in July 2007. The bald cypress in this plantation had an average DBH of 12.7 centimeters and an average height of approximately 9.1 meters. They were originally planted on 0.6 meters high beds that are 3.1 meters apart in somewhat poorly drained flatwood Pomona soils and received 2 surface applications of MSW compost (Morse, 2003). The first treatment applied 60 cubic meters of compost and was done during the bald cypress planting in March 2000. The second treatment applied 38 cubic meters of compost in August 2001. No soil data were collected from the plantation prior to establishing the phosphatic clay and compost mixtures.

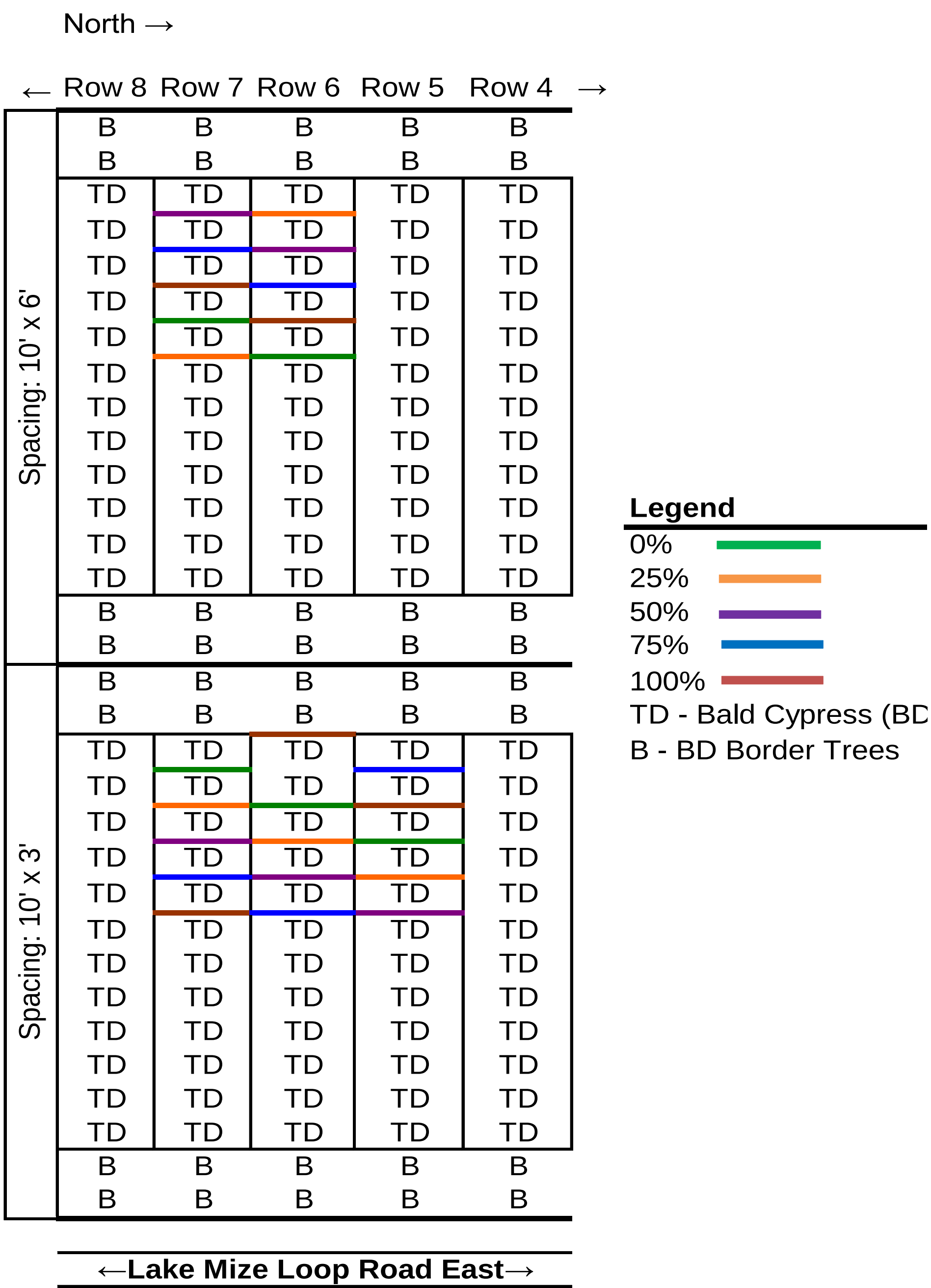

Figure 3-3. ACMF site layout

A total of 20 plots were established in a randomized block design. The compost and phosphatic clays were mixed into 30.5 x 30.5 centimeters holes at 5 different compost percentages: 0, 25, 50, 75, and 100% (Table 1) positioned systematically throughout the overall study site (Figure 3-3). At 0.9-meter spacing, Replications 1 and 2 were established in Rows 5 and 6, respectively.

On 1.8-meter spacing, Replications 1 and 2 were established in Rows 6 and 7, respectively. The plots were established systematically on top of the beds under the canopy of the cypress because of initial observations that significantly more root growth occurred on the beds. This is probably due to a combination of factors including distance between the rows, soil compaction, and/or an advantageous moisture regime on the beds. Each plot had at least one border row of cypress. The plots were established between trees with similar growth, form, and size. Existing roots were trimmed back to the edge of the hole. Furthermore, no weed control measures were necessary as the closed canopy significantly reduced groundcover and unwanted roots. The roots of the mature trees were allowed to grow into the mixture without any obstruction. The plot samples were collected in March 2008, approximately 36 weeks after establishment.

Figure 3-3 also shows a replication in Row 7 in the 0.9-ft spacing. This replication was lost because of extraction tests. In addition, the 100% compost treatment in Rep 1 was moved because the 2 trees where the treatment was supposed to go were too close together. This move should not negatively the results because the border tree that on the west side of the treatment is a bald cypress of similar size and spacing.

UF

The UF study, the control study, was conducted at the School of Forest Resources and Conservation (SFRC) plant growth complex on the UF campus. Most of the time, the pots were in a shadehouse, an open air structure with no walls and a roof made of shadecloth. The irrigation system in the shadehouse watered the trees at regular intervals, approximately 296 ml per day.

A total of 25 black, round, approximately 25.4 centimeters deep with a top diameter of 25.4 centimeters, pots were filled with compost and phosphatic clay at 5 mixing rates of compost: 0, 25, 50, 75, and 100% (Table 3-1). The soil mixture that was placed into the pots was approximately one-half the volume used in the Site D and ACMF studies.

Containerized cuttings of Nanjing beauty cypress, a hybrid clone between Mexican cypress and bald cypress, from Stephen F. Austin University in Texas were planted into each pot on March 29, 2007. No root pruning occurred prior to planting. The pots were hand weeded multiple times. On July 10, 2007, DuPont® Landscaping Fabric was installed on pots to further control weeds. The roots were extracted on February 14, 15, and 16, 2008, approximately 49 weeks after planting.

Soil Extraction and Analysis

The Site D samples used to determine pH, NH_4-N, P, K, Ca, Mg, Mn, and Zn were extracted with a standard sized soil probe (T shaped probe, approximately 1.1-m tall). The probe could extract 405.6-cm^3 of soil or more, but due to the different physical characteristics of the clay and compost mixtures, the extracted volumes varied. The extracted samples were sealed in ZipLoc® freezer bags for transport and placed in cool storage at UF between the dates of extraction and analysis, September 7-10, 2007.

pH was sampled from plots 1-10 and 41-50 on September 7, 2007 (Figure 3-2). Soil pH was determined in a 1:2 soil volume to distilled-deionized (DDI) water volume ratio using a glass electrode (pH meter) (Mylavarapu and Kennelley 2002). The standard buffer solutions were calibrated for the pH meter prior to measurements. A mixture of 20-cm^3 of soil with 40-ml of pure water was stirred with a glass rod and allowed to rest for approximately 1 hour. The mixture was continuously stirred during the measurements.

Extractable P, K, Ca, Mg, Mn, and Zn were determined by utilizing the Mehlich-1 extraction solution. P was sampled from plots 6-10 and 41-45 (Figure 3-2) on September 7, 2007, and analyzed on September 18, 2007. Between the time of extraction and analysis the samples were kept in cool storage at UF research facilities. The remaining minerals were sampled from plots 1-5 and 46-50 on September 10, 2007.

Mehlich-1 extraction solution was determined in a 1:4 soil weight to extraction solution volume ratio. Soil samples weighing 5 g were mixed with 20 ml of Mehlich-1 extraction solution, shaken for approximately 5 minutes, placed into a centrifuge for approximately 5 minutes, and filtered. The centrifuge was used because phosphatic clay particles did not filter well and stayed in suspension for an undetermined amount of time. Mehlich-1 solution was added to the Murphy and Riley (1962) method to find the amounts of extractable P. After multiple attempts to adjust the pH to create the light blue/purple solution color that is required by the Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) for the most accurate calculation of extractable P, it was determined that only 0.1-mL of extracted soil solution was necessary in a 100-mL volumetric graduated cylinder. Reagent B (16-mL) and DDI water were then added to fill the 100-mL volumetric graduated cylinder. Final nutrient concentrations for extractable P were determined using ICP-AES (Mylavarapu and Kennelley 2002).

A standard curve was created by putting 1 mL of 1000-ppm P standard into a 100-mL volumetric graduated cylinder and adding DDI water, equaling 10 ppm of solution. Blanks were set up in 25 mL volumetric to equal 0, 0.2, 0.4, 0.6, 0.8, and 1.2 ppm of the P solutions that would be analyzed by the ICP-AES (Table B-11).

Extractable K was sampled from plots 1-5 and 46-50 (Figure 3-2) on September 7, 2007, and analyzed on December 12, 2007. Between the time of extraction and analysis, the samples were kept in cool storage at UF research facilities or in a climate controlled research laboratory.

Final nutrient concentrations for extractable K were determined using the Perkin Elmer AAnalyst 200 – Atomic Absorption Spectrometer (AAS) (Mylavarapu and Kennelley 2002).

K required no additional additives to the Mehlich-1 solution. A standard curve was created by putting 0.2 mL of 100 ppm of K standard into a 50-mL volumetric graduated cylinder and adding DDI water to equal 10 ppm of solution. Blanks were set up to equal 0, 0.2, 0.4, 0.6, 0.8, 1.0, 2.0, and 4 mg/L of the P solution that would be analyzed with AAS to determine the standard curve (Table B-11).

Bulk density (BD) plots were established in the original planting holes on March 26, 2008. Samples were collected by pressing a tin soil canister firmly into the ground and gently scraping the excess soil/compost from the top of the canister. The canisters had a diameter of 6.2 cm and a height of 4.5 cm. Care was taken during this process so that the canister was not over-pressed, which would have adversely compressed the soil. The soil inside the canister was removed, placed into a ZipLoc®, and analyzed at UF.

BD was sampled from plots 1-10 and 41-50 on July 16, 2008 (Figure 3-2). BD was determined in the lab due to the distance of travel between Site D and UF Forest Soils Lab, schedules, and the soil characteristics and past agricultural operations which may not have provided better onsite data than the lab analysis.

The phosphatic clay/compost samples were oven dried and then extracted from the tin soil canister by gently moving the samples from the canisters to plastic filter heads for easy transfer from one container to another. The samples were then saturated, placed on funnels for drainage, covered, and allowed to sit for approximately 24 hours. Small scoops of the samples were extracted from the drained filter heads and weighed. The small portions were then oven dried and the amount of water loss was recorded.

Ca, Mg, Zn, and Mn were sampled from plots 1-5 and 46-50 on September 7, 2007, and analyzed on December 13, 2007 (Figure 3-2). Between the time of extraction and analysis, the samples were kept in cool storage at UF research facilities or in a climate controlled research laboratory. These 4 elements were analyzed at UF Analytical Research Laboratory (ARL) following the procedures of Mylavarapu and Kennelley (2002). The elements were extracted using Mehlich-1 and given to ARL for analysis using ICP-AES following EPA 200.7 standards.

NH_4-N was sampled from plots 14, 25, 33, 35, and 48 on September 7, 2007, and analyzed in January 2008 (Figure 3-2). Between the time of extraction and analysis the samples were kept in cool storage at UF research facilities or in a climate controlled research laboratory. NH_4-N was analyzed at ARL following the procedures of Mylavarapu and Kennelley (2002). The samples were air dried, screened, and given to ARL as solid soil with no added extraction solution for analysis using the Air-segmented Continuous Autoflow Analyzers - Flow IV following EPA Method 350.1 (modified) standards.

Root Extraction and Analysis

To compare compost effects on cypress root growth, *Taxodium* roots at Site D, ACMF, and UF studies were measured for average root diameter, total root length, total root volume, root volume by diameter class, and root length by diameter class (Table 3-2). *Taxodium* roots at Site D were extracted by visually determining the original plot size. Although the original plots did have pin flags marking the extent of the plot after the compost was mixed into the 30.5 by 30.5 centimeters plots, the plots formed a concave shape at the soil surface. This was probably due to the difference in the larger pore spaces of the initial mixing and smaller pore spaces after the mixture settled. As rain and gravity compressed the compost and filled the large pore spaces with clay particles, the soil surface of the plots subsided. Therefore, it was not difficult to

Table 3-2. Response variables analyzed at three sites and overall in *Taxodium* compost study

Responses	Site D	ACMF	UF	Across Studies
pH	✓	X	X	X
BD	✓	X	X	X
Nutrients	✓	X	X	X
Root Diameters	✓	✓	✓	✓
Root Volumes	✓	✓	✓	✓
Root Lengths	✓	✓	✓	✓

✓= analysis done, x=no data

determine the original plots. The concavity was generally 2.5 to 5.1 centimeters deeper than the surrounding soil surface. For the UF study, all roots were removed from the planting pots and soil.

Great care was taken during the extraction of roots from Site D. The roots were extracted by hand utilizing a common spade. During the extraction, the soil was moist and workable, not wet or dried solid. Roots that had grown outside of the plot into the phosphatic clays were carefully pruned and removed from the sample so that measurements would only be taken from root growth that had occurred within the original plot. The roots from plots 1 - 4, 6 - 9, 11 - 13, 15 - 22, 24, 26, 30, 31, 34, 40, 42, 43, and 45 - 47 (Figure 3-2) were bagged and taken to UF for analysis.

At ACMF, the roots were extracted using a metal "T" soil collector with a cylinder approximately 15.2 centimeters in diameter and 25.4 centimeters in height. The tool also had sharp teeth-like grooves on the base which cut through roots with ease. Because the tool could extract only 4633.3 cm^3, the entire 30.5 by 30.5 centimeters plots could not be extracted with the tool. Furthermore, the flatwoods soils surrounding the plots had encroached into the outer 8 centimeters of the plots. Therefore, the "T" collector was an appropriately sized instrument to sample the actual extent of the remaining, undisturbed phosphatic clay and compost mixture. Other tools were tested but were incapable of properly extracting the study mixture. Due to the tool testing, the plots in the 3 m x 0.9 m spacing of Row 7 were lost (Figure 3-3). The remaining 20 samples were extracted and analyzed. No special tools were used to extract the roots from the entire 10,766.3 in^3 in the 25 pots in the UF study.

At the UF research facility, the roots were carefully extracted from the phosphatic clay/compost by gently but aggressively sparing the clay off of the roots or by simply pulling the clumps of clay apart and carefully extracting the roots. Once the roots were extracted from the clay, they were pruned from the main stem, bagged, and put into cold storage. Some of the roots and soil mixture had to be submerged to facilitate pulling the clay away from the roots. Each tree was worked down and placed into a clean plastic tub. When removing the roots from the soil, there was significant breaking of the fine roots, which were largely caught in the plastic tubs; however, an undetermined amount of fine roots were lost during the extraction process.

Upon the completion of the extraction process, the roots were further cleaned and scanned at UF's Forest Biotechnology and Forest Genomics Labs. The scanner was configured to scan the roots at 800 dpi in the grayscale (at a width of 5102 pixels and a height of 6599 pixels). Scans were downloaded and analyzed with the WinRhizo™ program, an image analysis system specifically designed for root measurement in different forms (Regent Instruments, Inc. 2003). WinRHIZO "uses Regent's unique root measurement method which is non-statistical and requires no calibration by the operator. It detects overlapping root parts and takes them into account when calculating area. Samples can be analyzed interactively or in batch" (NASA 2003). WinRhizo was programmed to find the average root diameter (mm), total root length (cm), total root volume (cm^3), root volume (cm^3) by diameter class, and root length (cm) by diameter class (Table 3-3).

Before statistical analysis, the data were standardized. Data from ACMF and UF were

Table 3-3. Root variables by diameter classes

Actual Diameter Class (mm)	Root Volume (cm^3)	Root Length (cm)
0 to ≤ 0.5	V0005	L0005
0.5 to ≤ 1	V0510	L0510
1 to ≤ 1.5	V1015	L1015
1.5 to ≤ 2	V1520	L1520
2 to ≤ 2.5	V2025	L2025
2.5 to ≤ 3	V2530	L2530
3 to ≤ 3.5	V3035	L3035
3.5 to ≤ 4	V3540	L3540
4 to ≤ 4.5	V4045	L4045
> 4.5	V45+	L45+

matched with the extraction volume at Site D (22237 cm^3). Root volumes data were converted into $cm^3/1000cm^3$, and root lengths were converted to $cm/1000cm^3$. General Linear Model (GLM) Procedure, Duncan's Multiple Range Test (MRT) and Tukey's Test in the Statistical Analysis System (SAS) were utilized. JMP 7 and SAS (Pearson Correlation) were used to determine simple linear regression for the soil data.

CHAPTER 4
RESULTS AND DISCUSSION

At Site D, the effect of MSW compost amendment rates on soil variables was assessed by NH_4-N, P, K, Ca, Mg, Zn, Mn, pH, BD, and porosity. Correlations and differences were analyzed for each variable. .

Compost Influence on Soil Variables

The MSW compost in this study was extracted for the soil sampling after the compost had been left in the ground for approximately 7 to 8 months; although, BD and porosity measurements were made after 4 months. Research has shown that "amending soil with compost provides a slow-release source of nutrients" and "is immediately available to plants" (Smith 1994). Therefore, by allowing the compost to release nutrients for 7 to 8 months the compost should have begun to release noticeable nutrients into the phosphatic clays, but not yet have decomposed to an extent that the nutrients were complete absorbed.

Compost rate did not influence pH_w in Site D (Table 4-5, Figure 4-4). Individually, pH was not linearly or logarithmically correlated with compost rate (Table 4-4). On average, pH was linearly correlated with compost rate. On average, pH significantly lowered pH. However, pH was not lowered to 7.3 or below, which would be a positive influence for nutrient uptake by plant roots (Harris et al. 2004, Phillips and Eneritus 2006). On average, the results are similar to findings by Wahid et al. (1998) who found that OM, such as compost, effectively lowers pH. Therefore, the result could potentially represent a flaw in the composting process at FORCE or the unknown additives that may be mixed into the MSW compost. Generally pH of Class A compost is between 6 and 7 (nearly neutral), while Class B compost is between 6 and 7.5 (MU 2008). The compost used in this study may be a less than optimal type of MSW compost (Class A), but even so, Class B compost is considered a good soil amendment for row crops, sod, and

Table 4-4. Correlations of Site D soil variables with compost rates on individual plot and mean bases

Variable	Individual Basis					Mean Basis		
	n	Prob.	Non Transformed r	Prob.	Transformed r	n	Prob.	r
NH_4-N	12	<.0001	0.70	0.0011	0.76	5	0.19	0.70
P	30	<.0001	-0.67	<.0001	-0.67	5	0.0082	-0.96
K	30	0.1475	-0.19	0.3164	-0.24	5	0.4802	-0.75
Ca	30	<.0001	0.51	0.0136	0.50	5	0.1085	0.79
Mg	30	0.0044	0.36	0.1160	0.32	5	0.27	0.61
Zn	30	0.016	-0.40	0.1203	-0.34	5	0.1	-0.71
Mn	30	0.0039	-0.37	0.1257	-0.37	5	0.08	-0.71
pH	20	<.0001	-0.16	0.1549	-0.67	5	<.0001	-0.96
BD (Surface)	20	<.0001	-0.76	0.0004	-0.75	5	0.0025	-0.81
BD (@ 15.2 cm)	20	<.0001	-0.88	<.0001	-0.86	5	0.0008	-0.92
PR (Surface)	20	<.0001	0.76	0.0001	0.76	5	0.0137	0.81
PR (@ 15.2 cm)	20	<.0001	0.88	<.0001	0.90	5	0.0034	0.92

Individual Basis means that the data was analyzed individually (no averaging). Mean basis that means that the data was analyzed after the data was averaged. Not transformed refers to data no calculated with log and transformed data refers to data calculated with log-10

Table 4-5. Significance of replication (R), compost (C), spacing (S), and other factors on soil and root variables by site

Variable	Site D					ACMF				UF	
	N-S	E-W	R	C	R x C	S	R	C	R x C	C	Overall
NH_4-N	<.0001	<.0001	<.0001	<.0001	0.1077	-	-	-	-	-	
P	0.011	0.011	0.011	0.0016	<.0001	-	-	-	-	-	
K	0.6815	0.6815	0.6815	0.787	0.1406	-	-	-	-	-	
Ca	0.9431	0.9431	0.9431	0.0084	0.0111	-	-	-	-	-	
Mg	0.5838	0.5838	0.5838	0.0249	0.0695	-	-	-	-	-	
Zn	0.7996	0.7996	0.7996	0.117	0.0099	-	-	-	-	-	
Mn	0.6721	0.6721	0.6721	0.2132	0.0875	-	-	-	-	-	
pH	0.7902	0.7456	0.9763	0.684	0.5182	-	-	-	-	-	
BD (Surface)	0.0271	0.3437	0.2988	0.049	0.2705	-	-	-	-	-	
BD (@ 6 in)	0.0396	0..6761	0.1411	0.0593	0.2209	-	-	-	-	-	
PR (Surface)	0.0272	0.3442	0.2991	0.0491	0.2704	-	-	-	-	-	
PR (@ 6 in)	0.0397	0.6764	0.1413	0.0594	0.2209	-	-	-	-	-	
Avg. Dia.	0.0155	0.143	0.0172	0.0056	0.6463	0.876	0.3246	0.0681	0.0009	0.0868	<.0001
Total Len.	0.0692	0.1136	0.0919	0.0051	0.4931	0.0269	0.8497	0.0527	0.0323	0.154	<.0001
Total Vol.	0.0279	0.0789	0.0088	0.0093	0.5	0.5689	0.4606	0.13	0.0045	0.144	<.0001
V0005	0.2137	0.0367	0.5299	0.0073	0.5736	0.0766	0.8848	0.0411	0.0264	0.1347	<.0001
V0510	0.1421	0.1217	0.0142	0.0028	0.508	0.0144	0.1327	0.6449	0.0536	0.2505	<.0001
V1015	0.0193	0.1528	<.0001	0.0002	0.5888	0.026	0.6604	0.2425	0.0677	0.1843	<.0001
V1520	0.0214	0.0219	0.0004	0.0021	0.5315	0.0127	0.7693	0.1516	0.1158	0.2444	<.0001
V2025	0.0227	0.1494	0.0343	0.021	0.545	0.0212	0.7847	0.0756	0.0294	0.2868	<.0001
V2530	0.0045	0.0104	<.0001	0.0231	0.2627	0.0278	0.8828	0.2479	0.0586	0.2511	<.0001
V3035	0.0105	0.0013	<.0001	0.0096	0.3061	0.0661	0.678	0.2059	0.0896	0.2454	<.0001
V3540	0.0012	<.0001	<.0001	0.0095	0.3598	0.2809	0.9855	0.3242	0.0413	0.1739	<.0001
V4045	0.0019	0.001	0.0541	0.0005	0.4778	0.4121	0.8525	0.415	0.1022	0.0881	<.0001
V45+	0.091	0.2871	0.5367	0.043	0.6559	0.5516	0.3439	0.1224	0.0528	0.1467	<.0001
L0005	0.1657	0.0588	0.6497	0.0082	0.5711	0.0448	0.0241	0.8686	0.0276	0.1281	<.0001
L0510	0.1783	0.1768	0.0337	0.0034	0.5226	0.0241	0.8686	0.0448	0.0464	0.2551	<.0001
L1015	0.0225	0.1557	<.0001	0.0002	0.5808	0.0213	0.6116	0.1306	0.0652	0.1798	<.0001
L1520	0.0199	0.0206	0.0005	0.0018	0.536	0.0229	0.6405	0.2297	0.1071	0.2465	<.0001
L2025	0.027	0.1393	0.023	0.0359	0.5503	0.0117	0.8054	0.1447	0.0315	0.292	<.0001
L2530	0.004	0.0098	0.0239	<.0001	0.2718	0.027	0.8922	0.2519	0.0585	0.268	<.0001
L3035	0.0107	0.0012	<.0001	0.0092	0.2971	0.0695	0.6873	0.2025	0.0877	0.2911	<.0001
L3540	0.0011	<.0001	0.0093	<.0001	0.3581	0.265	0.9954	0.3121	0.0396	0.7743	<.0001
L4045	0.0018	0.0006	0.0003	0.0489	0.4714	0.418	0.8347	0.3978	0.0986	0.2284	<.0001
L45+	0.0271	0.2772	0.1969	0.0649	0.5756	0.2023	0.1831	0.4695	0.0817	0.6209	<.0001

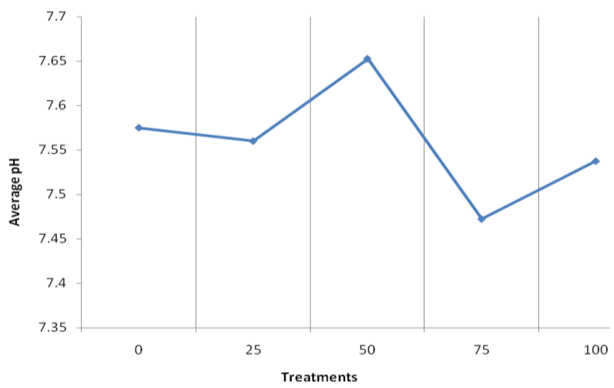

Figure 4-4. Mean pH by compost % at Site D

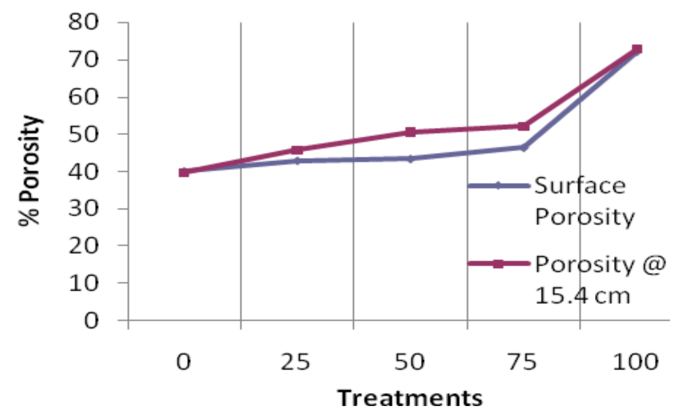

Figure 4-6. Porosity at surface and 15.4 cm by compost % at Site D

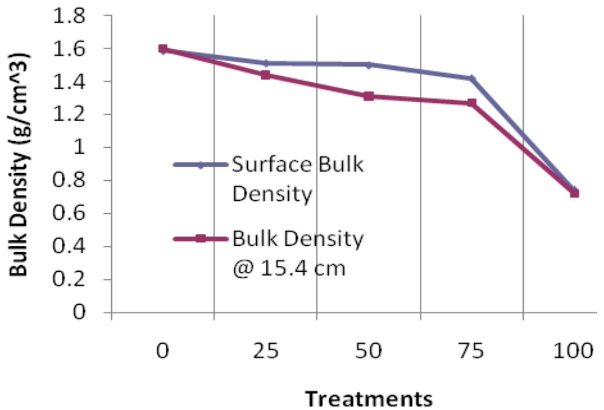

Figure 4-5. BD at surface and 15.4 cm by compost % at Site D

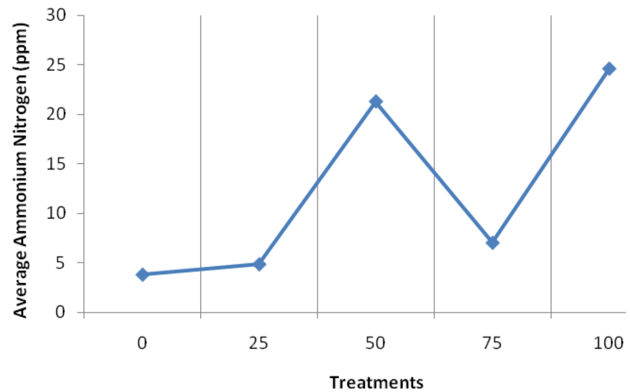

Figure 4-7. Mean NH_4-N by compost t% at Site D

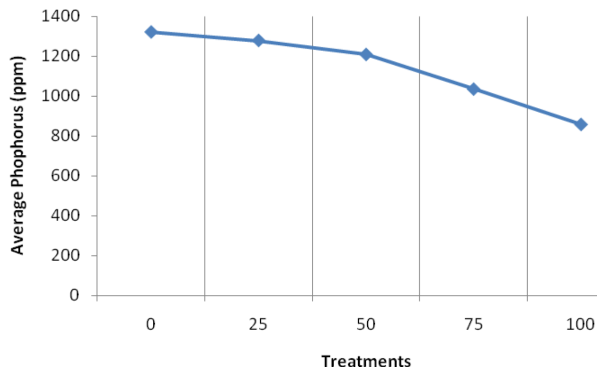

Figure 4-8. Mean P by compost % at Site D

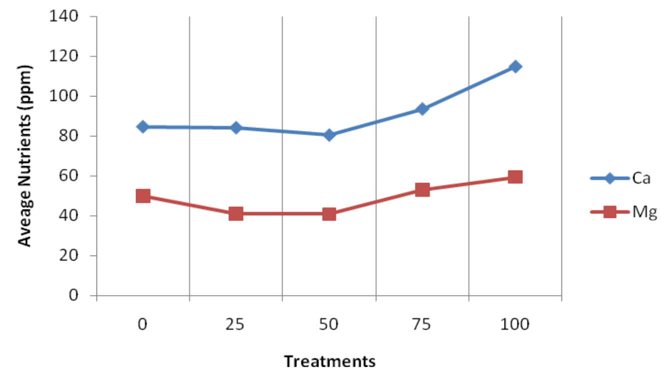

Figure 4-10. Mean Ca and Mg by compost % at Site D

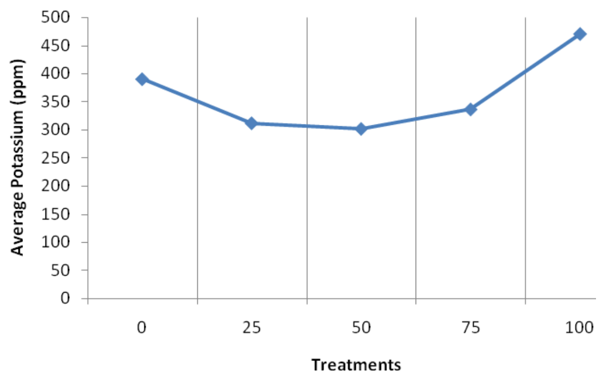

Figure 4-9. Mean K by compost % at Site D

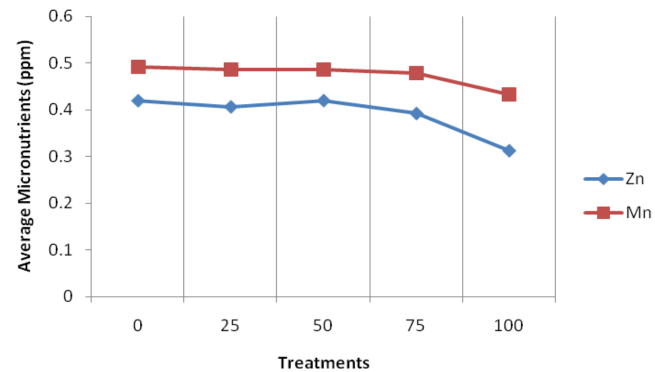

Figure 4-11. Mean Zn and Mn by compost % at Site D

other field grown landscaping plants (MU 2008). Therefore, sub-hypothesis 1 could not be rejected, because the compost treatments did not significantly affect the pH level of the phosphatic clay on an individually basis. However, on average there is a potential for pH to be lowered but not to level suitable for optimal growth. Similar pH results were found by Bouzaiane et al. (2007). Their study reviewed MSW compost amendments on the microbial biomass of cultivated and non-cultivated soil. They found that incorporating MSW compost at different rates did not affect the pH levels in clay and loamy soils.

Furthermore, research showed that when pH levels exceed 7.3, extractable P and other micronutrients are limited (Harris et al. 2004, Evans 2000, and Stricker 2000). Almost all pHlevels in this study exceeded 7.3 (Tables B-12 - B-16). However, almost all the samples for P exceeded 1,000 ppm, but there was a deficiency in micronutrients (Zn and Mn) (Tables B-12 - B-16).

Compost addition to phosphatic clays decreased BD and increased porosity (Tables 4-4 and 4-5, Figures 4-5 and 4-6). BD and porosity was influenced by the rate of compost, although, individually these were significantly but weak correlated (r=0.75 at the surface and r=0.88 at 15.4 centimeters). On average, BD and porosity were significantly correlated with compost rate, especially at a depth of 15.4 centimeters (r=0.92). Furthermore, on a logarithmic scale only, the lower BDs were weakly correlated (Table 4-4). However, porosity below the surface was correlated when based on a logarithmic scale. Therefore, it can be concluded that porosity below the surface layers was correlated with compost rate, but even at the surface there was positive changes to the soil structure due to compost rate. Overall, compost had a positive effect on soil structure.

By lowering BD and increasing porosity, the phosphatic clays became less compacted, a very important benefit for root growth in compacted soils. These improvements can potentially improve compaction situations which can limit vegetative root growth, especially at the depth of 15.4 centimeters. The addition of compost may improve soil surface characteristics and help with crusting at the surface of phosphatic clays.

Rivernshield and Bassuk (2007) found similar BD and porosity results. They incorporated sphagnum peat or food waste compost to compacted sandy loam and clay loam and found that compost decreases BD and increases porosity. Molla et al. (2005) and Shelton (1991) also determined that MSW compost reduces soil bulk density.

Replication, N-S, and E-W influenced P levels. The higher side of Site D had less P than the lower side, indicating that the very slight slope moved P from high elevation to low elevation. This may have been caused by water movement and/or clay particle movement. NH_4-N differences based on N-S and E-W was probably a product of the small sample size.

Individual NH_4-N levels were significantly influenced by treatment, E-W, and replication (Tables 4-5). NH_4-N was not correlated with compost rate and the log of N was weakly correlated (Table 4-4 and 4-5).

Individual P was significantly influenced by all 4 factors (treatment, N-S, E-W, and replication), but was weakly correlated with compost rate (Tables 4-4 and 4-5). Average P was correlated (probability = 0.0082 and r = 96) with compost rate (Figure 4-8).

Individual Ca and Mg levels were both significantly different and uncorrelated by treatment (Tables 4-4 and 4-5).

Individual K levels were not correlated by treatment nor were they significantly different for all 4 factors (Tables 4-4 and 4-5). Individual Zn and Mn levels were not correlated by treatment and not significantly different for all 4 factors (Tables 4-4 and 4-5).

Of all nutrients, only average P was linearly correlated by compost rate. Average Ca, Zn, and Mn had insignificant correlation of 79, 81, and 83 respectively. Therefore, this suggests that compost may increase some nutrient levels, but not in a controllable manner.

Compost Influence on Root Development

MSW compost influences on *Taxodium* root development were assessed by root diameter and soil volume adjusted root length and volume in the Site D, ACMF, and UF studies. Seedling survival was also assessed at Site D.

Site D

Field observations and data indicated that the seedlings were of good stock. Seedling roots grew substantially in the brief time between planting and extraction. This growth was observed during excavation because all the original roots were pruned to 5.1 centimeters from the main stem during planting. Root excavation revealed that many of the primary roots, for each treatment, grew outside of the plot and significant amounts of fibrous roots were found throughout the soil inside the plots. The field extraction was hastened due to unexpected onset of mortality in approximately 8 months (February to September) (Table 4-6). In July, seedling

Table 4-6. Seedling survival (%) at Site D by treatment and time

	Seedling Survival			
Treatment	February	May	July	September
0%	100	80	80	30
25%	100	80	70	10
50%	100	60	50	20
75%	100	80	80	10
100%	100	30	20	0

survival had decreased only slightly from May. It appeared that the seedlings had "taken-root" and were growing well. At the beginning of September, many seedlings were dying. They had elasticity in the main stem and in many of the branches, but had defoliated or the majority of the leaves were brown. Other evidence such as dead crowns and stump sprouts further highlighted approaching mortality. Mortality was highest at 100% compost rate. After planting in February, 70% of the seedlings had died by May. By September, all of the seedlings in 100% compost were failing. Only 2 seedlings at 100% still retained elasticity and had some stump sprouts during excavation in September, but they were unlikely to survive past September. Therefore, all seedlings were extracted before December, the planned date of extraction.

Mortality at Site D was not due to poor seedling stock, the phosphatic clay, or contamination problems with the MSW compost, but rather the lack of rain after planting. At the Lakeland Linder Regional Airport approximately 32.1 kilometers northwest of Site D, between January 2007 and May 2007 (dormant season through early growing season), there was a significant drought (Figure 3-1).

This study was part of a larger approximately 12-hectare cypress planting. Approximately 9.2 hectares was an operational planting of cypress and approximately 2.2 hectares was a density and genetics study with cypress and cottonwood (Figure A-16). The cypress seedlings in this study were the same cypress used in the operational planting and density studies. Shortly after planting, the cypress in the operational planting and in the density study began to rapidly die. Likewise, the cottonwood genetic study failed. In fact, morality at Site D was so severe and sudden, no survival counts were ever conducted on the operational planting or the density/genetics study. Most of the seedlings had perished by July, except for the cypress seedlings in this study, which survived for a few months more before succumbing to the drought.

In fact, all the treatments, including the 0% compost survived well until after July. Remarkably, even with the poor soil conditions associated with clay setting areas and the drought, the cypress seedlings in this study grew during a time that would significantly tax many tree species. The most likely cause of this mortality was the lack of rain after planting (Figure 3-1). CSAs have extreme seasonal moisture variations in the top soil (Segrest 2008, CPI 2003, Stricker 2000, Mislevy et al. 1989). The soils completely dried out because of the lack of rain, as potentially did the MSW compost. The high seedling mortality rate for 100% compost has been reported in other research projects (Smith 1994). Also, a company in Maine that makes Cycle-Gro compost from forest floor materials has encountered a problem with it. If the compost ever dries out, it is nearly impossible to re-wet (Cycle-Gro 2008).

Plot location influence on root volumes, root diameters, root lengths, and seedling morality was also examined. As previously mentioned, Site D was located in a relative flat area with a slight topographic change from east to west. There were significant differences north/south blocks based on average diameter, total volume, V1015-V4045, and L1015-L45+. However, east /west blocks had lesser differences (Table 4-5). Only total volume, V0005, V1520, V2530-V4045, L0005, L1520, and L2530-L4045 were significantly different. There were no significant differences in root variables based on replication by compost rate. However, compost by replication indicates that almost all root variables are significantly different. Therefore, the slight change in topography at the study site may be influencing root growth. However, from north to south there is practically no visible topographic change, but the north/south blocks were the most significantly different. This occurrence cannot be explained by this study. Furthermore, due to the significant differences in the north/south blocks and east/west blocks, the replications are almost all significantly different.

Table 4-7. Correlations of Site D soil variables with root growth variables

	pH	BD (Surface)	BD (@ 6 in)	PR (Surface)	PR (@ 6 in)	Ca	Mg	Zn	Mn	K	P
Avg. Dia.	-0.20	0.15	0.04	0.20	0.26	-0.39	0.01	-0.56	0.16	0.17	0.11
Total Len.	0.01	-0.04	0.12	-0.42	0.20	-0.38	0.24	0.51	-0.67	0.30	0.10
Total Vol.	-0.20	-0.15	0.42	0.17	-0.01	0.23	-0.67	0.31	-0.55	0.51	0.19
V0005	0.35	0.50	0.26	-0.50	-0.26	-0.69	-0.55	0.53	0.35	0.15	0.35
V0510	0.02	0.34	0.16	-0.34	-0.16	-0.68	-0.59	0.49	0.34	0.11	0.02
V1015	-0.54	0.21	0.00	-0.21	0.00	-0.75	-0.46	0.69	0.35	0.01	-0.04
V1520	0.01	0.13	-0.09	-0.13	0.09	-0.04	-0.34	0.49	0.09	0.38	0.27
V2025	-0.04	0.36	0.17	-0.12	0.08	-0.32	-0.22	0.23	-0.05	0.29	-0.04
V2530	-0.13	0.30	0.13	-0.30	-0.13	-0.68	-0.52	0.22	0.26	-0.06	-0.13
V3035	0.09	0.22	0.06	-0.22	-0.06	-0.29	-0.40	0.12	0.18	-0.06	0.09
V3540	0.15	0.21	0.03	-0.21	-0.03	-0.39	-0.52	0.18	0.31	-0.16	0.15
V4045	0.18	0.19	0.04	-0.19	-0.04	-0.30	-0.44	0.12	0.27	-0.17	0.18
V45+	0.16	0.12	-0.08	-0.12	0.08	-0.25	-0.40	0.09	0.24	-0.17	0.16
L0005	0.34	0.50	0.29	-0.50	-0.29	-0.64	-0.54	0.47	0.30	0.14	0.34
L0510	0.06	0.12	-0.08	-0.36	-0.17	-0.45	-0.60	0.48	0.35	0.10	0.06
L1015	-0.04	0.22	0.02	-0.22	-0.02	-0.77	-0.48	0.70	0.37	0.26	-0.04
L1520	0.00	0.12	-0.08	-0.12	0.08	-0.54	-0.34	0.49	0.09	0.39	0.00
L2025	-0.08	0.09	-0.09	-0.09	0.10	-0.31	-0.21	0.22	-0.06	0.30	-0.08
L2530	-0.13	0.31	0.14	-0.31	-0.14	-0.48	-0.56	0.23	0.29	-0.08	-0.13
L3035	0.08	0.22	0.08	-0.22	-0.08	-0.30	-0.44	0.12	0.20	-0.09	0.08
L3540	0.14	0.21	0.02	-0.21	-0.02	-0.38	-0.50	0.17	0.29	-0.14	0.14
L4045	-0.25	0.19	0.03	-0.19	-0.03	-0.31	-0.45	0.12	0.27	-0.17	0.17
L45+	0.16	0.13	-0.07	-0.13	0.07	0.17	-0.40	0.09	0.24	-0.17	0.16

No correlations are significant at $p \leq 0.01$ or $p \leq 0.05$.

Table 4-8. Correlations of log 10 transformed and untransformed root variables with compost rate in three studies

	Site D				ACMF				UF			
Root Variables	**Prob.**	**Untransformed**	**Prob.**	**Transformed**	**Prob.**	**Untransformed**	**Prob.**	**Transformed**	**Prob.**	**Untransformed**	**Prob.**	**Transformed**
Avg. Dia.	0.43	-0.15	0.26	-0.21	0.01	0.58	0.00	0.71	0.87	-0.04	0.87	0.04
Total Len.	0.31	-0.19	0.39	-0.16	0.01	0.56	0.02	0.51	0.52	-0.14	0.56	-0.13
Total Vol.	0.39	-0.16	0.18	-0.25	0.02	0.52	0.01	0.60	0.43	0.17	0.40	0.19
V0005	0.40	-0.16	0.68	-0.08	0.01	0.59	0.01	0.56	0.58	-0.12	0.68	-0.09
V0510	0.42	-0.15	0.43	-0.15	0.03	0.49	0.05	0.44	0.46	-0.16	0.48	-0.15
V1015	0.53	-0.12	0.39	-0.16	0.04	0.46	0.11	0.37	0.35	-0.20	0.36	-0.20
V1520	0.39	-0.16	0.93	0.02	0.04	0.46	0.07	0.42	0.45	-0.16	0.49	-0.15
V2025	0.29	-0.20	0.83	-0.04	0.01	0.56	0.02	0.51	0.42	-0.18	0.50	-0.15
V2530	0.15	-0.27	0.39	0.16	0.03	0.49	0.08	0.41	0.64	-0.10	0.68	-0.09
V3035	0.15	-0.27	0.27	0.21	0.04	0.47	0.06	0.43	0.64	-0.10	0.68	-0.09
V3540	0.20	-0.24	0.70	-0.07	0.03	0.48	0.12	0.36	0.42	-0.18	0.20	-0.28
V4045	0.18	-0.25	0.51	0.13	0.04	0.45	0.12	0.36	0.38	-0.19	0.19	-0.29
V45+	0.62	-0.09	0.92	0.02	0.00	0.61	0.01	0.54	0.97	0.01	0.74	0.07
L0005	0.31	-0.19	0.55	-0.11	0.01	0.59	0.01	0.54	0.56	-0.13	0.63	-0.11
L0510	0.43	-0.15	0.51	-0.13	0.03	0.50	0.04	0.45	0.48	-0.15	0.51	-0.14
L1015	0.52	-0.12	0.40	-0.16	0.04	0.46	0.10	0.38	0.36	-0.20	0.37	-0.19
L1520	0.40	-0.16	0.48	-0.14	0.04	0.46	0.07	0.42	0.45	-0.16	0.48	-0.16
L2025	0.30	-0.20	0.37	-0.17	0.01	0.56	0.02	0.51	0.42	-0.18	0.51	-0.14
L2530	0.15	-0.27	0.89	0.03	0.03	0.49	0.08	0.40	0.64	-0.10	0.67	-0.09
L3035	0.15	-0.27	0.55	0.11	0.04	0.47	0.06	0.43	0.63	-0.11	0.68	-0.09
L3540	0.43	-0.24	0.45	-0.14	0.02	0.48	0.05	0.36	0.41	-0.18	0.20	-0.28
L4045	0.18	-0.25	0.77	0.06	0.04	0.46	0.11	0.37	0.37	-0.19	0.18	-0.29
L45+	0.20	-0.15	0.89	-0.03	0.03	0.53	0.12	0.45	0.91	-0.03	0.96	-0.01

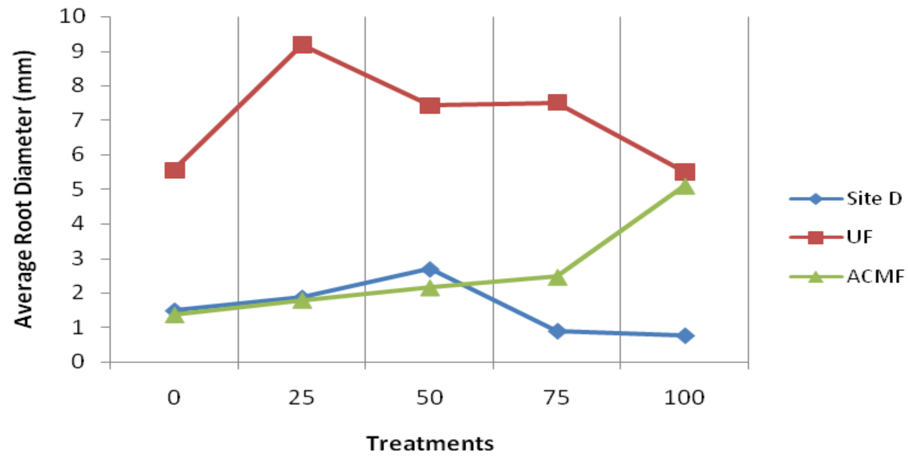

Figure 4-12. Mean root diameter by site and compost treatments

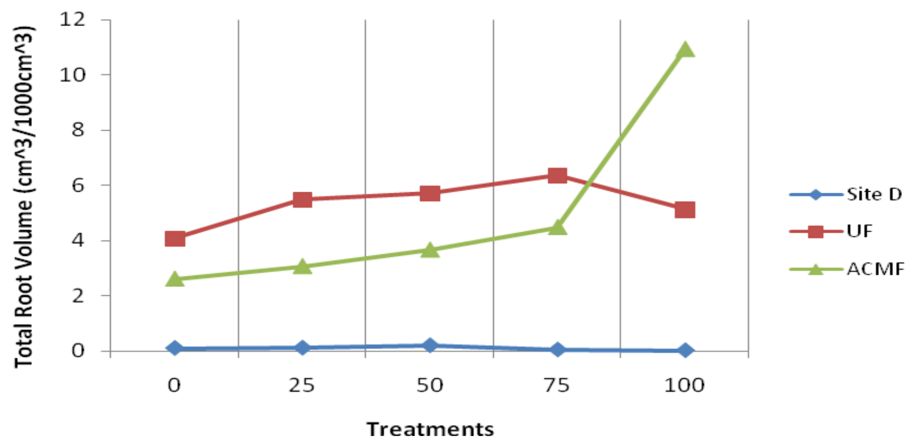

Figure 4-13. Mean root volume per soil volume by site and compost treatments

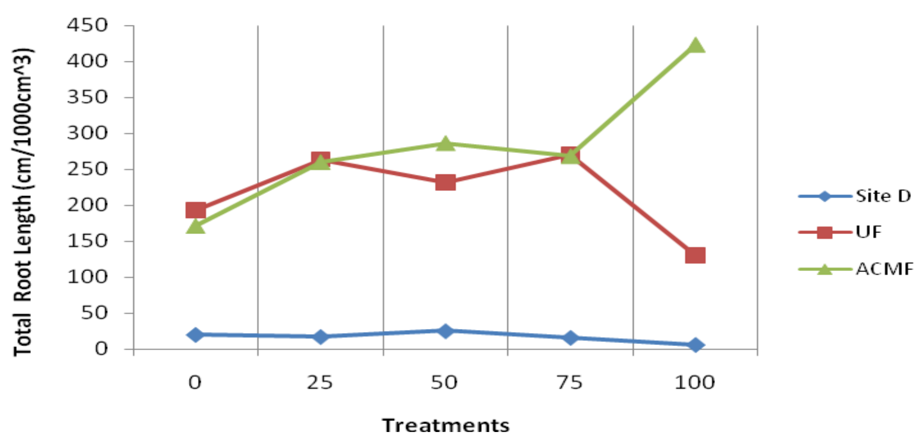

Figure 4-14 . Mean root length per soil volume by site and compost treatments

Table 4-9. Means, standard deviations (±), and significant differences for total root volume (cm^3/1000 cm^3), average root diameter (mm), total root length (cm/1000 cm^3), root volume by diameter class (cm^3/1000 cm^3), and root length by diameter class (cm/1000 cm^3) by compost treatments in three studies

Dia. Class	Site D					ACMF					UF				
	0%	**25%**	**50%**	**75%**	**100%**	**0%**	**25%**	**50%**	**75%**	**100%**	**0%**	**25%**	**50%**	**75%**	**100%**
Avg Dia	1.68±1.49^{ab}	1.86±1.86^{ab}	2.69±2.73^{a}	0.9±0.44^{b}	0.77±0.53^{b}	1.38±0.41^{b}	1.8±0.8^{b}	2.16±0.89^{b}	2.47±0.24^{ab}	5.1±3.55^{a}	5.55±3.83	9.19±4.8	7.43±1.97	7.51±4.15	5.5±3.23
Total Len	17.23±12^{a}	17.23±11^{a}	25.24±17^{a}	15.99±8^{a}	6.2±3^{b}	171.46±41^{b}	260.13±77^{ab}	286.4±119^{ab}	268.23±93^{ab}	423.3±191^{a}	193.37±12	263.66±12	231±108	270±109	130±48
Total Vol	0.11±0.1^{ab}	0.11±0.16^{ab}	0.2±0.24^{a}	0.04±0.03^{b}	0.02±0.02^{b}	2.61±1.28^{b}	3.07±1.52^{b}	3.66±2.46^{ab}	4.48±1.16^{ab}	10.93±9.41^{a}	4.07±2.74	5.48±1.45	5.7±2.62	6.35±3.28	5.12±3.17
V0005	0.01±0^{a}	0.01±0^{a}	0.01±0^{a}	0.01±0^{a}	0±0^{b}	0.05±0.02^{b}	0.09±0.03^{ab}	0.1±0.04^{ab}	0.09±0.03^{ab}	0.15±0.07^{a}	0.07±0.04	0.08±0.04	0.08±0.04	0.09±0.03	0.05±0.02
V0510	0.02±0.01^{ab}	0.02±0.01^{ab}	0.03±0.02^{a}	0.01±0.01^{bc}	0.01±^{c}	0.2±0.04^{b}	0.27±0.08^{ab}	0.31±0.14^{ab}	0.29±0.09^{ab}	0.4±0.19^{a}	0.17±0.11	0.22±0.11	0.21±0.09	0.23±0.1	0.1±0.04
V1015	0.02±0.02^{bc}	0.02±0.02^{b}	0.04±0.0^{a}	0.01±0.01^{bc}	0±0^{c}	0.24±0.03^{b}	0.32±0.1^{ab}	0.38±0.19^{ab}	0.36±0.12^{ab}	0.48±0.25^{a}	0.22±0.15	0.29±0.14	0.26±0.12	0.28±0.14	0.13±0.05
V1520	0.02±0.02^{ab}	0.02±0.01^{b}	0.03±0.03^{a}	0.01±0.01^{b}	0.01±0.01^{b}	0.25±0.07^{b}	0.35±0.13^{ab}	0.43±0.2^{ab}	0.37±0.12^{ab}	0.53±0.27^{a}	0.24±0.17	0.36±0.16	0.31±0.13	0.35±0.19	0.15±0.06
V2025	0.02±0.01^{ab}	0.02±0.02^{ab}	0.02±0.03^{a}	0.01±0.01^{b}	0.01±0.01^{b}	0.28±0.09^{b}	0.35±0.13^{b}	0.38±0.10^{ab}	0.43±0.11^{ab}	0.6±0.27	0.27±0.19^{ab}	0.43±0.2^{a}	0.35±0.16^{ab}	0.38±0.21^{ab}	0.16±0.07^{b}
V2530	0.01±0.03^{a}	0.01±0.01^{ab}	0.02±0.02^{a}	0.01±0.01^{b}	0±0^{b}	0.28±0.09	0.34±0.1	0.42±0.22	0.46±0.14	0.55±0.32^{a}	0.27±0.21	0.47±0.2	0.36±0.14	0.44±0.29	0.19±0.1
V3035	0.01±0.03^{a}	0.01±0.02^{ab}	0.02±0.02^{a}	0±0^{b}	0±0^{b}	0.27±0.08^{b}	0.34±0.14^{ab}	0.39±0.21^{ab}	0.35±0.14^{ab}	0.53±0.2	0.26±0.18	0.43±0.13	0.39±0.17	0.44±0.22	0.18±0.09
V3540	0.01±0.04^{a}	0.01±0.02^{ab}	0.02±0.03^{a}	0±0.01^{b}	0±0^{b}	0.26±0.07	0.3±0.13	0.33±0.22	0.36±0.17	0.5±0.14	0.27±0.15^{ab}	0.41±0.11^{a}	0.33±0.12^{ab}	0.4±0.25^{a}	0.15±0.09^{b}
V4045	0.01±0.02	0.01±0.02	0.01±0.02	0±0.01	0±0	0.23±0.07	0.21±0.09	0.32±0.22	0.33±0.11	0.41±0.2^{a}	0.27±0.18^{ab}	0.45±0.15^{a}	0.38±0.17^{ab}	0.44±0.25^{a}	0.12±0.09^{b}
V45+	0.08±0.07^{ab}	0.08±0.21^{ab}	0.15±0.21^{a}	0±0.01^{b}	0±0^{b}	1.9±1.47^{b}	3.01±1.67^{ab}	3.41±2.56^{ab}	4.59±1.86^{ab}	6.01±2.51^{a}	3.95±2.71	4.48±1.35	5.83±2.44	6.47±2.55	3.09±1.01
L0005	8.9±6.11^{a}	8.9±5.01^{a}	12.21±6.36^{a}	10.36±5.86^{a}	4.02±1.49^{b}	67.54±24^{b}	122.47±42^{b}	122.24±4^{b}	114.76±47^{b}	208.97±94^{a}	96.62±55	127.9±63	107.79±55	130.79±43	69.91±25.7
L0510	4.91±3.15^{ab}	4.91±3.6	6.93±5.27^{a}	3.78±2.03^{bc}	1.4±0.95^{c}	48.7±11.67^{b}	66.22±20^{ab}	79.07±34^{ab}	70.78±22^{ab}	99.8±45.83	41.07±27	53.57±26	51.28±22	56.55±24	25.99±9.85
L1015	1.57±1.66^{bc}	1.57±1.49^{b}	2.97±2.7^{a}	1.04±0.74^{bc}	0.36±0.26	20.5±2^{b}	26.42±8.3^{ab}	31.81±15^{ab}	29.73±10^{ab}	40.15±20^{a}	17.99±12	23.83±11	21.54±9.72	23.29±11	10.61±4.01
L1520	0.66±0.86^{ab}	0.66±0.53^{b}	1.29±1.47^{a}	0.45±0.32^{b}	0.25±0.36^{b}	10.66±2.81^{b}	14.68±5.5^{ab}	18.12±8.3^{ab}	15.46±5.0^{ab}	22.29±11^{a}	10.2±7.11	15.15±6.72	12.92±5.54	14.65±7.89	6.24±2.6
L2025	0.42±0.35^{ab}	0.42±0.5^{ab}	0.59±0.77^{a}	0.18±0.13^{b}	0.14±0.2^{b}	7.16±2.19^{b}	8.93±3.4^{b}	9.81±4.84^{ab}	11.01±2.9^{ab}	15.37±6.83^{a}	6.82±4.79^{ab}	11.03±5.07^{a}	9.02±4.04^{ab}	9.9±5.43^{ab}	4.11±1.7^{b}
L2530	0.22±0.46^{a}	0.22±0.24^{ab}	0.36±0.41^{a}	0.09±0.1^{b}	0.02±0.03^{b}	4.81±1.56	5.79±1.74	7.2±3.78	7.92±2.38	9.54±5.63	4.68±3.56	8.02±3.41	6.16±2.47	7.58±4.91	3.27±1.66
L3035	0.15±0.32^{a}	0.15±0.18^{ab}	0.25±0.3^{a}	0.04±0.05^{b}	0.02±0.02^{b}	3.23±0.93^{b}	4.09±1.7^{ab}	4.72±2.56^{ab}	4.28±1.69^{ab}	6.48±2.42^{a}	3.22±2.21	5.19±1.59	4.8±2.11	5.29±2.72	2.15±1.12
L3540	0.12±0.39^{a}	0.12±0.17^{ab}	0.2±0.26^{a}	0.02±0.05^{b}	0±0^{b}	2.41±0.6	2.71±1.18	2.97±1.99	3.23±1.58	4.56±1.33	2.43±1.37^{ab}	3.75±1.03^{a}	3±1.15^{ab}	3.69±2.24^{a}	1.33±0.8^{b}
L4045	0.08±0.17^{a}	0.08±0.15^{ab}	0.08±0.11^{ab}	0.02±0.06^{ab}	0±0^{b}	1.66±0.49	1.52±0.67	2.31±1.63	2.39±0.79	3±1.42	1.94±1.26^{ab}	3.19±1.11^{a}	2.71±1.19^{ab}	3.14±1.75^{a}	0.88±0.63^{b}
L45+	0.21±0.29^{ab}	0.21±0.55^{ab}	0.36±0.49^{a}	0.01±0.02^{b}	0±0^{b}	4.79±2.73^{b}	7.32±3.58^{ab}	8.15±5.65^{ab}	8.66±2.9^{ab}	13.14±6.49^{a}	8.41±5.75^{ab}	12.03±4.9^{ab}	12.34±5.5^{ab}	15.21±7.47^{a}	6.05±2.73^{b}

Means with the same letter (a, b, c, ab, bc) within are not significantly different (α=0.05).

Table 4-10. Percent root volume and length by diameter class for three studies

	Root Volume			Root Length		
Dia. Class	Site D	UF	ACMF	Site D	UF	ACMF
0005	3.8	1.0	1.5	56.7	49.0	45.1
0510	10.3	2.5	4.3	25.2	21.0	25.9
1015	10.5	3.2	5.3	8.5	8.9	10.5
1520	9.7	3.8	5.7	3.9	5.4	5.8
2025	7.9	4.3	6.0	1.9	3.7	3.7
2530	7.4	4.7	6.1	1.2	2.7	2.5
3035	6.8	4.6	5.6	0.8	1.9	1.6
3540	7.2	4.2	5.2	0.6	1.3	1.1
4045	5.1	4.5	4.5	0.3	1.1	0.8
45+	31.2	67.0	56.0	0.8	5.0	3.0
Total	100	100	100	100	100	100

At Site D, average root diameter, total root volume, and total root length were positively correlated with each other. These root variables were not linearly or logarithmically correlated with any of the soil variables in Site D (Table 4-7) or compost rate (Table 4-8). However, compost rate did significantly influence average root diameter, total root volume, and total root length (Table 4-5). Total root volumes, average root diameters, and total root lengths increased from 0 to 50% compost in the phosphatic clays (Table 4-9, Figures 4-12 – 4-14). Fifty percent compost had the greatest root volumes and lengths by diameter class. After 50% compost root, volumes, lengths, and diameters significantly decreased (Figures 4-12 – 4-14). This means that the greatest average sized root diameters, lengths, and volumes are associated with 50% compost. There was also significant morality at 100% compost (Table 4-6). Based on the 10 cypress seedlings treated with 100% compost, 80% or approximately 1.33 seedlings per month were lost due to mortality over an 8 month period of time. The other treatments had much higher survival over the same period of time.

Sub-hypotheses 2 can be rejected and sub-hypothesis 3 could not be rejected for Site D. Root volumes and diameters were lowest when the phosphatic soils had no compost. At Site D, 50% compost has the largest root volumes and diameters.

Root volumes and lengths by diameter class were influenced by the compost rate (Table 4-5) but were not linearly or logarithmically correlated with soil variables (Table 4-8). All root diameter classes were significant but only somewhat linearly correlated with each other. Almost all total root volumes, total lengths, and average diameters were significantly correlated with diameter classes.

When individual treatments were compared with root variables, only V4045 was not significantly different (Table 4-9). All other root variables were significantly different by individual compost rate. Consistently, 50 and 100% were the most significantly different compost rate. Furthermore, 50% compost appears to be the most different compost rate because 0, 25, 75, and 100% compost were consistently more similar. Only 0 and 25% compost was consistently similar to 50% compost.

Roots were consistently larger at 50% compost than the other treatments, and consistently smaller at 100% compost. This separation between 50 and 100% compost was consistent. The 50% compost treatment resulted in larger root volumes in all diameter classes. Consistently, 100% compost had the lowest volumes. Lastly, volumes and lengths were greatest for small diameter roots and steadily decreased as diameter sizes increased with only a slight increase at the largest diameter class (Table 4-10 and Figures C-17 and C-18).

When the root data were assessed with respect to the soil data, there were many unexpected differences. Generally, increasing compost levels decreased BD but on average there was not a significant change in BD between 25, 50, and 75% compost. A more dramatic decrease in BD as compost rates increased was expected. Furthermore, MSW compost may not control surface compaction on a CSA. The surface BD leveled out at 25 to 75% compost (Figure 4-5). Although, at a depth of 38.7 centimeters, compost does appear to steadily reduce BD as compost rates increase. Fifty percent treatments were basically at the middle of the BD levels (Tables B-12-B-16, Figure 4-5).

Hundred percent compost had the highest NH_4, K, Ca, Mg, Zn, and Mn, but the lowest P. Generally, this would signify that 100% compost was very advantageous for root growth. However, 50% compost showed the lowest levels of K, Ca, Mg, and Zn, mid-level P content (1,209 ppm), and second highest NH_4 level (21 ppm). This might appear to be less than advantageous growing conditions for roots, but this treatment still contained significant amounts of P and plenty of NH_4. Therefore, higher amounts of nutrients may negatively affect the root growth of *Taxodium* species. Furthermore, P and NH_4 appear to be very important soil nutrients for *Taxodium* seedling root growth.

There were no significant differences among compost treatments for average root diameters, total root volume, and total root lengths. Likewise, percent length and volume based on soil volume were not significantly influenced by Rep, N-S, E-W, and Treatment (Table 4-5). Fifty percent compost had the greatest root volume and lengths based on diameter class. The most significant difference between the treatments was the separation between 50% compost and 100% compost.

Fifty percent compost had the highest root volume, lengths, and diameter. There was a steady increase in total volume, total length, and average diameter from 0% compost to 50% compost, but after 50% compost the root growth steadily declined from 75% compost to 100% compost.

ACMF

This study was conducted in a mature cypress plantation with trees of similar form and size. No tree decline was noticed.

Compost rate only influenced V0005 and L0510 (Table 4-5). Replication only influenced V0005. However, replication by compost rate was significantly different for almost all root variables. Tree spacing influenced total root length, V0005-V2530, and L0005-L2530. Compost rate was not linearly or logarithmically correlated with root variables (Table 4-8). V2530, V3540, 4045, L2530, L3540, and L 4045 were all similar based on individual compost rates (Table 4-9). Root variables consistently were similar between 0, 25, 50, and 100% and 25, 50, 75, and 100% compost. Therefore, the most significant difference was between 0 and 100% compost (Table 4-9). Lastly, root growth from mature trees was not influenced by compost rate. Instead, tree spacing most greatly influenced root growth, especially between 0 and 100% compost rate.

The mature trees were planted at 0.9 m x 3.1 m or 1.8 m x 3.1 m intervals on bedded rows (Figure 3-3). Therefore, the higher NH_4, K, Ca, Mg, Zn, and Mn levels and the lower BDs provided by the compost were advantageous for mature roots, and in contrast, the lowered phosphorus levels in the phosphatic clays and higher BDs created by the increasing amounts of compost potentially inhibit mature root growth. These growing conditions are likely to be favorable because root diameters, lengths, and volumes increased from 0 to 100% compost (Table 4-9, Figures 4-12 – 4-14). Furthermore, Figures 4-12 and 4-14 showed that diameters, lengths, and volumes also increased from 0 to 100% compost when based on soil volume. The greatest increase in length, diameter, and volume was from 75 to 100% compost. There was a strong linear correlation between average root diameter and total root volume. All root variables were not logarithmically correlated with compost rate (Table 4-8).

As anticipated, root diameter, length, and volume increased as compost rates increased. Therefore, sub-hypothesis 3 could not be rejected. Surprisingly, sub-hypothesis 2 could be rejected (Table 4-9, Figures C-12 – C-14). Volume, diameter, and length of the roots from the mature cypress increased as the compost rates increased. Therefore, the primary null hypothesis was rejected because as compost rates increased in the phosphatic clays, the root growth increased from 0 to 100% compost.

Root V0005, V0510, V1015, V1520, V2025, V2530, and V3035 were significantly correlated with each other. V3540, V4045, and V45+ were slightly significantly correlated. Lengths by diameter classes were greatest for small diameter roots and steadily decreased as diameter sizes increased (Table 4-10, Appendix Figure C-20). Volumes by diameter classes were greatest for large diameter roots and decreased immediately as diameters decreased (Table 4-10, Figure C-19). However, the volumes created a logarithmic pattern where they began low as large diameters and increased to mid-sized diameters and then decreased at small diameters. V45+, (the largest roots) significantly increased as composts rates increased to 100%. Furthermore, the volumes of the remaining diameter classes steadily increased as the compost rates increased to 100%. Zero percent compost consistently had the lowest root volume and lengths by diameter class while 100% compost consistently had the largest root volumes and lengths by diameter class. Therefore, lower treatment rates negatively affected the root volumes by diameter class, and greater treatment rates positively affected the root volume by diameter class.

Lastly, average diameter and total volume were not significantly influenced for each diameter class. Average diameter and total volume were not linearly correlated with the diameter classes (Table 4-8).

In summary, 100% compost increased root volume and diameter for all tested parameters. As compost was added to the phosphatic clay, mature tree roots steadily increased volume and diameter from 0 to 100% compost. The greatest increase in volume and diameter was from 75% compost to 100% compost.

UF

The UF study provided optimal growing conditions for the seedlings. The 2 cypress seedlings that died during this study (25% compost) were not analyzed.

There was an increase in total root volume, total root lengths, and average root diameters to 75% compost (Table 4-9, Figures 4-12 – 4-14). After 75% compost, the root diameters, lengths, and volumes significantly decreased. There was a decrease in root lengths at 50% compost. Total volumes steadily increased to 75% and decreased at 100% compost. Twenty-five percent compost had the largest average diameters and total lengths. However, total volume indicates that 25% compost obtained volumes significantly less than 75% compost and almost the same root volume as 50% compost.

Sub-hypotheses 3 can be rejected. Total lengths, lengths by diameter class, and volume by diameter class were less at 100% compost (Figures 4-12 - 4-14, Figures C-21 and C-22). Total root volumes and average root diameters were lowest at 0% compost but were significantly low at 100% compost. Sub-hypothesis 2 could not be rejected. Total root volumes and total root length were highest at 75% compost. Average root diameter was largest at 25% compost. The 25 and 75% compost levels had the greatest amounts of roots in all diameter classes. For this study, 75% compost was the superior compost rate for improved root growth. Although, 25% compost did achieve good root growth the mortality of the trees suggest that 25% compost may not be a good choice.

Total root volume was linearly correlated with average root diameter. Compost rate was not linearly correlated with total volume, total root lengths, and average diameter (Table 4-8).

Together, 25 and 75% compost were consistently similar to 0 and 50% compost. Hundred percent compost was consistently different from 25 and 75% compost. Total volume and average diameters were only somewhat correlated with root volume and length by diameter classes. Total root length was correlated with root length by diameter classes, but only somewhat correlated with volume by diameter class. Only V2025, V3540, V4045, L2025, V3540, and L4045 differed with compost rates (Table 4-9). Root volumes and lengths by diameter class were not significantly influenced by compost rate (Table 4-5) but were significantly correlated with each other.

Total lengths and volumes were largest at 75% compost (Figures 4-12 – 4-14). However, 25% compost had the largest average diameter, but this may be an effect of only having 3 of the 5 trees available for sampling. Therefore it can be concluded that the lack of 2 trees did skew the data. Furthermore, 0 and 100% compost consistently had the smallest root volumes, lengths, and diameters. Therefore, 0% and 100% compost negatively affected root volumes, root volumes steadily decreased with root diameter. Although, Figure C-5 indicates that on a per diameter basis root volumes contained the greatest amount or roots.

The most significant treatment difference for root length and volume was between 75 and 100% compost (Table 4-9 and Figures 4-12 and 4-14). Lastly, 75% compost increased total root volume and average diameter the most. As compost was added to the phosphatic clay, the roots steadily increased volume and diameter from 0% compost to 75% compost for all parameters, but after 75% compost the root sizes significantly decreased.

Summary

Overall, the Site D phosphatic clays were improved by adding compost. Soil compaction was improved by adding compost, which is a major limit to root growth. Compost did not reduce the soil pH to a more neutral level. The improved soil structure will help the soil surface water permeability and potentially reduce crusting, and the controlled addition of MSW compost as a fertilizer can potentially improve crop and tree survivability.

However, there were inherent problems with this study. The study sites were established at different times of the year and removed at different times. Furthermore, there were slightly different sized growing areas or sampled areas, differences in cypress age (mature trees at ACMF, seedlings at Site D and UF), and differences in weather.

At Site D, an actual CSA, inadequate root growth occurred at 100% compost. There was also an issue of seedling survival, as seedlings planted in 100% compost died before the first site inspection. By the time the seedlings were extracted, the only two live cypress seedlings were in poor condition and probably would not have survived another month. Therefore, root growth increased from 0 to 50% compost and then decreased from 75 to 100% compost. Fifty percent compost fostered the greatest root growth at Site D

The ACMF study examined only a small portion of the root area from which the mature trees extracted nutrients and water. Because the roots already were established in natural soils, the 100% compost simply was the easiest to grow in or contained better nutrients for mature root growth. Furthermore, due to the closed canopy, the 100% compost generally stayed moist for the duration of the study. Of course, the excellent growth of the roots into the 100% compost may also be the difference between nutrient requirements for seedlings and mature trees. Therefore, high quantities of compost appear to foster mature root growth as root volumes and diameters.

The potted cypress seedlings in the UF study had the greatest root growth potential due to ample sunlight, protection from freezes, and regular irrigation. It vividly showed that 100% compost was not the superior treatment, but overall it was better than 0% compost. Therefore, under the best possible growing conditions, the root systems of the seedlings preferred 25 and 75% compost, grew well in 50% compost, were decent at 100% compost, and grew least at 0% compost, although, 25% compost may not preferred because of the mortality associated with this compost rate.

Overall, 100% compost was not the best treatment for seedling survival and root growth. The properties of the FORCE MSW compost indicate that it was Class B compost, with pH was constantly above 7.3, well within the Class B pH range of 6 to 7.5. Furthermore, this compost contained a large amount of glass which indicates that the compost was not sorted well, although its extractable nutrient levels were ample: NH_4-N (25 ppm), P (860 ppm), and K (1493 ppm). Hundred percent compost fostered the greatest root growth at ACMF but resulted in less than adequate growth at Site D and in the UF study. Hundred percent compost also had the greatest mortality at Site D. Zero percent compost negatively affected root growth in almost every case. Root volumes, lengths, and diameter were good at 25% compost in the UF study; however, 25% was not the best for ACMF and Site D and had the only morality associated with the UF study. Fifty percent compost provided the greatest seedling root growth at Site D, and fostered ample mature root growth at ACMF and seedling root growth in the UF study. Seventy-five percent compost gave the greatest seedling root growth at the UF study, fostered ample mature root growth at ACMF, but obtained less than adequate growth at Site D.

These findings are somewhat similar to those of other researchers. Sanderson and Martin (1974) found that a soil media of mixed 33% MSW compost allowed cedar and holly to grow better than 0%. Apple trees in the Northeast grew more quickly and produced greater amounts of fruit when the soil was amended with compost (not MSW compost) (Moran and Schupp 2005). Biosolid compost amendment increased corn growth (Molla et al. 2005). MSW compost media enhanced root growth of *Juniperus* and *Thuja* species (Chong 2000). Lastly, Herrera et al. (2008) found that 65% MSW compost with 30% peat improved the rate of emergence, height, and diameter of tomato plants.

However, some studies have shown that MSW compost did not improve growth. Fitzpatrick and Verkade (1991) found that *Viburnum suspensum* grew equally well when planted in 0, 40, and 100% MSW compost. Sanderson and Martin (1974) found that burkwood viburnum 33% MSW compost was not better than 0%.

Krauss et al. (1999) found that potted *Taxodium distichum* seedling roots grew 1594 mm long (0.16 cm/1000cm^3) in 99 days when flooded with deionized water. Average total root length at Site D indicates that the roots of the Taxodium seedlings can potentially grow 0.09 cm/1000cm^3 per day or 9 cm/1000cm^3 in 99 days in at 0% compost. At 0% compost, ACMF average total root length was 0.56 cm/1000cm^3 per day (56 cm/1000cm^3 in 99 days), and at UF roots grew 0.68 cm/1000cm^3 per day (67 cm/1000cm^3 in 99 days). Furthermore, average total length per day at Site D for 25, 50, 75, and 100% compost was 0.08, 0.11, 0.07, and 0.03 cm/1000cm^3, respectively. At ACMF the average total lengths for 25, 50, 75, and 100% compost were 0.77, 0.68, 0.79, and 0.38 cm/1000cm^3, respectively. At UF the average total lengths for 25, 50, 75, and 100% compost were 1.03, 1.14, 1.06, and 1.68 cm/1000cm^3, respectively. Therefore the *Taxodium* roots grown in the phosphatic clays and/or with compost amendments exceeded *Taxodium* root growth in flooded conditions.

Shortleaf pine and loblolly pine have shown similar root growth under similar BDs. Shortleaf pine and loblolly pine seedlings grown in Clarksville and Argent soils, respectively, at different soil BD constraints, showed that root lengths increased as BD decreased (Siegel-Issem et al. 2005).

Coast et al. (2001) found that root lengths for red ash (*Fraxinus pennsylvanica*), silver maple (*Acer saccharinum*), and hackberry (*Celtis occidentalis*) ranged from 250 to 320 cm and honey locust (*Gleditsia triacanthos*) and Norway maple (*Acer platanoides*) ranged from 100 to 175 cm. This research was based on a WinRhizo outputs after 6 months of growth in containers at a tree nursery. Similarly, after 8 months of growth Site D results indicate average root lengths ranged from 140 cm at 0% compost to 560 cm at 50% compost. However *Taxodium* average diameters ranged from 0.77 mm at 0% compost to 2.69 mm at 50% compost, while silver maple and hackberry diameters were much smaller, 0.36 and 0.20 mm respectively. The root diameter differences may be due to specie root growth differences, whereas, some tree species promote belowground growth early in life or because of environmental differences.

Although, this research only examined the influence of compost incorporation on soil characteristics in Site D, there were some important responses. K, Ca, and Mg were inversely correlated with average total root volume, total root lengths, and average root diameter, except at the UF study where it appears that low levels of K, Ca, and Mg hindered root growth. Low pH may hinder root growth. Overall, mid-level BDs appear to influence root growth, as the greatest root volumes, lengths, and diameters were associated with 50 and 75% compost. Although, at the UF study there was a large increase in root growth at 25% compost, but this is probably due to only having 3 of the 5 root sample available during analysis.

Therefore, incorporating 50% compost into phosphatic clays will most greatly improve seedling survival, foster ample root growth from mature cypress trees, and improve soil characteristics. Extractable NH_4-N was significantly increased by this treatment, which also was near the middle of the extractable P rates, thereby reducing the extremely high P levels in phosphatic clays. Although, 50% compost had the lowest amounts of extractable K at Site D, increasing amounts of extractable K may decrease root volume and diameter. Fifty percent compost also had the highest pH level which may indicate that cypress seedlings require a high pH for improved root growth in phosphatic clay (potentially near 7.65). Fifty percent compost was the mid-level BD (meaning the soil was more compacted at 0 and 25% compost and less compacted at 75 and 100% compost), indicating that cypress seedling roots grown in phosphatic clays require and prefer mid-level soil compaction (potentially near 1.3 g/cm^3). In addition, optimal BD for cultivated clay soils is between 1.2 and 1.3 (Brady et al. 2000).

Across studies, total root volume and average root diameter were strongly correlated (r = 0.91). Root characteristics by diameter class were highly correlated with each other. However all studies were significantly different from one another. This difference in the total root variables across all of the sites was due to the extraction date and the resulting amounts of roots.

Large quantities of compost can be obtained from a variety of sources including waste management facilities and private companies. Many agricultural operations produce onsite compost to accommodate their management requirements. In 2005, Florida had “198 registered or permitted yard trash processing facilities,” “5 permitted composting facilities”, and undetermined number of agricultural composting facilities in operation (Kessler Consulting, Inc. 2006). Furthermore, loaders and spreaders can be employed to transport and spread the compost to help obtain desired mixture levels. The mixing of the compost into the soil could simply be completed with normal agricultural cultivating equipment, although timing and season limitations should be recognized.

Care should also be taken if the compost is not obtained from FORCE or if the compost is a lesser quality MSW compost. As previously mentioned, there are many sources of compost, and all have potentially undesirable nutrient levels, bulk density, pH, water holding capacity, etc.

Therefore, it is always recommended that before incorporating compost into phosphatic clays or any type of soil which will be planted with any agricultural crop, the compost should be tested.

However, based on all these studies, compost treatments can improve cypress survival and root growth (volume and diameter) in phosphatic clays. Similar results were found by Rockwood (1996a and 1996b) who concluded that soil amendments appear to help with establishment of cypress on CSAs.

CHAPTER 5
CONCLUSION

Soil samples from Site D helped determine soil characteristics associated with CSAs, changes in the phosphatic clays due to compost, and if those changes are due to increasing rates of compost. As the amount of compost added increased, soil BD decreased and soil porosity in the upper 30.5 centimeters of the soil profile improved. Generally, phosphatic clays become highly compacted, restricting root growth and water infiltration. Furthermore, the upper 8 centimeters of phosphatic clays crust during periods of extended droughts, negatively affecting root growth. Extractable NH_4, K, Ca, Zn, Mg, and Mn can be increased and extractable P can be reduced in phosphatic clay by amending the soil with MSW compost. However, the pH levels can not be reduced to an optimal pH level by adding MSW compost. Only P can be controlled by compost rate. Therefore, MSW compost may not be a suitable source of fertilizer for CSAs.

Increasing MSW compost rates into phosphatic clay tended to enhance root growth, 100% compost was not the best treatment for seedling survival and root growth, and 0% compost negatively affected all measures of root growth. Root volumes, lengths, and diameter were good at 25% compost; however, it was not the preferred rate. The greatest seedling root diameters, lengths, and volumes at Site D were with 50% compost. The mature trees at ACMF and the seedlings in the UF study had ample root growth at 50% compost. The greatest seedling root growth of the UF study was with 75% compost, and at ACMF it was 100% compost. At 75% compost, the ACMF study showed significant root growth, and at Site D 75% compost had less than adequate root growth. Average root growth showed that 50% compost was the best for all studies.

When extractable K, Ca, and Mg was lowest, root growth was greatest. Low pH levels appear to hinder root growth. BD appears to limit root growth as more compacted soils generally had reduced root growth. Therefore, the roots grew better in mid-level soil compaction (potentially near 1.3 g/cm^3). Thus, the bulk density at 50% compost can be considered optimal.

Many studies, including this one, demonstrate that trees can be grown on CSAs. This study showed that the incorporation of 50% compost into phosphatic clays most greatly improved *Taxodium* seedling root growth and survival, thus increasing *Taxodium* planting success on CSAs. It also encouraged ample root growth from mature *Taxodium* trees. Any CSA land manager could obtain MSW compost and incorporate it into the soil in the economically feasible manner.

CHAPTER 6
FUTURE RESEARCH

The Site D study was conducted without irrigation, bedding, mulch, and/or fertilizer. Therefore, there are a wide range of management options that could be explored before investing time and money into a *Taxodium* plantation with compost on a CSA.

For instance, it is still somewhat unclear if 75% compost could be a successful treatment. The irrigated UF study showed that 75% compost had superior root growth. Therefore, if the phosphatic clay was incorporated with 50% compost and irrigated, the seedlings may or may not achieve optimal root growth; 75% compost may be better if irrigation were used.

Even though there are many management alternatives that can be explored using compost and *Taxodium* species, this one specifically investigated the incorporation of the compost into the soil. Some of the other management options not investigated in this study include surface application of compost in the form of beds, soil incorporation of compost with irrigation, soil incorporation of compost and fertilizer, compost beds with compost soil incorporation, and the use of other OM such as mulch.

Control of cogongrass is very important for a successful establishment of a tree plantation of a CSA. Cogongrass will dominate a CSA quickly if no management is done to control its growth. Therefore, it is imperative that site preparation, such as disking, is conducted prior to planting and future cogongrass control is planned and implemented until the canopy of the trees (DBH of 10.2 centimeters or more) are significantly above the cogongrass. It is also recommended that the seedlings are planted very densely so that the future tree canopy controls the cogongrass by controlling the amount of sunlight that reaches the ground.

Taxodium species have been considered an appropriate species for CSAs with or without soil amendments like compost. One of the reasons why they are considered appropriate species is their ability to survive in altered or contaminated sites, but there are other native tree species that can also be used for tree plantations on CSAs in central Florida. Some of these trees include sweetgum, red maple, loblolly bay (*Gordonia lasianthus*), swamp bay, sweet bay, eastern red cedar (*Juniperus virginiana*), live oak, slash pine, willow, and cottonwood. Any of these have the potential for successful establishment on CSAs if the correct type of land management option is utilized such as compost, fertilization, bedding, and irrigation.

REFERENCES

Bengough A.G., M.F. Bransby, J. Hans, S. J. McKenna, T.J. Roberts, and T.A. Valentine. 2006. Root responses to soil physical conditions; growth dynamics from field to cell. Journal of Experimental Botany 57(2): 437–447.

Bengtson G.W., and J.J. Cornette. 1973. Disposal of composted municipal waste in a plantation of young slash pine: Effects on soil and trees. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America. Journal of Environmental Quality. 2:441-444.

Bilerback, T.E., A.H. Bruneau, S.C. Hodges, L.T. Lucas, W.A. Skroch, and S.L. Warren. 2008. Urban integrated pest management. North Carolina Cooperative Extension Service College of Agriculture and Life Sciences. North Carolina State University. Manuel # 919-515-3173.

Bouzaiane, O., H. Cherif, N. Saidi, N. Jedidi and A. Hassen. 2007. Effects of municipal solid waste compost application on the microbial biomass of cultivated and non-cultivated soil in a semi-arid zone. Journal of Waste Management and Research. 25.4(9): 334.

Brady, N.C., and R.R. Weil. 2000. Elements of the nature and properties of soils. Prenctice Hall. 12th edition. 108, 322-355.

Breeden, G., and M. Kessler. 1998. Sumter County solutions: Innovative, intergrated MSW composting and recycling. Composting in the Southeast – Proceedings of the 1998 Conference. 135-137.

Brown, C.A. and G.N. Montz. 1986. Baldcypress: The tree unique, the wood eternal. Claitor's Publishing Division. 3-17.

Brown, M.J. 1995. Forest statistics for Florida, 1995. USDA Forest Service Southern Research Station Resource Bulletin SRS-6: 44p.

Chong C. 2000. Relationship of soluble salts content in MSW compost media and rooting of evergreen cuttings. Compost Science and Utilization 8(1): 29-35.

Coder, K.D. 2000. Trees and soil compaction: A selected bibliography. University of Georgia School of Forest Resources Extension Publication FOR00-1.

Costa, C., L.M. Dwyer, C. Hamel, D.F. Muamba, X.L. Wang, L. Nantais, and D.L. Smith. 2001. Root contrast enhancement for measurement with optical scanner-based image analysis. Can. J. Bot. 79: 23–29

CPI. 2003. Short rotation woody crops in Florida for biomass co-firing: 3rd year field operations & maintenance support for Central Florida short rotation woody crop (SRWC) tree farm. Page 15. Common Purpose Institute, Temple Terrace, Forida.

Cycle-Gro. Hill Gardens of Maine. Fertilizer & compost FAQ. Accessed in July 2008. www.hillgardens.com

Dicke, S.G. and J.R. Toliver. 1988. Effects of crown thinning on bald cypress (*T. distichum*) height, diameter, and volume growth. S.J. Appl. For. 12: 252-256.

Dickerson, G.W. 2006. Description and use of municipal solid waste composts in New Mexico Circular 562. College of Agriculture and Home Economics New Mexico State University.

DOF. 2004. Statewide timber damage summary for 2004 hurricanes. Florida Division of Forestry (DOF). Accessed in October 2007 www.fl-dof.com

EPA. 2003. The biosolids composting process. United States Environmental Protection Agency. EPA/625/R-92/013. Appendix J. 174-177.

Evans, E. 2000. Nitrogen deficiency: Action mode, deficiency and toxicity symptoms of the 17 essential nutrients. North Carolina State University. Accessed in November 2007 www.ces.ncsu.edu

Ewel, K.C. 1990. Multiple demands on wetlands. BioScience 40:660-666.

Faulkner, S. and J. Toliver. 1983. Genetic variation of cones, seeds, and nursery-grown seedlings of baldcypress (*T. distichum* (L.) Rich.) provenances. Proc. 17th. S. For. Tree Imp. Conf. 281-288.

Farjon, A. 2005. A monograph of *Cupressaceae* and *Sciadopitys*. Royal Botanic Gardens, Kew.

Ferrini, F., A. Giuntoli, F.P. Nicese, S. Pellegrini, and N. Vignozzi. 2005. Effect of fertilization on backfill amendments on soil characteristics, growth, and leaf gas exchange of english oak (*Quercus robur* L.). Journal of Arboriculture 31(4): 182-190.

Fitzpatrick, G.E., and S.D. Verkade. 1991. Substrate influence on compost efficacy as a nursery growing medium. Proceedings of the Florida State Horticultural Society 104: 308-310.

Torres, W., D.C. Schmitz, Eva Armstrong, S. Hardin, R. Clark, S. Wilhelm, L. M. Coffman, S. Bohl, D. Thayer, B. Nelson, W. Corbin, C. Sutter, J.T. Valenta, J. Caster, and K Langeland. 2002. Statewide invasive species strategic plan for Florida. Bureau of Invasive Plant Management. 2001. Florida Department of Environmental Protection, Tallahassee, FL.

Gaviria, L.T. 1998. Early evaluations of genetic and silvicultural factors affecting productivity of cypress (*T. distichum* (L.) Rich.) planted for mulch production. M.S. Thesis, University of Florida. 50p.

Harrell, J.B., 1987. The development of techniques for the use of trees in the reclamation of phosphate lands. Final Report for FIPR Contract. Florida Institute of Phosphate Research Publication. No. 03-001-049: 43.

Harris, R.W., J.R. Clack, and N.P. Matheny. 2004. Arboriculture: Integrated management of landscape trees, shrubs, and vines. Prentice Hall. 4th edition. 81.

Herrera, F., J.E. Castillo, A.F. Chica, and L.L. Bellido. 2008. Use of municipal solid waste compost (MSWC) as a growing medium in the nursery production of tomato plants. Bioresource Technology 99: 287–296.

Hodges, A.W., W. D. Mulkey, J. R. Alavalapati, D. R. Carter and C. F. Kiker. 2005. Economic impacts of the forest industry in Florida, 2003; final report to the Florida Forestry Association. University of Florida, Institute of Food & Agricultural Sciences Food & Resource Economics Department and School of Forest Resources and Conservation.

Ingwersen, W. W. 2006. Viability of wetland trees after twenty years on phosphate clay settling areas and their role in ecosystem development. M.S. Thesis. University of Florida. 118p.

Jerez, R.A., E.A. Hanlon, and E.F. Gilman. 1996. The mined lands agricultural research/demonstration project. Tree production on reclaimed phosphate clay. Prepared for Florida Institute of Phosphate Research.

Kessler Consulting, Inc. 2006. FORCE: Florida composting regulatory report. 145p.

Krauss, K.W., J.L. Chambers, J.A. Allen, B.P. Luse, A.S. DeBosier. 1999. Root and shoot responses of *Taxodium distichum* seedlings subjected to saline flooding. Environmental and Experimental Botany 41: 15–23.

Lakeland Linder Airport. 2005. Lakeland climate scorecard. National Oceanic and Atmospheric Administration (NOAA). National Weather Service. Accessed in January 2008. www.srh.noaa.gov

Lampurlanos, J. and C. Cantero-Martfnez. 2003. Soil bulk density and penetration resistance under different tillage and crop management systems and their relationship with barley root growth. Agron J. 95:526-536.

Langholtz, M.H. 2005. Economic and environmental analysis of tree crops on marginal lands in Florida. Dissertation. University of Florida. 141p.

Liu, E.H., E.M. Iglich, R.R. Sharitz, and M.H.Smith. 1990. Population genetic structure of baldcypress (*Taxodium distichum*) in thermally affected swamp forest. Silvae Genet. 38: 129–133.

Lopez-Zamora, I., N.B. Comerford, and R.M. Muchovej. 2004. Root development and competitive ability of the invasive *Melaleuca quinquenervia* (Cav.) S.T. Blake in the south Florida flatwoods. Plant and Soil 263: 239-247.

Marinescu, M. 2007. Growing Florida's forest products industry. Florida Forest. Published by Florida Forestry Association 11(2): 9-12.

McTague, J.P. and R.W. Tinus. 1996. The effects of seedling quality and forest site weather on field survival of ponderosa pine. Tree Planters' Notes 47: 16–23.

Mislevy, P., W.G. Blue, and C.E. Roessler. 1989. Productivity of clay tailings from phosphate mining .1. Biomass Crops. Journal of Environmental Quality 18(1): 95-100.

Molla A.H., A. Fakhru'l-Razi, M.M. Hanafi, and Z. Alam. 2005. Compost produced by solid state bioconversion of biosolids: A potential resource for plant growth and environmental friendly disposal. Taylor & Francis, Inc. Communications in Soil Science and Plant Analysis 36: 1435–1447.

Moran, R.E. and J.R. Schupp. 2005. The effect of preplant monoammonium phosphate fertilizer and compost on the growth and yield of 'macoun' apple trees. Journal of HortScienc 40(6): 1854-1856.

Morse, D.M. 2003. Silvicultural influences on cypress (*Taxodium distichum* (L.) Rich.) in plantations in Florida. M.S. Thesis. University of Florida. 78p.

MU. 2008. Compost analysis. University of Missouri Extension. Accessed in January 2008. soilplantlab.missouri.edu/soil/compost.htm

Murphy, J. and J.P. Riley. 1962. A modified single solution method for the determination of phosphate in natural waters. Anal. Chim. Acta. 27: 31-36.

Mylavarapu R.S., and E.D. Kennelley. 2002. UF/IFAS extension soil testing laboratory analytical procedures and training manual. Soil and Water Science. Cooperative Extension Service. Circular 1248: 19p.

Nair, V.D., D.A. Graetz, K.R. Reddy, and O.G. Olila. 2001. Soil development in phosphate-mined created wetlands of Florida, USA. Wetlands 21(2): 232-239.

NASA. 2003. MacRHIZO & WinRHIZO image analysis system for root measurement, entry ID: Rhizo-99 (revised). National Aeronautics and Space Administration (NASA) Goddard Space Flight Center. Accessed in April 2008 gcmd.nasa.gov

Phillips L, and A. Eneritus. 2006. Understanding soil pH: Why it is important, and how to maintain optimum levels. Arbor Age. 26 (6): 12-14.

Pospichal, T. Personal correspondences with senior agricultural land manager concerning past management at study site. Correspondences in January 2008.

Raven, P., R.F. Evert, and S.E. Eichhorn, 1999. Biology of plants. WH Freeman and Company. 6th edition. 746 & 912.

Regent Instruments, Inc. 2003. WinRhizo: In root analysis. Online brochure. Accessed in August 2007 www.regent.qc.ca

Rendig, V. V., and H. M. Taylor. 1989. Principles of soil plant-interactions. McGraw-Hill, New York: 275p.

Richardson, S. 2005. Reclamation of phosphate lands in Florida. Florida Institute of Phosphate Research. Accessed in February 2008 www.fipr.state.fl.us

Rivernshield A. and N.L. Bassuk. 2007. Using organic amendments to decrease bulk density and increase macroposity in compacted soils. Arboriculture & Urban Forestry 33(2): 140-146.

Rockwood D.L. and T.F. Geary. 1991. Growth of 19 exotic and 2 native tree species on organic soils in southern Florida. USDA Nat. Park Serv. Rpt 20: 283-302.

Rockwood D.L. 1996 (a). *Eucalyptus* – pulpwood, mulch or energywood? Univ. of Fla. Cooperative Extension Service, Circular 1194.

Rockwood D.L. 1996 (b). Using fast-growing hardwoods in Florida. Univ. of Fla. Cooperative Extension Service, Fact Sheet EES-328.

Rockwood, D.L. 1997. *Eucalyptus* – pulpwood, mulch, or energywood? Florida Cooperative Extension Service. Circular FOR-1194.

Rockwood, D.L., D.M. Morse, and L.T. Gaviria. 2001. Genetic and silvicultural factors affecting productivity of planted cypress in Florida. In: Pro. 26th South. For. Tree Improvement Conf., June 26-29, 2001, Athens, GA. p74-83.

Rockwood D.L., D.R. Carter, and J.A. Stricker. 2004. Commercial tree crops for phosphate mined lands. Fourth Year Progress Report for Project Number: 99-03-141R. Florida Institute of Phosphate Research, Bartow, Florida.

Rockwood D.L., D.R. Carter, M.H. Langholtz, and J.A. Stricker. 2006. *Eucalyptus* and *Populus* short rotation woody crops for phosphate mined lands in Florida USA. Biomass & Bioenergy 30: 728-734.

Rybicka E.H. 1996. Impact of mining and metallurgical industries on the environment in Poland. Applied Geochemistry 11: 3-9.

Sanderson, K.C., and W.C. Martin, Jr. 1974. Performance of woody ornamentals in municipal compost medium under nine fertilizer regimes. HortScience 9(3): 242 – 243.

Segrest, S.A. Plant power energy and the environment. A research commitment on renewable biomass energy & global warming by using nature's own power plants. Accessed in January 2008 www.treepower.org

Shelton J.E. 1991. Soil facts: Using municipal solid waste compost. North Carolina Coropertaive Extension Service. AG-439-19.

Siegel-Issem, C.M., J. A. Burger, R. F. Powers, F. Ponder, and S. C. Patterson. 2005. Seedling root growth as a function of soil density and water content. Soil Sci. Soc. Am. J. 69: 215–226

Silva M.T., A.M. Menduina, Y.C. Seijo, and F.D. Vigueria. 2007. Assessment of municipal solid waste compost quality using standardized methods before preparation of plant growth media. Waste Manage. Res 25 (2): 99-108.

Smith T. 1996. Compost trials in orchards in 1995-96. Published by Wisconsin State University Extension Service.

Smith, W. H. 1994. Beneficial uses of composts in Florida. Environmentally Sound Agriculture Proceedings of the Second Conference. April 20-22. p247-253.

Stricker J.A. 2000. High value crop potential of reclaimed phosphatic clay soil. Paper presented at the 2000 Annual Meeting of the American Society for Surface Mining and Reclamation, Tampa, Florida, June 11-15.

Tamang B. 2006. Vegetation and soil quality changes associated with reclaiming phosphate-mine clay settling areas with fast-growing trees. M.S. Thesis. University of Florida. 134p.

Wahid, A., S. Akhtar, I. Ali, and E. Rasul. 1998. Amelioration of saline-sodic soils with organic matter and their use for wheat growth. Commun. Soil Sci. Plant Anal. 29: 2307-2318.

Watson, F.D. 1993. *Taxodium* Richard. in: Flora of North America editorial committee (ed.). Flora of North America. Oxford University Press, New York. 403-404.

Wilson, S.B. and P.J. Stoffella. 2006. Using compost for container production of ornamental wetland and flatwood species native to Florida. Native Plants Journal 7(3): 293 -300.

Wong, M. 2005. Use of soil amendments in landscape plantings. Cooperative Extension Service. College of Tropical Agriculture and Human Resources. University of Hawaii at Manoa. Soil and Crop Management, SCM-11.

Wullschleger, S.D., S.A. Segrest, D.L. Rockwood, and C.T. Garten, Jr. 2004. Enhancing soil carbon sequestration on phosphate mine lands in Florida by planting short-rotation bioenergy crops. In: Third Annual Conference on Carbon Sequestration, Wash., DC.

APPENDIX A
DESCRIPTION OF SITE D

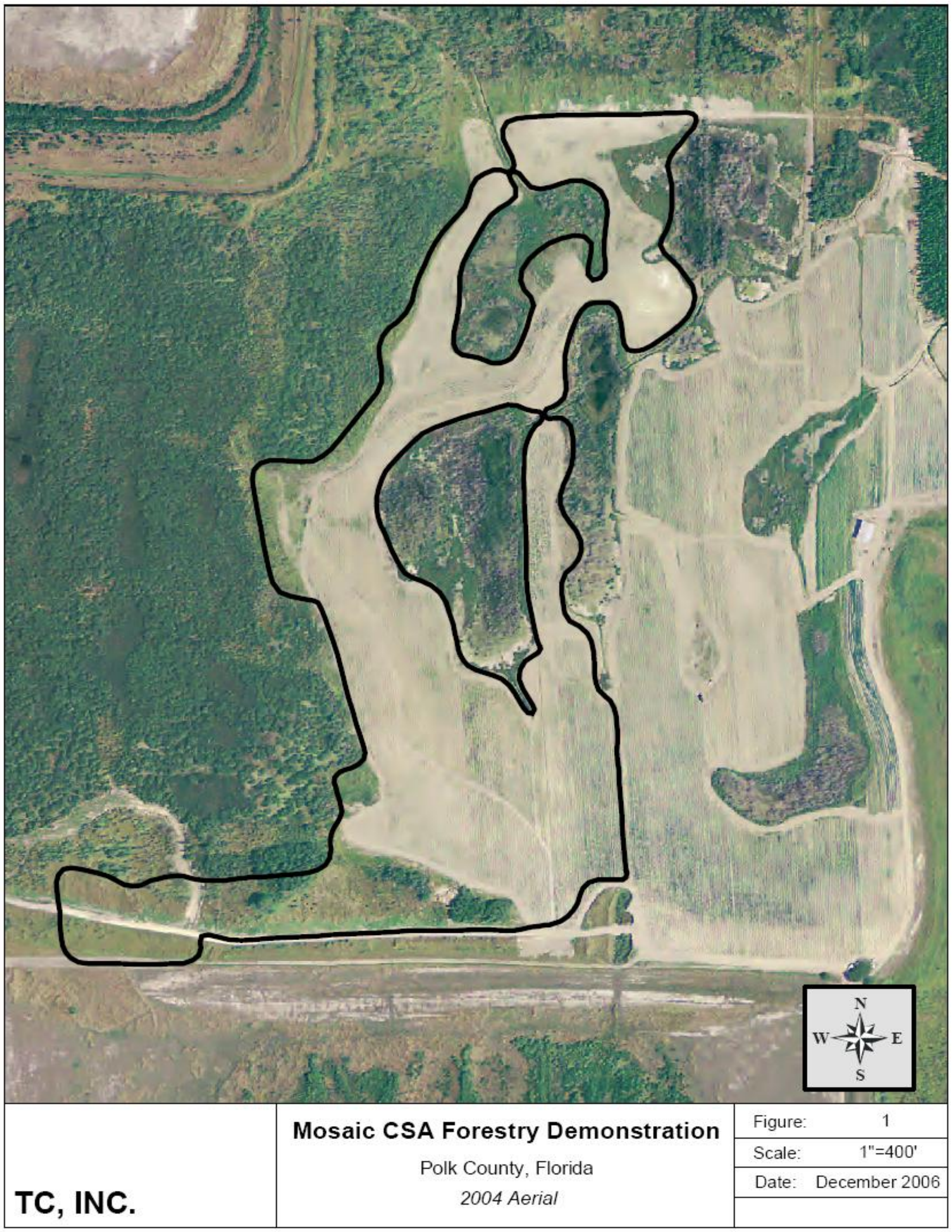

Figure A-1. Aerial view of Site D

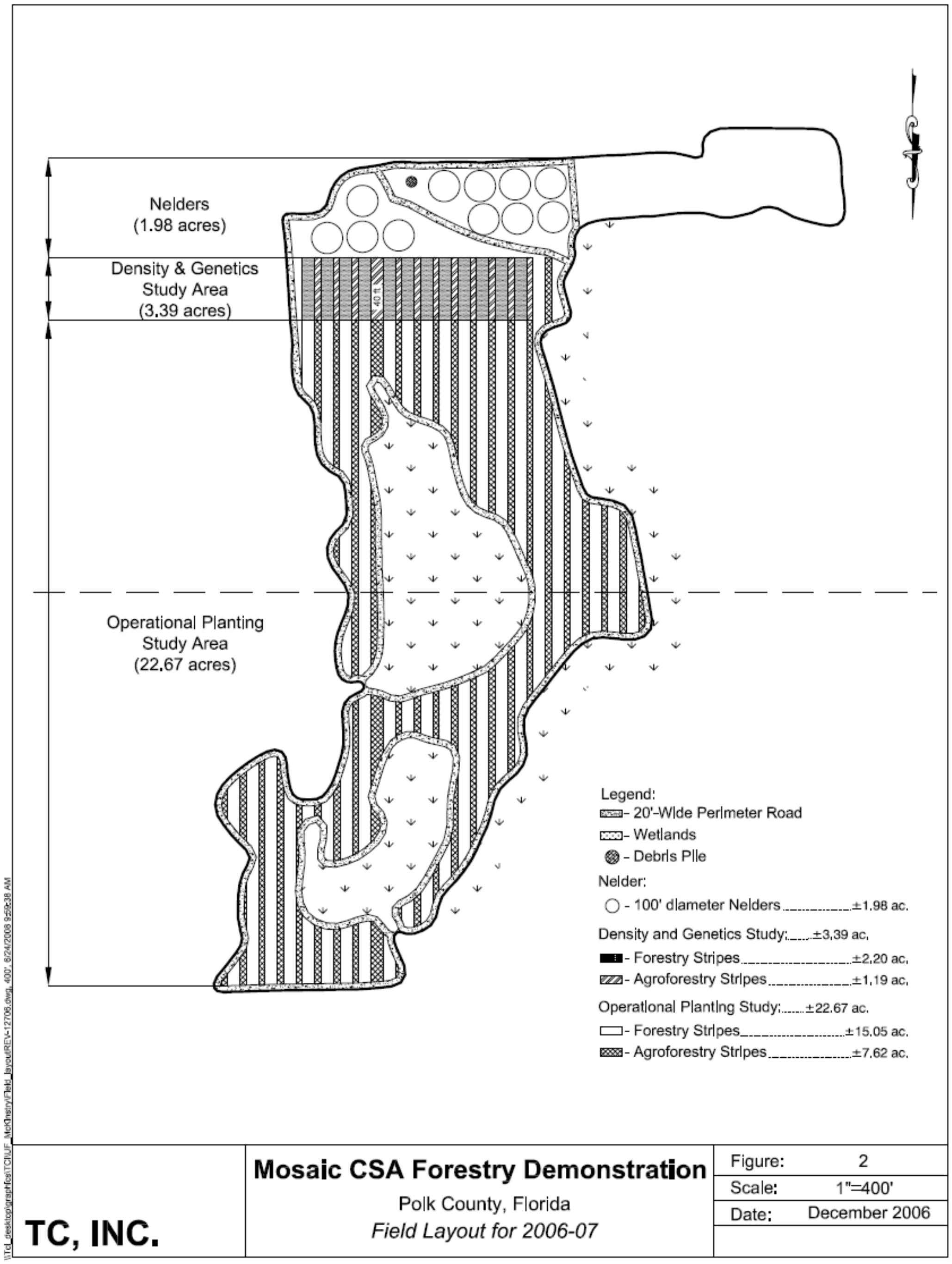

Figure A-2. Site D Layout for density, genetics, and operational planting

APPENDIX B
SUPPORTING TABLES

Table B-1. Composition of the standard curves for P and K

P Standards			K Standards		
Blanks (ppm)	P Solution (mL)	DDI Water (mL)	Blanks (ppm)	K Solution (mL)	DDI Water (mL)
0	0.0	25	0	0.0	50
0.2	0.5	24.5	0.2	0.1	49.9
0.4	1.0	24	0.4	0.2	49.8
0.6	1.5	23.5	0.6	0.3	49.7
0.8	2.0	23	0.8	0.4	49.6
1.2	3.0	22	1.0	0.5	49.5
			2.0	1	49
			4.0	2	48

Table B-2. Soil data from Site D for the 0% compost treatment

Characteristics	Sample Number						Average	St. Dev.
	1	2	3	4	5	6		
NH_4-N	3.80	3.94	3.69	-	-	-	3.81	0.13
P	1589.46	1636.54	1424.18	1238.34	1000.80	1043.37	1322.12	271.56
K	415.43	390.95	405.67	384.54	358.49	383.99	389.85	19.76
Ca	81.64	80.52	75.24	88.28	89.63	93.49	84.80	6.79
Mg	50.13	50.05	50.03	36.55	56.38	56.17	49.88	7.21
Zn	0.44	0.44	0.44	0.40	0.44	0.36	0.42	0.03
Mn	0.52	0.52	0.48	0.48	0.48	0.48	0.49	0.02
pH	7.63	7.63	7.56	7.48	-	-	7.575	0.07
BD (Surface)	1.58	1.45	1.64	1.68	-	-	1.59	0.10
BD (@ 6 in)	1.6	1.63	1.62	1.54	-	-	1.59	0.04
%PR (Surface)	37	38	45	40	-	-	40	3.79
%PR (@ 6 in)	42	39	38	40	-	-	40	1.52

Nutrient data in mg/kg; Bulk Density (BD) in g/cm^3; Porosity (PR) in %; Dash lines (-) signify no data.

Table B-3. Soil data from Site D for the 25% compost treatment

Characteristics	Sample Number						Average	St. Dev.
	1	2	3	4	5	6		
NH_4-N	4.99	4.91	4.67	-	-	-	4.86	0.16
P	1397.04	1292.42	1150.03	1490.82	1172.39	1175.69	1279.73	158.29
K	196.24	204.60	181.21	467.10	411.99	409.11	311.71	31.40
Ca	73.23	80.06	79.93	125.37	66.80	80.56	84.32	4.34
Mg	36.11	50.08	50.58	38.47	33.78	35.94	40.83	5.30
Zn	0.44	0.48	0.48	0.28	0.36	0.40	0.41	0.04
Mn	0.48	0.52	0.52	0.44	0.48	0.48	0.49	0.02
pH	7.52	7.56	7.48	7.68	-	-	7.56	0.09
BD (Surface)	1.21	1.73	1.55	1.56	-	-	1.51	0.22
BD (@ 6 in)	1.48	1.48	1.43	1.36	-	-	1.44	0.06
%PR (Surface)	41	42	35	54	-	-	43	8.22
%PR (@ 6 in)	49	46	44	44	-	-	46	2.14

Nutrient data in mg/kg; Bulk Density (BD) in g/cm^3; Porosity (PR) in %; Dash lines (-) signify no data.

Table B-4. Soil data from Site D for the 50% compost treatment

Characteristics	Sample Number						Average	St. Dev.
	1	2	3	4	5	6		
NH_4-N	21.80	21.39	20.75	-	-	-	21.31	0.53
P	1148.22	1144.17	1430.96	1383.79	1106.17	1044.69	1209.67	158.29
K	332.09	283.73	337.31	290.81	254.76	311.31	301.67	31.40
Ca	83.06	74.54	87.24	80.74	77.96	80.18	80.62	4.34
Mg	41.59	36.09	43.26	49.88	37.35	36.64	40.80	5.30
Zn	0.40	0.40	0.36	0.48	0.44	0.44	0.42	0.04
Mn	0.48	0.52	0.48	0.48	0.48	0.48	0.49	0.02
pH	7.68	7.67	7.58	7.68	-	-	7.6525	0.05
BD (Surface)	1.45	1.54	1.41	1.6	-	-	1.50	0.09
BD (@ 6 in)	1.3	1.27	1.45	1.22	-	-	1.31	0.10
%PR (Surface)	40	47	42	45	-	-	43	3.25
%PR (@ 6 in)	54	45	52	51	-	-	51	3.74

Nutrient data in mg/kg; Bulk Density (BD) in g/cm^3; Porosity (PR) in %; Dash lines (-) signify no data.

Table B-5. Soil data from Site D for the 75% compost treatment

Characteristics	Sample Number						Average	St. Dev.
	1	2	3	4	5	6		
NH_4-N	7.27	6.85	6.98	-	-	-	7.03	0.21
P	1057.09	1252.85	1189.76	942.94	823.15	953.41	1036.53	162.42
K	396.45	312.11	333.57	315.56	341.63	317.98	336.22	31.64
Ca	89.06	75.99	79.37	102.99	107.21	107.42	93.67	14.12
Mg	44.35	39.27	39.55	63.53	65.46	65.39	52.92	13.14
Zn	0.40	0.40	0.40	0.40	0.44	0.32	0.39	0.04
Mn	0.48	0.52	0.52	0.48	0.52	0.36	0.48	0.06
pH	7.2	7.7	7.56	7.43	-	-	7.4725	0.21
BD (Surface)	1.43	1.59	1.49	1.17	-	-	1.42	0.18
BD (@ 6 in)	1.11	1.48	1.35	1.14	-	-	1.27	0.18
%PR (Surface)	56	44	40	46	-	-	46	6.76
%PR (@ 6 in)	57	49	44	58	-	-	52	6.64

Nutrient data in mg/kg; Bulk Density (BD) in g/cm^3; Porosity (PR) in %; Dash lines (-) signify no data.

Table B-6. Soil data from Site D for the 100% compost treatment

Characteristics	Sample Number						Average	St. Dev.
	1	2	3	4	5	6		
NH_4-N	24.80	24.30	24.74	-	-	-	24.61	0.27
P	1076.55	1051.58	963.69	590.59	746.75	728.25	859.57	198.55
K	553.96	544.42	544.26	400.28	397.60	379.57	470.02	85.30
Ca	143.57	133.13	134.46	84.69	99.86	93.58	114.88	25.02
Mg	75.31	72.59	71.31	37.24	55.99	43.70	59.36	16.24
Zn	0.32	0.36	0.04	0.40	0.40	0.36	0.31	0.14
Mn	0.28	0.44	0.44	0.48	0.48	0.48	0.43	0.08
pH	7.66	7.17	7.64	7.68	-	-	7.5375	0.25
BD (Surface)	0.78	0.81	0.74	0.63	-	-	0.74	0.08
BD (@ 6 in)	0.75	0.76	0.68	0.7	-	-	0.72	0.04
%PR (Surface)	76	72	69	71	-	-	72	2.97
%PR (@ 6 in)	74	74	71	72	-	-	73	1.46

Nutrient data in mg/kg; Bulk Density (BD) in g/cm^3; Porosity (PR) in %; Dash lines (-) signify no data.

APPENDIX C
ROOT VOLUME AND LENGTH BY DIAMETER CLASS FIGURES

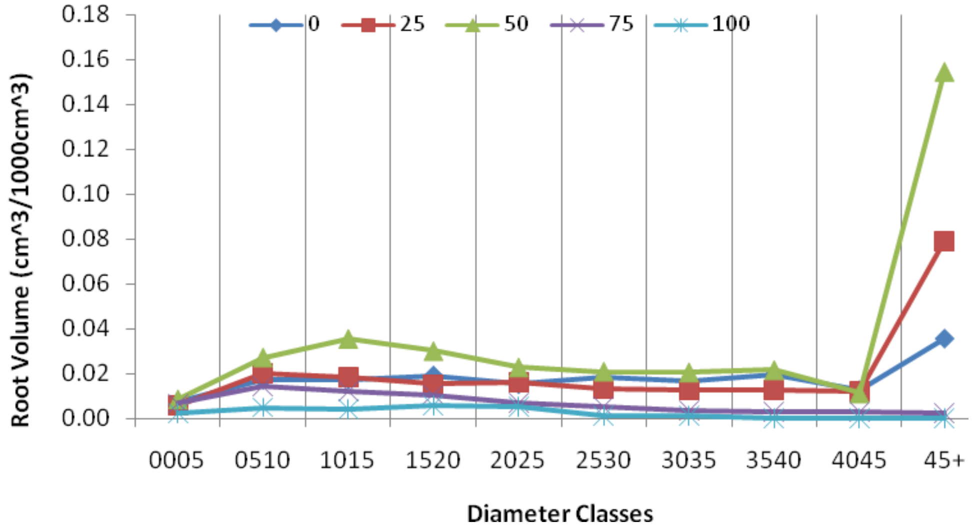

Figure C-1. Site D mean root volume by root diameter classes and compost treatments (%)

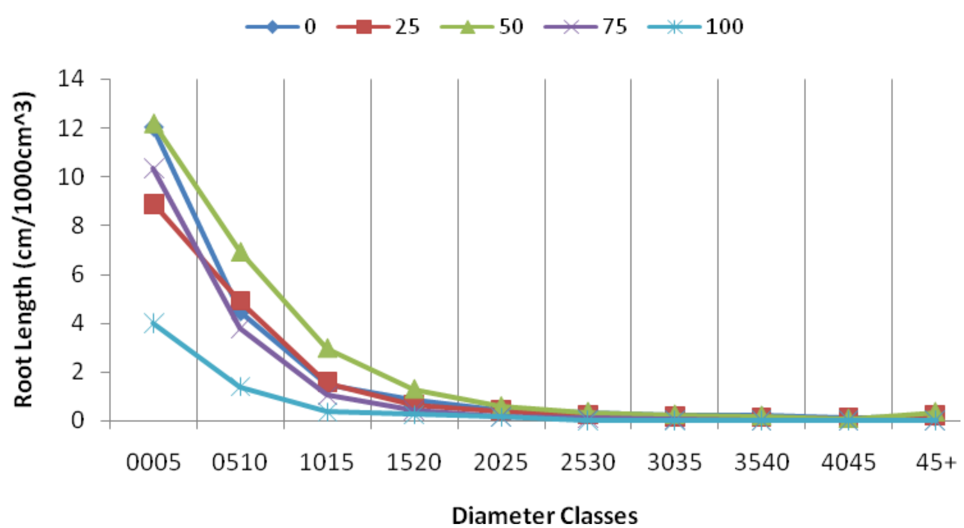

Figure C-2. Site D mean root length by root diameter classes and compost treatments (%)

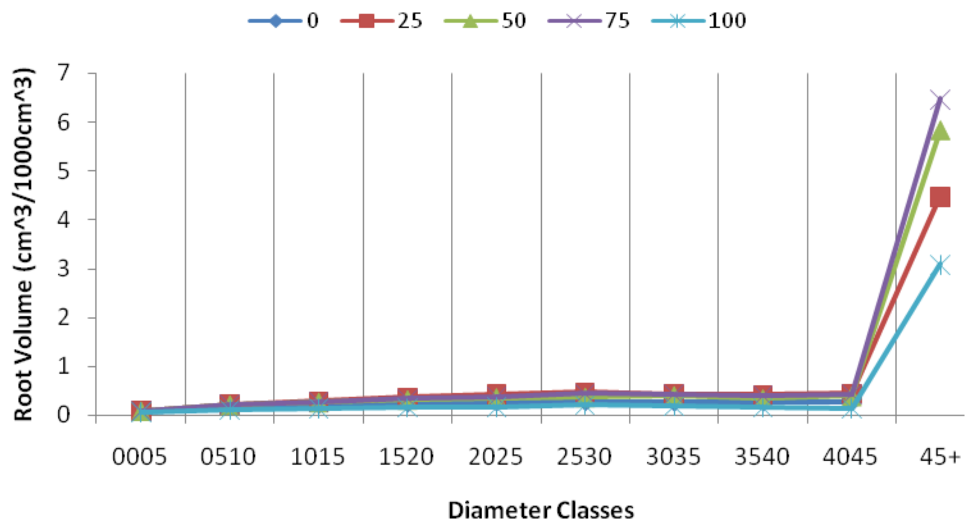

Figure C-3. ACMF mean root volume by root diameter classes and compost treatments (%)

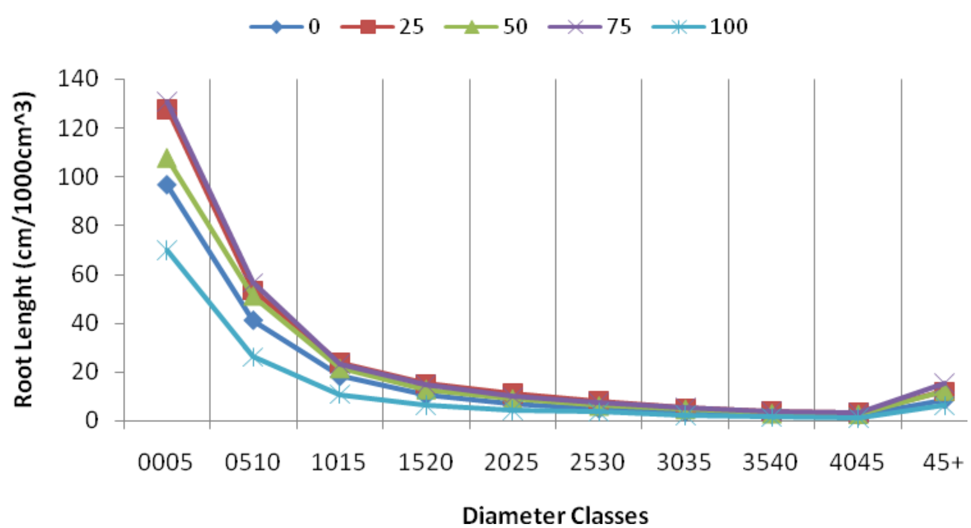

Figure C-4. ACMF mean root length by root diameter classes and compost treatments (%)

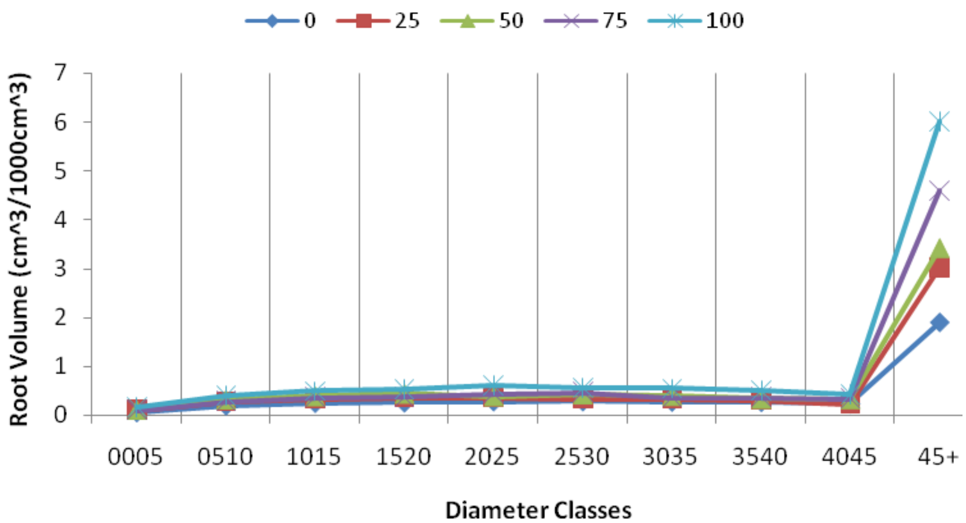

Figure C-5. UF mean root volume by soil volume based on diameter classes and compost treatments (%)

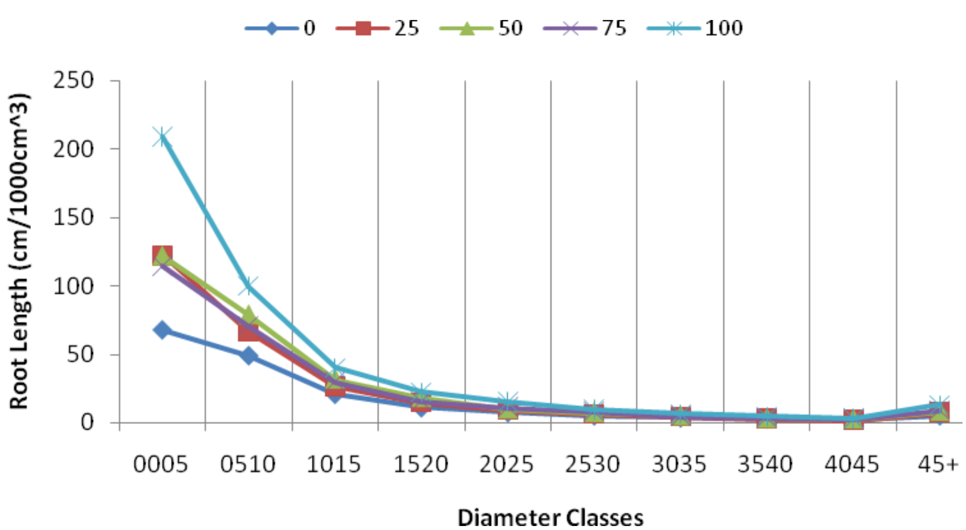

Figure C-6. UF mean root lengths by soil volume based on diameter classes and compost treatments (%)

BIOGRAPHICAL SKETCH

The author was born in 1980 in Gainesville, Florida, and raised in Chiefland, Florida. He spent much of his younger years playing a variety of sports and exploring the ecosystems of Levy County, Florida. He graduated from Chiefland High School in 1999 and has always felt fortunate to have been raised in such a small, religious, and agricultural based community. This community provided him with a wealth of knowledge about agriculture, forestry, and life. He attended Santa Fe Community College and Lake City Community College, obtaining an Associate of Arts degree in 2001 from Lake City Community College. In 2004, he obtained a Bachelor of Science in Natural Resource Conservation from University of Florida (UF) School of Forest Resources and Conservation (SFRC) with a specialization in Wetland Ecosystems, and a minor in Soil and Water Sciences. During his two years at UF, he worked as a hydrology research Technician, wildlife biologist technician (black bears), forestry technician, and tree improvement research technician. He also volunteered many hours helping with research on alligators, wild turkeys, and ocean soils. From 2004 to 2007, he worked in the Jacksonville, Florida, area as an environmental and forestry consultant where he quickly went from a technician position to a management position and even helped start a forestry consulting program for a large environmental firm. In 2006, he began his Master of Science degree at SFRC with a research assistantship while still working as a consultant. In 2007, he began working for the Alachua County Land Conservation Department where he was in charge of the approximately 1,700 acre Balu Forest, which is being restored to a longleaf pine dominated ecosystem. In 2008, he obtained his Master of Science degree.