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EVALUATION OF ALTERNATIVES FOR RESTORATION OF SOIL AND VEGETATION ON PHOSPHATE CLAY SETTLING PONDS

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EVALUATION OF ALTERNATIVES FOR RESTORATION OF SOIL AND VEGETATION ON PHOSPHATE CLAY SETTLING PONDS

FINAL REPORT

FIPR Contract #86-03-076R

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DISCLAIMER

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EXECUTIVE SUMMARY

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A new technique, measuring near infrared solar energy absorption, showed wide differences among the vegetation types and stages of succession, thus allowing quantitative inferences about the transpiration and water budgets for present and future mining landscapes. Along with our three previous reports on managing ecosystem succession for reclamation purposes (1983, 1986, 1988), guidelines are given for controlling vegetation type so as to control water budget. Some vegetation such as pond cypress, conserves water by reflecting the sun's infra-red insolation and reducing transpiration, whereas bottom land hardwoods absorb more infra-red insolation and transpire more.

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In Chapter 3, S. Everett compared the growth and survival of pond cypress to those of bald cypress on five mined soils. Sites were chosen on three abandoned phosphate clay settling ponds and two lime rock mines. Soils ranged from essentially pure clay to sand and gravel. Early results from paired field plots revealed negligible growth differences between species, but survival of bald cypress was much greater than survival of pond cypress. Large inter-site growth variations were noted for both species. Better growth was observed on a mixture of sand and

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perches and in the seedbank were negatively correlated with increased seed weight. Less than 0.06% of the dispersed seeds survived to become juvenile plants. There was a shift in relative species composition away from a greater dominance of seedfall of later successional and large-seeded tree species towards small-seeded early successional shrubs in the seedling community.

In Chapter 8 field measurements of transpiration were made of successional vegetation in clay settling ponds, with about 0.5 grams water per gram dry biomass per hour in daylight hours. A sample calculation as follows shows very substantial drying out processing by the successional plant cover. With dry biomass of live plants 1500 grams per square meter and a 10 hour sunny transpiration day,

$$\text{Transpiration} = (0.5\ \text{g/g/hr})(1500\ \text{g/m}^2)(10\ \text{hr/day}) = 7500\ \text{g/m}^2\text{/day}$$
$$= 7.5\ \text{mm/day with less on cloudy days.}$$

In Chapter 9 McClanahan and Odum, using a Li-cor Spectral Reflectance Scanner, showed changing percentages of the infrared solar energy being absorbed with stages of plant succession. Open waters absorbed 90%; the bare clay surfaces absorbed 70%; Early successional plants--cattails, etc.-- absorbed 50% and floodplain type hardwoods and bald cypress 70%. Thus, the progress of vegetational succession increased the absorption and use of infrared insolation. The bare clay absorbed less insolation and thus had less drying out potential than the vegetation cover.

Since about half of the infrared is absorbed in the successional vegetation in clay ponds, about 2000 kilocalories per square meter per sunny day, water which can be transpired by this heat absorption at 0.54 kilocalorie per gram water is:

$$(2000\ \text{kcal/m}^2\text{/day})/(0.54\ \text{kcal/g}) = 3702\ \text{g/m}^2\text{/day} = 3.7\ \text{mm/day}$$

Thus about half of the considerable transpiration that was observed is attributable to the infrared absorptive characteristics of the successional vegetation.

Much of the settling ponds stop their sequence of plant succession for lack of seeding of the more mature tree species. Thus, areas of old willows stand indefinitely that would be replaced by the diverse, "climax" species coming up underneath, if seedling were planted (by nature or by human hand). The willows absorb 40% of the infrared, which is more than the bare crust but not as good as the later successional trees.

Much of the mining area away from the stream floodplains was previously covered with pond cypress growing in oligotrophic waters. These only absorb 20% of the infrared (reflecting 80%). Compared to other vegetation, the pond cypress reflection conserves regional water supplies. The difference between pond cypress absorption (20%) and open water absorption (90%) and normal successional vegetation now covering the area (40%-50%) represents water now lost from the area. For reclamation lakes that replaced cypress ponds the water equivalent to the the water lost due to extra heat absorbed is

$$\frac{(0.9 - 0.2)(0.5 \text{ insolation infrared})(4000 \text{ kcal/m}^2\text{/day})}{(0.54 \text{ kcal/g water evapotranspired})} = 2592 \text{ g/m}^2\text{/day}$$

This is 2.59 mm/day water loss, an inch per day. Restoration of pond cypress ponds has very high potential for water savings compared to the open lakes or marshes in current reclamation patterns. A general mapping of vegetation with infrared reflectance values can generate a map of potential transpiration for better water management planning.

These studies show low-cost ways to accelerate and control post-mining ecosystem succession and thus prepare lands for alternative uses, and to control water regimes. Manipulation of vegetational type after mining can be used in settling ponds to increase low-cost drying out, in water storage areas to save water, and through establishment of seed-supplying gene pool areas, to enhance the work of the natural process of general restoration of soil quality of the region. Based on these preliminary findings, our report back to the Board of the Florida Institute of Phosphate Research is that mapping of the present and projected vegetation and infrared absorption can improve reclamation measures to achieve economic goals and regional water management.

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1. INTRODUCTION, ACKNOWLEDGEMENT

After phosphate mining, lands may be restored to various surface uses such as agriculture, forestry, wetland-water conservation, wildlife-wilderness-recreation, or other uses. For most of these, restoration of soil structure and fertility is desirable as quickly as possible. For the clay settling ponds, the slow breakdowns of colloidal stability of suspended clays and dewatering prevents immediate use as land. Many research efforts have been directed at finding the most rapid and inexpensive way to restore lands to beneficial productivity.

On the one hand, special machinery on the surface of the soft clays can develop crusts with the baking of direct sunlight, a method that minimizes vegetation. Costs are high, several thousand dollars per acre. Soils are not restored in the normal way.

From previous studies and the expectations that come from a general principle of nature, we have sought to find the best method of cheap rapid restoration maximizing vegetation by aiding colonization and succession of self organizing ecosystems with relatively small human efforts. The principle is that self organizing ecosystems reinforce those species and processes that restore productivity after disturbance the most rapid way possible for the resources available. In other words, the multiple initiatives of natural systems mechanisms are operating to do the same thing as humans, restore productivity.

Our efforts starting in 1973 try to develop understanding and guidelines for use of natural processes to accelerate wetland and other land restoration after mining. Taking advantage of the self organizing processes of ecosystems is the new field of ecological engineering (Mitsch, 1989).

This report has the results of a one year project with four goals, all part of the continuing mission to develop best guidelines for post mining restoration:

1. Evaluate results of growths on plots and planting that were studied previously in the short run (2 years) to see what were the results after a longer time (6 years).

2. Conduct additional tests in the field and in greenhouse to better identify the species, fertilizers, and soil management most conducive to rapid reclamation.

3. Further identify the water management regimes necessary to generate various kinds of vegetation, wetlands, and soils.

4. Explore the use of infra-red reflectance to delineate heat and water roles of various vegetation types, and their respective roles in drying out clay settling ponds and augmenting succession.

Since the infra-red scanning was a new approach, the FIPR board authorized a one year preliminary test, postponing consideration of our 5 year proposal to see what the early results would be. Because the equipment for the infra-red reflectance was delivered a year late, when the project was supposed to be over, the project received no-cost extensions twice. This final report includes work done on our own funds after the FIPR monies had been spent. Spreading the effort over 3 years was not all bad, because new approaches need more thought, more long-range measurements were made, and more thorough consideration of data was possible where there was time for the theses and dissertations to be completed and reviewed by faculty committees.

In Chapters 2-7 that follow results of monitoring vegetation survival and growth lead to guidelines for acceleration of revegetation, control of vegetation type, and good use of water.

In Chapters 8 and 9 on transpiration and reflectance, the sharp difference in role of water using vegetation and water conserving vegetation begins to make sense. The two extremes in vegetation adaptation are readily separated by their remote-sensed reflectance. Each may have an appropriate role in post-mining reclamation.

2. FACTORS INFLUENCING THE ESTABLISHMENT OF HARDWOOD SWAMPS ON CLAY SETTLING PONDS

MARY PAULIC

INTRODUCTION

The success of planted seedlings on disturbed clay soils is influenced by a variety of factors. Some are of major importance such as nutrient availability and hydrology. Other parameters such as seedling height and planting methodology though of minor importance should be considered in the success of tree planting.

Both field and greenhouse experiments were performed to investigate the influence of soil age, nutrients, and initial seedling height on the growth and survival of planted hardwoods.

EFFECTS OF SOIL AGE ON RED MAPLE TREE SEEDLINGS

As clay settling ponds age, changes occur in the physical structure, chemical and biotic properties of the soil. A major factor in this change is the establishment of vegetation on the barren ground. Plants, through the process of transpiration, are able to remove water from the soil, thus drying the clay and enhancing consolidation. Upon death, herbaceous plant materials add organic matter to the soil. Organic matter is recognized as a primary ingredient in the aggregation of soil or development of stable soil structure (Brady, 1974). Chemical properties of the soil change by the addition of nutrients, either from the direct decomposition of plant material or from plant associated microorganisms. Organisms, such as earthworms, help to till and aerate the soil.

Trees can have an even greater impact on the properties of soil than herbaceaous cover because of the larger amounts of leaf litter added to the soil and their more extensive root systems. Little if any research has been directed to determining the extent of biological modification of phosphate clay soil and its impact on tree growth and success. Whether or not the growth of trees would be influenced by the developmental stage of the clay soil was the question to be answered by this experiment.

Greenhouse experiments were performed to compare tree growth on clays from different aged clay settling ponds. Age of clay in these experiments infers longer exposure to vegetative cover and associated biological modifications of soil properties. A control medium of potting soil was used for comparison.

Methods

The soil used in these experiments came from five clay settling ponds which ranged in age from 8 years to 37 years. Age was calculated from the approximate time of abandonment or reclamation to the start of this study. Table 2.1 contains a list of the sites, their ages, and locations. In addition, trees were planted in a control potting soil composed of sand, perlite and peat.

The maples were grown from seeds collected from a stand of maple and mixed hardwoods near Gainesville, Florida. The seeds were planted in a soil mixture composed of terlite, sand and sterile Florida peat. The potting mixture did not contain any additional nutrients. Seedlings were grown for 2 months (from the time the seeds were planted) in this medium before transferral to experimental and control soils.

Trees were planted as seedlings in one gallon plastic pots in May 1987. Measurements of tree height were made at intervals over a period of one year. Throughout the experiment plants were kept in a greenhouse to provide uniform light and prevent cold damage. All trees were watered from overhead sprinklers every other day to maintain moist soil conditions.

Soil Source. Clay soil was collected from settling ponds at Gardinier, O.H. Wright, Tenoroc, Alderman Ford Ranch, and International Mineral and Chemical Corporation (IMC).

Gardinier was estimated to be a 15 year old clay settling pond. The soil collected there had a gray color with a depth to water table of 26 cm at time of collection. An orange and blue mottled zone was reached in the soil profile. The vegetation at the site was primrose willow (Ludwigia peruviana), cogon grass (Imperata cylindrica), and carolina willow (Salix caroliniana).

O. H. Wright was an approximately 27 year old clay settling pond. The soil was orange in color with a water table located 4 cm below the surface. Vegetation at the site was red maple (Acer rubrum).

The settling pond at Tenoroc state park was abandoned 20 years ago. Soil at that location had a gray color with a water table at a below ground depth of 23 cm. Dominant plant cover at the time of collection consisted of primrose willow (Ludwigia peruviana), carolina willow (Salix caroliniana), and wax myrtle (Myrica cerifera).

The oldest clay settling pond, 37 years, was located at Alderman Ford Ranch. The soil at that site was orange with a mottled zone at a depth of 40 cm. The water table was reached at 47 cm below the ground surface.

The youngest site, 8 years, was IMC's Phosphoria Mine (P-1). As part of its reclamation the area had been ditched and drained. Clay

Table 2.1. Summary of information of clay soil ages and sources.

Site	Age (years)	Reclamation	Mined	Owner	Location
Gardinier	15	1975 ditched	no	Gardinier, Inc. Ft. Meade	T32S, R25E Section 9
O.H. Wright	27	None	yes	Gardinier, Inc. Ft. Meade	T32S, R25E Section 9
Tenoroc	20	None	yes	Florida Dept. Natural Resources	T27S, R24E Section 36
Alderman Ford Ranch	37	None	no	C.L. Knight	T30S, R22E Section 16
IMC Phosphoria Mine	8	Ditched and drained	yes	International Minerals and Chemical Corp.	T30S, R25E Section 33

soil was collected from inside a ditch and had a distinct red color. Vegetative cover was primrose willow (*Ludwigia peruviana*).

Statistical Analysis. The experiment was designed as a completely randomized design to be analyzed as a one way analysis of variance. Tree height was used as the measured parameter for tree growth. Twenty-four replicates were made of each soil age class. Comparisons of mean tree height for different soil classes were made using Duncan's Multiple Range Test. Tree growth rate was determined between day 38 and day 145. These two end points were selected because growth between them was the most rapid and linear. Rate of growth was estimated as the line slope between these two days. A regression analysis was performed between tree height and soil age.

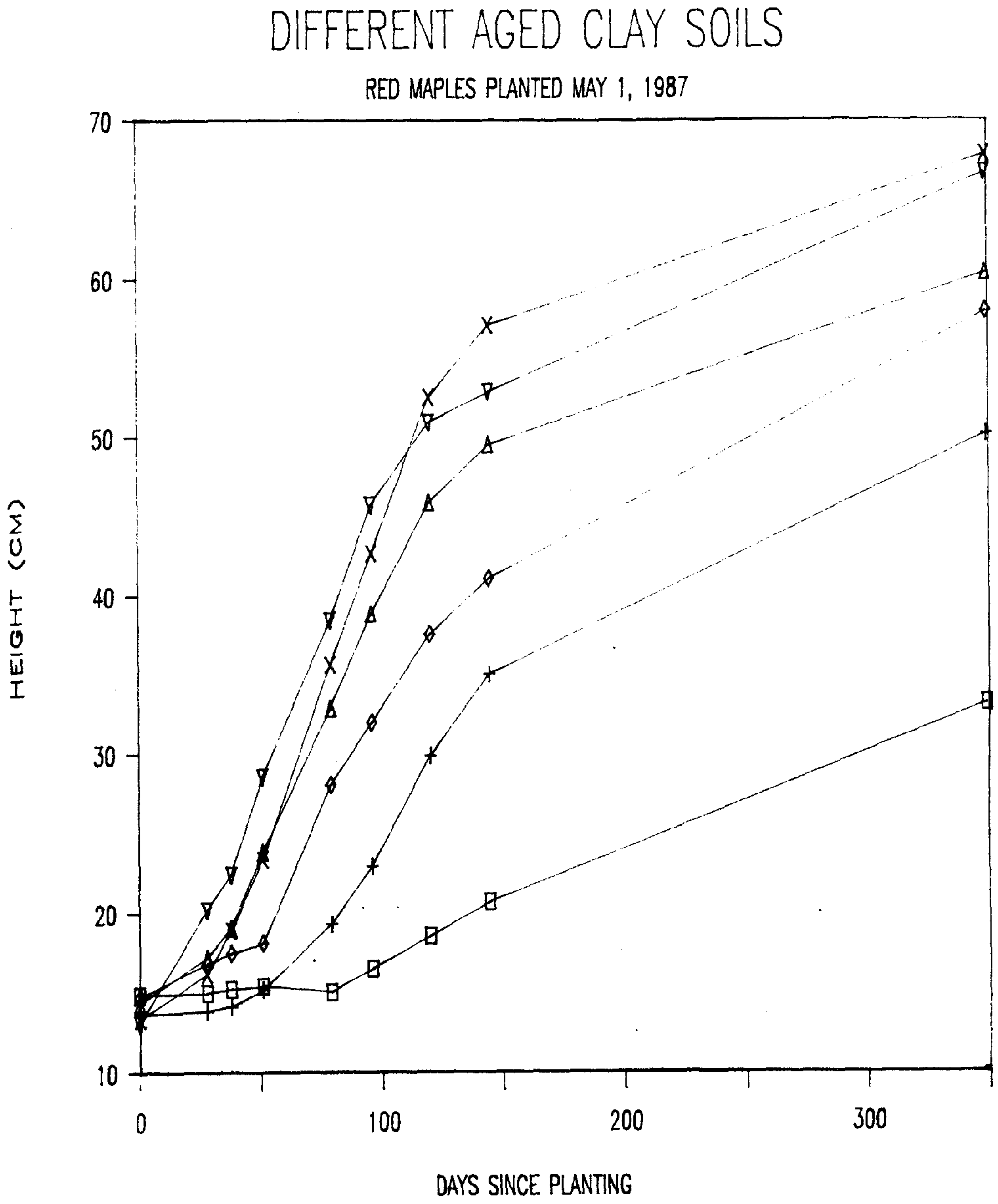
Results

Mean tree heights for each age class at each sampling interval were plotted (Figure 2.1). Trees grown in the youngest soil (IMC) grew the least while those planted in the oldest soil (Alderman Ford) grew the most. The other age classes fell in order by age between these two end age groups. The oldest clay soil produced tree growth that was comparable to the nursery potting medium. Differences in tree height were evident after 50 days.

The rates of tree growth between days 38 and 145 are listed in Table 2.2. Rates of growth followed the same pattern as net tree growth. The oldest clay soil supported faster growth and the other soils followed in a continuum to the slowest grower at IMC. Trees planted in soil from IMC grew at a rate of 0.05 cm/day while trees in soil from Alderman Ford Ranch grew at a rate of 0.36 cm/day. Growth was better in the soil from Alderman Ford Ranch than the nursery potting medium.

Analysis of variance of the final tree heights showed that there was a significant difference, at the $p=0.05$ level, in tree growth between the different clay ages. Comparison of the final mean heights using Duncan's Multiple Range Test indicated that there were three distinct groups of trees statistically significant at the $p=0.05$ level. Trees grown in the youngest clay soil from IMC had a mean growth that was significantly different from all other age classes. The next group of trees included the 15, 20 and 27 year old clays (Gardinier, Tenoroc, and O. H. Wright). The height of trees grown in the 37 year old clay settling pond soil and the nursery potting medium were not statistically different. In addition, the 20 and 27 year old clays were not significantly different from the nursery potting soil and soil from the 37 year old clay settling pond (Alderman Ford).

Age of clay soil and mean tree height appear to be positively correlated. A linear regression was performed between tree height and clay age (Figure 2.2). A value of 0.93 was obtained for the correlation coefficient, r, indicating good correlation between tree growth and clay soil age. The r2 value was 0.87.



Age of soil: ▯ 8 yrs + 15 yrs ◇ 20 yrs △ 27 yrs X 37 yrs

▽ potting soil

Figure 2.1. Tree heights of red maples, measured over one year, grown in different aged clay soils.

Table 2.2. Rate of growth of maple trees planted in different aged clay soils. Data are mean values (--replicates) ± standard error.

Site	Age (years)	Rate of growth (cm/day)
IMC	8	0.05 ± 0.025
Gardinier	15	0.20 ± 0.06
Tenoroc	20	0.21 ± 0.05
O.H. Wright	27	0.28 ± 0.05
Alderman Ford Ranch	37	0.36 ± 0.07
Nursery Potting Soil	--	0.28 ± 0.06

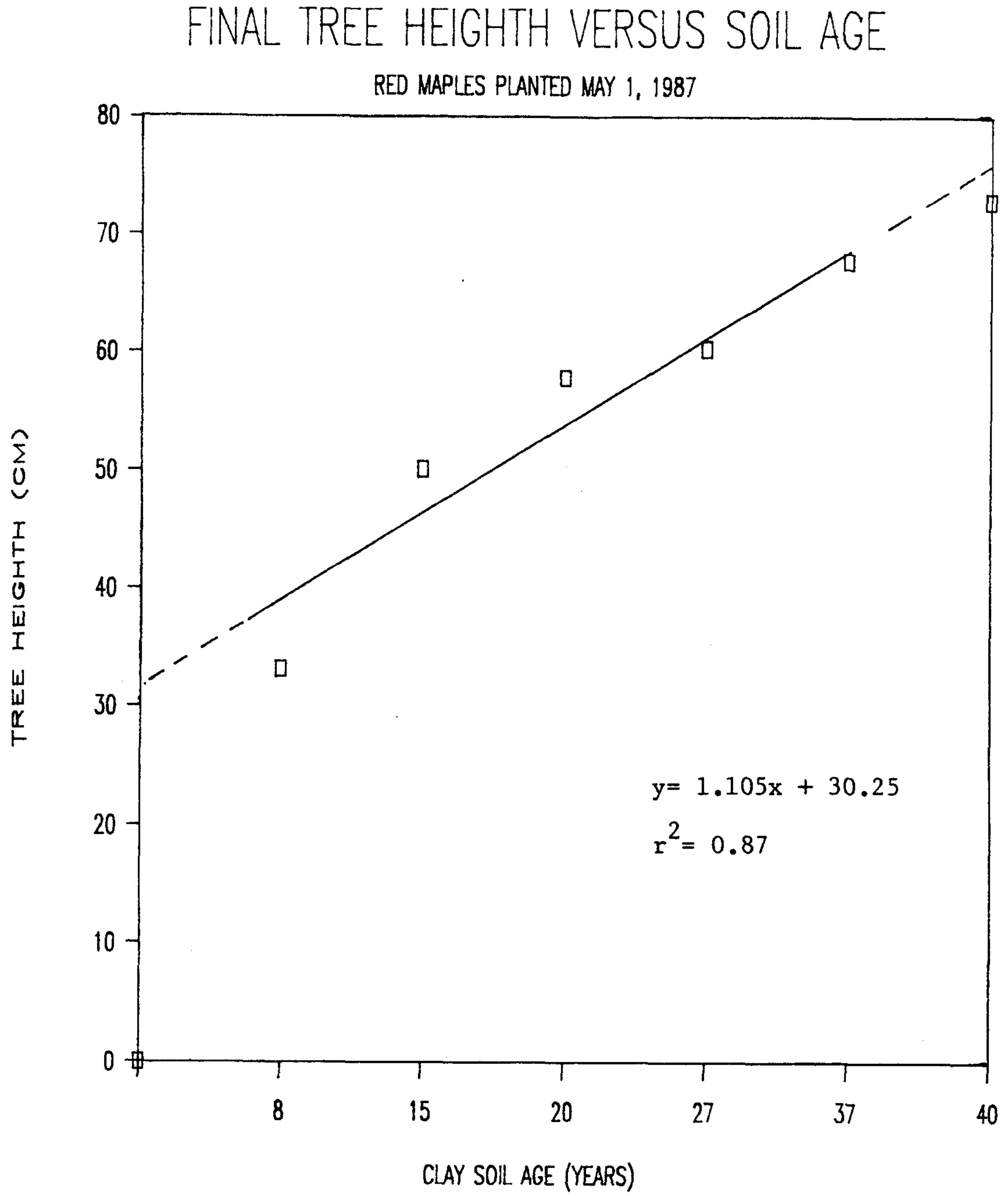


Figure 2.2. Regression analysis of clay soil age and final tree height for trees grown on different aged clay soils.

Discussion

The results of this experiment indicate that older clay waste soils enhanced the growth rate of trees. The mechanism for this response is unknown. Possible reasons include initial differences in soil nutrient levels, the better development of microbial communities in older soils associated with nutrient recycling, tighter nutrient cycling between biotic and abiotic soil components, and increased nutrient availability to the tree's roots.

Starting with the most obvious, differing initial nutrient levels could account for the differing rates of growth. All of the experimental soils used were waste clays. Phosphorous, magnesium, and calcium are typically very high in these soils and are considered adequate for tree growth (Wallace and Best, 1983, Hawkins, 1983). What would be lacking is available nitrogen, potassium, and/or micronutrients. Soil nitrogen should increase with age through increases in organic matter and the release of nitrogen compounds by microbes.

Coupled with nitrogen availability is the development of a microbial community capable of making nitrogen and other nutrients available to the trees.

FERTILIZER ADDITION TO MAPLE TREES POTTED IN CLAY SOILS

Soil nutrient content and nutrient availability are important factors in the success and growth of hardwood trees on waste clays from phosphatic rock mining. Waste clays have been characterized as a calcium-magnesium-bicarbonate-sulfate dominated sytem with high buffering capacity (Bromwell, 1982). Typically, the clays are high in phosphorous, magnesium and calcium. Concentrations of these nutrients are considered adequate for plant growth (Pritchett, 1979). What is lacking is available nitrogen.

The addition of a nitrogen containing fertilizer at planting may be a viable means of enhancing tree growth and survival on clay settling ponds. A greenhouse experiment was performed to test the effect of adding fertilizer pellets containing nitrogen, phosphorous, potassium, and micronutrients to one year old maple trees (*Acer rubrum*) planted in clay soils.

Methods

The trees used for this experiment were grown for a year in clay soils from 5 different clay settling ponds. In addition, one set of trees was grown in an organic nursery potting medium, Southern Garden potting soil. These were the same trees used for the preceeding experiment on differing aged clay soils. The soils used in this experiment were listed in Table 2.1. Descriptions of them are contained in the proceeding section on Different Aged Clay Soils.

Fertilizer pellets were added to half the trees in each age soil class. The pellets are sold commercially under the name Agriform Forest Starter Tablets 22-8-2. Their nutrient content is listed in Table 2.3. The major nutrients in these pellets were nitrogen, phosphorous, and potassium.

Tree height was measured monthly for a period of three months. Trees were kept in a greenhouse throughout the experiment and were watered from an overhead sprinkler system every other day to maintain moist soil conditions. Comparisons of final height were made between fertilized and unfertilized trees of the same age class using the Students T-Test. Net growth of fertilized trees was compared to clay age by graphical methods.

Results

Final tree heights of fertilized and unfertilized trees were graphed in Figure 2.3. In all cases fertilized trees grew more than unfertilized trees. These results are comparable with other researchers' findings of tree response to the addition of fertilizers. Differences in final height between fertilized and unfertilized trees of one age class were statistically significant at the p=0.05 level. Final tree heights with and without fertilizer of soils older than or equal to 20 years and the control potting soil are comparable.

Final heights of the two younger age classes are still less than the other ages, which is in agreement with data from the previous experiment using different aged clay soils.

The two youngest soil age classes did not repond as well to the addition of nutrients as the trees grown on older soils. The difference between fertilized and unfertilized trees was smaller than for the older age classes.

Net growth and relative growth of fertilized trees are listed in Table 2.4. Net growth is defined as the difference between initial and final tree height, and relative growth is this difference divided by the initial height.

The greatest net growth response was from plants grown in soil from a 20 year old clay settling pond, Tenoroc. The poorest response was from the youngest soil from IMC. In contrast, when compared on a relative basis, the trees grown in the youngest soil were comparable to the trees grown in the 20 year old soil.

Variability in net growth as a tree response was greater in fertilized trees than in unfertilized trees with the exception of the oldest clay soil. One standard error bar was included in Figure 2.3 to indicate this variability. More variability in height was evidenced in trees grown in younger soils than those trees grown in the oldest clay soil.

Table 2.3. Nutrient content of Agriform Forest Starter Tablets.

Nutrient	% Composition per 9.0 gram tablet
Total nitrogen (N)	22.0
Phosphoric acid (P_2O_5)	8.0
Potash (K_2O)	2.0
Combined calcium (Ca)	3.0
Combined sulfur (S)	1.0
Iron (Fe)	0.5
Zinc (Zn)	0.1

Table 2.4. Net and relative growth of fertilized trees grown in different aged clay soils.

Soil age (years)	Net growth (cm)	Relative growth
8	20	0.59
15	22	0.44
20	32	0.55
27	32	0.53
37	22	0.32
Control	30	0.43

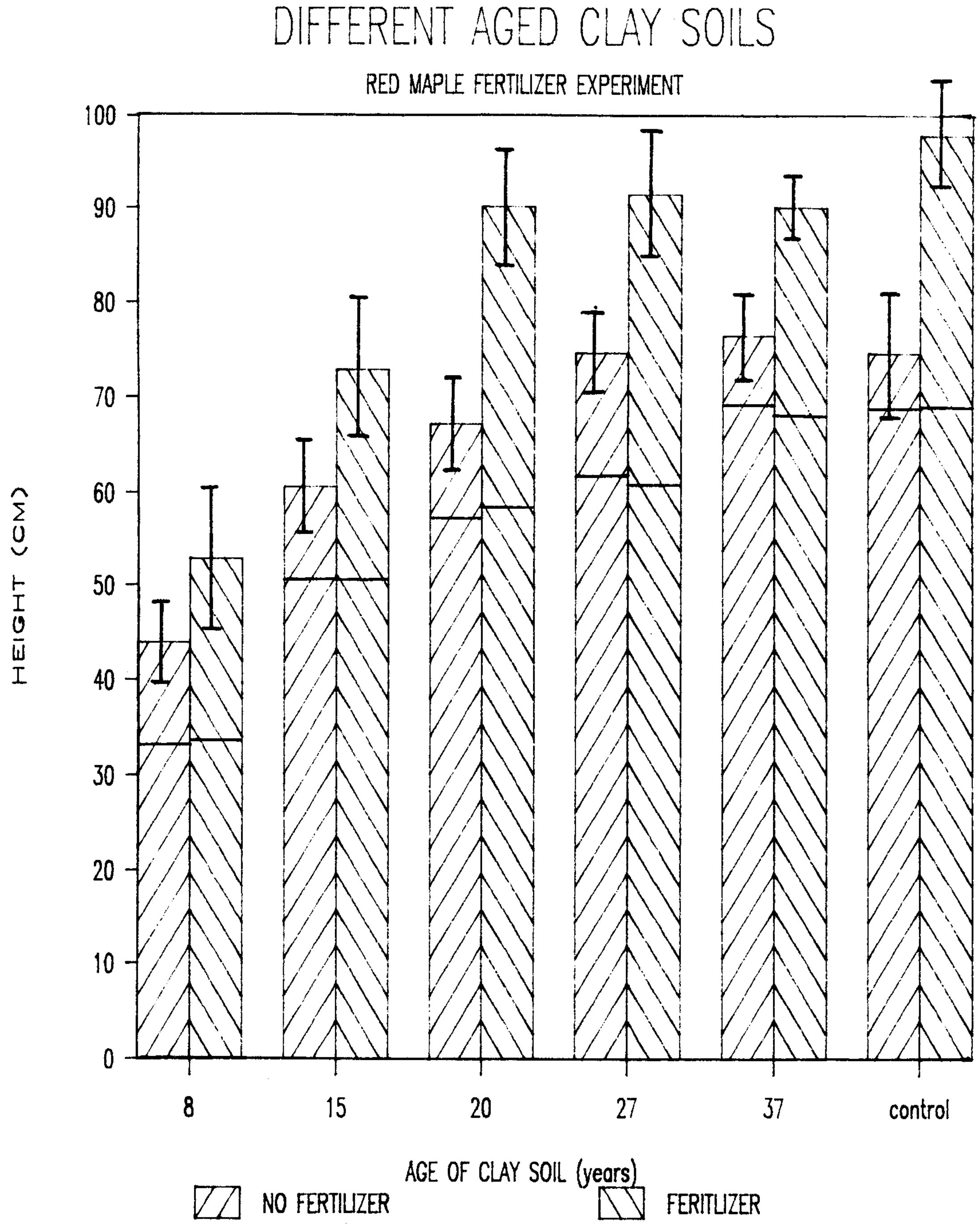


Figure 2.3. Final mean tree heights of fertilized and unfertilized red maple trees compared by age of clay soil. Initial tree heights are indicated on the graph by a solid horizontal line. Trees were grown for 3 months with fertilizer. One standard error bar was included to provide an estimate of the variability of tree heights obtained.

Discussion

Trees in all age classes responded to the addition of fertilizer by an increase in height. These results are comparable to data from other researchers. An important condition in this experiment was the maintenance of moist soil conditions. Pham et al. (1978) found that red maples grown on moist soil increased significantly in size with fertilization; those grown on dry soil showed only slight increases in height. Pritchet and Smith (1975) found that slash pine grown on wet sites increased in height by 130% from initial height.

Results of the previous experiment (maple trees grown in different aged clay soils) would indicate that the greatest response to added nutrients would be trees grown in the oldest clay soil, 37 years, with decreasing response to the youngest soil. That was not the case in this experiment. Best growth as measured by mean net height increase was for the 20 year old clay soil with decreasing response with increasing age past 20 years. There are two plausible explanations for this result.

First the trees growing on the older soils (27 and 37 years old) may have put additional nutrients into increased basal area rather than tree height. Unfortunately, basal area was not quantitatively measured in this experiment.

Secondly, these are containerized trees. When final heights are compared there appears to be a maximum tree height of 90 cm for clay soils for the size of container used. This explanation is reinforced by the reduced variability in net tree growth of fertilized trees growing in the oldest clay soil. Trees attaining this maximum height may be growing by increasing basal area and not by height.

Pot size in this experiment turned out to be an important factor in the growth of planted seedlings. It appears that a maximum size is obtained for a given pot size. In view of this, the parameter used to determine growth should be selected carefully so that it will truly represent the desired response.

One further observation that needs to be addressed was the smaller response of trees grown in younger soils to the addition of fertilizer. There are two possible explanations. Though net growth was small, on a relative growth basis the trees grew substantially compared to their initial heights. A shorter tree may simply not be able to grow as much with the same available nutrients as a taller tree. Secondly, the possibility exists that the soil itself was lacking, thus preventing the tree's complete utilization of increased nutrient. Such a deficiency could be either the lack of soil microbes or a missing or inadequate concentration of a minor nutrient element. Both these explanations should be viewed as purely speculative.

SEEDLING SIZE AS A FACTOR IN GROWTH AND SURVIVAL

There is an intuitive perception that the taller a tree seedling is when planted the better is its chance of survival and growth. Few if any experiments have been performed to justify this perception. A field experiment was initiated to test this hypothesis by comparing net growth and survival of tall and short planted seedlings. In addition, root lengths were measured before planting and later compared to tree survival. The purpose of this latter exercise was to determine if root length was an important factor in the survival of seedlings irregardless of tree height.

Methods

Five species of hardwood trees were planted on a 20 year old clay settling pond near Homeland, Florida. These included water hickory (Carya aquatica), green ash (Fraxinus pennsylvanica), baldcypress (Taxodium distichum), swamp chestnut oak (Quercus michauxii), and overcup oak (Quercus lyrata). Trees were selected to be classified as either short or long. Short trees were less than 20 centimeters in height at planting. Tall trees were selected to be approximately twice that height, 40 cm.

Trees were hand planted using a KBC planting bar (dibble) during March, 1988 and their heights recorded. In addition, root lengths were measured before planting. Remeasurement of tree height was performed in November, 1988 allowing one complete growing season.

Plot Design. Trees were planted in two sets of paired plots of 60 trees with 6 short and 6 tall trees of each species per plot in a randomized complete block design.

Plot sets were located under differing hydrological regimes. Two plots were planted in a ruderal ground cover consisting of dog fennel (Eupatorium capillifolium), shy-leaves (Aeschynomene indica), (Sesbania macrocarpus), and ragweed (Ambrosia artemisiifolia). Surficial water table levels never rose above ground at these sites between March and November. These plots were defined as dry. The other two plots were planted under a vegetative cover of soft rush (Juncus effusus), cogon grass (Imperata cylindrica), and primrose willow (Ludwigia peruviana). Surficial water table levels were at or above the ground surface for at least half the time period between March and November. These plots were defined as wet. All plots were kept as open as possible to avoid shading from cottonwood and willow trees.

Statistical Analysis. Comparison of survival of short versus tall seedlings was made using a chi square test. Net tree growth by species and initial seedling height classification compared by hydrology was tested by Students T-test. Net growth of trees was not statistically compared between tree species because of inherent differences in genetic and physiological responses of different species to the same growing conditions. Tree survival and root length at planting were compared using a chi square test.

Results

Percent survival was computed by species comparing short and tall trees by hydrology. Final tree heights of short and tall trees were compared against hydrology (Figures 2.4 to 2.8).

Tall trees growing in wet plots had better survival than short trees with one exception. Tall and short green ash survived equally well (100%) (Figure 2.5). For the other four species only overcup oak did not show a statistically significant difference in survival at the p=0.1 level between short and tall trees.

Percentage-wise more tall trees survived than short trees in dry plots. Statistically, there was no significant difference at the p=0.1 level.

Hydrology had less of an impact on tree growth. Only two species changed growth response to changed hydrology. Tall overcup oak grew taller on wet plots compared to dry plots (Figure 2.6). Both tall and short green ash grew better under wet rather than dry conditions (Figure 2.5).

New trees growing in dry areas frequently experienced tip die back or basal sprouting. Short and tall trees were divided into five classes by planting root length and hydrology. Classes covered 10 centimeter increments in increasing root length starting from zero. The fifth class used was a larger increment because of the paucity of trees in that class. Results are presented in Figure 2.9. The total number of trees planted is included on the graph above each bar. For short trees percent survival was not statistically different between trees in wet and dry plots with root lengths less than 20 cm at the time of planting or greater than 30 cm. The longest class (roots > 41 cm) was not included in the analysis because there was only one tree in that class.

For tall trees, significant differences at the p=0.05 level were detected between wet and dry plots for root classes 31-40 cm and 21-30 cm. As in the case of short trees, the longest root class was not included because only two trees were present in the dry hydrological condition.

Discussion

The effect of initial tree height on survival and growth appears to be determined by hydrology and species of tree. Three of the species planted had significantly better survival (at the p=0.1 level of significance) of tall trees than short trees when planted in wet plots. Both classes of green ash had good survival.

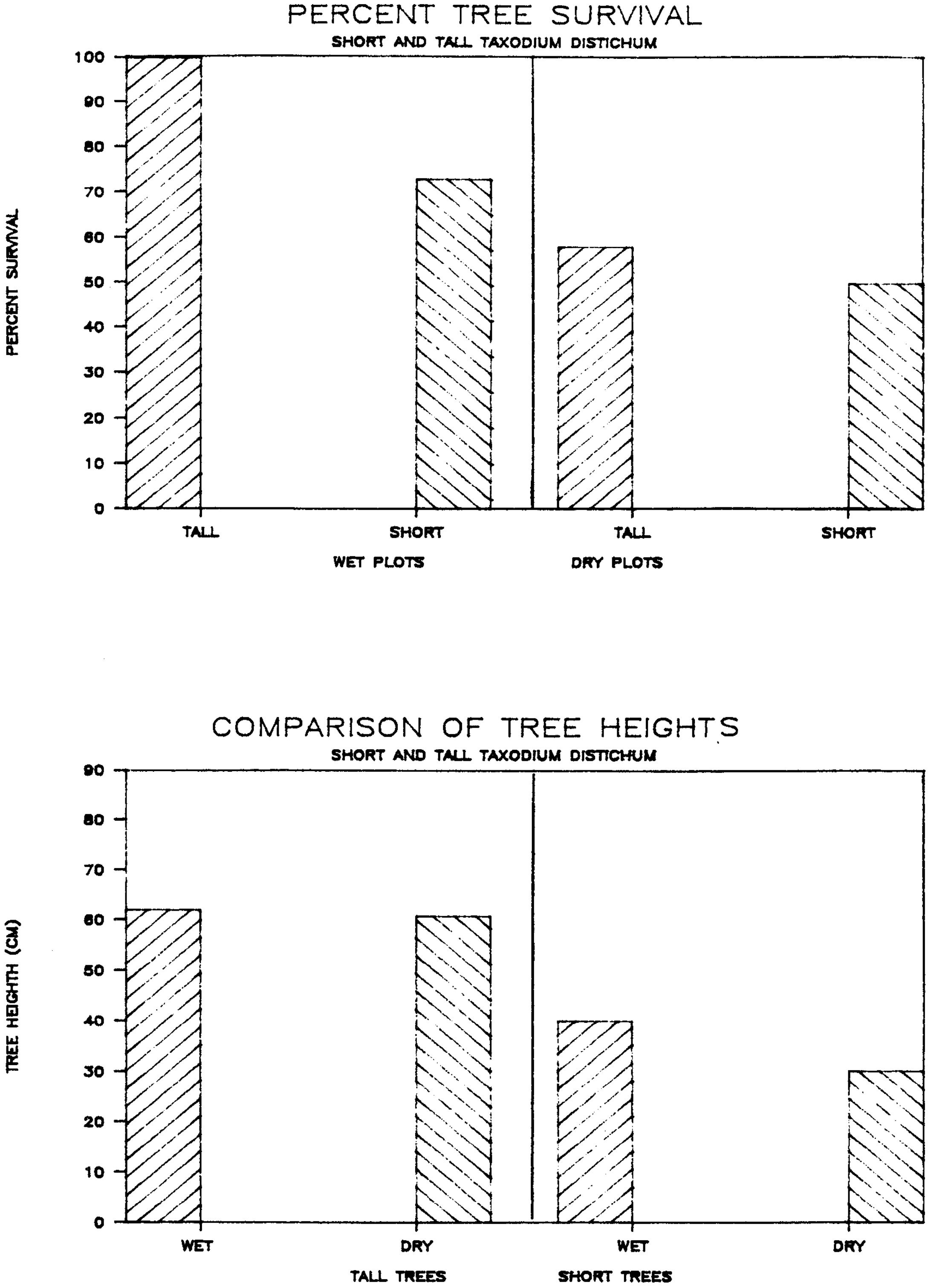


Figure 2.4. Comparison of short and tall trees of baldcypress, Taxodium distichum. (a) Percent tree survival compared by hydrology; (b) tree heights compared by hydrology.

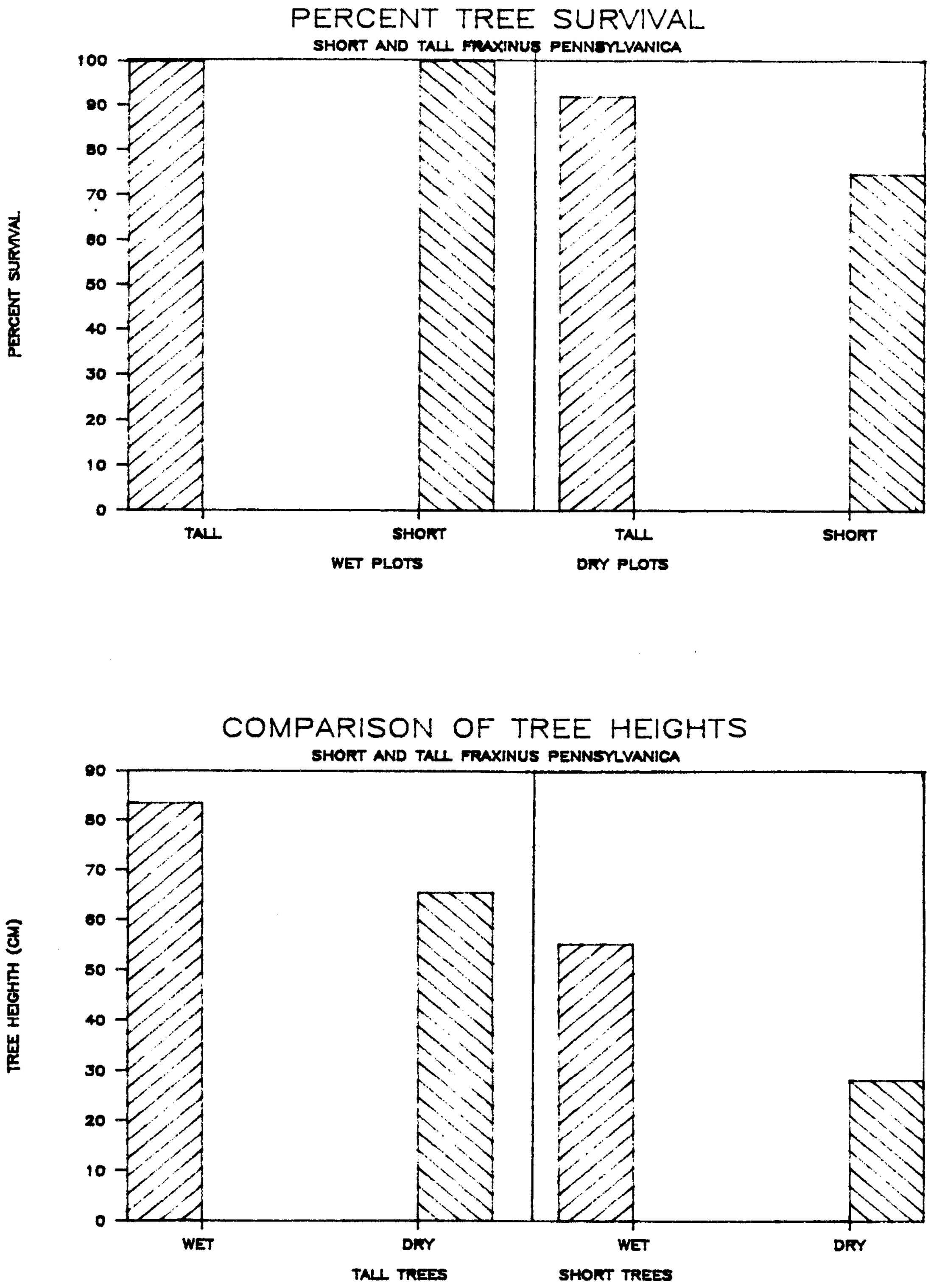


Figure 2.5. Comparison of short and tall green ash, Fraxinus pennsylvanica. (a) Percent tree survival compared by hydrology; (b) tree heights compared by hydrology.

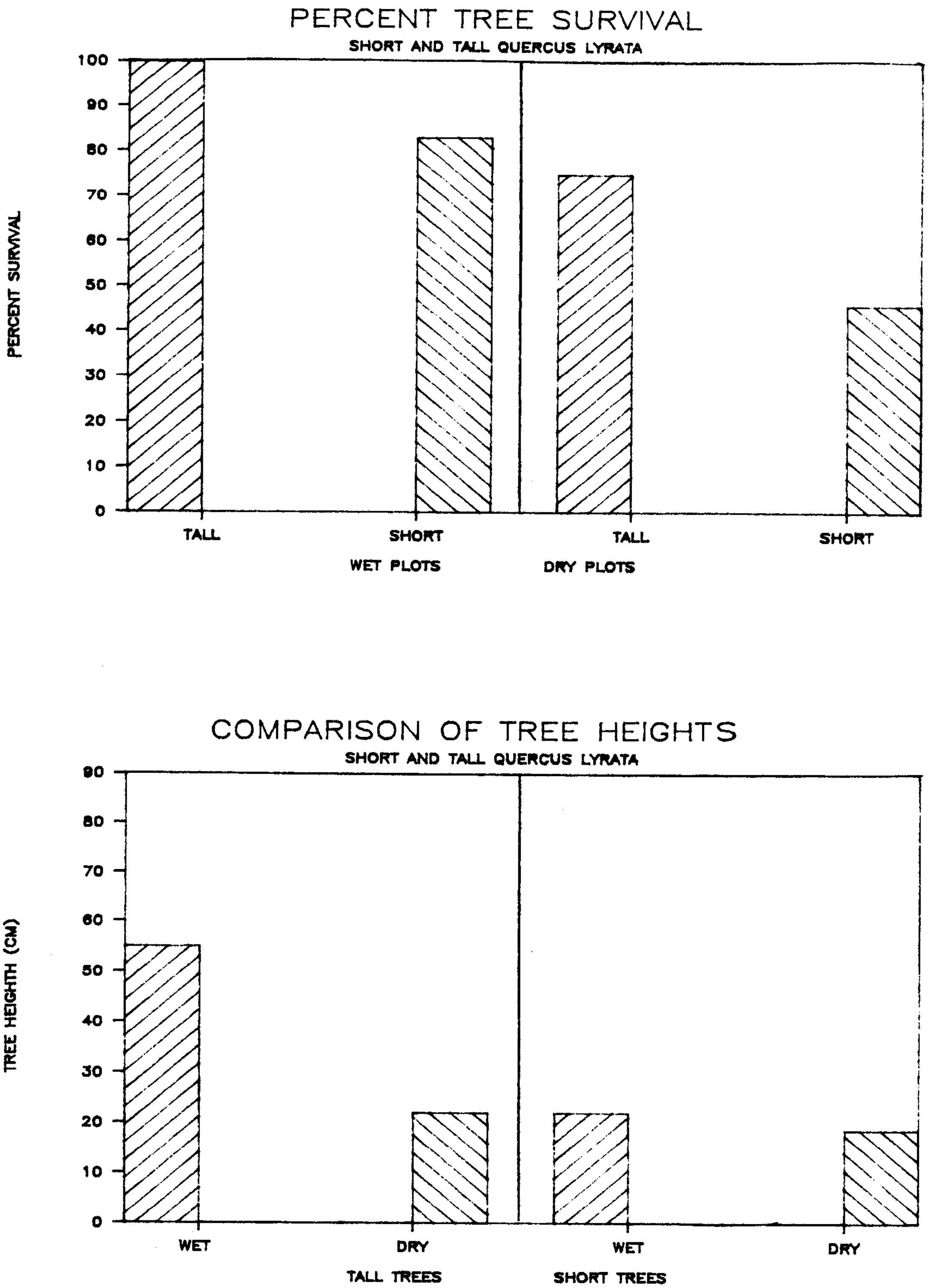
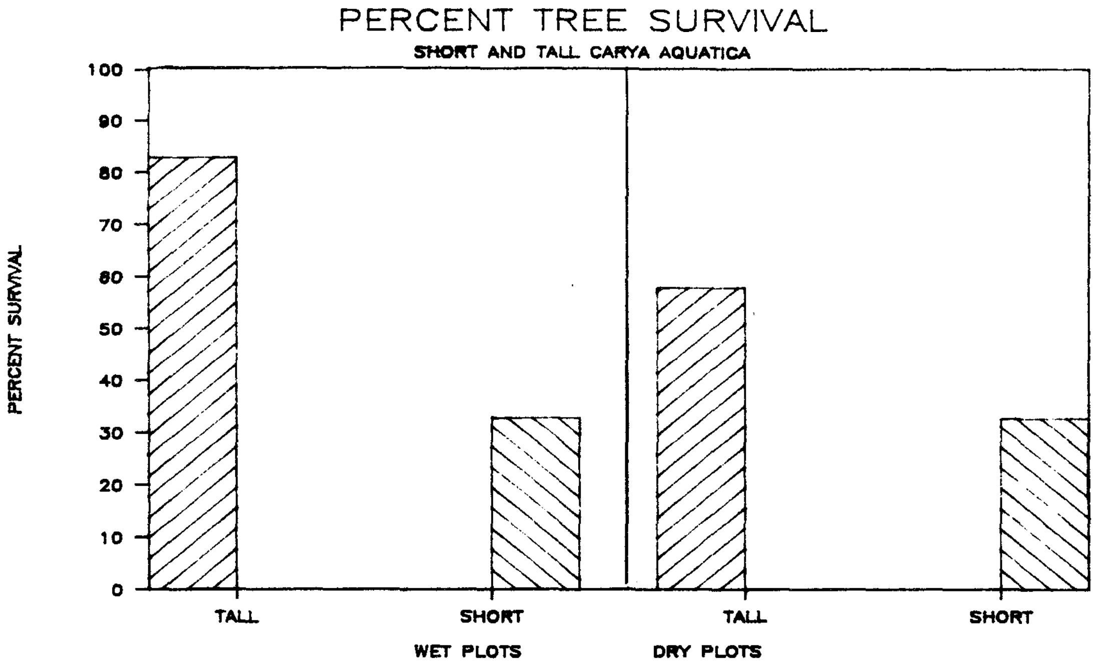


Figure 2.6. Comparison of short and tall overcup oak, Quercus lyrata. (a) Percent tree survival compared by hydrology; (b) tree heights compared by hydrology.



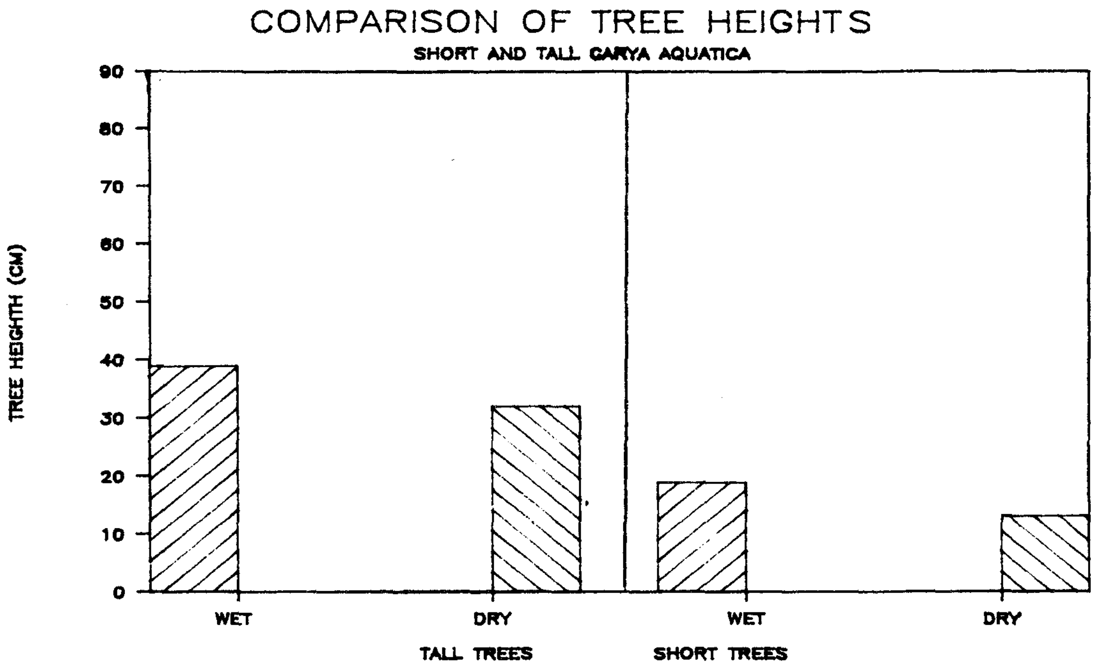


Figure 2.7. Comparison of short and tall water hickory, Carya aquatica. (a) Percent tree survival compared by hydrology; (b) tree heights compared by hydrology.

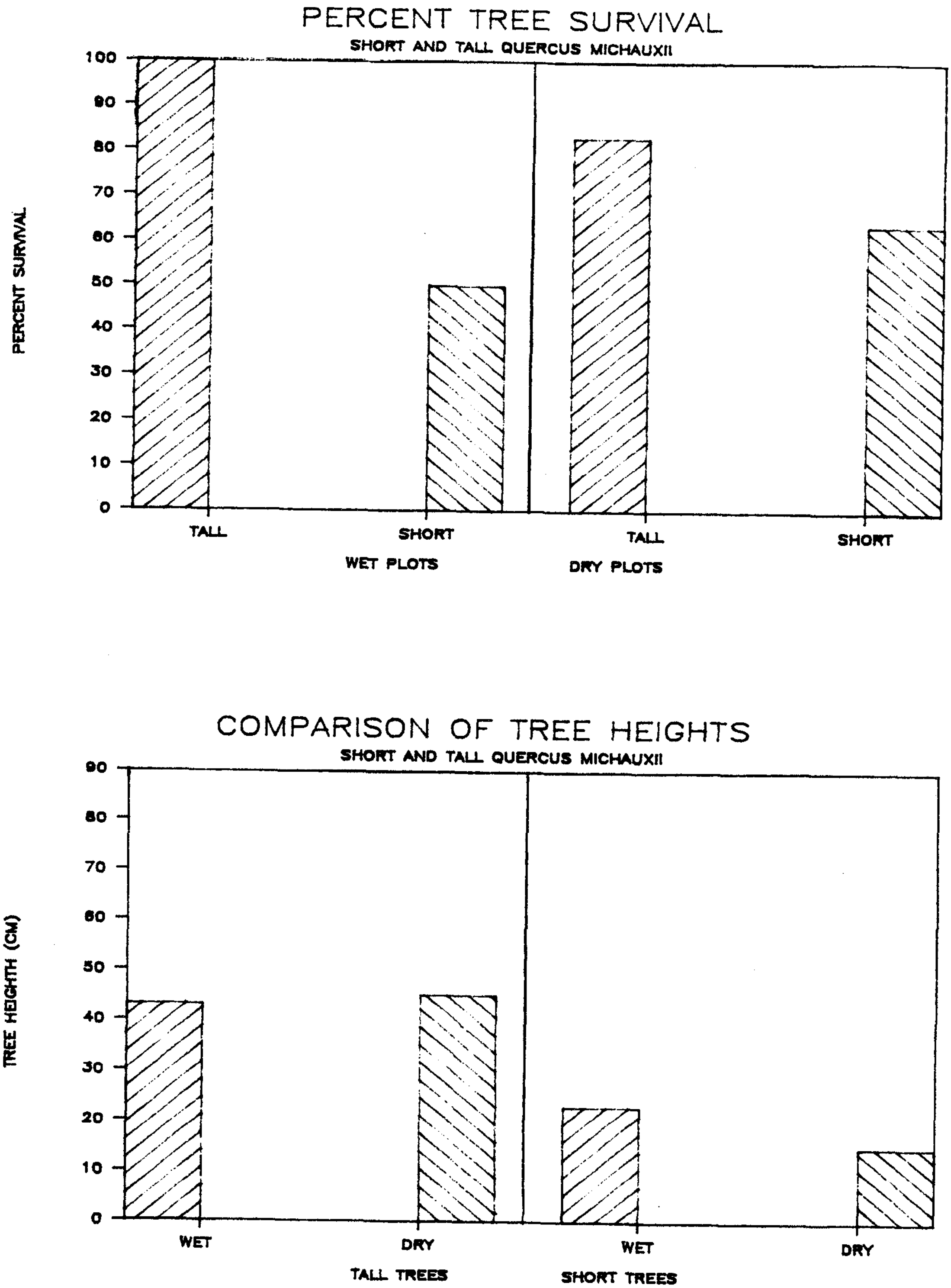


Figure 2.8 . Comparison of short and tall swamp chestnut oak, *Quercus michauxii*. (a) Percent tree survival compared by hydrology; (b) tree heights compared by hydrology.

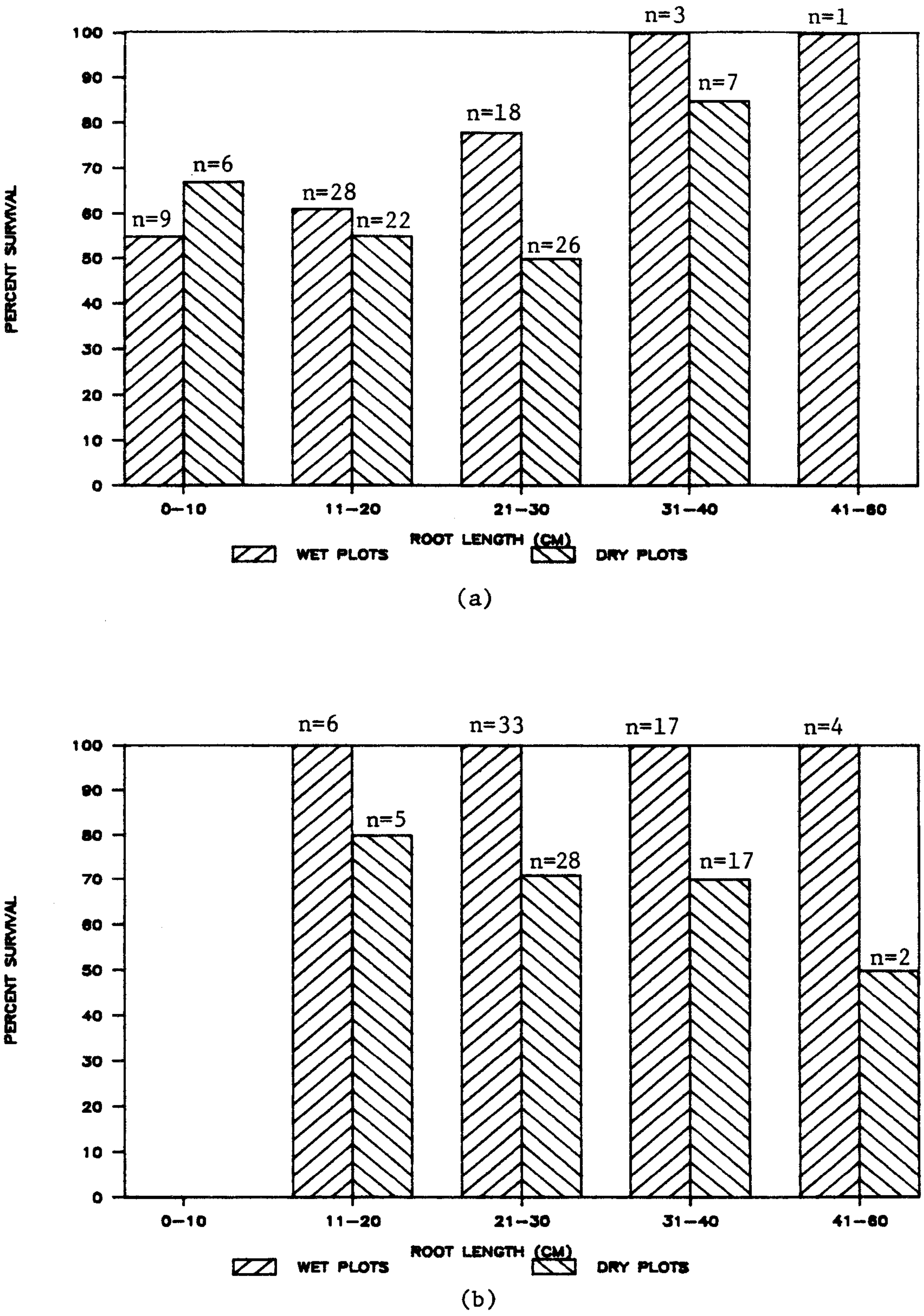


Figure 2.9. Percent tree survival of all trees compared by root length at planting. (a) Tall trees; (b) short trees.

Trees in the wet plots were planted in standing water and were exposed to extended periods of flooding during the growing season. Many of the short trees were completely submerged for part of the year. An obvious advantage of tree height would be to keep the trees' apical bud above flood waters. The variability of species response is not unusual. Green ash can tolerate flooding for up to 40% of the growing season (Fowells, 1975). Louchs and Keen (1973) planted seedlings of baldcypress, green ash, and black walnut with seven other hardwood species and then submerged the seedlings for variable time periods. After four weeks survival varied from 0% for black walnut to 100% for green ash.

Short and tall trees suffered in the drier plots. The stress of too little available water reduced survivorship of all trees compared to the wet plots. Tip die back and basal sprouting of trees was evident in the dry plots and not in the wet ones.

Percentage-wise, mortality of tall trees was lower than short trees, but there was no statistical difference. The cause of this discrepancy is unclear.

Short trees with root systems greater than 30 cm had good survival in both dry and wet plots. Tall trees performed at 100% in all wet plots and averaged 70% survival when root lengths were between 11 and 40 cm. Root length appears to be a positive factor for short trees, but does not have an effect on tall tree survival. For both classes of trees the longer roots were most effective in increasing survival under wet hydrological conditions.

In conclusion, hydrology and species were key factors in determining experimental results. Tree height does appear to be a positive factor adding to tree survival, but of minor importance compared to available water and the individual genetic tolerances of a given species.

Summary

Experiments were performed to test the influence of soil age, nutrients and initial tree height on survival and growth of hardwood trees. Both greenhouse and field experiments were performed.

The age of soil or length of biological amelioration affected tree growth. Older soils produced taller trees. The addition of nutrients was beneficial to tree growth in all age classes of soil. What appears to be contradictory is that best growth (net change in height) was not obtained for the oldest soil, but rather a mid aged one. This experiment highlights design considerations for future experiments. Trees grown in greenhouses will probably reach a maximum size depending on pot size. In some instances final heights may not be a good indicator of experimental success but preferable parameters would be rate of growth or basal area changes.

Trees of different initial heights planted in a field experiment responded primarily to hydrology and the individual tolerance of each species to site conditions. An influence of inital tree height was indcated by the larger percentage of surviving tall trees than short trees, under varying hydrological condiitons.

Each of these factors was tested independently and as such indicates an influence on tree survival and growth. What is not known is the effect on trees of interactions between these factors.

3. GROWTH OF BALD CYPRESS AND POND CYPRESS SEEDLINGS AND THE EFFECT OF NUTRIENT TABLETS

STEVE EVERETT

The succession of wetland areas often becomes arrested at the shrub or willow stage due to lack of a seed source availability (Rushton, 1983, McClanahan, 1986). In order to move beyond this arrested stage and accelerate the return of pre-disturbance hardwood and conifer species, seeds or seedlings must be transferred in (Gunderson, 1984, Rushton, 1987). Cypress, as a wetland species, has been widely planted, however few investigations have directly compared the two taxa, Taxodium distichum and Taxodium ascendens. Comparisons that have been done often lack reference to edaphic factors, and/or produce conflicting results.

In a study about light intensity, baldcypress consistently outgrew pondcypress in all light treatments except 100% of full sunlight (Neufield 1983). In a study using soils with identical conditions, pondcypress showed a 50% greater height growth than baldcypress, but the stem diameters were roughly equal (Murphy, Stanley, Hollis, 1974).

When survival, height and diameter growth of planted baldcypress were compared with pondcypress in several post-mining sites, no significant differences in growth or height appeared. However, survival rate of baldcypress was significantly greater than pondcypress (Rushton, 1987). Both pond and baldcypress performed best when planted on sites influenced by clay. Hydrologic factors appear to play a vital role in their survival and growth (Rushton, 1987, Miller, 1987).

In naturally occurring situations, pondcypress generally predominate in low nutrient soils, while baldcypress are more commonly associated with higher nutrient conditions (Odum, 1984, Monk, 1965).

In order to successfully utilize both species as transfer plants for wetland restoration, a more complete comparison of the trees is necessary. The purpose of this study was to directly compare baldcypress with pondcypress on 5 different post-mining soils. Since mining reclamation techniques create different mixtures of sand and clay, the soils chosen cover the spectrum from pure sand to pure clay and contain varying concentrations of macro- and micronutrients. The study involves both field and greenhouse experiments.

On reclaimed and frequently adverse sites, one of the main impediments to tree success is nutrient deficiency (Bloomfield et al., 1982, Schultz, 1978). Most likely to be deficient are the nutrient elements nitrogen, phosphorus, and potassium, in that order of frequency of deficiency (Smith, 1986, Bloomfield et al., 1982, Schultz, 1978, Date, 1973, Bengston, 1968).

Nutrient analyses of reclaimed phosphate land have repeatedly shown good fertility. High phosphorus, calcium and magnesium levels are frequently found with potassium and zinc occasionally below levels adequate for agricultural purposes (Mislevy, 1988, Wallace and Best, 1983, Hawkins, 1983, Rushton, 1987, Everett, 1987). Due to its reliance upon biological activity and often ephemeral nature, nitrogen is not routinely measured in nutrient analyses. Since the soil materials of reclaimed lands are generally overburden or residual clays from phosphate ore separation, initial plant available nitrogen is low (Hawkins, 1983).

Research studies on Florida phosphate clay settling ponds have indicated that a nitrogen source may be the sole factor necessary to enhance soil fertility (Farmer and Blue, 1978, Mislevy, 1988). Repeated applications of nitrogen to maintain a continuous supply for developing trees is a problem on the sometimes remote and difficult terrain of reclamation lands. Several commercially available, slow release nitrogen fertilizers offer a potentially cost effective solution (Mays and Bengston, 1978).

Numerous studies have demonstrated the effects of fertilization of southeastern pine forests but few studies have evaluated cypress tree fertilization. One such project (Dickson and Broyer, 1972), involving fertilization of baldcypress and tupelo gum, produced greatest height and biomass increases in saturated soils fertilized with urea source nitrogen.

Differences in growth and survival, related to water and nutrient availability have been noted for cypress planted on various sites (Rushton, 1987, Deghi, 1984, Gunderson, 1984, Murphy et al., 1974). Differences in success between cypress species have likewise been demonstrated. Baldcypress, typical of high nutrient alluvial floodplains, have been compared with pondcypress, commonly of low nutrient cypress domes, in several post mining sites (Rushton, 1987, Everett, 1988). Generally, no significant differences were noted between the species in height growth response, however baldcypress did show a greater survival rate.

In general, addition of nitrogen and phosphorus produces the greatest growth responses in all hardwood and conifer forests (Schultz, 1978, Dickson and Broyer, 1972). Increases in height and basal area are frequently reported following nitrogen fertilizers, with urea nitrogen giving better results than nitrate sources (Armson et al., 1975), Hauch, 1968, Dickson and Broyer, 1972, Davey, 1968).

Height growth response to fertilizer has shown a 30% increase in some wet slash pine sites, although nitrogen applied alone may not benefit tree growth if phosphorus is deficient (Pritchett and Smith, 1972).

Fertilization of developing tree stands has even been shown to reduce leaf and needle diseases and reduce damage by defoliating and boring insects (Foster, 1968).

Fertilizer can obviously provide the nutrients necessary for enhanced site productivity, but several factors remain unknown. A better understanding is needed of optimum levels of fertilization, species-specific responses, methods of application and the bounds of energy and cost effectiveness.

The role of micro- and macronutrient soil amendments in establishment of cypress seedlings on clay settling ponds is reported in this chapter.

METHODS AND MATERIALS

Field Comparison of Pond and Bald Cypress

During July 1987, 220 pond and baldcypress seedlings were planted in 5 post-mining sites. Sites were chosen for their variation from almost pure sand to almost pure clay as well as differing levels of nutrients. Two sites were in Alachua County and 3 sites were in Polk County. The Alachua sites were mined for foraminiferous limestone (Crystal River Formation) and the Polk sites were mined for phosphate. All sites had standing water and large growths of willows.

All seedlings were planted under willows to simulate natural successional processes (Brown and Montz, 1986, Wharton, 1977) and to provide optimal light conditions (Neufield, 1983). Seedlings were planted on 1 meter centers in paired 10 meter lines. When ground elevations and water levels were relatively homogeneous, each column was planted with a single species. When conditions did not favor single species lines, seedlings were alternated to balance exposure to water levels in series as follows:.

X X X X X X X	X 0 X 0 X 0 X 0 X
single species lines	alternate species lines
0 0 0 0 0 0 0	0 X 0 X 0 X 0 X 0

X = Bald   0 = Pond

Two replicate paired plots of 22 trees each were established at each site. The trees, all greenhouse-grown tubelings, were planted using a KBC planting bar. Water depth and tree height (ground surface to apical bud) were measured at planting.

Soil samples were taken from each site using a mud auger and placed in plastic bags for later analysis. A portion of each sample was analyzed (Wallace Lab, University of Florida) for macro- and micronutrients. Other portions were used (in the Center for Wetlands Lab) for determining sand, silt, and clay content using the hydrometer method (Klute, 1986) and sieving. Several liters of soil were also removed from each site for use in greenhouse studies.

Greenhouse Comparison of Pond and Bald Cypress

Fifty seedlings were planted in 20 centimeter diameter pots in the CFW greenhouse for more controlled study. Five pond and 5 baldcypress seedlings were planted in material removed from each field site. The pots were arranged in a random block design (Little & Hills, 1978). Measurements were made of each seedling's height above soil surface at planting.

Field Test of Nutrient Tablets

In March, 1988, two experimental plots were established at the Mobil Mining Reclamation Site in Homeland, Florida, on a 20-year-old clay settling pond. Site 1 had 60 bareroot baldcypress seedlings planted among Juncus and Salix, in saturated soil, under a nurse crop of cottonwood trees. Site 2 was at a higher elevation and had 60 baldcypress planted among cogon grass on unsaturated soil.

Both plots were 6 rows of 10 seedlings on 2 meter centers, planted with a KBC planting bar. Trees in alternate rows were fertilized at planting with a single 9 gram Agriform Forest Starter Tablet to provide a slow release of nutrients with an N,P,K ratio of 22-8-1 (Table 3.1). Water depth and tree height (ground surface to apical bud) were measured at palnting.

Greenhouse Test of Nutrient Tablets

Soil material was removed to the Center for Wetlands greenhouse for replicate studies involving both baldcypress (Taxodium distichum) and pondcypress (Taxodium ascendens). Seedlings were placed in 12 rows of 8 plants with baldcypress and pondcypress in alternate pots. Equal numbers of each specie were randomly fertilized at planting with Agriform tablets. Plants were watered twice daily from overhead sprinklers to maintain saturated soil conditions.

A portion of the Mobil site soil material was sent to Wallace Lab, University of Florida, for macro- and micronutrient analyses. No major pre-treatment deficits in P, K, or Ca were found (Table 3.2).

Site Descriptions

The Hollingsworth site (Figure 3.1) is in an abandoned limerock mine near High Springs. The area was abandoned in 1967, however active mining is taking place on adjacent land. All of the properties are owned by E.V. Hollingsworth. Transects are located along the edges of water filled mining cuts. The soil is a thin layer of overburden on limestone and is periodically flooded.

Hashknife (Figure 3.2) is the oldest site. It is an abandoned limerock mine, west of Gainesville, off Hwy. 241 N. The mine was last active in 1948 according to the Buchanan families, the landowners. Trees were planted along the banks of shallow ponds lined with willows.

Table 3.1 Chemical content of Agriform Forest Starter Tablets, 9 grams each.*

Component	% by weight
Total Nitrogen (N)	22.0%
Available Phosphoric Acid (P_2O_5)	8.0%
Soluble Potash (K_2O)	2.0%
Combined Calcium (Ca)	3.0%
Combined Sulfur (S)	1.0%
Iron (Fe)	0.5%
Zinc (Zn)	0.1%

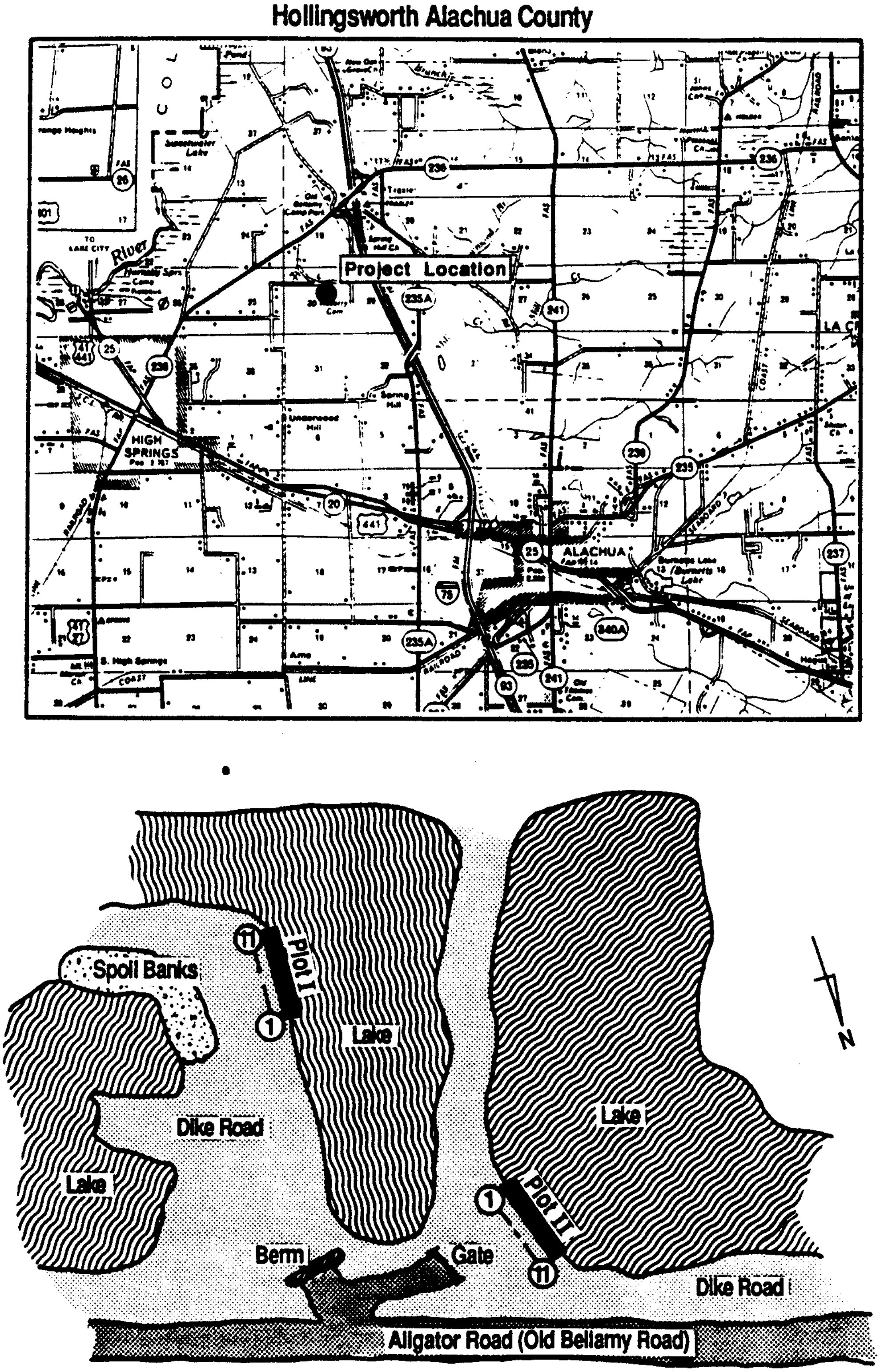
* Derived from Ureaformaldehyde, calcium phosphates, potassium sulfate, calcium sulfate, ferrous sulfate, and zinc sulfate.

Sierra Chemical Company
1001 Yosemite Drive
Milpitas, California, 95035

Table 3.2. Chemical analysis of soils used for tablet studies.* Nutrients in parts per million.

Sample	pH	P	K	Ca	Mg	Al
Mobil greenhouse sample	7.2	400	44	2000	800	272
Mobil greenhouse sample	7.2	400	52	2000	800	228
Mobil surface core	7.0	400	44	2000	800	268
Mobil surface core	7.1	400	44	2000	796	296
Mobil core 1 meter	7.2	400	48	2000	800	124

* IFAS Extension Soil Testing Laboratory
University of Florida
Gainesville, Florida, 32611



Hollingsworth Alachua County

Figure 3.1. Hollingsworth site.

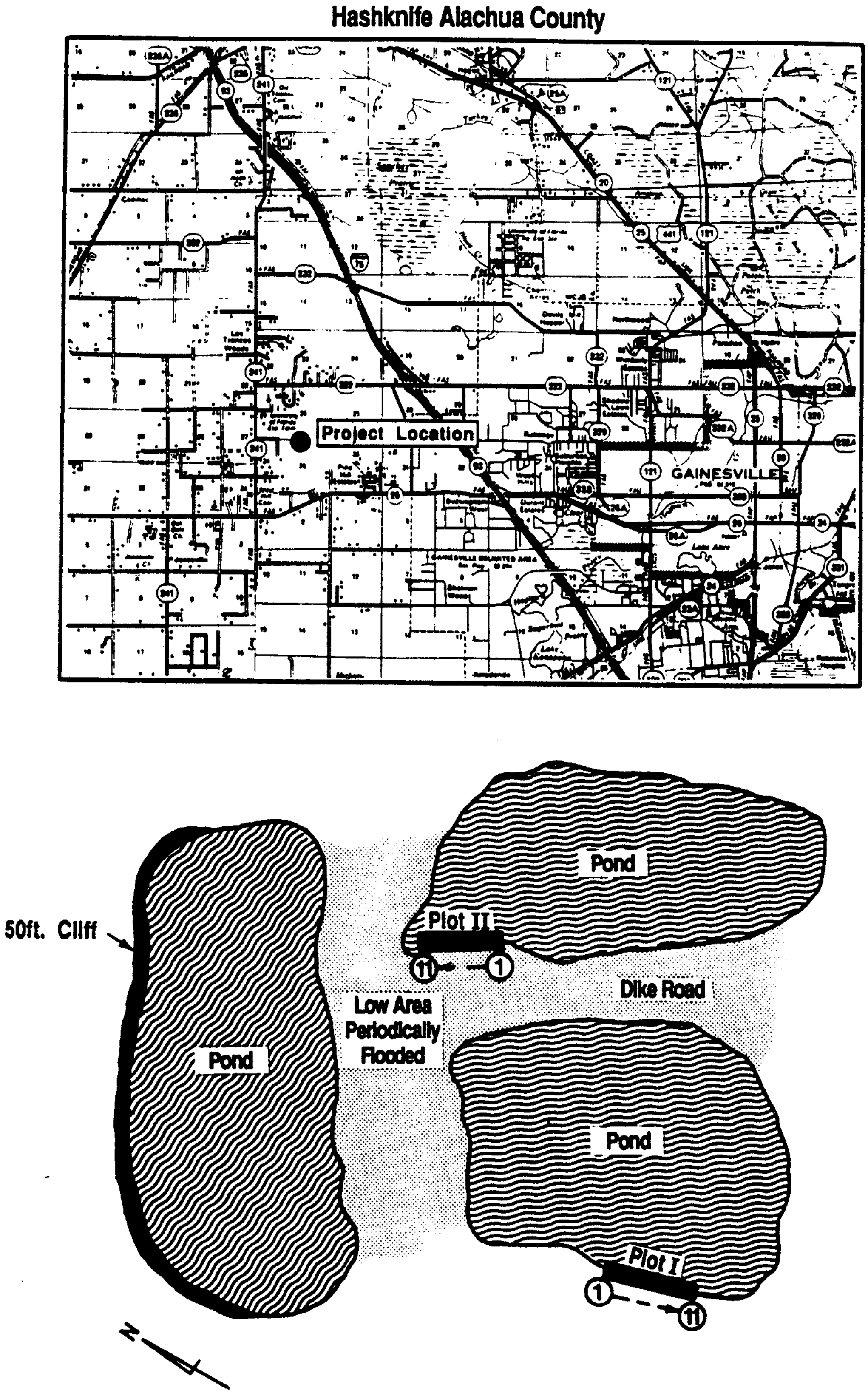


Figure 3.2. Hashknife site.

Tenoroc (Figure 3.3), in Polk County, is an old clay settling pond that is currently part of a State Reserve maintained by the Department of Natural Resources. The area was abandoned in 1972 and is surrounded by spoil piles. The transects were located in an intermittently flooded area. The eastern plot (I) was wetter, being on the edge of a small pond, while the western plot (II) was noticeably drier with no standing water nearby.

IMC-H9 and IMC-H9-A (Figure 3.4) are part of a reclamation project by the International Mineral & Chemical Corp. Both sites are adjacent and are a clay settling area abandoned in 1970 and capped with sand in 1979. The plots of IMC-H9 were planted in a wet swale, in soil that was essentially 100% sand. The IMC-H9-A plots were planted along the edge of a lake in flooded soil that was mixed sand and clay.

Particle sizes varied widely from site to site. Clay percentage ranged from a low of 0% at IMC-H9 to a high of 71.6% at Tenoroc. Sand percentages showed a reverse trend and went from a high of 100% at IMC-H9 to a low of 3.4% at Tenoroc (Figure 3.5).

With the exception of Tenoroc, all of the sites demonstrate a basic pH (Table 3.3). While all of the sites have large quantities of calcium, the Polk County sites have significantly larger amounts of phosphorus, magnesium, and aluminum due to the fact that they are phosphate rather than limerock mines. Nitrogen as NH4 and NO3 were highest at Hollingsworth, Hashknife, and Tenoroc.

RESULTS

Field Comparison of Pond and Bald Cypress

The 9 month height growth differences within each field plot were subjected to a paired-plot t test at a 0.05 level of significance. There was no significant difference in the growth performance of baldcypress when compared to pondcypress (Figure 3.6).

A comparison of sites did yield significant results. Both species performed much better at Hashknife than at any other plot. Tenoroc's poor growth results were, in large measure, influenced by rabbit grazing and actually approached Hashknife results when grazed plants are discounted.

A significant difference occurred in the survival of species. Baldcypress showed a 92% overall survival, whereas pondcypress managed only 76%. This variation was apparently due to the poor accommodation of pondcypress to innundation stress. Survival differences were particularly noticeable at IMC plots where water levels rose following planting. IMC-H9-A was essentially drowned (Figure 3.7).

Comparison of Pond Cypress and Bald Cypress in Greenhouse

In greenhouse experiments statistical analyses showed significant growth differences between species grown in soils from Hashknife and IMC-H9 with baldcypress outperforming pondcypress (Figure 3.8). Major

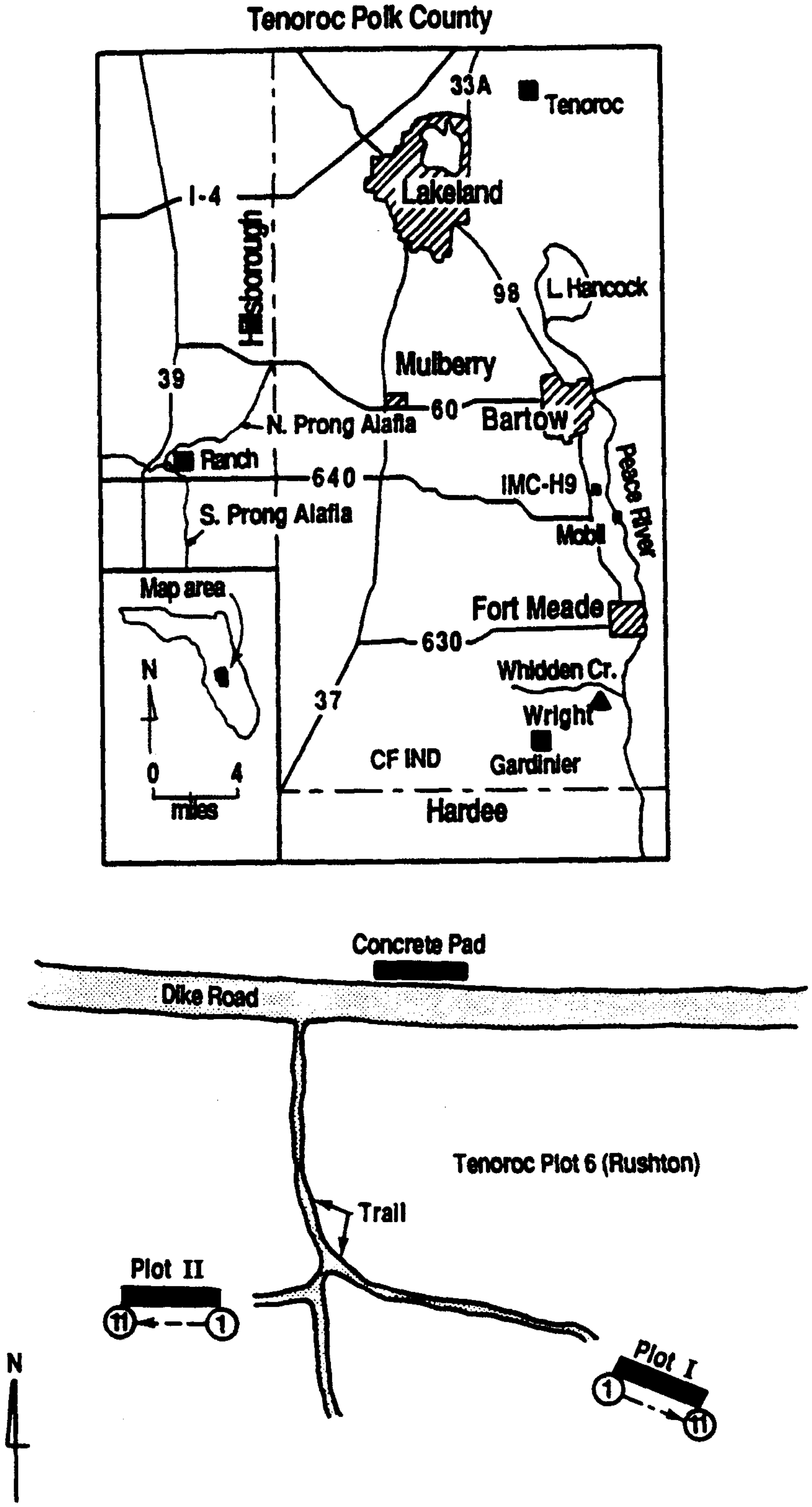


Figure 3.3. Tenoroc site.

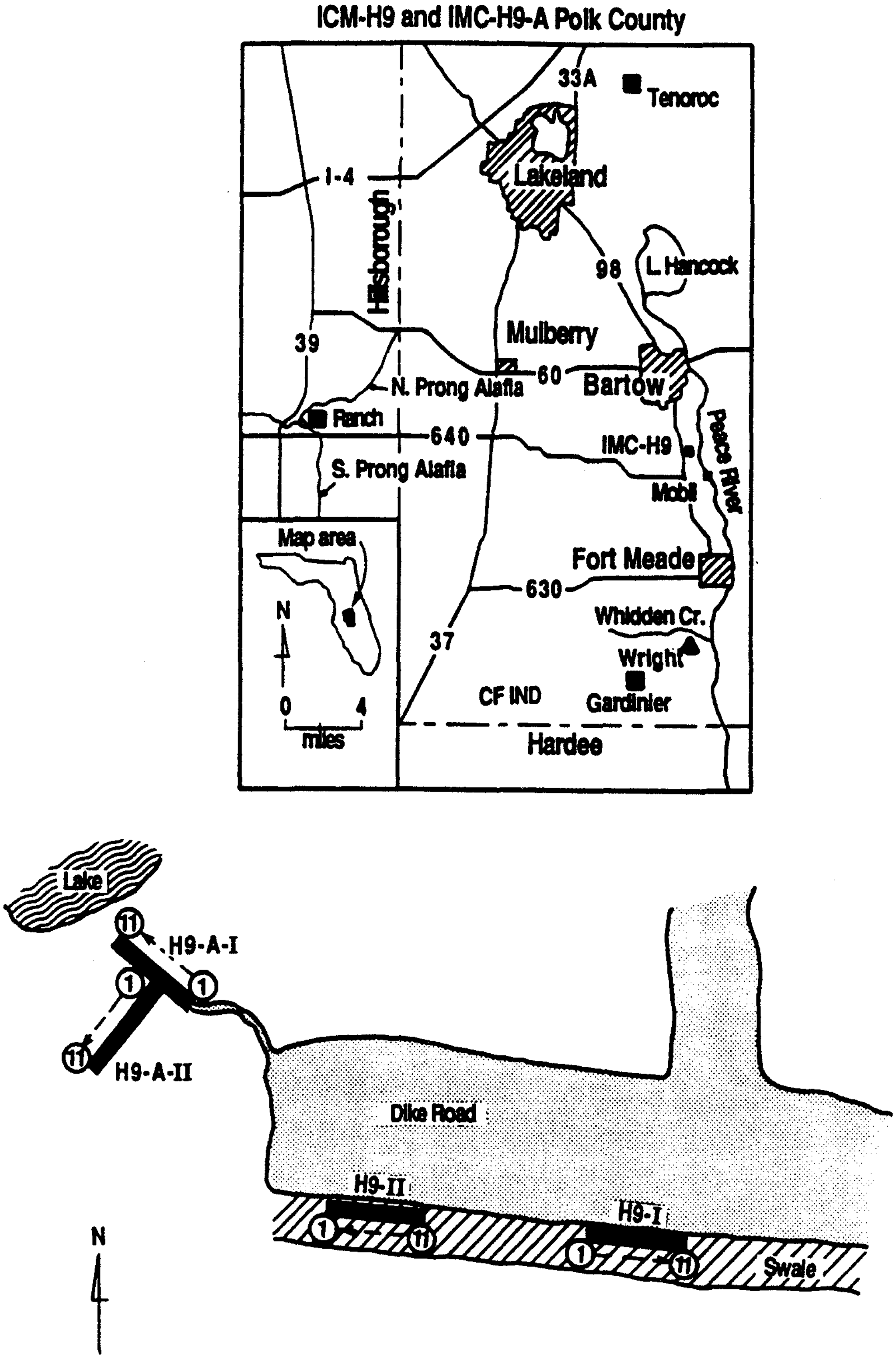

ICM-H9 and IMC-H9-A Polk County

Figure 3.4. IMC sites.

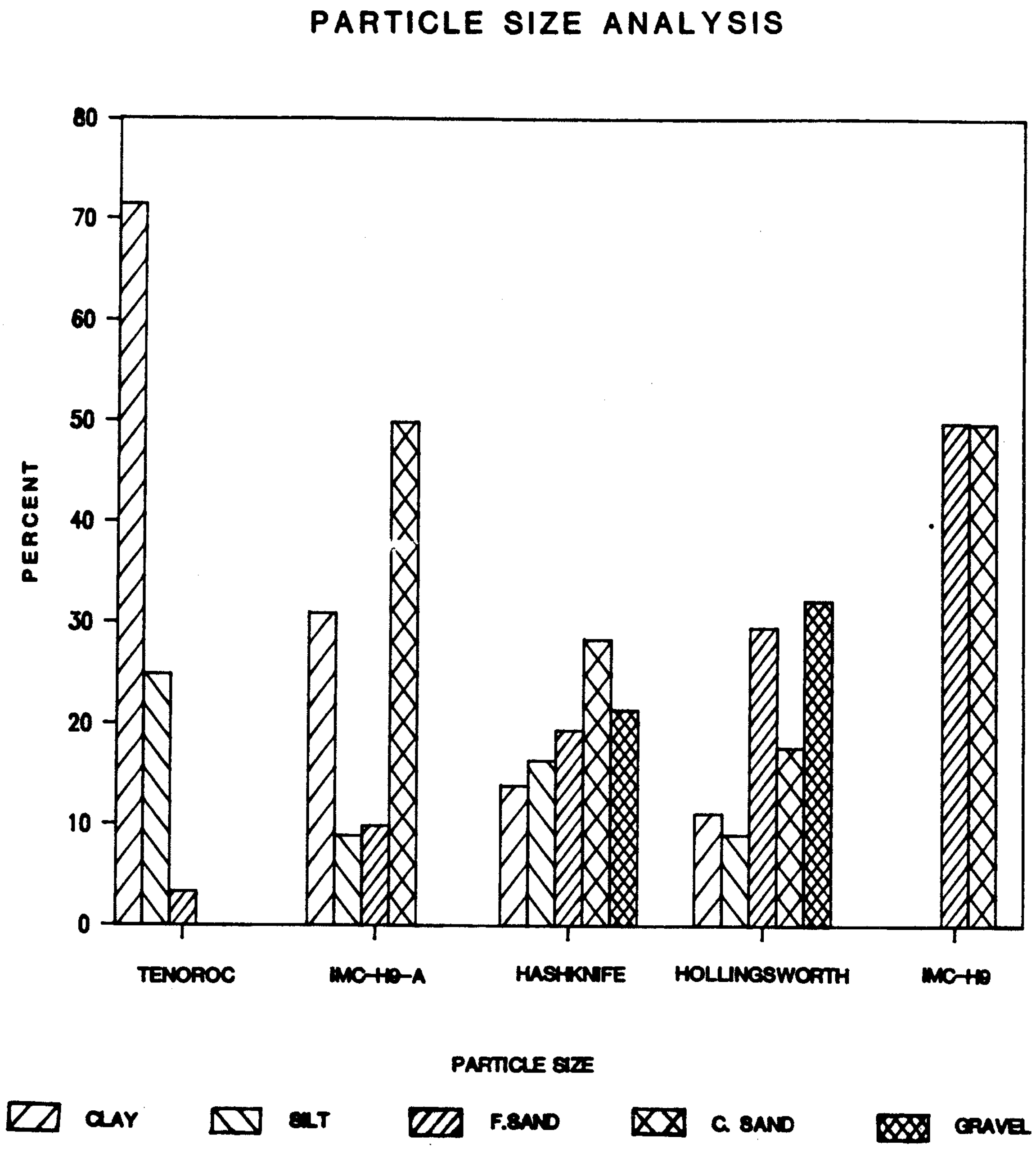


Figure 3.5. Particle size analysis of soils used to test growth of cypress seedlings.

Table 3.3. Soil nutrient analysis.

	PPM SOIL *									Concentration, mg N/L **	
SITE NAME	pH	P	K	Ca	Mg	Al	Zn	Cu	Mn	NH4-N	NO3-N
Hollingsworth	8.5	1	8	2000	56	4	<1	<1	<1	4.377	4.241
Hashknife	8.3	5	12	2000	72	4	<1	<1	1	5.882	4.970
IMC-H9	8.6	200	4	2000	72	60	3	<1	3	2.189	2.462
IMC-H9-A	7.9	200	8	2000	228	144	2	<1	7	3.055	2.417
Tenoroc	6.2	200	28	2000	522	-	-	-	-	10.382	3.648

* Soil analysis by IFAS Extension Soil Testing Laboratory, University of Florida

** Soil Analysis by Department of Soil Science, University of Florida; ratio of soil to water used in making the extract, 1:1.

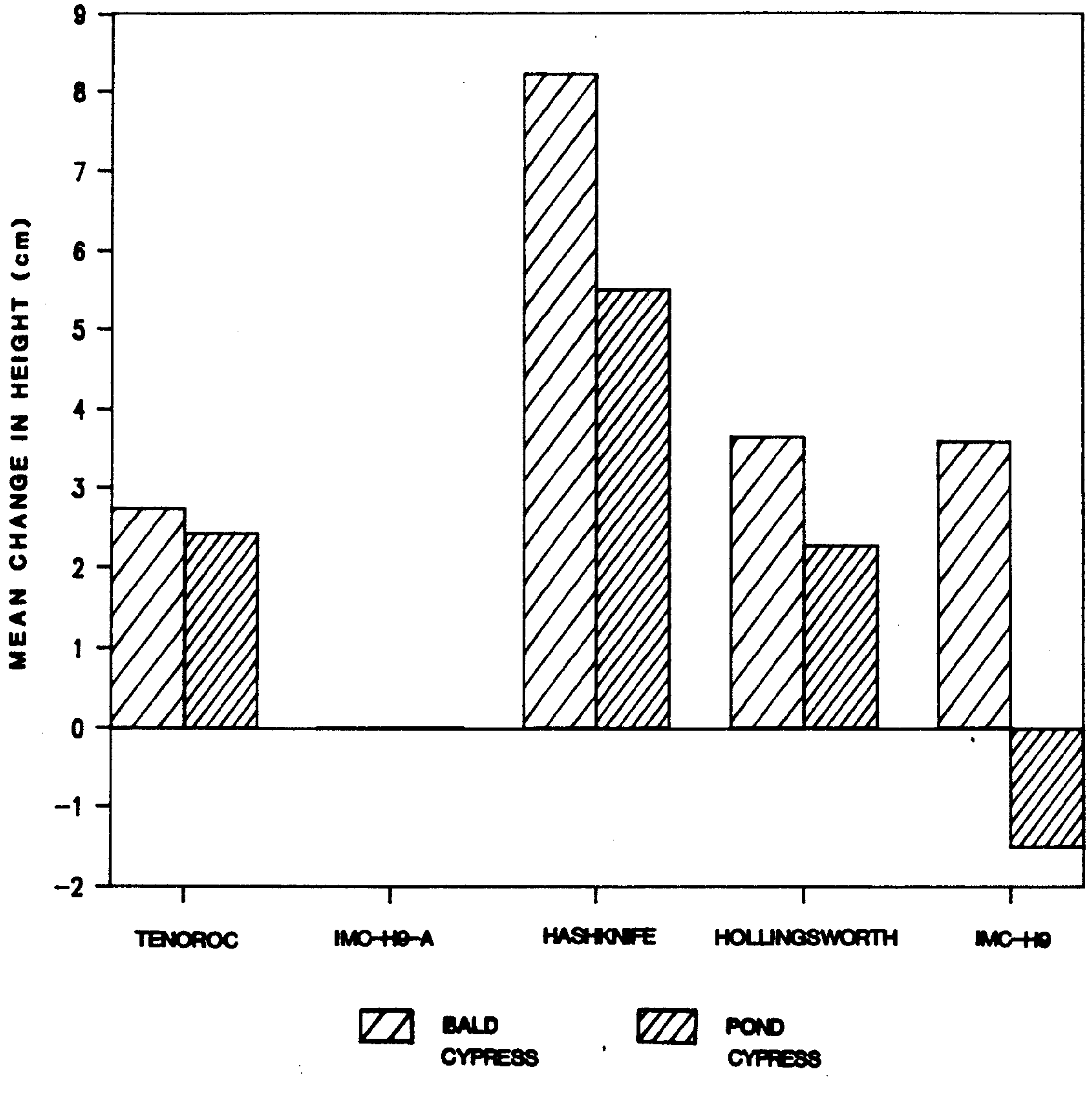


Figure 3.6. Comparison of growth of bald and pond cypress seedlings in field experiments.

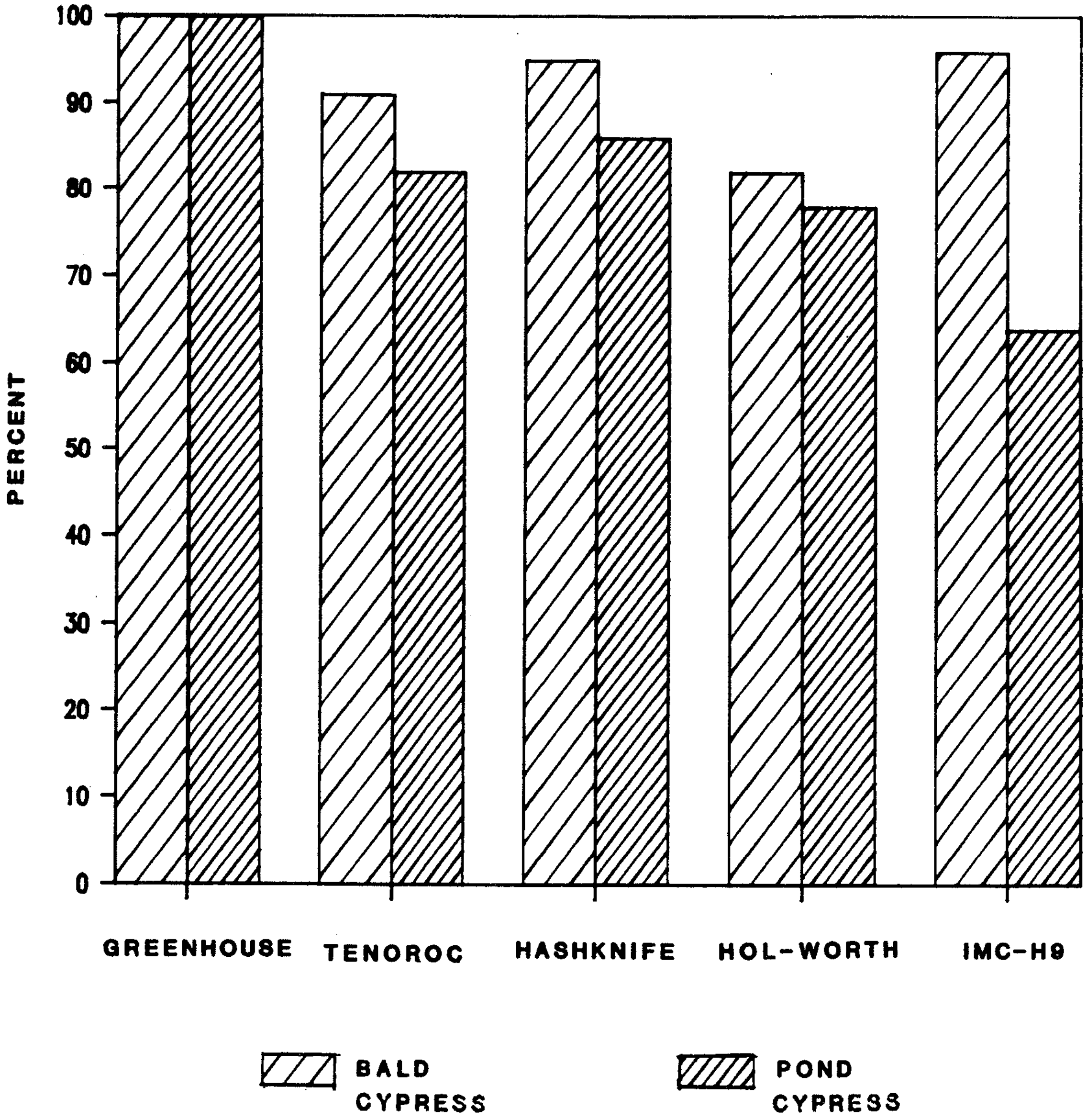


Figure 3.7. Comparison of survival of pond and bald cypress seedlings.

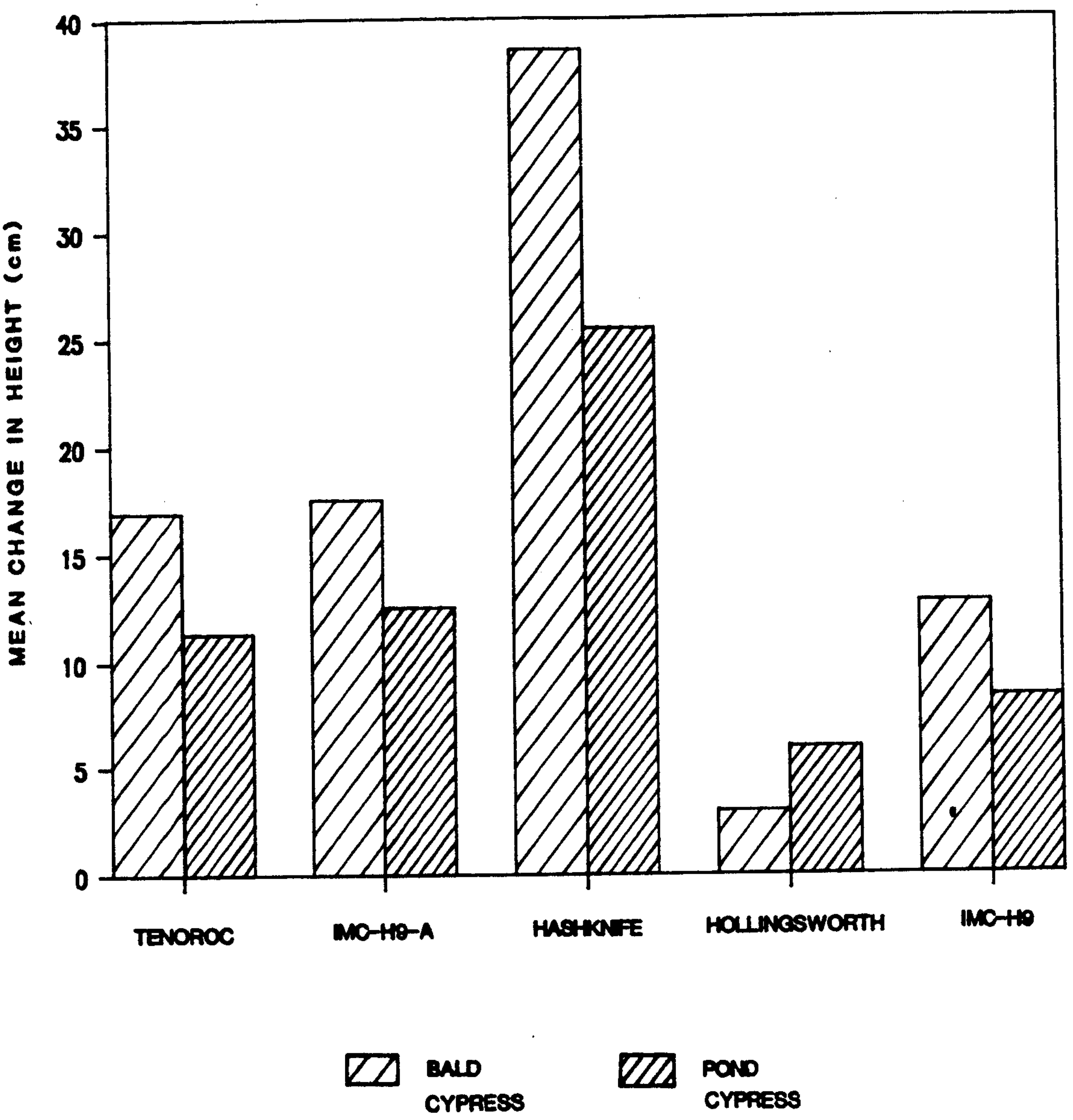


Figure 3.8. Comparison of growth of pond and bald cypress seedlings in greenhouse.

inter-site differences also occurred. Hashknife soil, once again, produced the greatest growth, almost doubling the height changes found elsewhere. Greenhouse survival for all plants was 100%.

Field Test of Nutrient Tablets

After 6 months of growth, plants receiving fertilizer showed significantly greater height than control plants when water was abundant. In the higher and drier field site (2) there was no significant difference noted in growth.

In field site 1, with saturated soil, the fertilized trees showed a mean change in height of 31.20 cm, while control plants showed only a mean change of 12.65 cm (Figure 3.9). When subjected to a t-test, the results were significant to a level of 0.0005.

Greenhouse Test of Nutrient Tablets

Greenhouse studies produced similar results. Fertilized baldcypress showed an average height gain of 41.27 cm and pondcypress averaged 33.85 cm. When compared to controls of each specie, results were again significant to the 0.0005 level.

Basal diameter measurements were done as an afterthought to the original project design, therefore only measures at 6 months were recorded, and then only on greenhouse specimens. These limited measures did prove interesting, however, as trees receiving fertilizer had basal diameters a minimum of 40% larger than unfertilized trees (Table 3.4).

Nutrient analyses demonstrated no major pre-treatment deficits in P, K, or Ca (Table 3.2).

Fertilization of seedlings provided no significant differences in survival of either species in the greenhouse or field sites.

Any results from this project should be viewed with caution as this reports only a 9 month growth period for the seedlings.

Survival and change-in-height results suggest that both pond and baldcypress seedlings do best in soil that is a mixture of sand and clay. The maximum growth occurred at Hashknife, where the sand to clay ratio was approximately 3.4 : 1. This is in agreement with previous studies (Ravina & Magier, 1984, Peterson, 1945) showing that clay soils influenced by medium to high levels of sand and coarse fragments were much better for tree growth than either pure clay or pure sand. The mixture provides better water conductivity as well as better aeration and resistance to compaction. Hashknife soil contained large quantities of gravel and chert fragments, and as particle size analyses showed (Figure 3.5), had the most even size distribution.

The use of height growth as the major criterion for seedling success may be inadequate. Bald cypress and pond cypress were observed to be using two different initial growth strategies. After 90 days of growth, pondcypress demonstrated a predilection for vertical growth

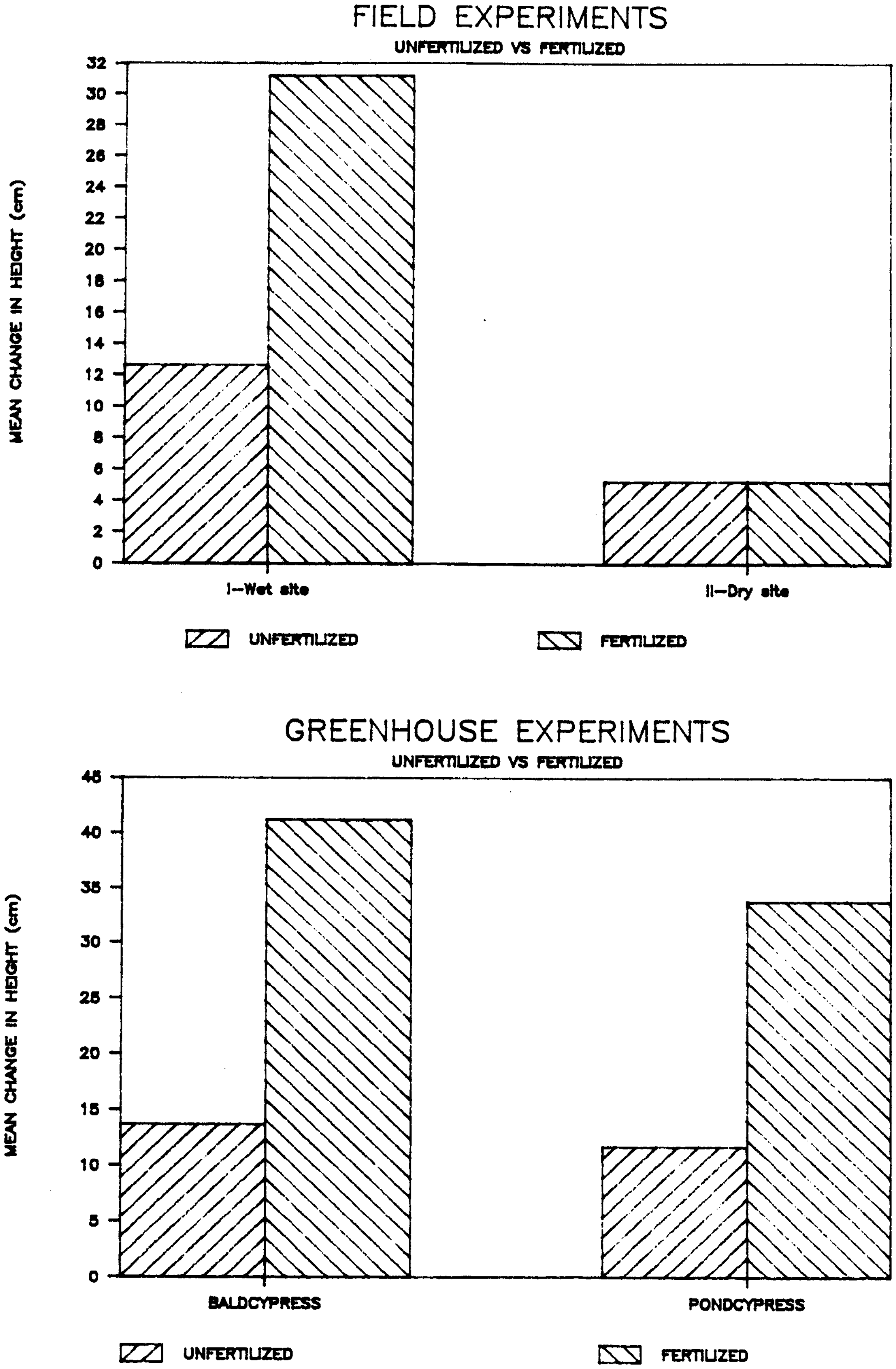


Figure 3.9. Effect of nutrient tablets on growth.

Table 3.4. Mean diameter after 6 months growth.

	cm
Baldcypress with fertilizer	0.85
Baldcypress without fertilizer	0.52
Pondcypress with fertilizer	0.53
Pondcypress without fertilizer	0.37

while baldcypress expended its energy in increasing foliation around the apical bud and increased basal diameter. At 9 months of growth, the height differences diminished and baldcypress appeared to be the height leader.

Establishment of cypress seedlings in saturated soil appears to have been greatly enhanced by the addition of a slow release fertilizer, high in urea (urea formaldehyde) source nitrogen. Growth enhancement was muted or masked in drier, unsaturated soil. Both findings are completely consistent with previous studies.

Survival differences between fertilized and unfertilized seedlings were not apparent during the short term of this project. Even so, the relatively inexpensive (6 cents/tablet) addition of forest starter pellets at planting seems warranted. Although further study is needed, increased height and basilar mass would seem to increase a cypress seedling's opportunity for early establishment and survival.

4. SUCCESS OF SEEDLINGS PLANTED UNDER A MATURE CANOPY

MARY PAULIC AND BETTY T. RUSHTON

INTRODUCTION

Clay settling ponds comprise one of the landscape artifacts of phosphate mining. One means of restoring these lands to a useful function is to reclaim them to forested wetlands. A method of achieving this goal is by accelerating natural succession. Succession is an orderly process by which early species prepare the environment for later species. Early pioneer tree species such as willow and cottonwood may act as "nurse" crops and assist in the establishment of a later successional hardwood forest. Does planting seedlings of later successional species under the canopy of early pioneer trees enhance the survival of those seedlings?

To answer this question, selected hardwood species were planted under cottonwood and willow trees. Comparable plots were also planted in an open pasture area containing cogon grass (*Imperata cylindrica*), soft rush (*Juncus effusus*), and a mixture of disturbed and old field weed species. Trees were planted in groups of northern and central Florida wetland trees. Northern trees are typically found growing together in the northwestern and northern peninsular couties of the state. The central group contained trees common to forested wetlands and floodplains in all parts of Florida.

In addition to investigating the influence of nurse trees on seedling growth and survival, competition for light, space, and response to available soil moisture was tested by planting trees under three different herbaceous cover types. These included softrush (*Juncus effusus*), cogon grass (*Imperata cylindrica*), and a mix of dog fennel (*Eupatorium capillifolium*), blackberry (*Rubus* sp.), ragweed (*Ambrosia artemiisifolia*), and shy leaves (*Aeschynomene indica*). The last cover type will be referred to as ruderal for this chapter. The three herbaceous classes are indirect indicators of the average hydroperiod at any location. In order from *Juncus* to ruderal, the cover types represent wetter to drier soil conditions. In all, nine different combinations of "nurse" tree canopy and herbaceous cover were tested.

The experiment was divided into two parts, (1) the response of each association of trees as a group measured as percent survival and (2) the response of each individual species of tree as measured by percent survival and net growth under varying combinations of canopy and herbaceous cover classes.

Experimental Site

The site selected for this experiment was a 20 year old clay settling pond located on U. S. Highway 17 south near Homeland, Florida.

The land is bordered on the east by the floodplain forest of the Peace River and on the north by Highway 640.

History. Prior to August 1988 the property was owned by Mobil Mining and Minerals. Since that time ownership has been transferred to the Department of Natural Resources of the state of Florida.

Mobil's Homeland mine was located on the site until 1968 and the area was actively mined and used as a disposal area for clay wastes. Most of the original mining site was capped with sand in the early 1970's. In 1981, Mobil initiated a revegetation effort on the part of the site that was not capped with sand. In the winter of that year cottonwoods (*Populus deltoides*) were planted. A large number of the trees survived and now constitute a closed canopy with approximate tree heights between 40 and 50 feet.

Two other plantings were initiated in 1981 and 1982. A Florida timber company planted three different species of pine, seed orchard loblolly, Marion County loblolly, and slash pine, on the site. Survival of trees was poor. The Division of Forestry, under a grant from Florida Institute of Phosphate Research, planted a variety of trees. Results of that study are contained in a publication by Harrell (1987).

The remainder of the site has been planted in bahia grass and sand hill live oak (*Quercus geminata*) and is presently being leased to local cattle ranchers. The length of their leases is indefinite.

Experimental Plots

Trees were planted in plots under various combinations of tree and herbaceous cover. The type of herbaceous cover indirectly indicates the average hydrology of the plot.

Description. The area used for tree planting has three primary canopy covers as defined by the presence or absence or species of tree. These included cottonwood, willow, and open pasture. The cottonwoods were planted in 1981 as part of a reclamation project by Mobil.

Following the moisture gradient of the land were three distinct herbaceous covers. These cover types were classified by the dominant plant species taller than 30 cm that occupied 50% or more of the plot area. Height of vegetation was selected as a criteria for dominance because the taller vegetation can compete with tree seedlings for light and space. The wettest areas were dominated by soft rush (*Juncus effusus*). Drier plots were vegetated with cogon grass (*Imperata cylindrica*). The driest locations had a mixed cover composed of dog fennel (*Eupatorium capillifolium*), ragweed (*Ambrosia artemisiifolia*), blackberry (*Rubus* sp.), and shy leaves (*Aeschynomene indica*). For the purposes of this chapter the three herbaceous covers are classified as *Juncus*, cogon grass, and ruderal.

Total acreage occupied by the experimental plots was approximately 14 acres. Of that total, 8 acres was in cottonwood, 3 acres was willow, and 3 acres was open pasture. The entire experimental site has been fenced to exclude cows.

Species Planted. The tree species selected for planting were common to floodplains and backwater areas of Florida. A total of twelve species were planted. Six species were common to both the peninsular and panhandle regions of Florida. These were classified as the central group and included sweetgum (*Liquidambar styraciflua*), laurel oak (*Quercus laurifolia*), American elm (*Ulmus americana*), cherry laurel (*Prunus caroliniana*), and water hickory (*Carya aquatica*). In areas with *Juncus* cover cherry laurel was replaced with baldcypress (*Taxodium distichum*). The other six species were more commonally found in the northwestern and northern counties of Florida. These were classified as the northern group and included river birch (*Betula nigra*), bitternut hickory (*Carya cordiformis*), yellow poplar (*Liriodendron tulipifera*), swamp chestnut oak (*Quercus michauxii*), and overcup oak (*Quercus lyrata*). In areas with *Juncus* cover, green ash (*Fraxinus pennsylvanica*) was planted instead of overcup oak.

Species were selected for their tolerance to clay soils with poor drainage and alkaline soil conditions. With the exception of baldcypress, all of the trees planted would occupy zones III and IV of an alluvial floodplain as determined by Clark and Benforado's (1981) zonal classification scheme for bottomland forested wetlands. Zone III is semipermanently flooded and Zone IV is only seasonally flooded. Baldcypress is classified as zone II; swamp with intermittent exposure.

Habitat generalists such as American elm (*Ulmus americana* var. *floridana*), laurel oak (*Quercus laurifolia*), and sweetgum (*Liquidambar styraciflua*) will naturally colonize abandoned clay settling ponds if a seed source is located nearby (Rushton, 1986). Baldcypress, green ash, and tulip poplar will typically follow willow in a successional sequence (Putnam et al., 1960).

METHODS

Experimental Design

Trees were planted in paired half plots of 50 trees each of northern and central species in a randomized complete block design. A total of 100 trees were planted per plot with ten replicates of each species. Plots were planted under each of the major tree canopies and also in the open pasture to provide a comparison site. Within each canopy cover four replicate plots were planted in each of the three herbaceous ground covers of *Juncus*, ruderal, and cogon grass. A total of 3600 trees in 36 plots were planted. Table 4-1 is a list of the plots and their classifications.

Plots. Each plot of 100 trees was 18 meters wide by 18 meters long with a distance of two meters between rows and columns of trees. Figure 4-1 contains an example of the plot design. One inch PVC stakes of three to five foot lengths were used to mark the beginning, end, and midpoints of each plot. One half the plot was planted with all five central species assigned randomly to a location within that half of the plot. The same design was used for the northern species. Figure 4-2 is a map of the site containing the location of all plots.

Table 4.1. Summary of plot, tree canopy, and herbaceous cover for plots planted in nurse crop experiment.

Plot number	Tree cover	Herbaceous cover
1A	cottonwood	ruderal
1B	cottonwood	ruderal
2A	cottonwood	*Juncus*
2B	cottonwood	*Juncus*
3A	cottonwood	*Juncus*
3B	cottonwood	*Juncus*
4A	cottonwood	cogon grass
4B	cottonwood	cogon grass
5	willow	*Juncus*
6B	cottonwood	cogon grass
6C	cottonwood	cogon grass
6D	cottonwood	cogon grass
7	open	*Juncus*
8A	cottonwood	ruderal
8B	cottonwood	ruderal
9A	willow	cogon grass
9B	willow	cogon grass
10A	willow	cogon grass
10C	willow	ruderal
10D	willow	cogon grass
11B	willow	ruderal
11D	willow	ruderal
12A	willow	ruderal
13A	willow	*Juncus*
13B	willow	*Juncus*
14A	open	cogon grass
15A	open	*Juncus*
15B	open	*Juncus*
16A	open	ruderal
16B	open	*Juncus*
17A	open	*Juncus*
18A	open	cogon grass
18B	open	cogon grass
19A	open	ruderal
19B	open	ruderal
20A	willow	*Juncus*
21A	none	ruderal

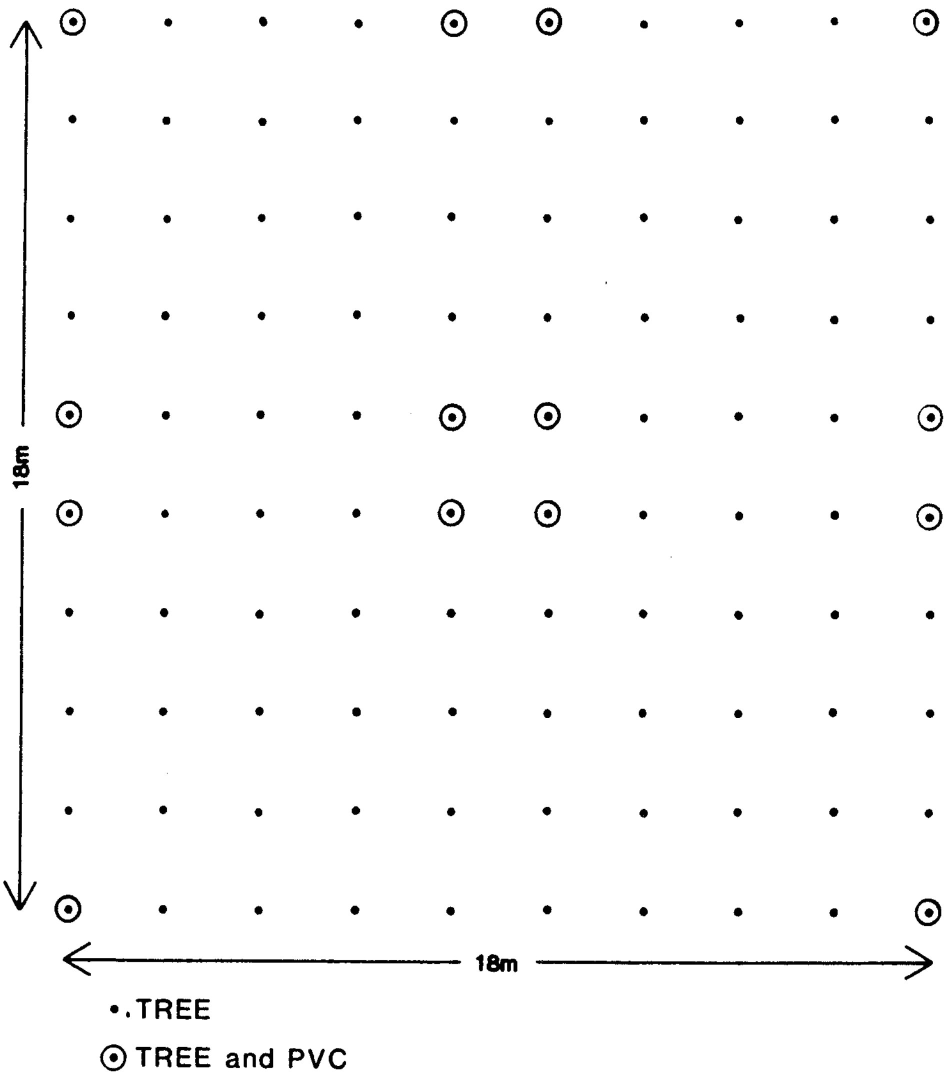


Figure 4.1. Design of plots. Half of plot was planted in northern trees and half in central.

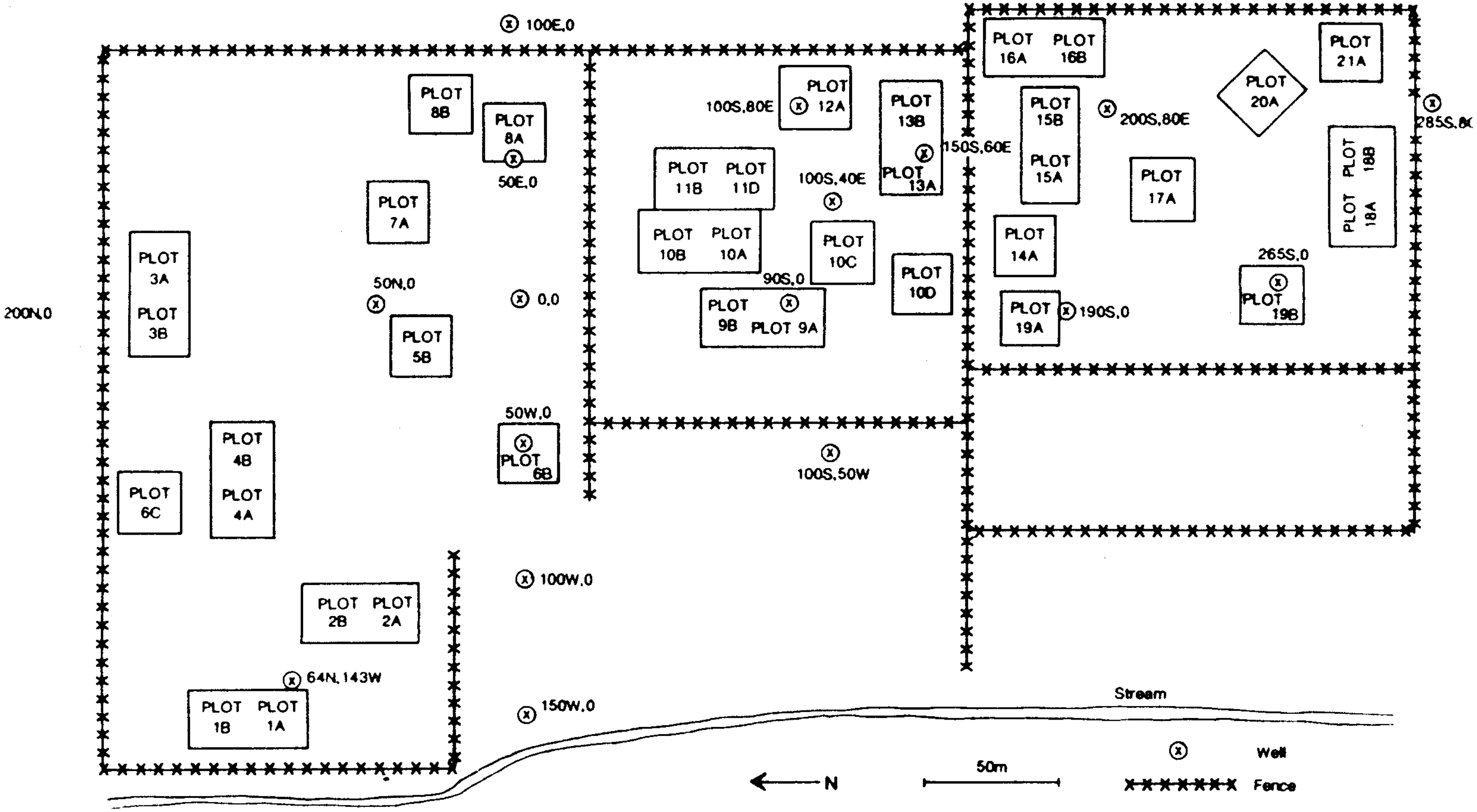


Figure 4.2. Site map of nurse crop experiment indicating location of wells and plots.

Trees were hand planted with KBC planting bars as bareroot seedlings between January and March of 1988. All of the tree species were purchased from Central Florida Lands & Timber, Inc. in Perry, Florida. Initial tree heights were recorded at the time of planting and survival and tree height of all trees were remeasured during the fall of 1988.

Water Level

A network of 20 shallow piezometer wells were installed on the site. The wells were placed along north-south and east-west transects across the site. Locations of wells are indicated in Figure 4-3. Wells were identified by their linear distance north, south, east, or west of the central 0,0 well.

Wells were made of 5 cm diameter PVC pipe fitted with 2 meters of wellscreen on the bottom and capped. Three of the wells (00, 65N 143W, 285S 80E) were made of 7.5 cm diameter PVC pipe to be used with continuous water level recorders. Other water levels were measured monthly.

Statistics

Comparison of mean survival of each association of trees under different combination of tree and herbaceous cover was performed by an analysis of variance with blocks for each herbaceous cover type. Because baldcypress and green ash were planted in exchange for other less water tolerant trees in areas with *Juncus*, they were excluded from calculation of plot percent survival and statistical analyses. Baldcypress and green ash were included in the analyses of individual tree species response. Comparison of individual means for each combination of herbaceous cover and tree canopy were made with Duncan's multiple range test.

The herbaceous cover type was selected as an indirect indicator of hydrology and as such, plots used for statistical purposes had similar ranges of water table measurements. Plots 9A and 9B were excluded from data analysis because the water table at those plots was not comparable to other areas where cogon grass grew. Additionally, plot 19B had to be removed from the data set for ruderal for the same reason.

Comparisons of percent survival between northern and central tree groups for each combination of herbaceous cover class and tree type canopy were made using a chi square test.

RESULTS

Experimental results are presented in the following sections. The order of presentation of data are water level, percent survival of northern versus central trees, and then percent survival and growth of individual tree species.

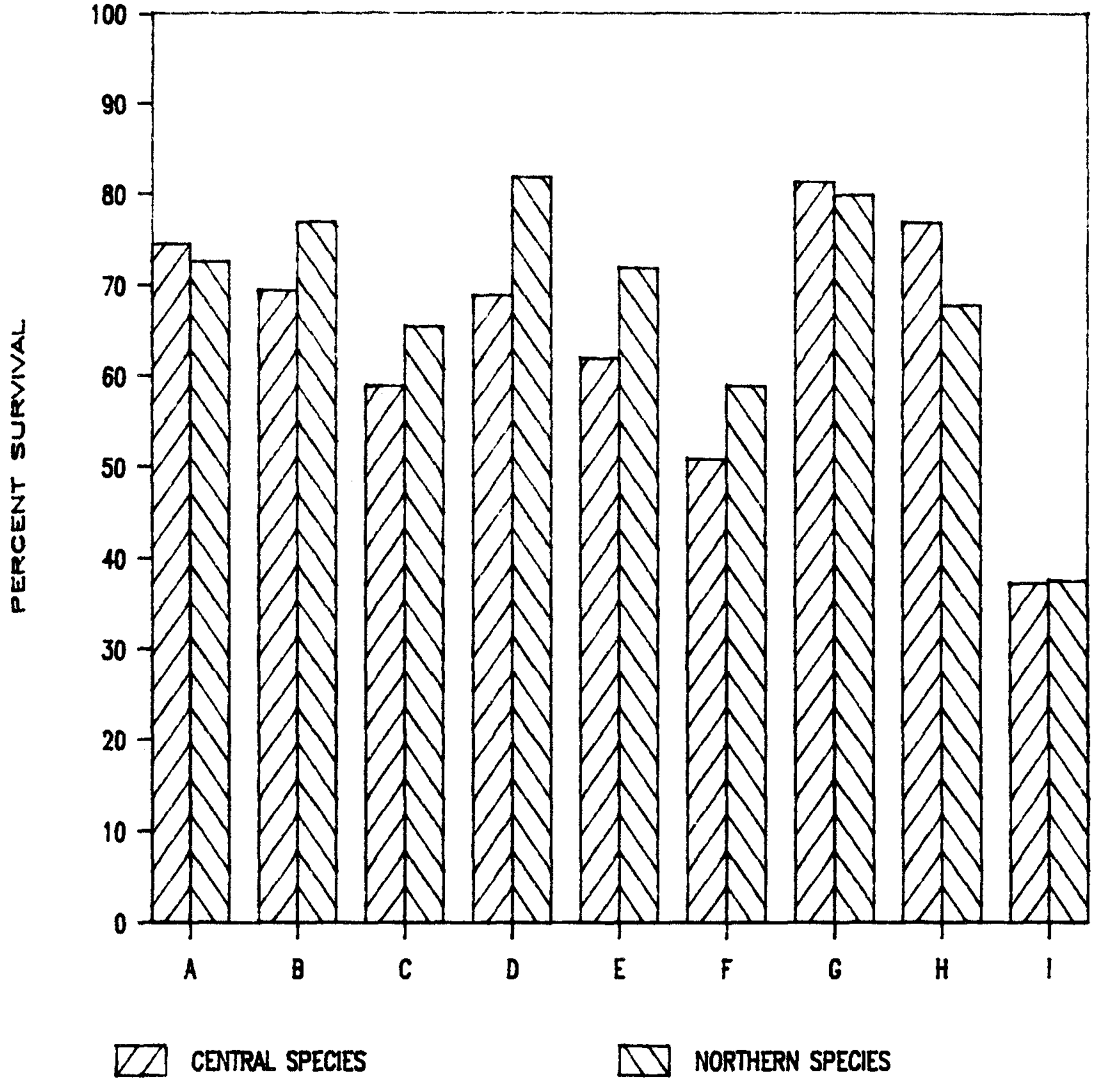


Figure 4.3. Comparison of percent survival of northern and central by different combinations of herbaceous cover and tree canopy.

A Open/ruderal
B Open/cogon grass
C Open/Juncus
D Willow/ruderal
E Willow/cogon grass
F Willow/Juncus
G Cottonwood/ruderal
H Cottonwood/cogon grass
I Cottonwood/Juncus

Water Table Measurements

A total of 21 wells were monitored between March and November, 1988. The range of water levels in each one is presented in Table 4.2. Included in that table are the general herbaceous cover and tree canopy type. To provide some relevancy to tree survival and growth, plots within 10 meters of each well are listed and the number of months between March and November during which the water table was either above or at the ground surface. Table 4.3 lists the average water table ranges for each cover class. Wells 0,100E and 0,360N were located either in or in close proximity to spoil piles and consequently were not used for calculations. Well 0,190S was in a mixed ground cover of cogon grass and ruderal. It was used in calculations for both those cover classes.

The range of water levels varied by herbaceous cover and in some instances tree canopy type. The most consistent water level ranges were in places where *Juncus* grew. In all areas with *Juncus* there was standing water at least part of the growing season.

The wettest depression on the site was located bewteen wells 0,0 and 0,200N. Tree canopy in this area included both cottonwood and willow. Except for the period from May to July, water levels in those wells were above ground level. Six plots were located near these wells; 7A, 5B, 3A, 3B, 2A and 2B. Trees were planted in these plots under varying hydrological conditions of saturated soil to a standing water depth of 27 cm.

The water table in areas covered with cogon grass varied by tree canopy. The consistently lowest water table readings and greatest range of values were recorded under willow trees. The water table where cottonwood grew and in the open sections was usually within the top one meter of the ground surface. Cogon grass tolerates a wide range of moisture conditions. it is also rapidly invading ruderal and drier *Juncus* areas.

Ranges of water table fluctuation for ruderal cover varied more by location within a canopy type on the experimental site than tree canopy. The low water level for ruderal sites ranged from greater than 2.5 meters below the surface to one meter. Water tables rose as close to the surface as 18 cm (7 in) where there were cottonwoods to as low as 2.2 meters in the open site.

Northern versus Southern Trees

Comparison of percent survival of northern versus central trees is presented in Figure 4.3. Average percent survival was calculated for each combination of tree canopy and herbaceous cover. Percent survival for individual plots is presented in Table 4. Included in that table is information regarding the date on which a plot was planted.

Variability in percent survival of both northern and central trees existed between plots planted under the same cover classes. Many of the plots planted in March had the poorest survival within their cover

Table 4.2. Range of water levels for well network. Included in the table are tree and herbaceous cover at each well, plots within 10 m of each well and number of measurements between March and November during which saturated soil conditions existed.

Well	Water level range (cm)	Tree/herbaceous cover	Plot within 10 m	Number of measurements of saturated soil between Mar. and Nov.
0,0	-63 to +19	Open/<u>Juncus</u>	7A	5
0,50E	-208 to -35	Cottonwood/Ruderal	8A	0
0,100E	>-237 to -175	Spoil	Removed 11-6-88	
0,50W	-101 to 0	Cottonwood/Cogon	6B	2
0,100W	-87 to +6	Cottonwood/Cogon		5
0,150W	-135 to -30	Cottonwood/Cogon		0
0,50N	-60 to +40	Willow/<u>Juncus</u>	5B	5
0,200N	-73 to +19	Cottonwood/<u>Juncus</u>	3B	5
0,330N	-77 to +5	Cottonwood/<u>Juncus</u>		2
0,360N	-238 to -145	Cottonwood/Ruderal	Spoil	0
0,70S	-96 to 7270	Willow/Cogon	9A	0
0,90S	-104 to 7280	Willow/Cogon	9B	0
0,190S	-100 to -29	Open/Cogon/Ruderal	19A	0
0,265S	-290 to -223	Open/Ruderal	19B	0
64N, 143W	-125 to -18	Cottonwood/Ruderal	1A, 1B	0
100S, 40E	-190 to -70	Willow/Ruderal	10C, 10B	0
100S, 80E	-160 to -25	Willow/Ruderal	12A	0
200S, 80E	-65 to +5	Open/<u>Juncus</u>	15B	3
285S, 80E	-66 to 0	Open/Cogon	18B	1
150S, 60E	-139 to +3	Willow/<u>Juncus</u>	13A, 13B	2
100S, 50W	>-236 to -142	Willow/Cogon		0

Table 4.3. Average water level range for each combination of herbaceous and tree cover.

Tree canopy	Herbaceous cover	Range of water levels (cm)
Cottonwood	Ruderal	-167 to -27
Cottonwood	Cogon grass	-107 to -8
Cottonwood	*Juncus*	-75 to +12
Willow	Ruderal	-175 to -52
Willow	Cogon grass	>-236 to -114
Willow	*Juncus*	-100 to +21
Open	Ruderal	-195 to -99
Open	Cogon grass	-83 to -15
Open	*Juncus*	-64 to +12

Table 4.4. Percent survival and planting time for each plot. Included in this table are average percent survival with one satndard error for each combination of tree and herbaceous cover classes.

Plot #	Canopy	Herbaceous cover	% Survival northern species	% Survival central species	Time of planting
1A	Cottonwood	Ruderal	82	86	1-29
1B	Cottonwood	Ruderal	82	92	1-29
8A	Cottonwood	Ruderal	96	92	2-7
8B	Cottonwood	Ruderal	60	56	3-19
Mean			80	81.5	
Standard error			7.4	8.6	
2A	Cottonwood	*Juncus*	40	45	3-19
2B	Cottonwood	*Juncus*	35.7	44.7	2-13
3A	Cottonwood	*Juncus*	37.5	25	1-28
3B	Cottonwood	*Juncus*	37.5	35	1-28
Mean			37.7	37.4	
Standard error			0.88	4.75	
4A	Cottonwood	Cogon	82	84	
4B	Cottonwood	Cogon	74	80	1-31
6B	Cottonwood	Cogon	56	62	2-7
6C	Cottonwood	Cogon	60	80	3-19
Mean			68	76.5	
Standard error			6.05	4.92	
10C	Willow	Ruderal	76	54	3-20
11D	Willow	Ruderal	88	72	2-13
12A	Willow	Ruderal	82	80	2-13
Mean			82	68.7	
Standard error			3.46	7.69	
13A	Willow	*Juncus*	62	56	1-30
13B	Willow	*Juncus*	64	58	1-30
20A	Willow	*Juncus*	56	30	2-14
5B	Willow	*Juncus*	54	60	2-13
Mean			59	51	
Standard error			2.06	6.10	
10A	Willow	Cogon	92	92	1-30
10D	Willow	Cogon	52	32	3-20
9A	Willow	Cogon	94	90	1-30
9B	Willow	Cogon	90	90	1-30
Mean			82	76	
Standard error			10.03	14.67	
			w/out 72	62	
			9A and 9B ±28.28	±42.45	

Table 4.4 (continued)

Plot #	Canopy	Herbaceous cover	% Survival northern species	% Survival central species	Time of planting
16B	Open	Ruderal	68	64	2-14
18A	Open	Ruderal	70	78	2-14
19A	Open	Ruderal	80	82	2-6
19B	Open	Ruderal	54	38	2-14
Mean			68	65.5	
Standard error			4.64	8.61	
		w/out 19B	72.7 ± 6.43	74.7 ± 9.45	
15A	Open	*Juncus*	82	62	1-31
15B	Open	*Juncus*	74	68	1-31
17A	Open	*Juncus*	50	32	2-6
7A	Open	*Juncus*	56	72.5	2-7
Mean			65.5	58.6	
Standard error			±6.5	±7.91	
14A	Open	Cogon	84	90	2-7
16A	Open	Cogon	90	82	2-6
18B	Open	Cogon	72	46	3-12
21A	Open	Cogon	62	60	3-12
Mean			77	69.5	
Standard error			5.41	8.73	

class. Trees had been in and out of cold storage for two months and this may have affected their viability in the field.

For all tree canopies and both associations of trees the poorest survival was recorded under a cover of *Juncus*. Survival of trees decreased in the order of open, willow, and cottonwood. Areas with *Juncus* represent the wettest location on the site. Those plots with the longest recorded time of saturated soil had the poorest survival, in particular plots planted under cottonwood.

An analysis of variance of mean percent survival for each tree association for all combinations of herbaceous cover and canopy type was performed. The treatment effects were considered to be the tree canopy with blocks for each of the herbaceous cover types. No statistically significant effect of tree canopy was noted for either central or northern trees. Blocks or herbaceous cover was statistically significant at better than at the P = 0.05 level. The F-values obtained and their probabilities are listed in Table 4.5.

Comparison of the means for percent survival by herbaceous cover classes with Duncan's multiple range test yielded two statistically significant groups. Ruderal and cogon grass were not different from each other at the P = 0.05 level, but both were statistically different from *Juncus*. The same results were obtained for both northern and central trees.

Northern and central trees performed comparably in each cover class with one exception. The percent surviving northern trees was statistically different from central (p=0.05) with a cover combination of willow and ruderal.

Percent Survival and Growth of Individual Tree Species

Percent survival, initial tree heights, and tree height after one growing season were plotted for all species of trees. The results are contained in Figures 4.4 to 4.15.

Trees were planted in groups of northern and central. As noted in the previous section, there was only one cover class in which a statistically significant difference in survival existed between northern and central trees. The reason for this was that within each group are trees that have a broad range of environmental tolerances and trees which require a more specific set of conditions for growth and survival. Due to the lack of differences in growth and survival between associations, comparisons in this section will not group trees into associations, but rather compare them as independent species. Green ash and baldcypress were included in this section.

Survival of individual trees as a response to different combinations of herbaceous cover and tree canopy was variable. Many species such as sweetgum (Figure 4.11), overcup oak (Figure 4.8), river birch (Figure 4.9), swamp chestnut oak (Figure 4.10) and water hickory (Figure 4.13) had 50% or better survival irregardless of cover class. Other tree species such as laurel oak (Figure 4.7), bitternut hickory (Figure 4.5), tulip poplar (Figure 4.12), and cherry laurel (Figure 4.6)

Table 4.5. List of F value and probabilities for analysis of variance of average survival for northern and central trees.

Northern	F value	Probability	Central	F value	Probability
Tree	2.38	.1114	Tree	0.32	0.7258
Herbaceous	11.38	0.0003	Herbaceous	7.48	0.0026

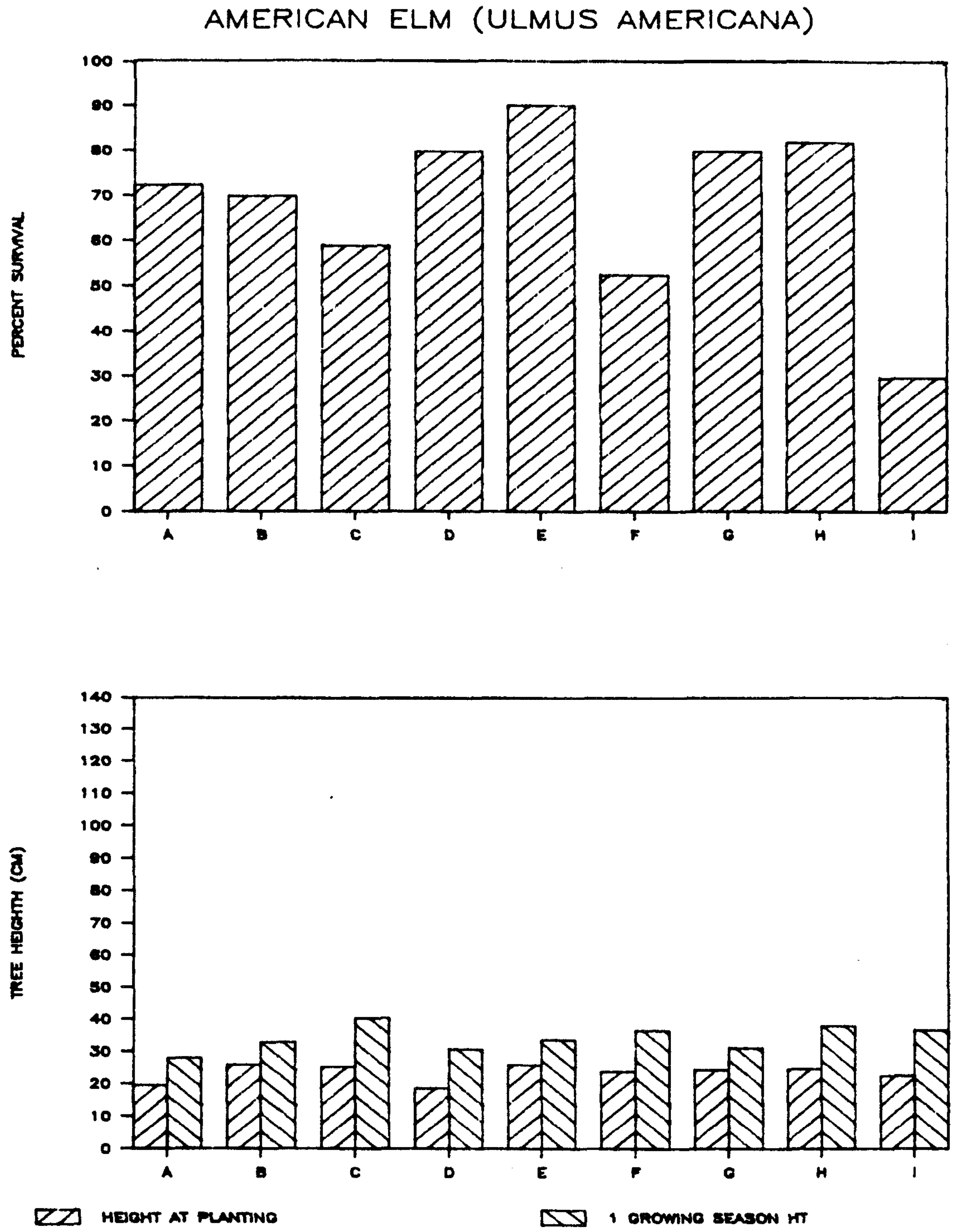


Figure 4.4. Percent survival and initial and final tree height of American elm planted under different combinations of herbaceous cover and tree canopy.

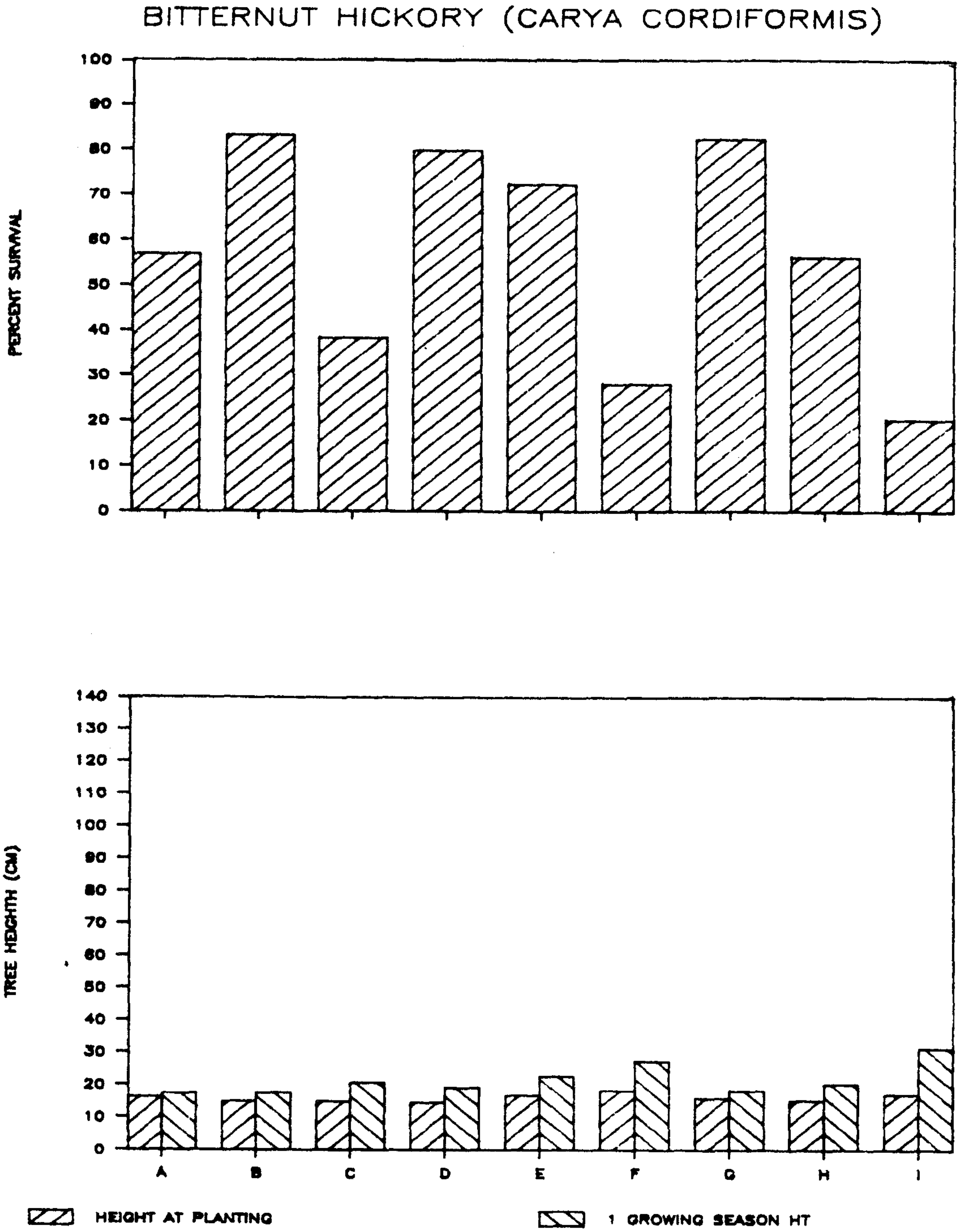


Figure 4.5. Percent survival and initial and final tree height of bitternut hickory planted under different combinations of herbaceous cover and tree canopy.

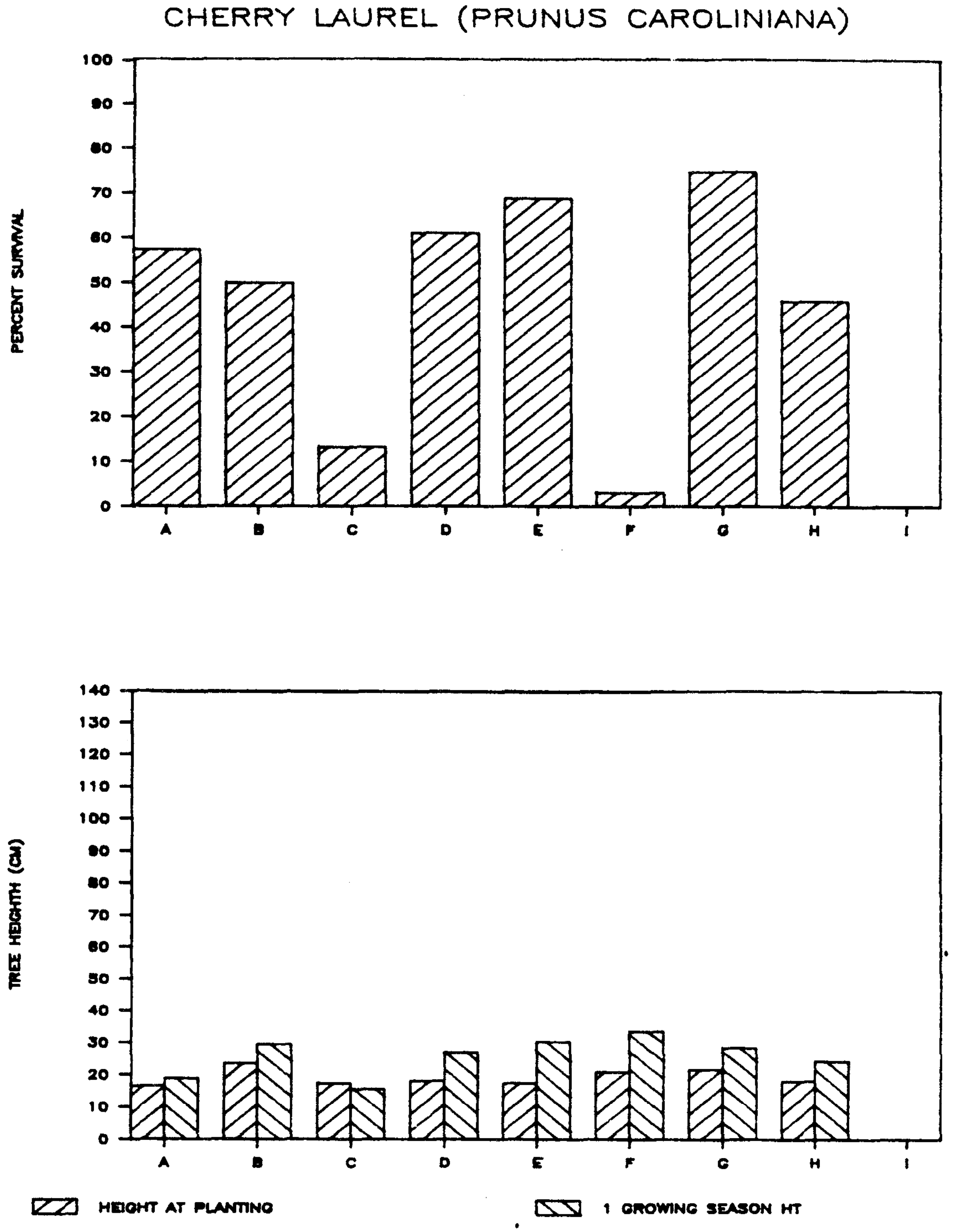


Figure 4.6. Percent survival and initial and final tree height of cherry laurel planted under different combinations of herbaceous cover and tree canopy.

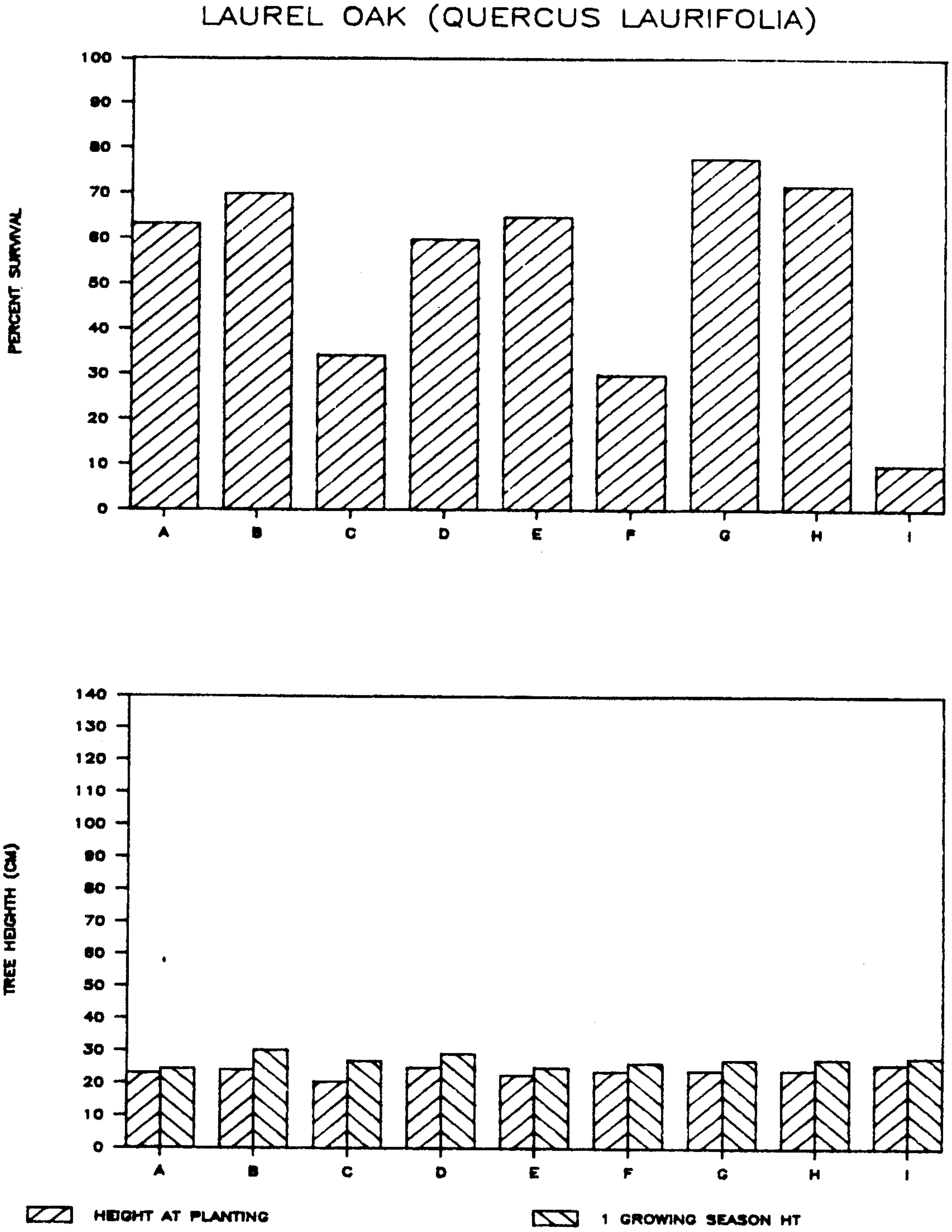


Figure 4.7. Percent survival and initial and final tree height of laurel oak planted under different combinations of herbaceous cover and tree canopy.

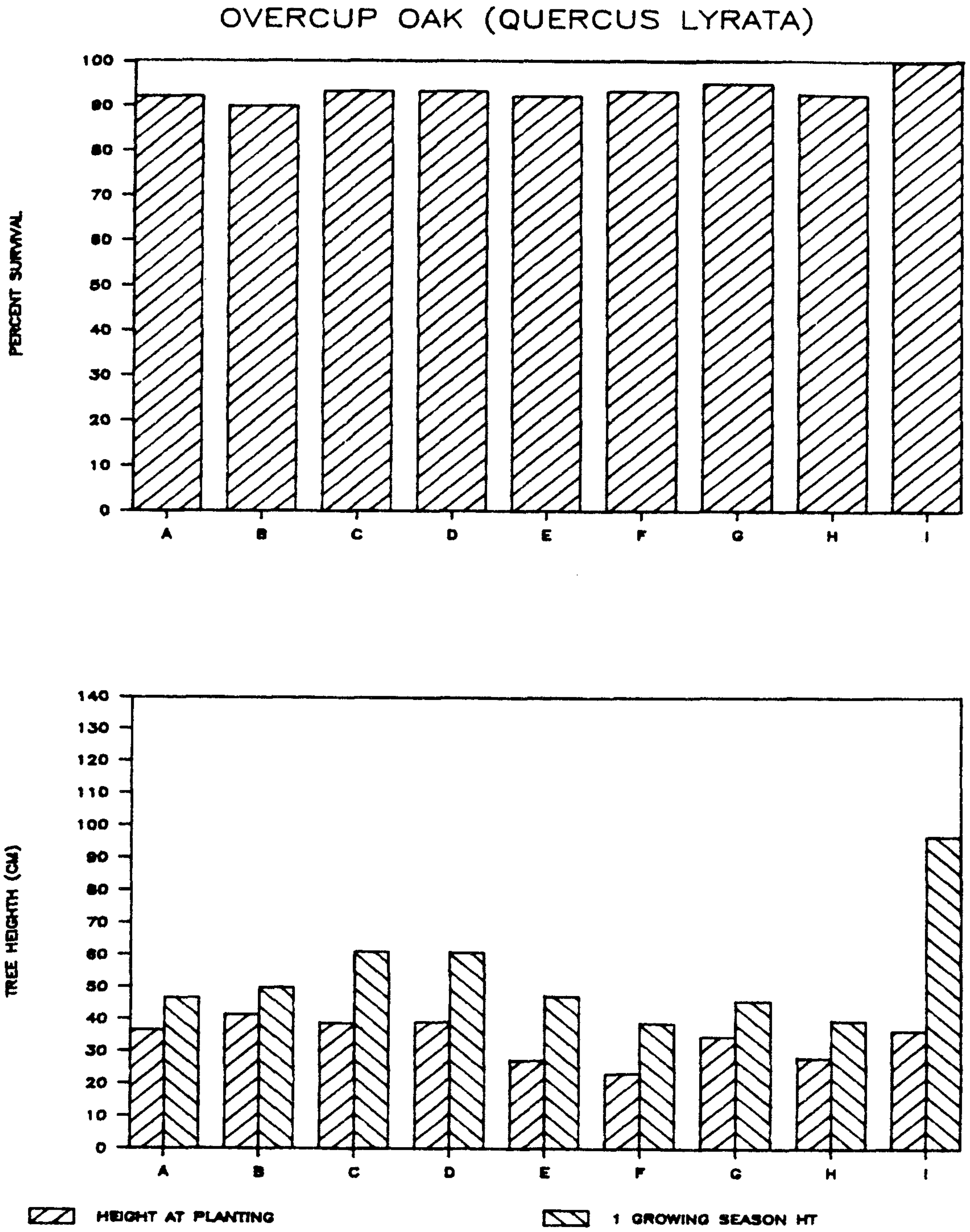


Figure 4.8. Percent survival and initial and final tree height of overcup oak planted under different combinations of herbaceous cover and tree canopy.

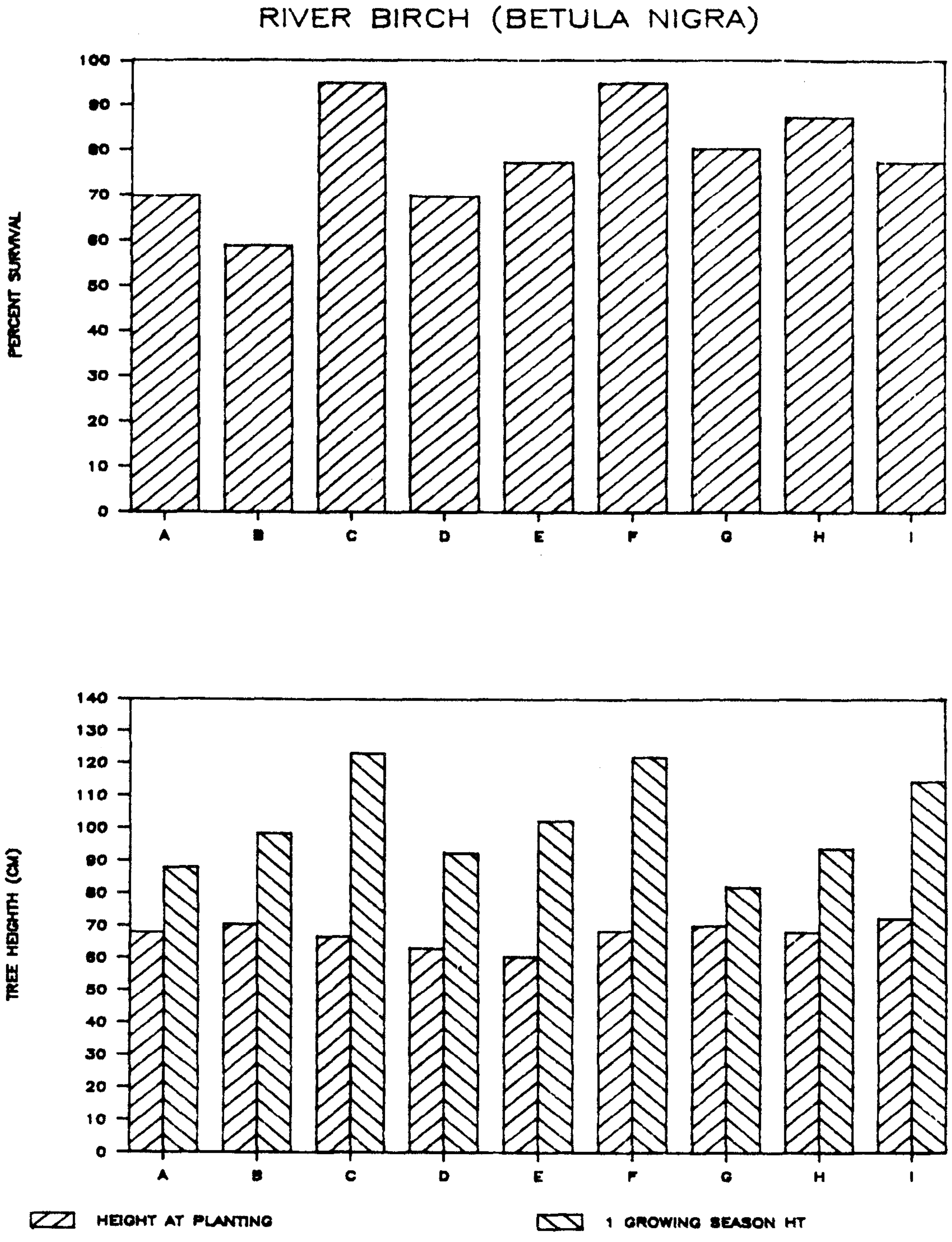


Figure 4.9. Percent survival and initial and final tree height of river birch planted under different combinations of herbaceous cover and tree canopy.

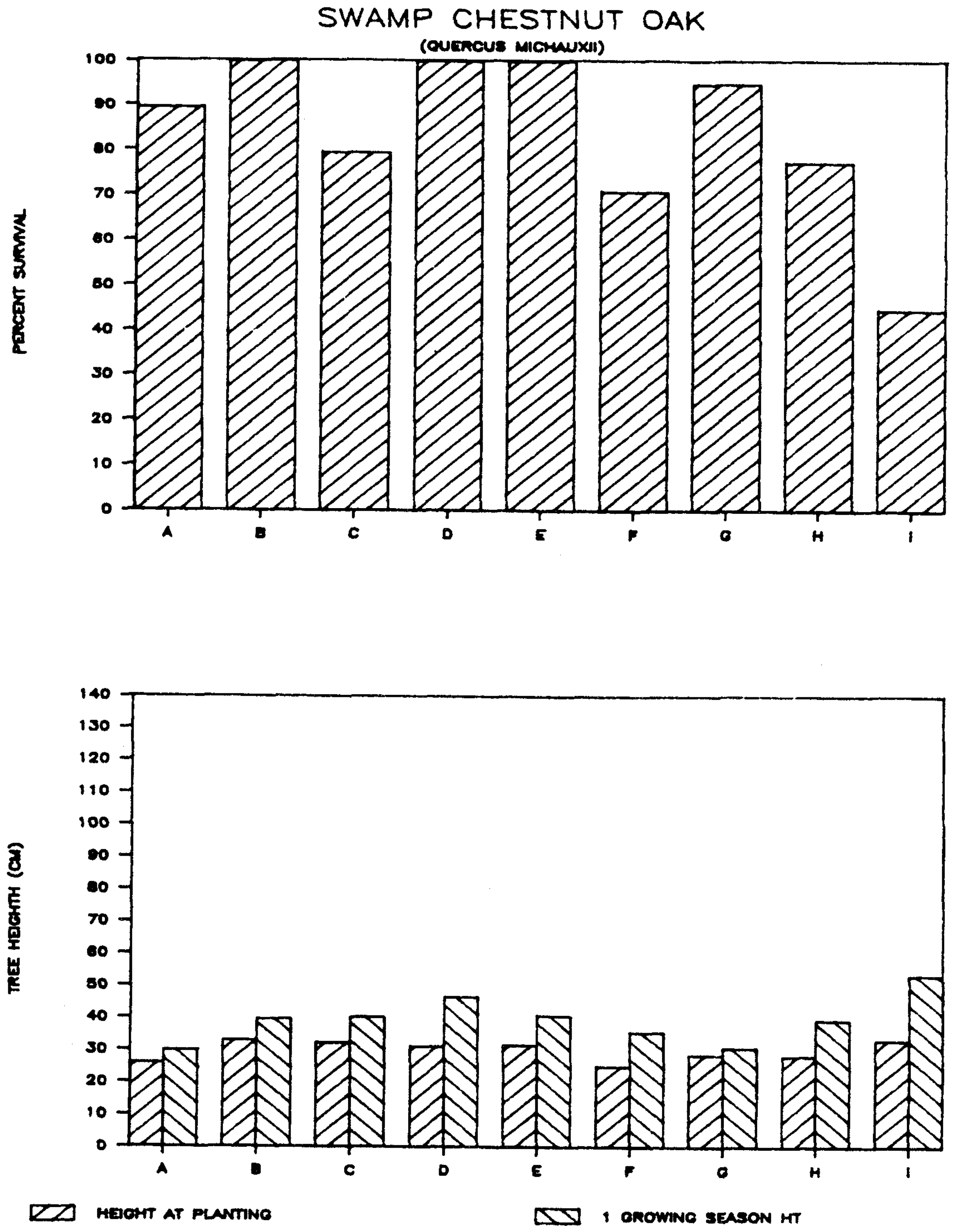


Figure 4.10. Percent survival and initial and final tree height of swamp chestnut planted under different combinations of herbaceous cover and tree canopy.

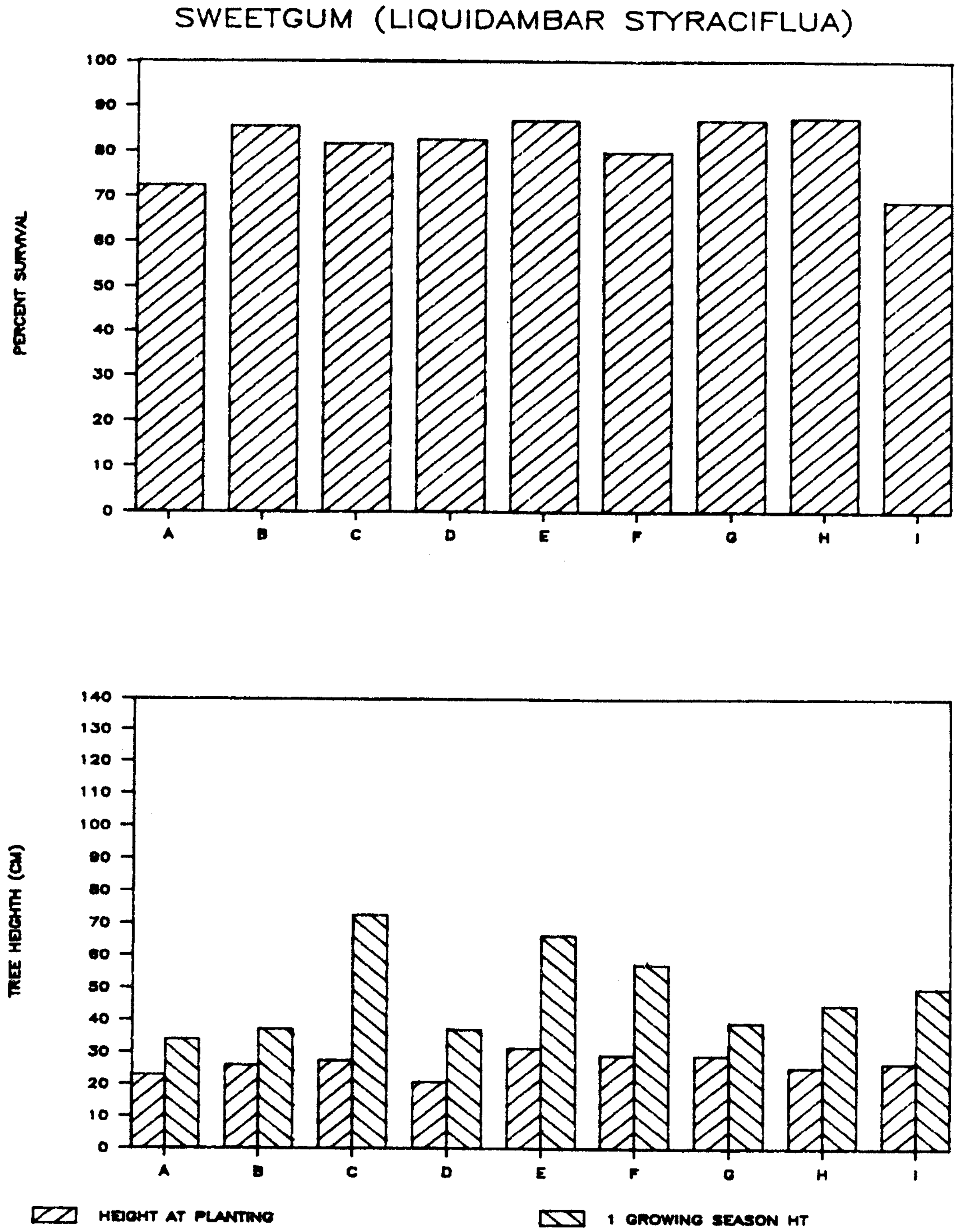


Figure 4.11. Percent survival and initial and final tree height of sweetgum planted under different combinations of herbaceous cover and tree canopy.

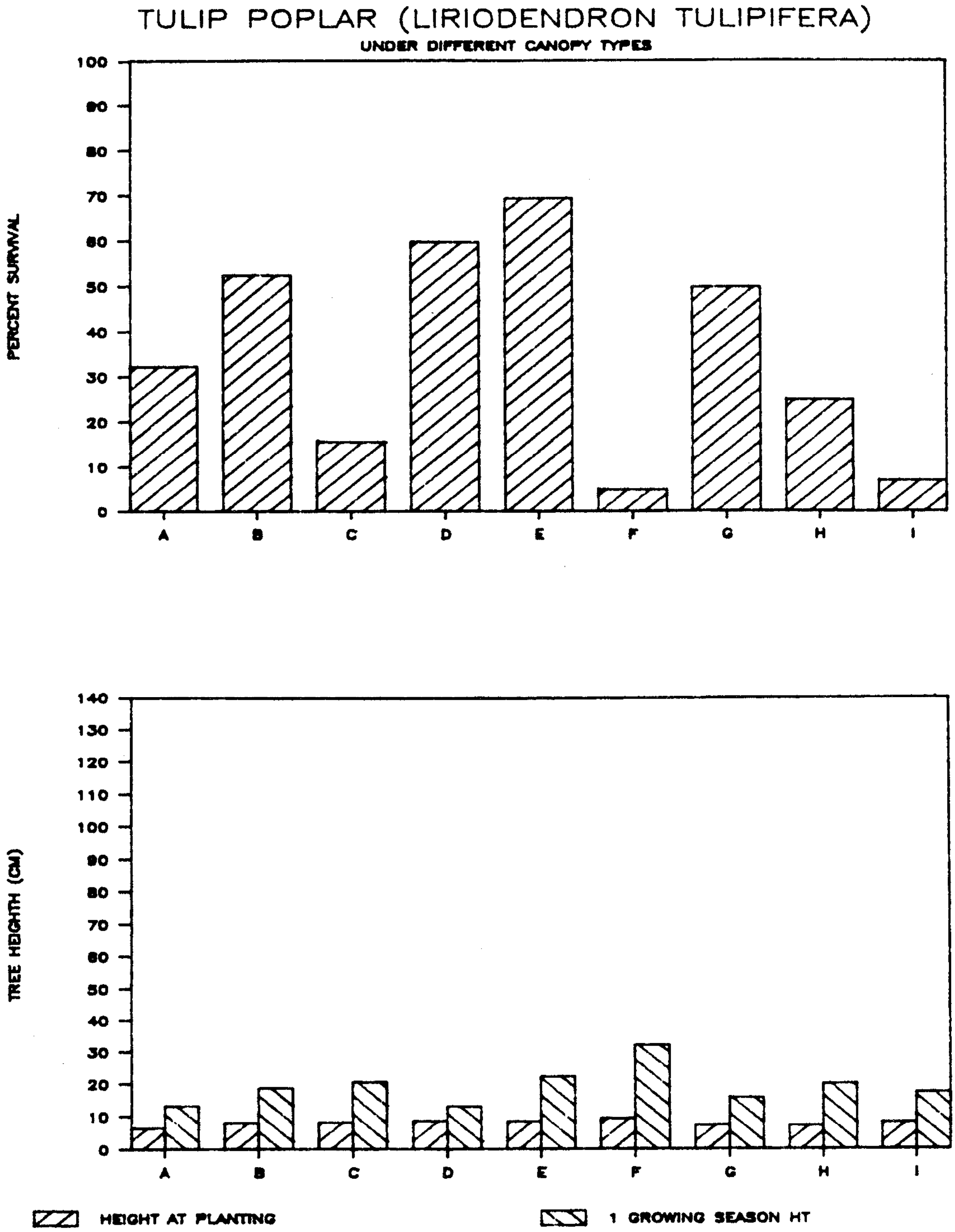


Figure 4.12. Percent survival and initial and final tree height of tulip poplar planted under different combinations of herbaceous cover and tree canopy.

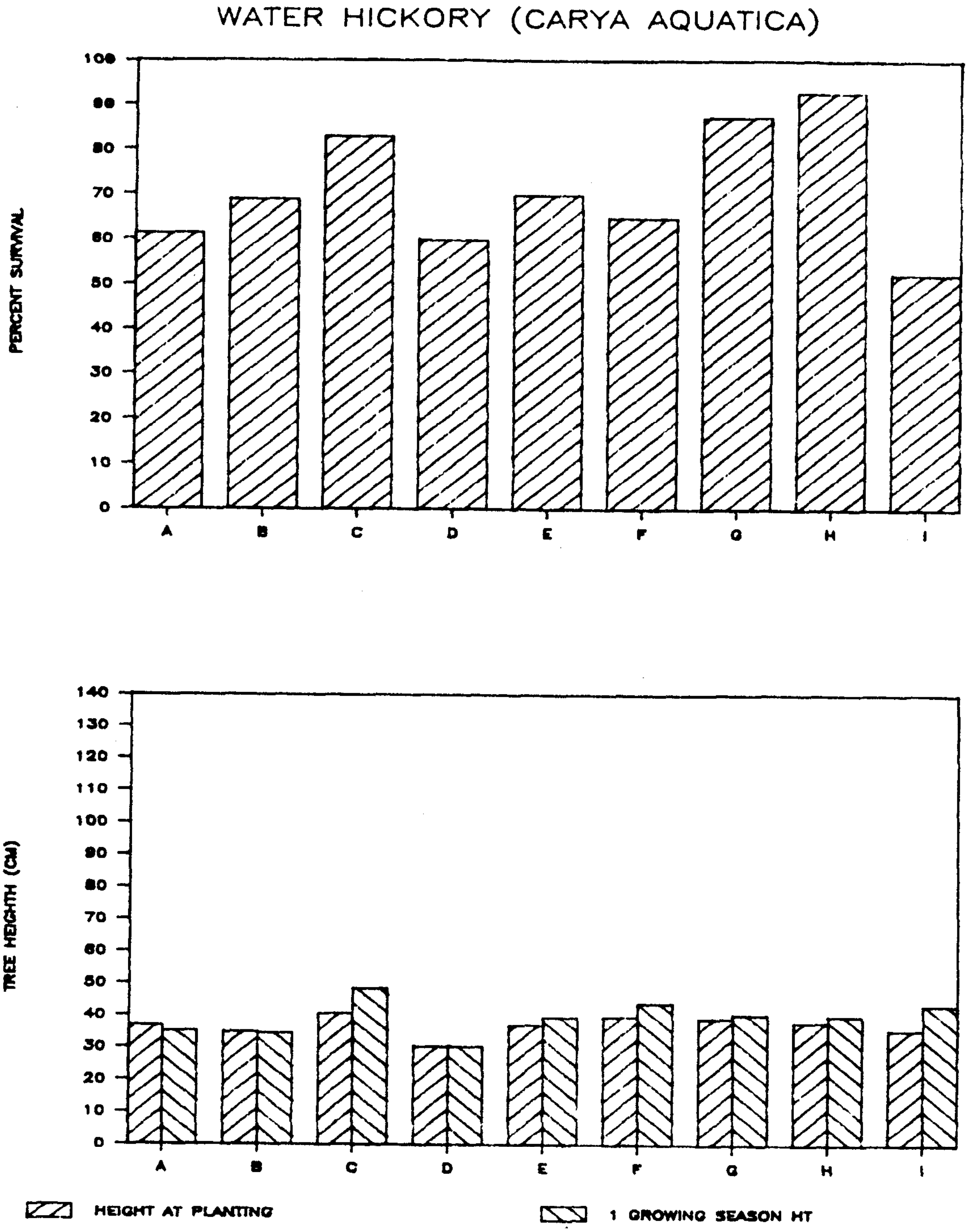


Figure 4.13. Percent survival and initial and final tree height of water hickory planted under different combinations of herbaceous cover and tree canopy.

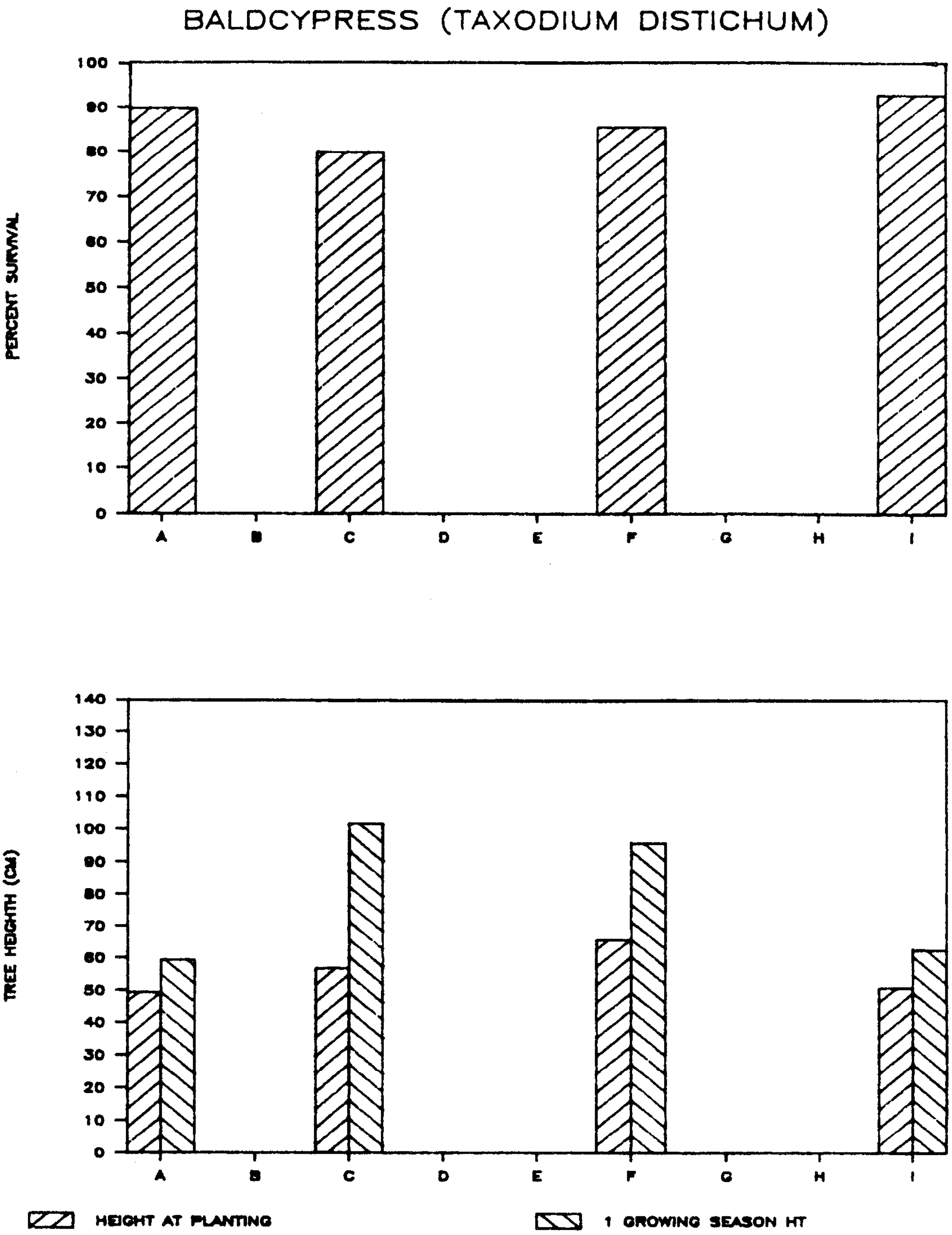


Figure 4.14. Percent survival and initial and final tree height of baldcypress planted under different combinations of herbaceous cover and tree canopy.

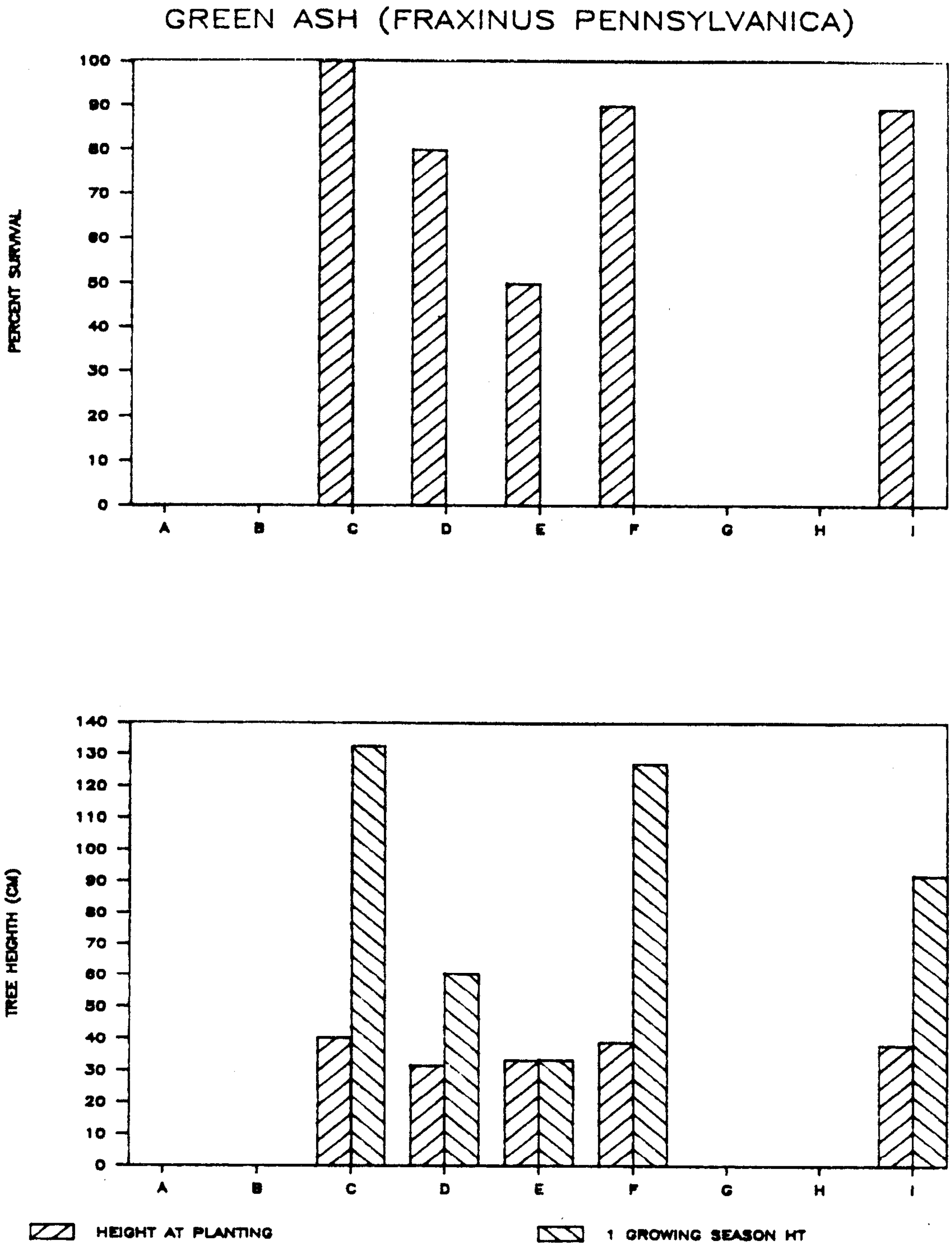


Figure 4.15. Percent survival and initial and final tree height of green ash planted under different combinations of herbaceous cover and tree canopy.

had poor survival when planted under a cover of Juncus, but performed better when planted in cogon grass and ruderal herbaceous species. The wetter soil conditions with Juncus appeared to be the determining factor for survival of these trees. Trees tolerant of wet soils such as baldcypress and green ash performed well when planted in a cover of Juncus (Figures 4.14 and 4.15).

Those tree species for which a stastical difference in survivorship between cover classes was detected included bitternut hickory, tulip poplar, cherry laurel, laurel oak, and swamp chestnut oak. With the exception of swamp chestnut oak, the difference was not between tree canopies, but rather herbaceous covers within a tree canopy. Survival in Juncus was statistically different at the $p = 0.05$ level from either cogon grass or ruderal. Swamp chestnut oak yielded a statistical difference ($p = 0.05$) between trees planted under cottonwoods and those planted either under willow or in the open area.

Growth of individual tree species also varied. In some instances trees grew more where the soil was wetter (Juncus areas), for example, sweetgum and river birch. Frequently good growth was dependent on the species, with earlier successional trees such as green ash growing more than later successional trees such as water hickory. Table 4.6 contains net growth data for each species of tree. One standard error was included with each mean. Net growth of several species was negative under certain combinations of tree and herbaceous cover. This can best be explained by tip die back of trees and the severe loss of trees in some plots. In some instances standard errors approached or were greater than the mean tree growth. This was caused by the variability in response of individual trees of the same species to the same site conditions.

Comparison of mean net tree growth of each species by an analysis of variance yielded variable results. Growth of several tree species was affected by both herbaceous cover and tree canopy. Results are listed in Table 4.7 . The value of the F statistics for both tree and herbaceous cover and respective probabilities are included. Growth of two species, American elm and overcup oak, was not statistically different between treatments. River birch was statistically different ($p = 0.05$) growing under cottonwood compared to willow and open. For cherry laurel growth was different for each tree canopy. Tulip poplar was statistically different in the open area compared to willow and cottonwood. The remaining tree species did not grow differently under varying tree canopies.

Except for cherry laurel, overcup oak, and American elm, differences in growth between herbaceous covers existed between Juncus and the other two cover types. Differences were detectable at the $p = 0.05$ level of significance.

DISCUSSION

The data presented in this chapter is the result of a study to test the influence of nurse trees on survival and growth of planted seedlings. This discussion is divided into two parts. The first is a discussion of the sites' hydrology. The second section addresses the

Table 4.6. Mean net tree growth with one standard error for each tree species under different combinations of tree and herbaceous cover.

Tree species	Open/ ruderal	Open/ cogon	Open/ *Juncus*	Willow/ ruderal	Willow/ cogon	Willow/ *Juncus*	Cottonwood/ ruderal	Cottonwood/ cogon	Cottonwood/ *Juncus*
River birch	23.8±5.7	25.3±6.1	51.8±4.2	30.0±7.6	27.0±9.75	54.8±2.9	13.2±3.1	25.0±5.3	40.1±5.4
Bitternut hickory	0.3±0.8	2.7±0.99	3.5±1.3	4.8±0.9	1.8±0.5	9.1±5.0	1.6±1.8	4.3±1.1	11.8±4.3
Water hickory	-4.6±2.8	-2.25±2.1	7.0±2.3	-0.9±2.1	3.0±0.6	2.4±1.8	0±1.3	2.3±1.7	7.0±3.0
Tulip poplar	6.2±10.9	11.3±1.8	11.7±	5.5±0.9	8.1±3.0	29.0±12.0	7.6±1.5	11.7±2.3	12.3±4.8
Sweetgum	11.8±2.4	10.5±1.5	40.6±4.9	16.3±3.1	25.4±5.1	27.6±3.0	9.6±1.2	19.1±1.9	22.9±2.8
Swamp chestnut oak	3.1±2.3	6.6±1.4	16.3±5.5	15.7±3.6	2.95±1.2	10.3±3.9	2.0±1.2	8.3±1.2	17.9±7.0
Laurel oak	3.4±1.9	5.5±1.7	4.4±3.2	3.1±2.0	1.7±2.7	-0.8±1.9	1.9±0.6	2.4±1.0	-2.0±5.6
Overcup oak	9.7±2.6	8.3±2.4	22.5±4.3	20.5±10.2	12.8±4.3	13.7±2.93	10.8±2.1	11.8±1.3	60.3±16.7
Cherry laurel	1.2±0.8	3.1±1.8	-3.5±2.9	9.0±2.3	15.0±5.7	17.0±*	6.3±1.4	5.6±1.9	
American elm	9.3±2.0	5.8±1.9	14.6±4.9	11.1±1.8	6.9±2.5	10.6±2.2	6.3±1.5	12.5±2.0	15.0±4.1

* One observation

Table 4.7. Values and probabilities of F statistics for analysis of net tree growth. The last two columns are the results of comparison of net growth by Duncan's multiple range test.

	F value Herbaceous cover	Pr>F	F value Tree cover	Pr>F	C O S*	J CR#
River birch	23.64	.0001	5.08	.0069		J CR
Water hickory	16.7	.0001	1.4	.2479	C OS	J CR
Cherry laurel	0.65	.5247	9.61	.0001	C O S	
Bitternut hickory	15.37	.0001	1.53	.2195		J CR
Sweetgum	29.51	.0001	1.57	.2102		J CR
Tulip poplar	3.98	.0220	4.15	.0188	O CS	J CR
Laurel oak	6.74	.0015	5.4	.0054		J CR
Overcup oak	2.84	.0604	0.27	.7642	none	
Swamp chestnut oak	5.48	.0047	0.43	.6533		J CR
American elm	2.15	.1196	0.42	.6605	none	

* C = cottonwood, O = open, and S = willow

\# J = *Juncus*, C = cogon grass, R = ruderal

Results between cover classes that were not statistically different were underlined. For example, J CR, cogon grass and ruderal are not different from each other, but both are different from *Juncus*.

growth and survival of trees as an association and as individual species.

Water Table

Variable is the best descriptor of the hydrology of the experimental site. Water table varied by ground cover type and by tree canopy for a given herbaceous cover type.

Herbaceous cover was selected as an indicator of hydrology. Two of the cover classes, ruderal and cogon grass, had broad ranges of tolerable water levels. The range of water level recorded for these two cover types was dependent on tree canopy. The most consistent water table measurements were obtained where *Juncus* grew.

The variability of water table levels within the same herbaceous cover class makes herbaceous cover a poor indicator of hydrology. Of particular concern is the apparent influence of tree canopy on two of the herbaceous classes. The last effect implies either an interaction between tree canopy and water table or differing soil structures between areas with the same herbaceous cover.

Tree Growth and Survival

What is the influence of nurse trees on seedling survival and growth? When viewed as associations, no effect of nurse trees was noted for either northern or central trees. Percent survival for both associations and all cover classes ranged from 50 to 80. Survival by varying tree canopy was comparable for each association with herbaceous cover type, though a significant result was the comparable performance of both tree associations, because northern trees were not indigenous to the area where planted.

The major impact on survivorship for an individual tree association was herbaceous cover. Consistently poor survival was obtained for both groups when planted in *Juncus* irregardless of canopy type. Because herbaceous cover was used as an indicator of hydrology, its impact on survivorship could be either a result of too wet of a soil (poor hydrological condition) or competition from ground cover. Unfortunately, the design of the experiment did not provide for the separation of the effect of hydrology from ground cover type. Support for a hydrological impact on tree survival was obtained from qualitative observations. Survivorship of trees growing in *Juncus* decreased moving from open, willow, to cottonwood. The wettest depression on the site was located in the cottonwood/*Juncus* areas. Several plots planted there recorded the greatest losses of trees. Range of water table fluctuations was comparable to the open and willow areas but water levels remained at their highest under cottonwood longer than the other two canopies. Survival and growth of trees in *Juncus* was species specific. Those trees that did display a variable response dependent on canopy cover had their poorest survival where cottonwoods were planted. These species included laurel oak, cherry laurel, bitternut hickory, swamp chestnut oak, tulip poplar, and American elm. It was not statistically clear what was the true effect of herbaceous cover on seedling survival.

Many of the trees planted from both associations were habitat generalists. These included river birch, sweetgum and overcup oak. These species survived well irregardless of tree canopy. For the remaining species herbaceous cover and not tree canopy was the deciding factor for survival.

Net growth of trees varied by species. Trees such as river birch and sweetgum grew well, particularly in wet sites. In contrast, the hickories are slow growers. Net growth after one growing season is probably not a good indicator of success because of species variability.

In conclusion, hydrology appears to be the primary factor controlling survival of trees and not nurse trees, but that is only a qualitative observation and not statistically proven. A recommendation for future research would be to define the hydrology for each individual plot such that it can be isolated as a source of variance separate from herbaceous vegetation. Another consideration is that the results presented in this chapter represent only one growing season and may represent the adjustment of the trees to the site. Stated simply, the trees may still be in a period of adjustment to soil and water conditions at the site and not responding to the experimental conditions of nurse trees and herbaceous cover.

5. LONGTERM SUCCESS OF PLANTED WETLAND TREES IN CLAY SETTLING PONDS

MARY PAULIC

Clay settling ponds are a common feature of the central Florida landscape. Of the land area used for phosphate mining, approximately 60-75% of it is designated for use as clay settling ponds. Over 30,000 ha of settling ponds have already been built while an estimated 1000 ha of new ponds will be constructed per year in the near future to accomodate the needs of the phosphate industry (Pittman and Sweeney, 1983).

The phosphate industry is faced with the problem of finding practical and workable means of restoring clay settling areas to a useful function. One alternative is the construction of forested wetlands. Experimental work was initiated in 1984 to address the problem of wetland reclamation of clay settling ponds. Selected wetland hardwoods were planted on various clay settling ponds in an effort to accelerate succession on these lands. The work outlined in this chapter details the results of those experiments after three growing seasons. The first year's results were reported in an earlier report to the Florida Institute of Phosphate Research under the title "Accelerating Natural Processes for Wetland Restoration After Phosphate Mining." The intent of this work is to evaluate the Bureau of Land Reclamation's guidelines of 50% survival of seedlings in the first year with regard to longterm success of planted tree seedlings in clay settling areas.

SUCCESS OF CYPRESS-GUM TRANSECTS AFTER THREE GROWING SEASONS

INTRODUCTION

The natural self-organizational processes of ecological succession regenerate vegetation and soils at no cost to the human economy. This may be one of the quickest and cheapest means of restoring clay settling ponds, a landscape artifact of phosphate mining, to a useful function. However, succession in many areas is not proceeding beyond an initial stage of herbaceous and shrub vegetation. A probable cause is the lack of adequate seeding. An experiment was initiated in 1985 to explore the possibility of using planted seedlings to encourage the ecological succession of clay settling ponds to forested wetlands. This chapter contains the results of the 2 1/2 years growth and survival of cypress swamp seedlings. That time period is equivalent to three growing seasons.

Clay settling ponds are elevated and isolated from the surrounding landscape by impoundment dikes varying in height from 5 to 15 m tall. Willow trees (*Salix caroliniana*) rapidly colonize these areas from the time the ponds are deactivated, and willows continue to dominate wet depressions in ponds 60 to 80 years old. These areas appeared suitable for succession to a more mature stage, possibly with establishment of cypress and gum trees, but succession was arrested because an adequate supply of water borne seeds was unable to reach the site (Rushton, 1983, Rushton, 1984).

In addition to planting trees that would accelerate forest succession in clay settling ponds, experimental transects were designed to test several different factors related to nursery and mining techniques: 1) To understand the role of competition, all existing above ground vegetation was removed from some of the transects before planting; 2) To determine if nursery practices have an effect both bareroot and tubeling seedlings were planted; 3) To test various reclamation, disposal, and mining techniques on tree success, several different sites representing different reclamation methods were used; 4) To identify substrate differences, various physical and chemical soil parameters were measured.

Species Planted

Seedlings common to different wetland types in Florida were selected for planting. Baldcypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatica*) often follow willow (*Salix* sp.) on alluvial floodplains while blackgum (*Nyssa sylvatica* var. *biflora*) and pondcypress (*Taxodium ascendens*) are more often found in headwater streams, quiet backwaters, or isolated swamps.

Pondcypress shows its best growth in the center of ponds with water depths ranging from 30 to 130 cm (Monk and Brown, 1965). It grows on both sandy and clay soils which usually have several centimeters of accumulated organic matter (Mitsch and Gosselink, 1986). Baldcypress is restricted to very wet soils consisting of mucks, clays, or the finer sands where moisture is abundant and relatively permanent (Fowells, 1965). It has a critical water depth of 3 to 6 m depending on duration of flooding (Brown and Lugo, 1982). Blackgum is frequently found in association with both cypress species, but pondcypress and baldcypress are rarely ever found growing together. The critical indicator appears to be the low pH of soils in cypress domes. According to Monk (1965), pH's typically range from 3.6 to 5.4.

Green ash (*Fraxinus pennsylvanica*), is a wetland species that often grows in association with cypress and tupelo. It is considered an early successional species either as a pioneer tree or following cottonwood or black willow (Shelford, 1954). It usually grows on alluvial soils along rivers and brooks and less frequently in swamps (Fowells, 1965).

Study Sites

Seven clay settling ponds representing different ages and reclamation techniques were planted during the winter of 1984-1985. Two of the sites, Gardinier and IMC H9, were abandoned in 1987 because of damage from fire and heavy equipment. Of the 2232 trees planted at Gardinier only 59 were still alive in the fall of 1987. Heavy equipment destroyed large sections of the transects at IMC H9 to the extent that only 33 trees are still alive of 558 that were planted. Site locations are shown on the map in Figure 5-1 and summary information is listed in Table 5-1.

Tenoroc, Area A, is a large clay settling pond located in a State Reserve under the jurisdiction of the Department of Natural Resources. The west end, where the majority of trees were planted, was mined and has many protruding spoil piles. Three transects were located on the edge of an intermittent pond. Four drier transects were planted in willows growing at the northwest corner.

O. H. Wright, owned by Gardinier, is located adjacent to the Whidden Creek floodplain. It is an old surface mine backfilled with clay around 1957. Some transects are located in a periodically flooded low area while others are in drier mine cuts.

Alderman Ford Ranch is an older clay settling pond located above the confluence of the north and south prongs of the Alafia River. Aerial photographs show the site being filled with clay in 1948. Twelve seedling transects were planted in two swales known to be periodically flooded. One was colonized by red maples (*Acer rubrum*) and laurel oaks (*Quercus laurifolia*) and the other by scrub willows (*Salix caroliniana*).

CF Industries used a sand-clay mix for clay disposal at their Hardee mining complex. This site was abandoned as an active clay pond in 1983. Tree transects were planted along the edge of a seasonally flooded pond.

The Mobil site is a pasture pond located south of Highway 640 near Homeland. The clay settling pond had been capped with sand tailings. At least part of the site was mined before clays were deposited. Seedlings were planted in a small shallow pond that seldom goes dry. Soil at the surface in these transects was 100% sand.

METHODS

Seedlings were established in wet depressions of clay settling ponds during the winter of 1984-85. Survival and net growth were statistically related to nursery practices, reclamation techniques, grazing, and soil characteristics.

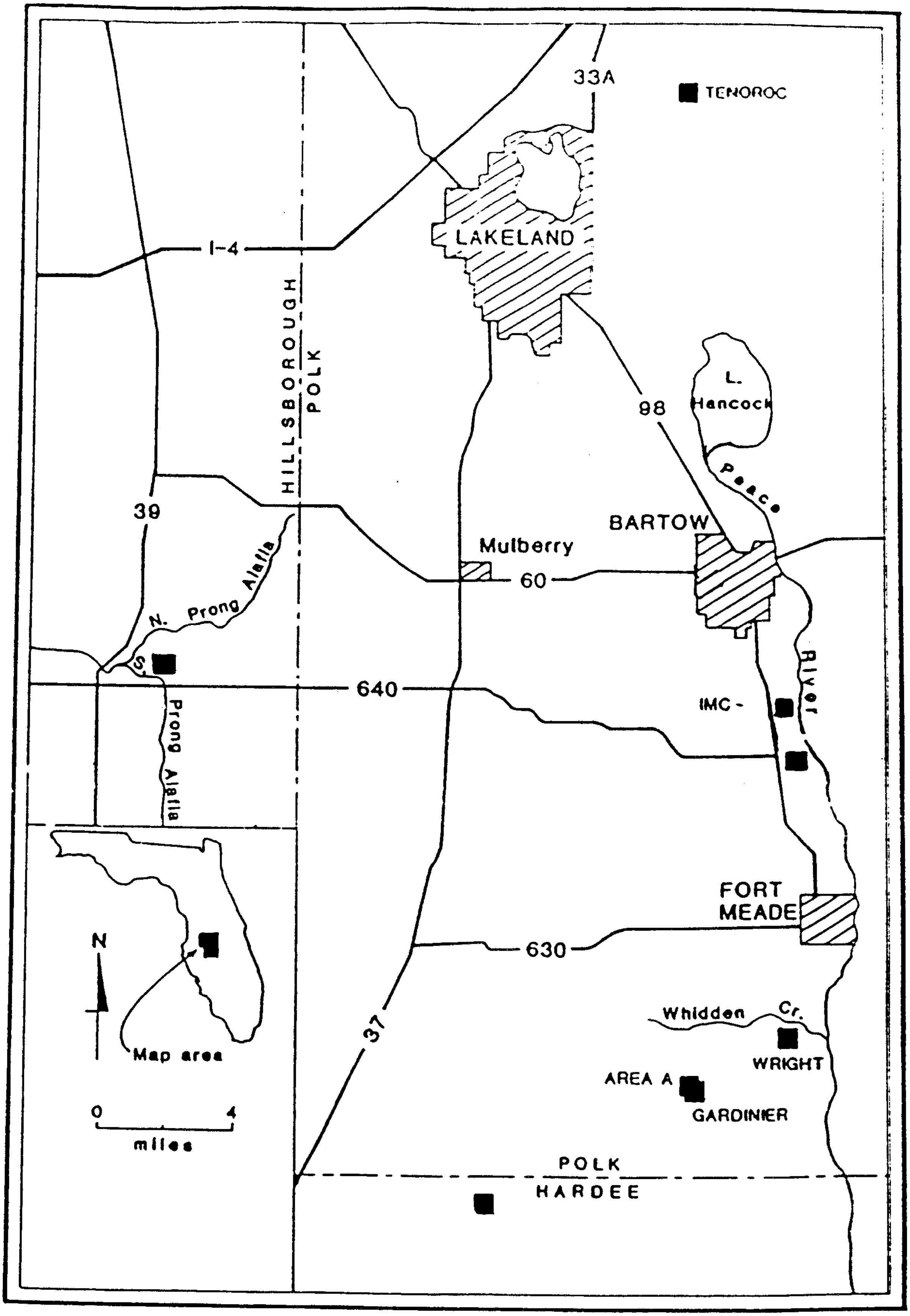
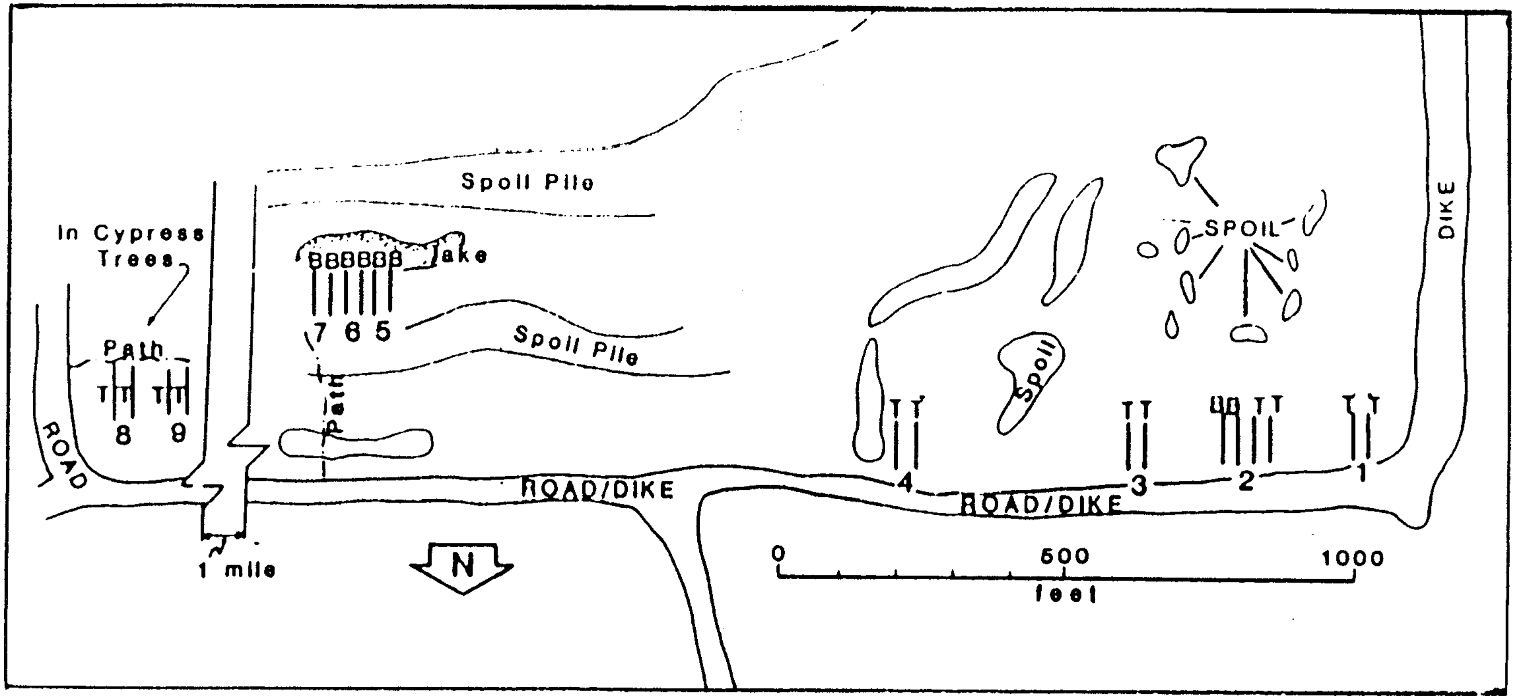


Figure 5.1. Location of study sites.

Table 5.1. Summary information about study sites for cypress-gum transects.

SITE	ABANDONED (EST)	RECLAIMED (EST)*	MINED	OWNER	LOCATION	# TREES PLANTED	DATE PLANTED
A.F.RANCH	1950	NONE	NO	C.L.KNIGHT	T30S,R22E SECTION 16	558 558	FEB 1985 TB** MAR 1985 BR***
O.H.WRIGHT	1960	NONE	YES	GARDINIER INC. FT. MEADE	T32S,R25E SECTION 9	1116 558	DEC 1984 TB MAR 1985 BR
GARDINIER AREA A	1973	1975 DITCHED	NO	GARDINIER INC. FT.MEADE	T32S,R24E SECTION 24	1674 558	OCT 1984 TB MAR 1985 BR
TENOROC ZONE 4A	1972	NONE	YES WEST	FLORIDA DEPT. NATURAL RESOURCES	T27S,R24E SECTION 36	774 774	NOV 1984 TB MAR 1985 BR
CF IND. SP-1	1983	SAND/CLAY MIX	YES	CF INDUSTRIES HARDEE	T33S,R24E SECTION 7	558	MAR 1985 BR
MOBIL HOMELAND	1960	1975 SAND CAP	PART	MOBIL CHEMICAL AND MINERALS	T31S,R25E SECTION 3	774	MAR 1985 BR
IMC-H9	1970	1979 SAND CAP	YES	INTERNATIONAL MINERALS AND CHEMICAL CORP.	T30S,R25E SECTION 33	372	MAY 1985 BR

* ESTIMATED
** TB TUBELING
*** BR BAREROOT SEEDLING



KEY: Cypress-Gum Transects
T = tubelings in paired plots, cleared and uncleared
B = bareroot in paired plots, cleared and uncleared

Figure 5.2. Location of study sites at Tenoroc - Zone 4A.

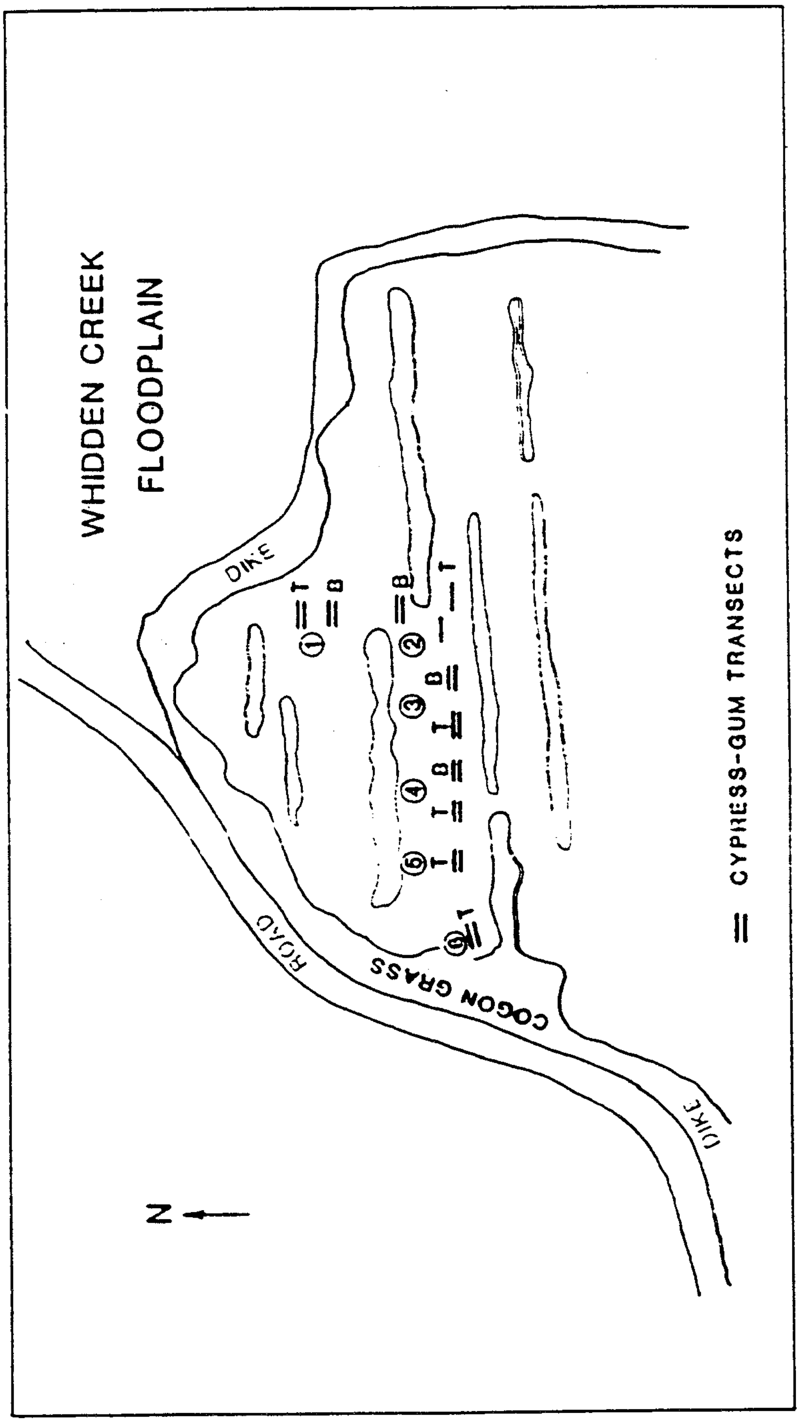


Figure 5.3. Location of study sites at Gardinier's O.H. Wright site. TB are the paired tubeling plots and BR are the paired bareroot seedling plots. In all cases the uncleared plot is to the north.

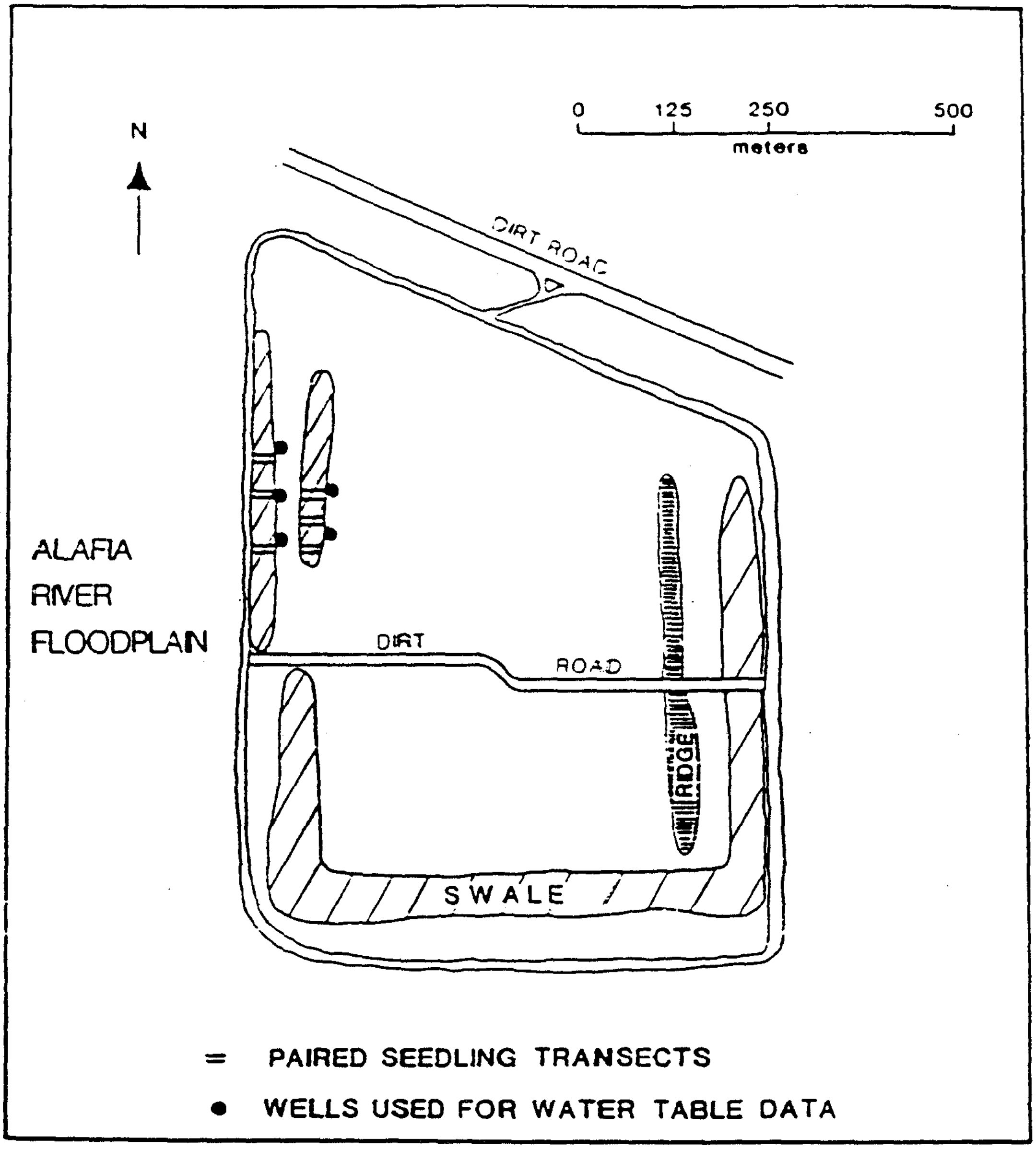
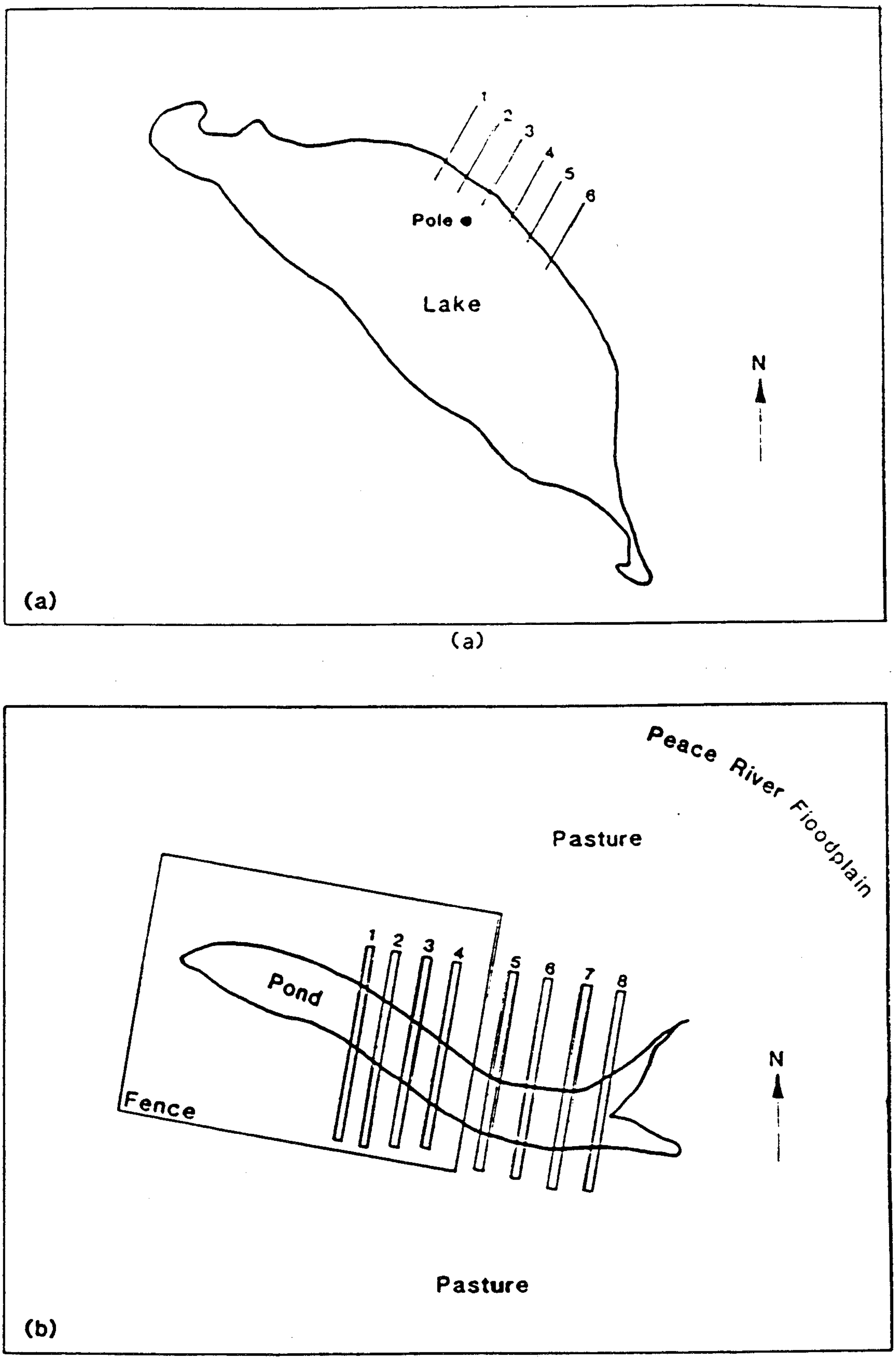


Figure 5.4. Sketch showing locations of tree seedling transects at Alderman Ford Ranch.



(a)

(b)

Figure 5.5. Sketch showing location of bareroot seedling transects. (a) C.F. Industries; (b) Mobil pasture pond at Homeland.

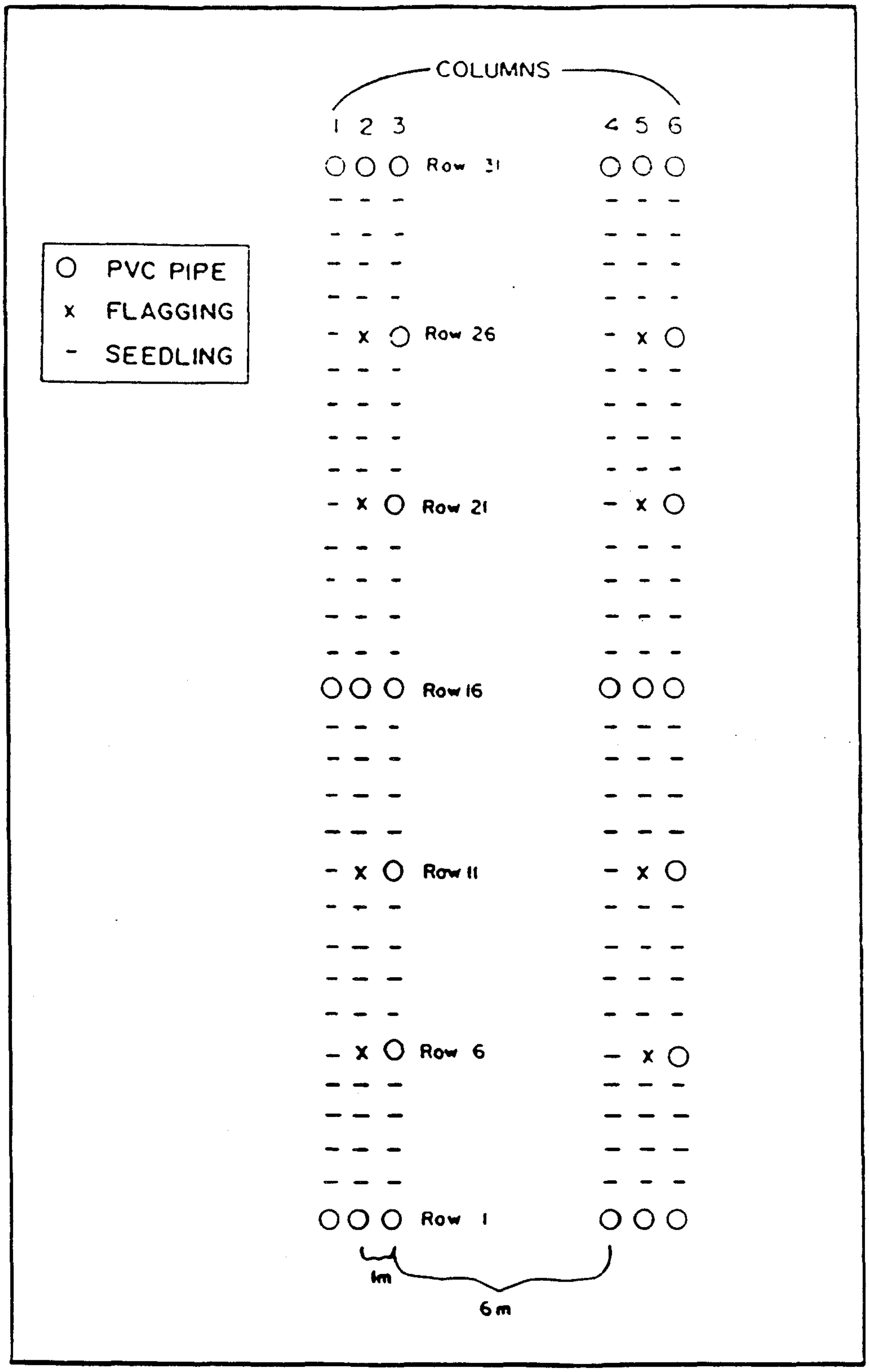


Figure 5.6. Design for paired transects used in cypress-gum seedling experiments. Trees were also planted at PVC pipe and flagging. The transect which included columns 4, 5 and 6 were cleared of all aboveground vegetation at time of planting.

was expected to enhance the growth and survival of seedlings by releasing them from competition for light and nutrients.

Grazing Experiments

An experiment was implemented at Mobil pasture pond to test the influence of cows on seedling establishment. Eight transects were planted with bareroot seedlings of which four were fenced to exclude cows from grazing. Ninety-three trees were planted per transect. Those transects with cows were not included in any of the statistical analysis other than the experiment for grazing.

Comparison of Growth and Survival of Pond and Bald Cypress

Paired transects of pond and baldcypress tubelings were planted at O. H. Wright, Tenoroc, and Alderman Ford Ranch. Comparisons of net growth and survival over the last 2 1/2 years were made at each site.

Reclamation Methods

Different sites represent different reclamation techniques. Comparisons were made of seedling growth and survival on clay, sand cap and sand - clay mixed soils. All comparisons were made of uncleared transects planted with bareroot seedlings. The ungrazed plots at Mobil pasture pond represent sand capping, CF Industries was a sand clay mix, and Tenoroc and OH Wright were representative of clay type soils. The transects used at each site were lake edge with comparable hydrology.

Monthly Rainfall Data

Rainfall data for 1985 to December 1987 were supplied by mining companies with measurements as close as possible to the study sites. For O. H. Wright the weather station was located about 2 miles away from the site. Agrico supplied data from their Saddlecreek mine for the Tenoroc site. Rainfall data from International Minerals and Chemical Corp. Clear Springs Mine was used for Mobil pasture pond. CF Industries' weather station was approximately a half mile from the study site at SP-1.

The average rainfall from 1951 to 1980 is reported by the National Weather Service for specific observation sites. An average of 4 weather stations in the area where the sites were located was used to compare the 30 year average rainfall with rainfall during the planting and establishment. Qualitative correlations of rainfall to seedling survival were made for each site.

Soil Measurements

Soil cores were taken with a soil sampler using a mud auger head. The ground was cleared of all leaf litter prior to sampling. Multiple small samples were removed from the top 15 cm of soil and combined into one large aliquot. Soils were analyzed for water content, particle size, organic matter, pH, and selected nutrients. Particle size was determined by the hydrometer method (Day, 1965) and divided into sand, silt, and clay using the U.S Department of Agriculture scheme (<0.002 mm clay, 0.002-0.05 mm silt, and >0.05 mm sand. Soil moisture was measured gravimetrically (Gardner, 1965). Other measurements were made by The Institute of Food and Agriculture Sciences at their extension soil testing laboratory. Standard methods were used as described by Rhue and Kidder (1983). Soil pH was determined in a 1:2 soil:water suspension. The Walkley-Black technique was used to measure organic matter. The double acid method, Mehlich I, was used for the determination of potassium, calcium, magnesium, and phosphorus.

Statistical Evaluation

Statistics were performed using the Statistical Analysis System (Ray et al., 1982). Significance tests of frequencies for survival data were determined with a chi-square test. A t-test for the difference between two means analyzed net growth. To test differences between multiple means the Duncan multiple-range test determined significant differences at the $p=0.05$ level. Analysis of variance was used for multiple treatment analysis.

RESULTS

Experimental data are presented in the following section. Reported first are information on rainfall and soil parameters. Second are data for seedling growth and survival under varying test conditions.

Rainfall

Rainfall data for the experimental sites is supplied to show conditions over the last 2 1/2 years of tree growth (Figures 5-7 through 5-10). The dashed line on each graph represents the thirty year monthly average of rainfall for four regional stations as published by the National Climatic Data Center.

Rainfall at Tenoroc and CF Industries at the time of tree planting (Nov 1984 - March 1985) was below average followed by a period of very high rainfall (July and August 1985). Similar patterns were observed for 1986. Rainfall at Mobil Pasture Pond (IMC Clear Spring Mine) was lower than the other sites for all three years.

The spring of 1987 was wetter than the previous years. Both March and May had unusually large inputs of precipitation. Water levels were higher than normal for this part of the year. May is typically a drought month for wetlands.

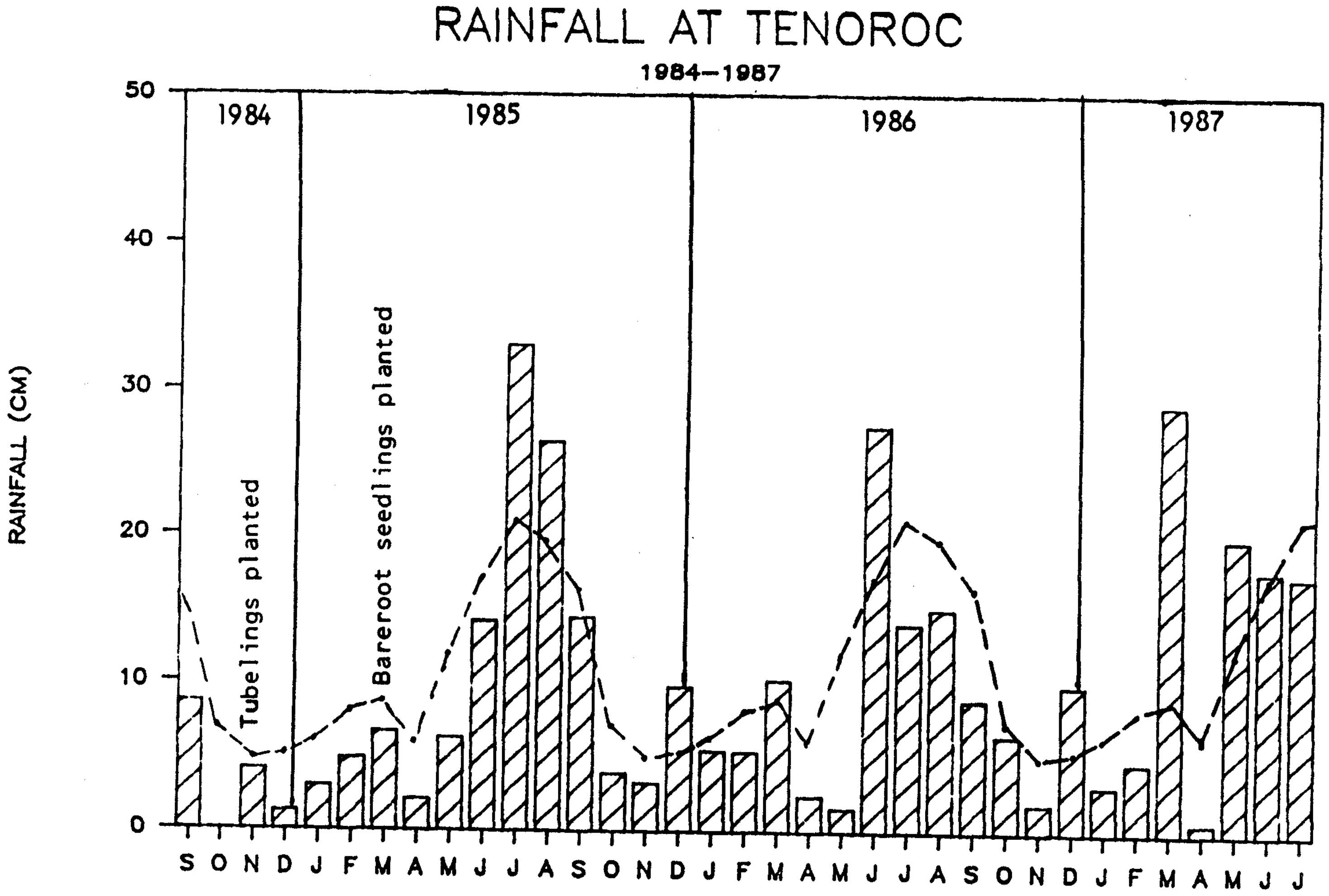


Figure 5.7. Monthly rainfall data for Tenoroc for the period from September 1984 to July 1987 provided by Agrico's Saddle Creek Mine. The dashed line represents the average rainfall (1951-1980) for four weather stations in the region published by the National Climatic Data Center.

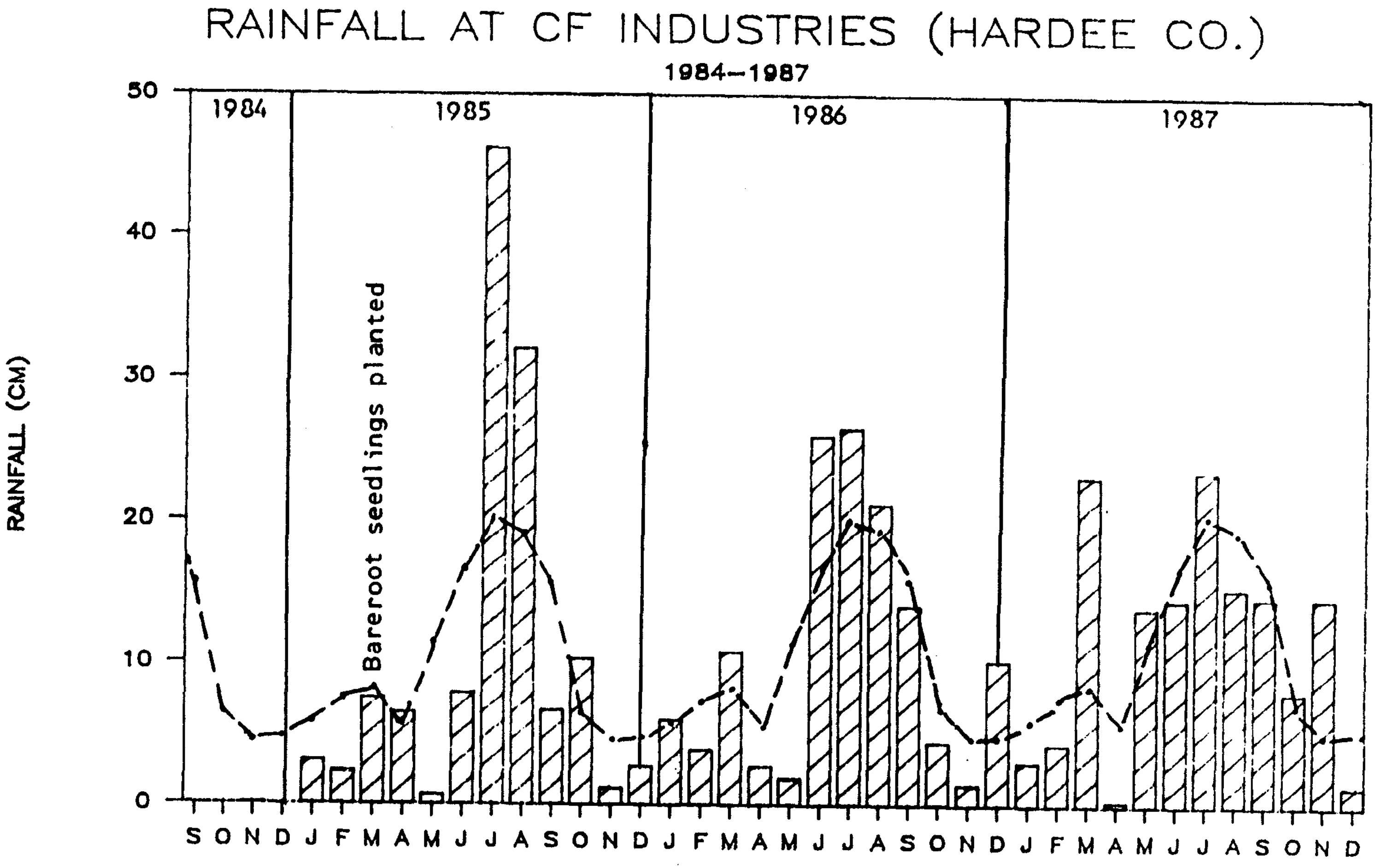


Figure 5.8. Monthly rainfall data for C.F. Industries for the period September 1984 to December 1987. The dashed line represents the average rainfall (1951-1980) for four weather stations in the region published by the National Climatic Data Center.

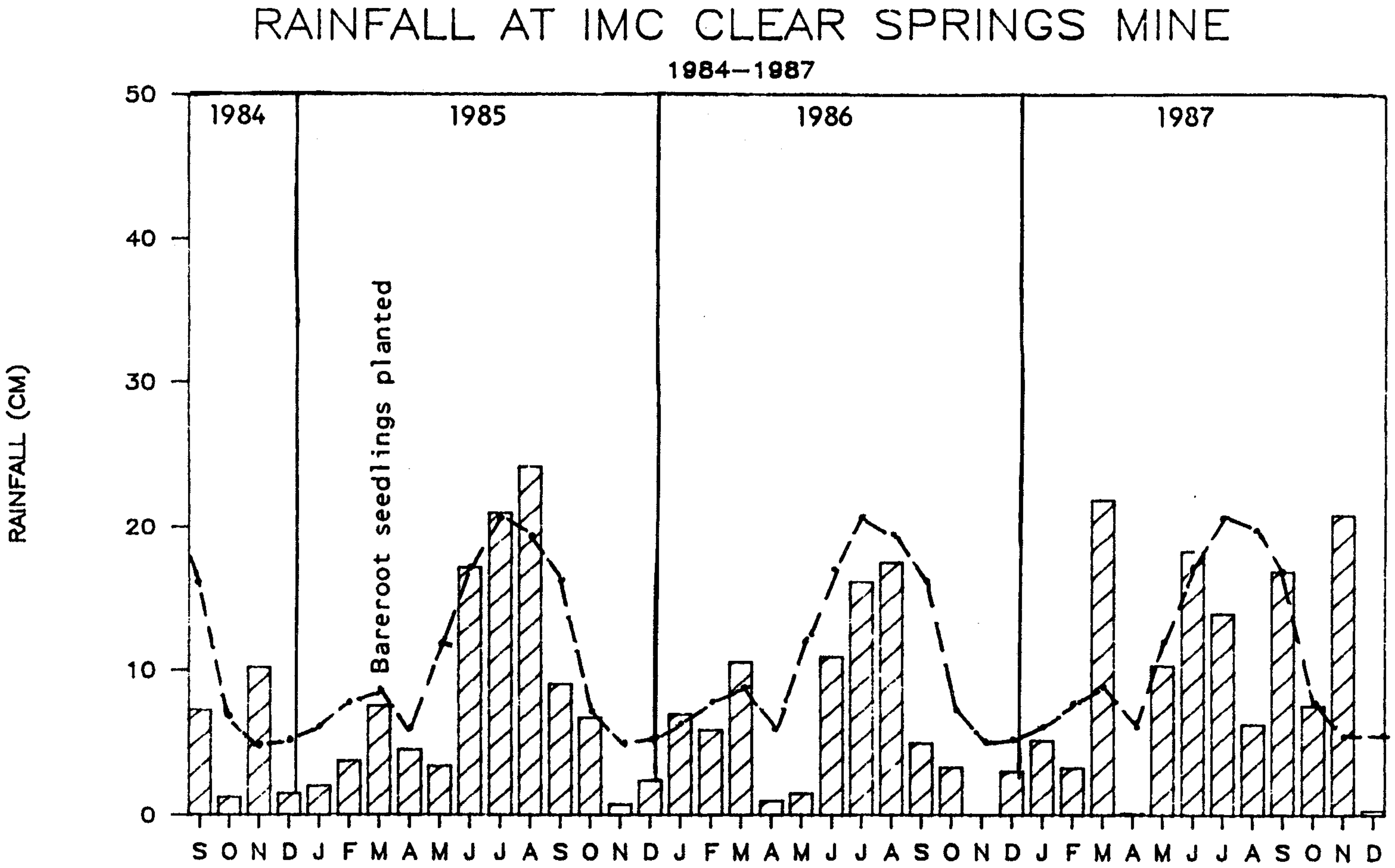


Figure 5.9. Monthly rainfall data collected at IMC's Clear Springs Mine for the Mobil Pasture Pond site. Data covers the period from September 1984 to December 1987. The dashed line represents the average rainfall (1952-1980) for four weather stations in the region published by the National Climatic Data Center.

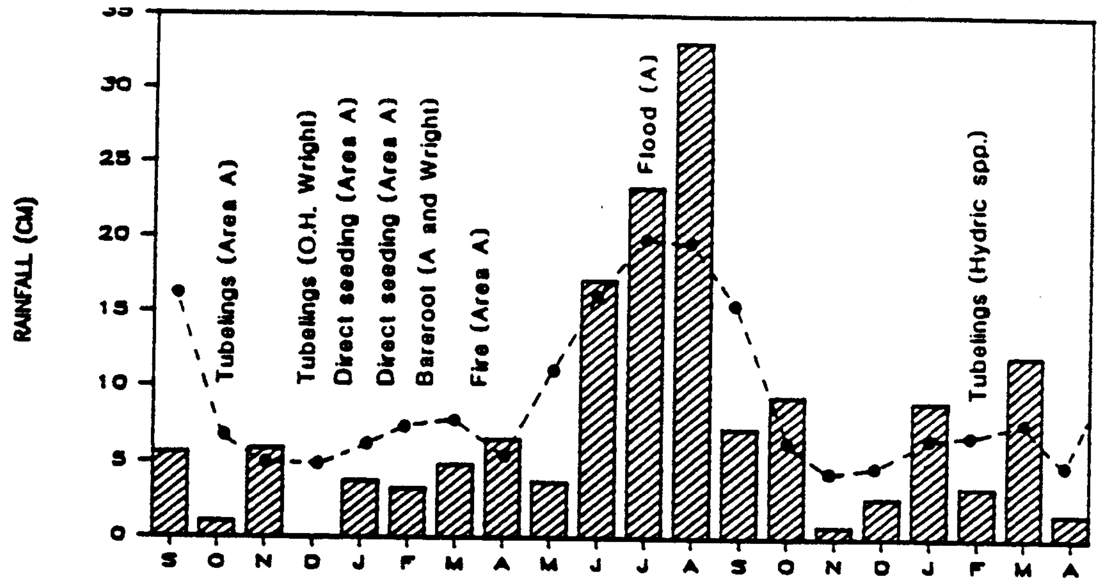


Figure 5.10. Monthly rainfall data (1984-1986) during the time seedlings were planted and seeds introduced. The Gardinier phosphate near Ft. Meade supplied data for Gardinier (Area A, and O. H. Wright.

Soil Parameters

Soil data are presented in Tables 5-2 and 5-3 and Figures 5-11 to 5-14. Parameters reported included particle size distribution, moisture content, organic content, pH, and concentrations of phosphorous, potassium, magnesium, and calcium.

Soils with a higher clay content had higher percentages of soil moisture when compared to sandier soils. Older clay settling ponds had less moisture in their soils than younger ponds.

The three clay settling ponds with no sand addition had similar sand, silt, and clay particle distributions. The youngest of the three, Tenoroc, had 75% clay particles, O. H. Wright had 78%, and Alderman Ford Ranch had 75%. These values were well within the range of average particle size distributions for clay discharged from beneficiation plants (Lamont et al, 1975, Bromwell, 1982, and Wissa et al. 1982). CF Industries used a sand clay mix which had 47% clay size particles. The clay settling pond at Mobil pasture pond was capped with sand. At the seedling site there was 100% sand in the top 30 cm of soil.

Percent organic matter varied between transects at a site and between clay settling ponds. The lowest average percent organic matter was found at Mobil pasture pond. Soil at that site was sand with sparse vegetation. Both Alderman Ford Ranch and C. F. Industries had large ranges, greater than 3%, in their organic matter content. Some of the variability in percent organic matter may be explained by the formation of large cracks in clay soils. Cracks fill with organic matter during dry periods and close up again when the soil becomes saturated, trapping organic matter below the surface.

Average soil pH ranged from 6.0 at Alderman Ford Ranch to 7.8 at C. F. Industries (Figure 5-13). With the exception of Tenoroc, soil pH between transects at any location were fairly consistent. Two comments can be made about soil pH with regard to the age of the site and the percent clay content. The older clay sites had a lower pH value than the younger ones. Typically, the older sites had the longest history of tree cover. The increased acidity, typical of most forest soils, would be the result of the release of organic acids during the decomposition of leaf litter (Pritchett, 1979).

Those sites with predominately clay soils had a lower average pH than sites that were either sand/clay mixed or pure sand. For example, Alderman Ford Ranch was a predominately clay soil, pH of 6.0, compared to a pH of 7.8 for the sand/clay mix at C.F. Industries and pH 7.4 for pure sand at Mobil.

Phosphorous levels for all sites were high if not off scale (Table 5-2). The process to remove phosphorous from the matrix at the beneficiation plants leaves a high percentage of the apatites in the clay wastes. Calcium was also high for all sites. With the exception

Table 5.2. Soil analysis for organic matter, pH, and selected double acid extractable nutrients in cypress-gum seedling transects.

	ORGANIC MATTER %	pH	PPM			
			P	K	Mg	Ca
TENOROC (18 years since decomissioned)						
TR-3 TB CL/UC (15)A	2.77	7.5	200*	32	800*	2000*
TR-3 TB CL/UC (15)B	1.98	7.6	200	40	784	2000
TR-3 TB CL/UC (25)	2.44	7.4	200	32	764	2000
TR-7 BR UC (5)	2.24	6.2	200	28	552	2000
TR-7 BR UC (25)A	3.16	6.2	200	28	512	2000
MEANS	2.52	6.6	200	32	682	2000
STANDARD DEVIATION	0.46		0	5	139	0
O. H. WRIGHT (25 years since decomissioned)						
WR-1 BR UC (20)	2.05	6.6	200	60	764	2000
WR-2 BR UC (15)B	1.92	6.4	200	52	672	2000
WR-2 BR UC (15)C	2.31	6.3	200	52	696	2000
WR-4 TB CL (30)C	2.90	6.6	200	56	716	2000
WR-4 TB CL (0)	2.64	6.6	200	60	724	2000
MEANS	2.36	6.5	200	56	714	2000
STANDARD DEVIATION	0.41		0	4	34	0
A. F. RANCH (35 years since decomissioned)						
AF-1 BR UC (15)	1.01	6.2	200	40	436	2000
AF-2 BR UC (15)B	1.20	6.3	200	40	504	2000
AF-4 BR UC (25)B	0.88	6.4	200	32	548	2000
AF-4 BR UC (25)C	1.07	6.1	200	28	484	2000
AF-5 BR UC (25)	4.26	5.6	200	32	404	2000
MEANS	1.68	6.0	200	34.4	475	2000
STANDARD DEVIATION	1.44		0	5.4	57	0

Table 5.2 (continued)

	ORGANIC MATTER %	pH	PPM			
			P	K	Mg	Ca
C. F. INDUSTRIES (SAND CLAY MIX - 3 years since decomissioned)						
CF-2 BR UC (25)	2.11	7.8	200*	36	800*	2000*
CF-3 BR UC (20)A	0.94	7.8	200	32	800	2000
CF-3 BR UC (20)B	1.46	7.8	200	36	800	2000
CF-5 BR UC (0)	4.18	7.8	200	40	800	2000
MEANS	2.17	7.8	200	36	800	2000
STANDARD DEVIATION	1.42		0	3.3	0	0
MOBIL PASTURE POND (SAND CAP OVER CLAYS - 10 years since reclaimed)						
MO-1 BR UC (15)	0.68	7.1	200	12	84	2000
MO-2 BR UC (0)	0.81	7.4	200	8	68	2000
MO-4 BR UC (20)C	1.07	7.1	200	12	124	2000
MO-7 BR UC (15)	0.29	7.6	200	8	132	2000
MEANS	0.71	7.25	200	10	102	2000
STANDARD DEVIATION	0.33		0	2	23.9	0

* Top of scale for method of soil analysis.

See Appendix A for abbreviations.

Table 5.3. Soil analysis for particle size in cypress-gum seedling transects. Duplicate and triplicate samples taken within one meter of each other are designated with letters A, B, C. Top 15 cm of soil core used for analysis.

	SAND (%)	SILT (%)	CLAY (%)
TENOROC (18 years since deactivated)			
TR-3 TB CL/UC (5)	3	25	72
TR-3 TB CL/UC (15)A	0	22	78
TR-3 TB CL/UC (15)B	0	19	81
TR-3 TB CL/UC (15)C	3	21	76
TR-3 TB CL/UC (25)	10	20	70
TR-7 BR UC (5)	5	23	72
TR-7 BR UC (25)A	0	22	78
TR-7 BR UC (25)B	12	16	72
TR-7 BR UC (25)C	8	12	80
MEANS	4.6	20.0	75.4
STD. DEV.	4.3	3.7	3.8
O. H. WRIGHT (25 years since deactivated)			
WR-1 BF UC (20)	0	18	83
WR-2 BR UC (15)A	0	0	100
WR-2 BR UC (15)B	1	23	76
WR-2 BR UC (15)C	4	27	63
WR-4 TB CL (0)	1	21	78
WR-4 TB CL (30)A	4	16	80
WR-4 TB CL (30)B	10	18	72
WR-4 TB CL (30)C	3	19	78
MEANS	2.9	17.8	78.8
STD. DEV.	3.1	7.4	9.8

Table 5.3 (continued)

	SAND (%)	SILT (%)	CLAY (%)
A. F. RANCH (35 years since deactivated)			
AF-1 BR UC (15)	1	21	78
AF-2 BR UC (15)B	7	21	72
AF-2 BR UC (15)C	0	20	80
AF-4 BR UC (25)A	5	26	69
AF-4 BR UC (25)B	2	28	70
AF-4 BR UC (25)C	3	21	76
AF-5 BR UC (25)	2	24	74
MEANS	2.9	23	74.1
STD. DEV.	2.2	2.8	3.8
C. F. INDUSTRIES (Sand Clay mix - 3 years since deactivated)			
CF-2 BR UC (25)	20	25	55
CF-3 BR UC (20)	35	19	46
CF-3 BR UC (20)B	37	20	43
CF-3 BR UC (20)C	29	20	51
CF-5 BR UC (0)A	34	18	48
CF-5 BR UC (0)B	46	13	41
MEANS	33.5	19.2	47.3
STD. DEV.	7.9	3.5	4.7
MOBIL PASTURE POND (Sand cap over clays - 10 years since reclaimed)			
MO-2 BR UC (0)	100	0	0
MO-1 BR UC (15)	100	0	0
MO-2 BR UC (15)	100	0	0
MO-4 BR UC (20)A	100	0	0
MO-4 BR UC (20)B	100	0	0
MO-4 BR UC (20)C	100	0	0
MO-7 BR UC (15)	100	0	0
MEANS	100.0	0.0	0.0
STD. DEV.	0.0	0.0	0.0

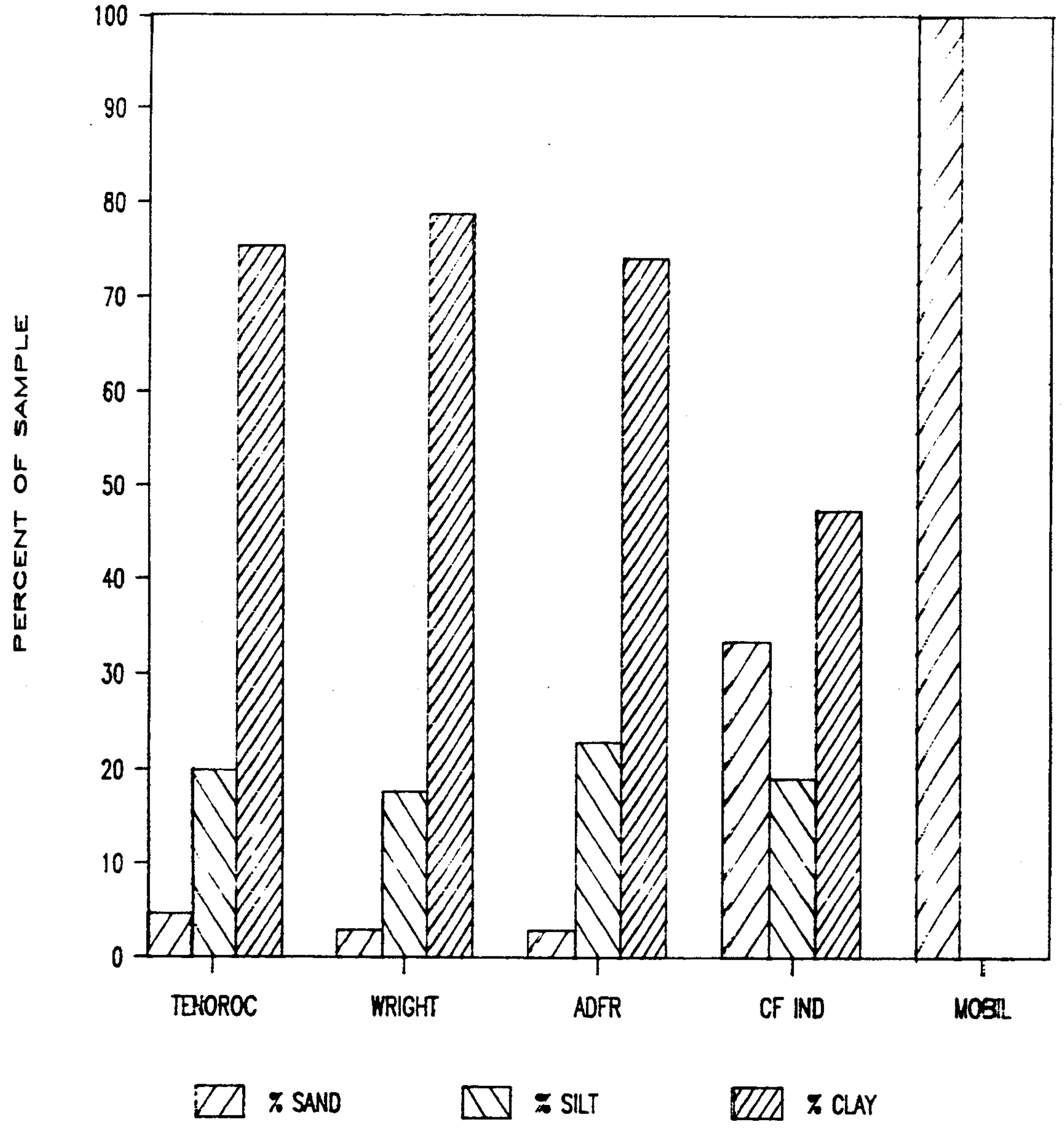


Figure 5.11. Comparison of particle size from top 15 cm of soil column for five clay settling ponds. The results were divided into percent sand, silt, and clay using the U.S. Dept. of Agriculture scheme (<0.002 mm clay, 0.002-0.05 mm silt, and >0.05 mm sand). Clay represents traditional settling ponds with no soil amendments, other designations are for sand treatments.

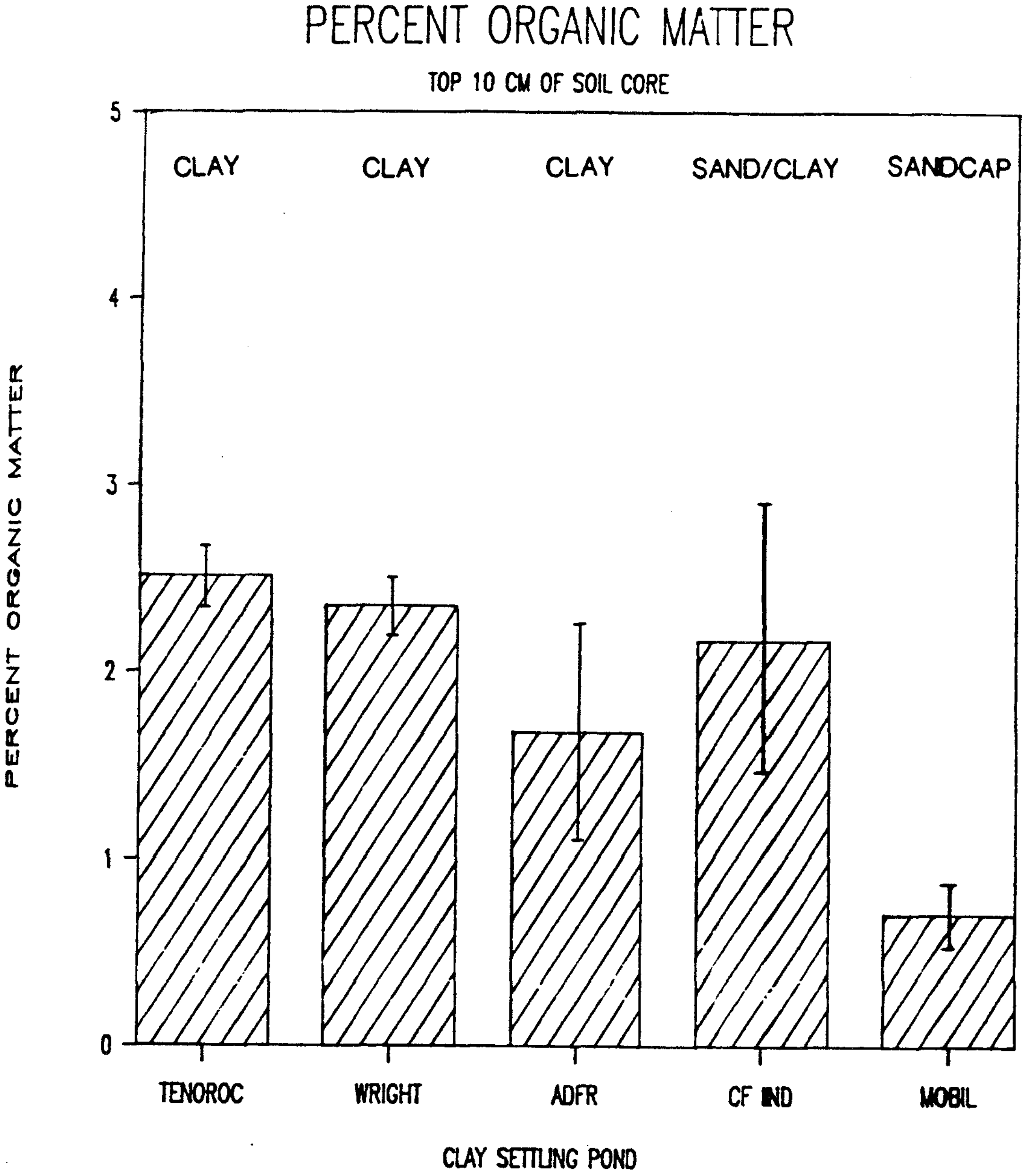


Figure 5.12. Comparison of average percent organic matter between sites measured in top 10 cm of soil. Error bars represent one standard error. Sites with the same letter are not statistically different. Clay indicates ponds with no reclamation such as sand additions.

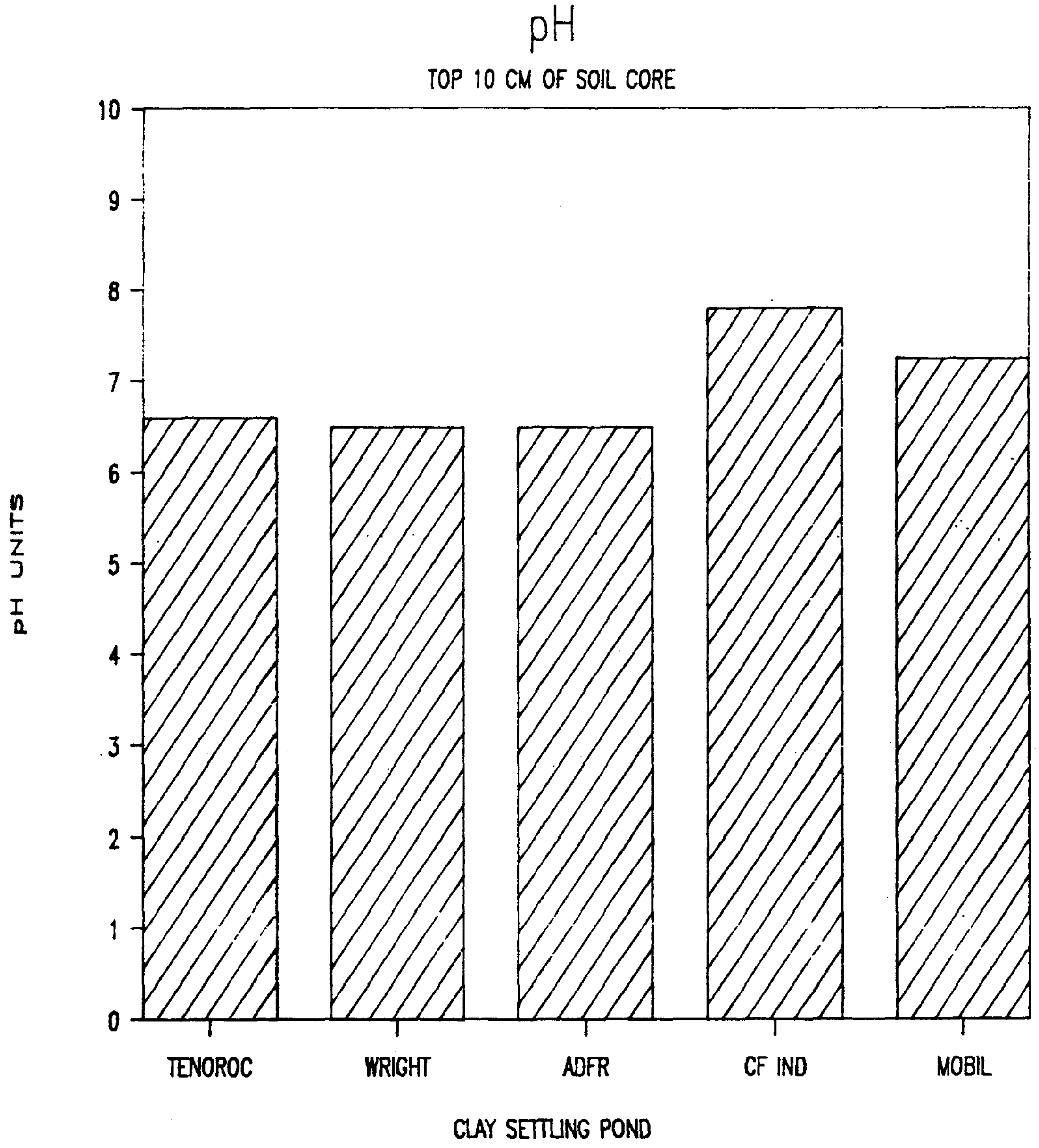


Figure 5.13. Comparison of pH measured in water in top 10 cm of soil. Clay indicates traditional settling ponds with no sand reclamation.

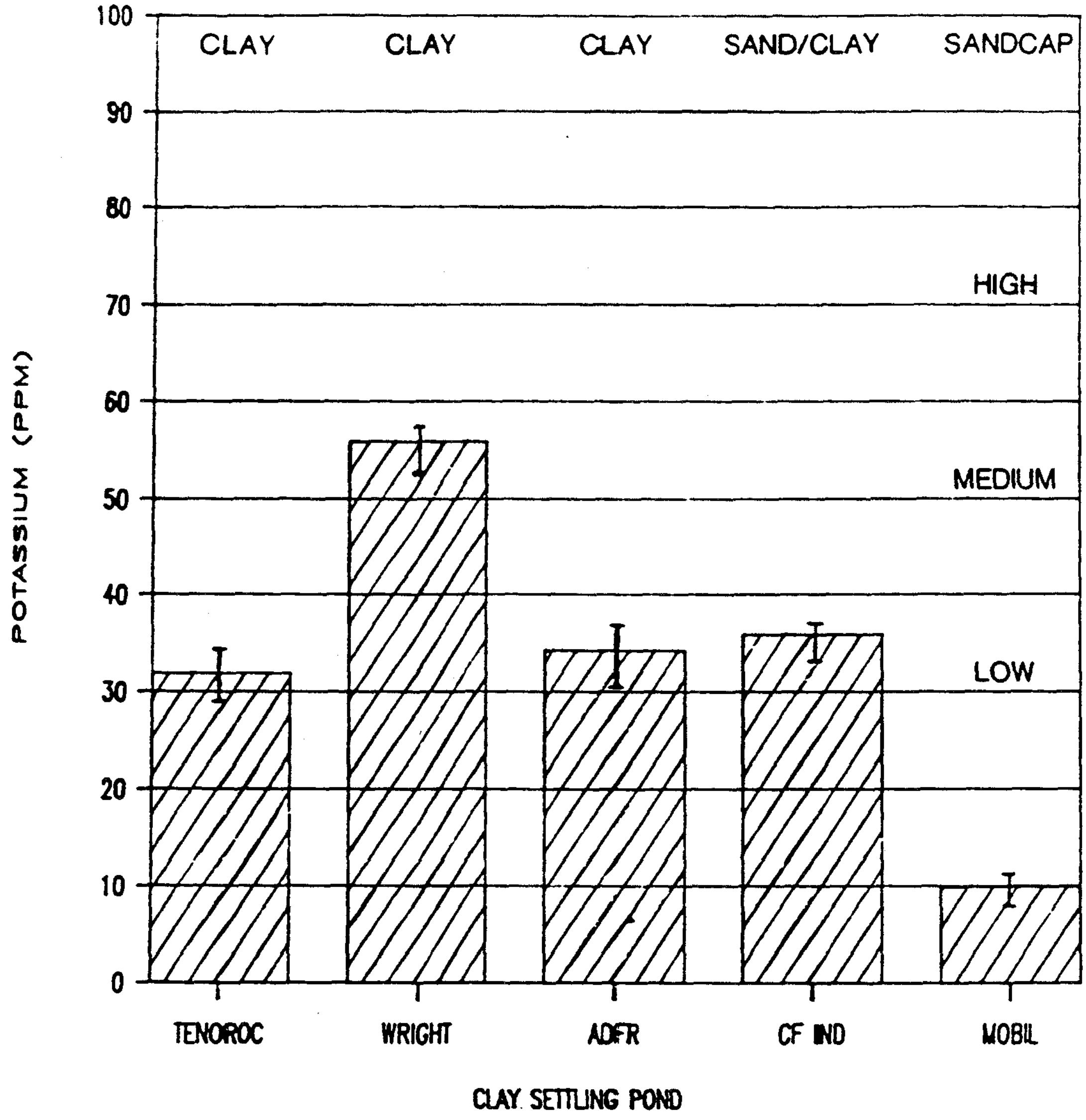


Figure 5.14. Comparison of potassium in ppm between sites. Error bars are one standard error. Clay indicates ponds with no reclamation such as sand additions. Potassium level designations were those reported by the IFAS Extension Soil Testing Laboratory and are related to needs of agriculture crops.

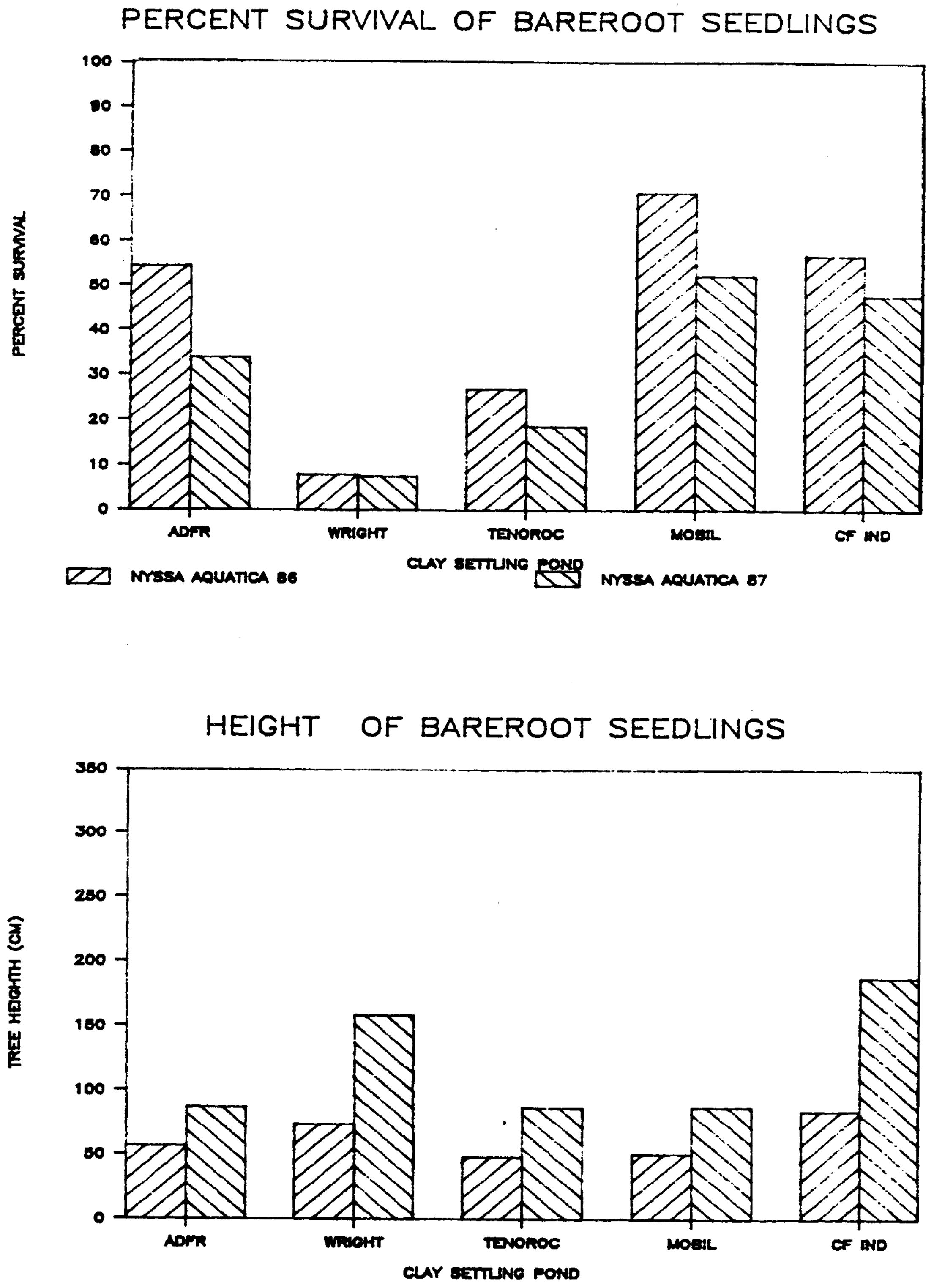
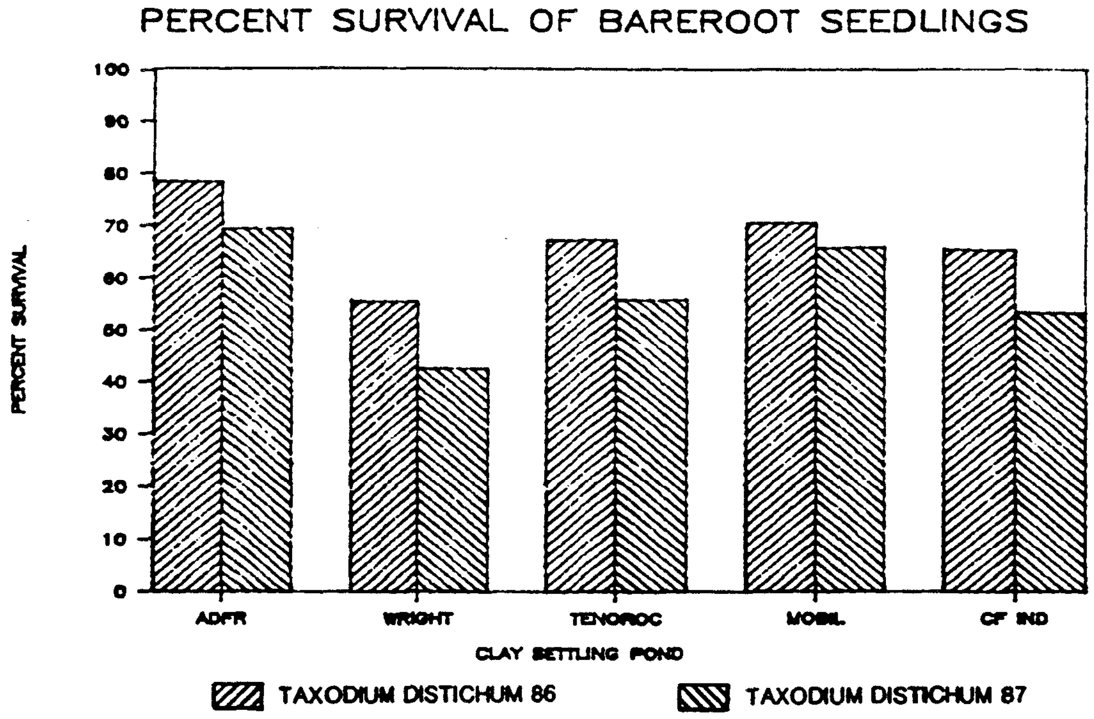


Figure 5.15. Percent survival and tree height of water tupelo (*Nyssa aquatica*), planted as bareroot seedlings, after 3 growing seasons (2 1/2 years). For comparison percent survival and tree height data form the first growing season (1 year) were included.


PERCENT SURVIVAL OF BAREROOT SEEDLINGS

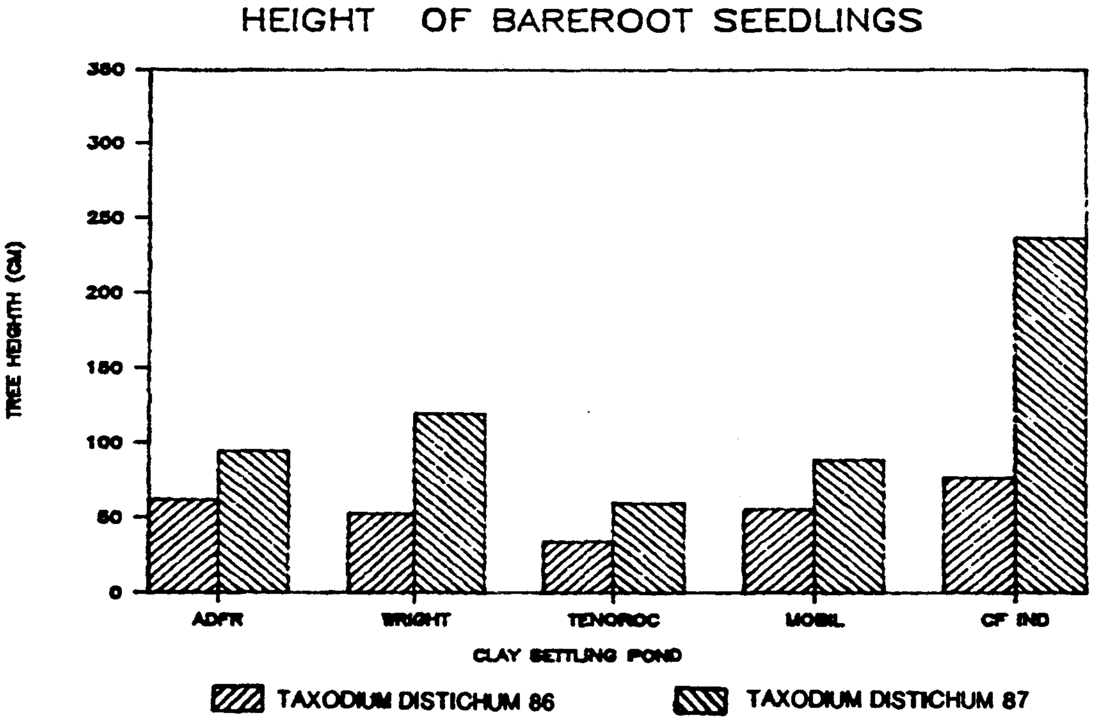

HEIGHT OF BAREROOT SEEDLINGS

Figure 5.16. Percent survival and tree height of bald cypress (Taxodium distichum), planted as bareroot seedlings, after 3 growing seasons (2 1/2 years). For comparison percent survival and tree height data from the first growing season (1 year) were included.

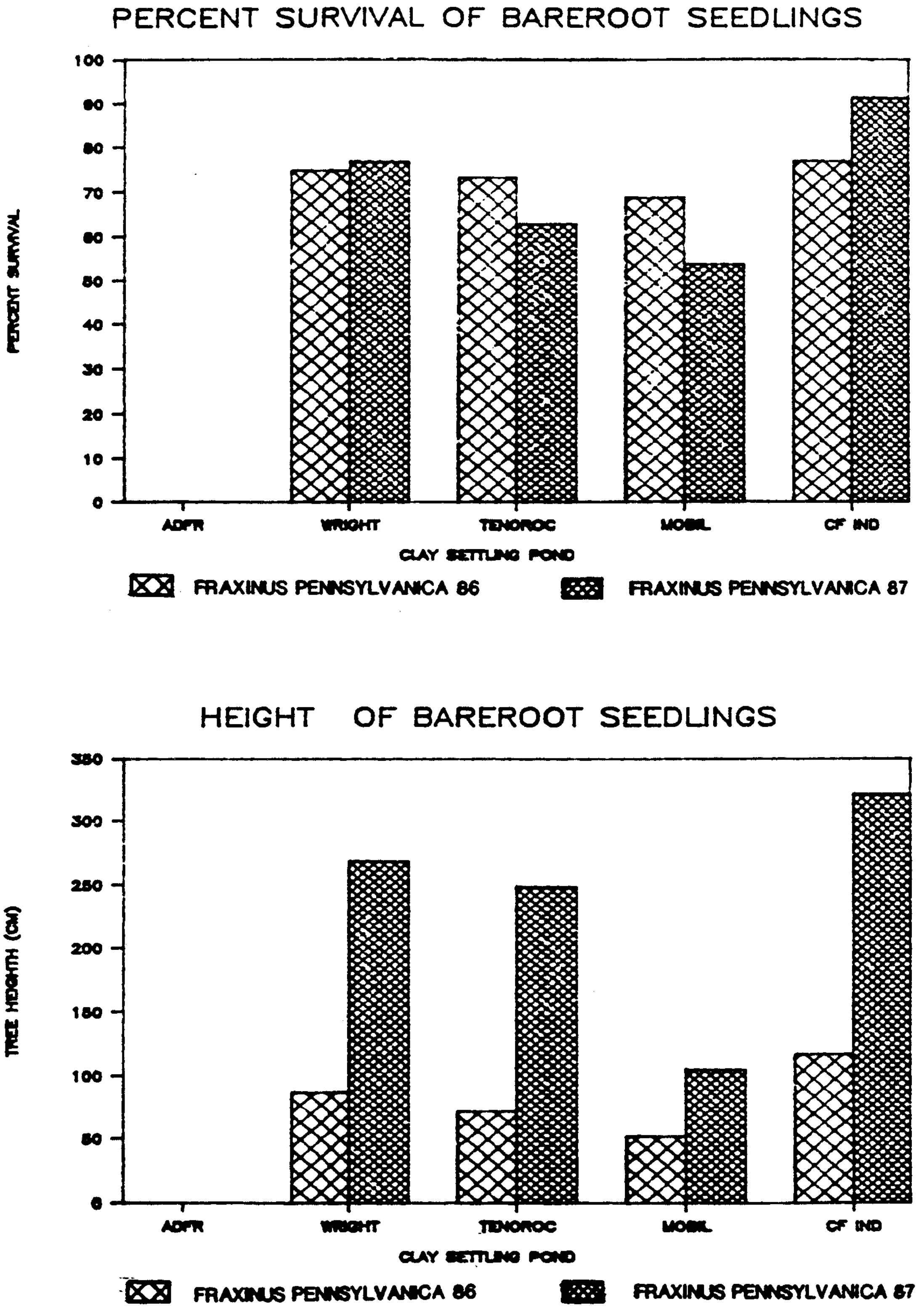


Figure 5.17. Percent survival and tree height of green ash (Fraxinus pennsylvanica), planted as bareroot seedlings, after 3 growing seasons (2 1/2 years). For comparison percent survival and tree height for the first growing season (1 year) were included.

of Mobil pasture pond, magnesium and potassium were present in the soil at adequate concentrations for good plant growth (Figure 5-14). Soil concentrations of potassium at Mobil were below the 20 - 100 ppm range

for exchangeable potassium necessary for the growth of most forest trees (Pritchett, 1979).

Seedling Survival

Bareroot. Comparisons of percent survival and mean tree height for bareroot seedlings planted at five consolidated clay settling ponds are presented in Figures 5-15 through Figure 5-17. Data was pooled from both cleared and uncleared transects to obtain mean tree height and percent survival. For comparative purposes data from 1986 were included on each graph. Data from 1986 were collected in April and represent one growing season. Data from 1987 were collected in November and represent three growing seasons. The acronyms ADFR and CFInd stand for Alderman Ford Ranch and C.F. Industries, respectively.

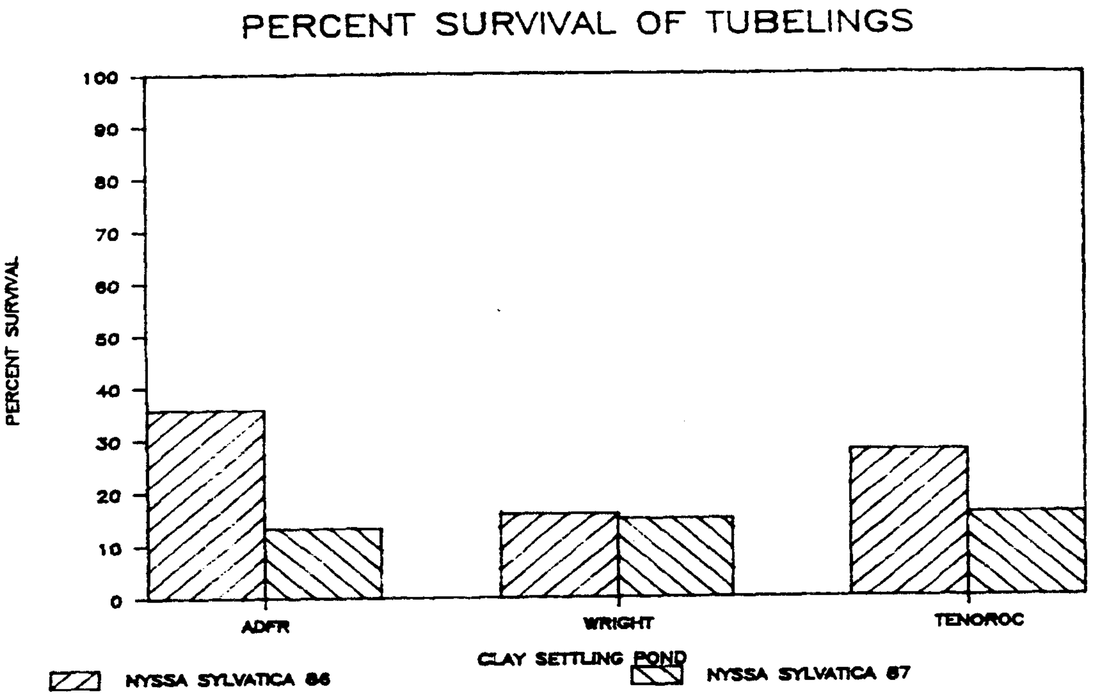
Water tupelo had the poorest survival of the three species planted (Figure 5-15). Percent survival in 1987 ranged from 8 at OH Wright to 54 at Mobil pasture pond. The greatest tree mortality had occurred in the first years growth, but from 20 to 1 percent more of the initial number of trees planted died in the third growing season. More of the water tupelo planted on clay sites (Alderman Ford Ranch, OH Wright, and Tenoroc) died than on either the sand/clay mix at CF Industries or the sand capped clay settling pond at Mobil.

The best growth of water tupelo occurred at OH Wright and CF Industries. Trees at those sites had doubled in height from the previous year. Surviving trees at other sites also grew, but not as well.

After two growing seasons, the percentage of surviving baldcypress ranged from 70 at Alderman Ford Ranch to 42 at OH Wright Figure 5-16). Tree mortality increased in the second year between 3 and 11 percent. Those trees planted at C. F. Industries grew very well during the second year, tripling in height.

Green ash had its best survival at CF Industries (92%) and worst at Mobil pasture pond (54%) (Figure 5-17). More live trees were found at CF Industries and O.H. Wright in 1987 than in 1986. The probable reason for this was the regrowth by basal sprouting of damaged trees. The other two sites lost approxiomately 10% more trees in the second year. Green ash grew very well at all sites except Mobil, which has been reclaimed by sand capping. At sites with soils composed of clay and a sand/clay mix tree heights tripled between fall 1986 and fall 1987.

Tubelings. Comparisons of percent survival and growth of tubelings planted at three consolidated clay settling ponds are presented in Figures 5-18 through 5-20. Data was pooled from both



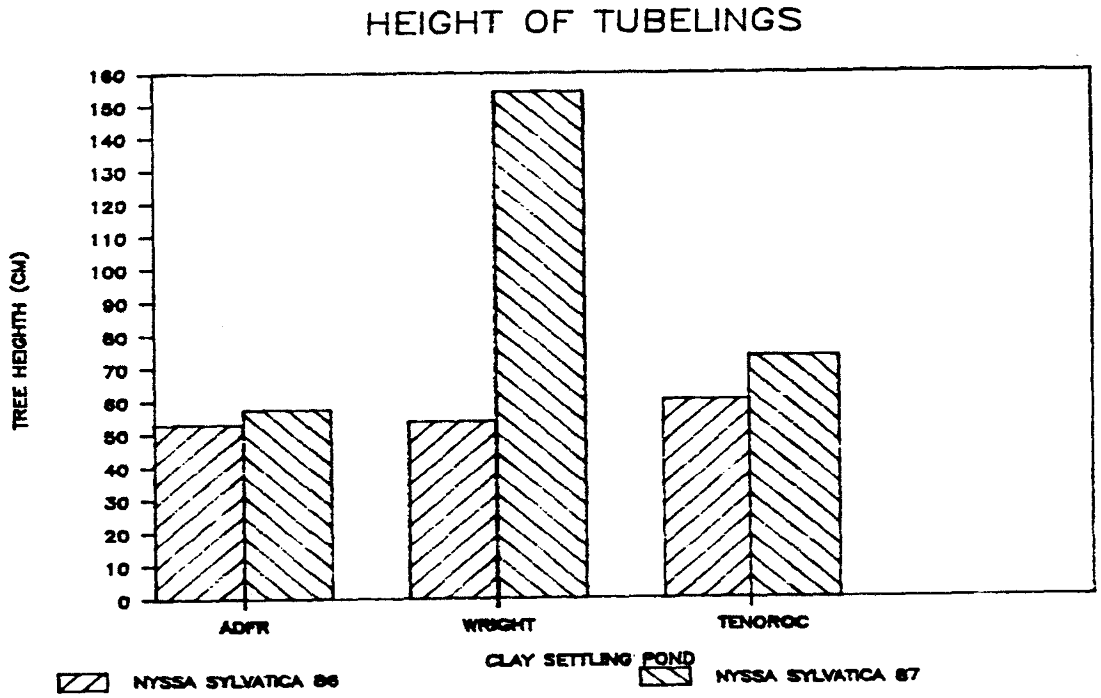


Figure 5.18. Percent survival and tree height of black gum (*Nyssa sylvatica*), planted as tubelings, after 3 growing seasons (2 1/2 years). For comparison percent survival and tree height after 1 growing season (1 year) was included.

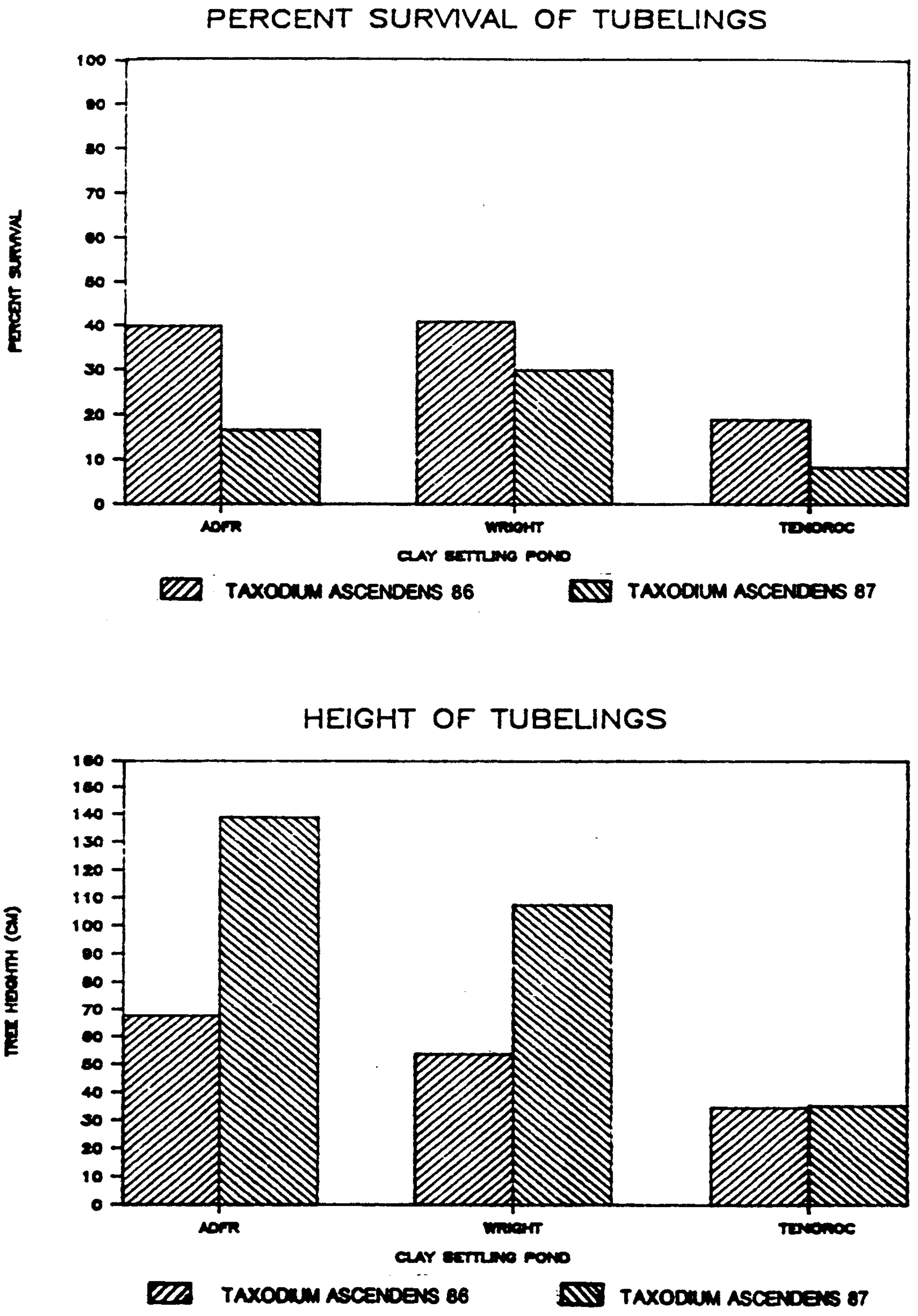
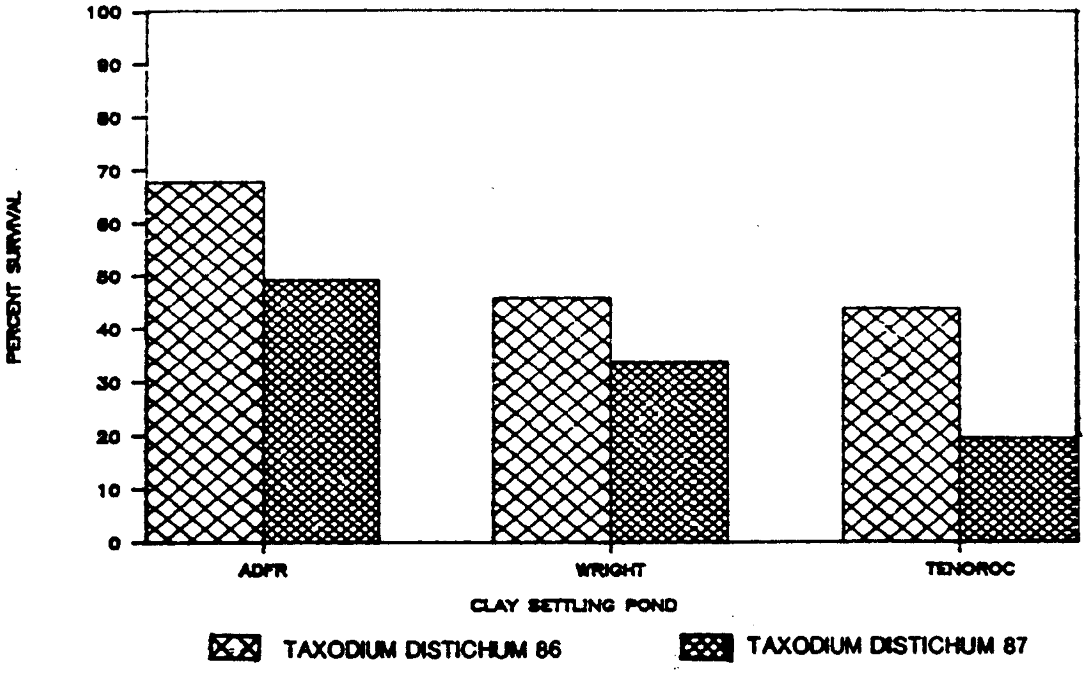


Figure 5.19. Percent survival and tree height of pond cypress (*Taxodium ascendens*), planted as tubelings, after 3 growing seasons (2 1/2 years). For comparison percent survival and height from the first growing season (1 year) were included.

PERCENT SURVIVAL OF TUBELINGS



HEIGHT OF TUBELINGS

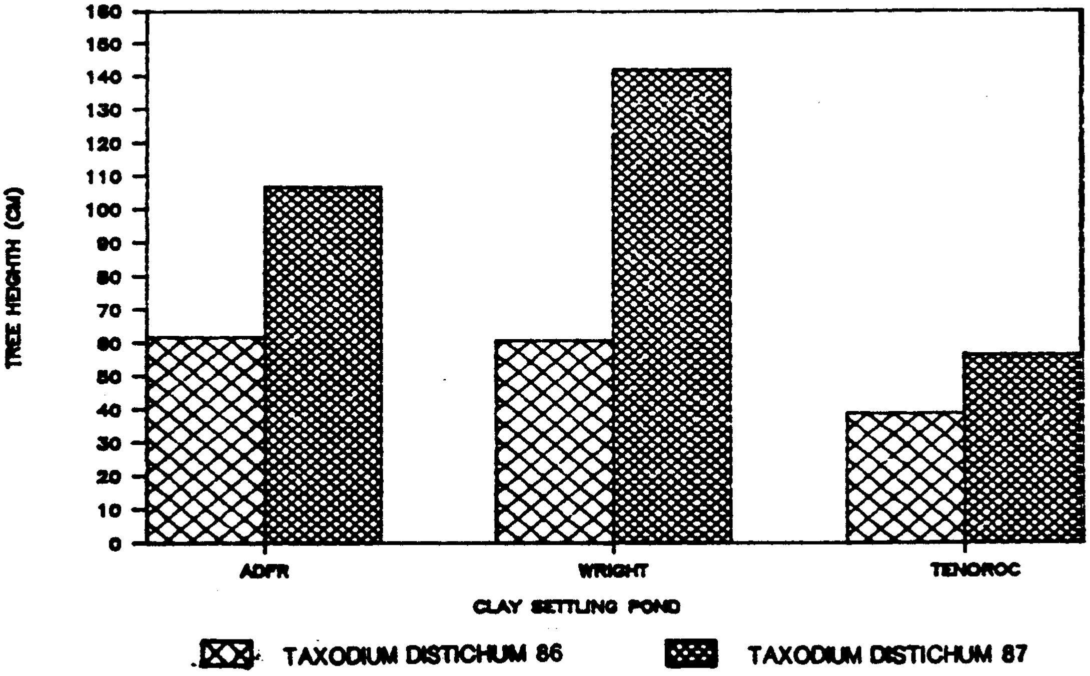


Figure 5.20. Percent survival and tree height of bald cypress (Taxodium distichum), planted as tubelings, after 3 growing seasons (2 1/2 years). For comparison percent survival and tree height from the first growing season (1 year) were included.

cleared and uncleared transects to obtain mean tree height and percent survival. For comparative purposes data from 1986 were included in each graph. Data from 1986 were collected in April and represent one growing season. Data from 1987 were collected in November and represent three growing seasons. The acronym ADFR stands for Alderman Ford Ranch.

Of the three species planted, blackgum had the poorest survival. For all three sites only 12-15% of the trees planted were still alive after 2 1/2 years (Figure 5-18). Tree losses of 20 and 10 percent occurred at Alderman Ford Ranch and Tenoroc. In addition, growth of surviving trees at those sites was poor. In contrast, trees at OH Wright that did survive tripled in height over the last growing season. None of these three clay settling ponds was reclaimed.

Both baldcypress and pond cypress fared better than blackgum in number of trees alive after 2 1/2 years (Figures 5-19 and 5-20). Both species experienced continued mortality (10 -20%) in the second growing season. Baldcypress grew taller at OH Wright while pond cypress grew more at Alderman Ford Ranch. Neither species grew particularly well at Tenoroc. A similar result was obtained for bareroot baldcypress seedlings. Heavy grazing pressure from wildlife was the cause of reduced survival and growth at that site.

Comparison of Grazed and Ungrazed Plots

Half of the transects planted at Mobil pasture pond were fenced to prevent cattle from gazing. Figure 5-21 contains percent survival and tree height information for grazed versus ungrazed plots 2 1/2 years after planting.

Those transects that were grazed had poorer survival of all species when compared to ungrazed transects. Chi square values of 76.95, 20.3, and 6.73 were obtained for water tupelo, baldcypress, and green ash. All three values were significant at the $p=0.05$ level.

The most dramatic effect was on water tupelo. Where cows were present only 4.5% of the trees survived compared to 52% in the ungrazed plots. Cattle had less of an impact on baldcypress and green ash, but it was still significant.

Those baldcypress and water tupelo that survived grew equally well whether subjected to grazing pressure or not. Comparisons of mean net growth between treatments by a t-test did not reveal any differences in growth. In contrast, green ash grew better without cows. Differences between treatments were significant at the $p=0.05$ level (t statistic = -5.59).

Comparison of Baldcypress and Pond Cypress

Paired transects of bald and pond cypress tubelings were planted at O. H. Wright, Tenoroc, and Alderman Ford Ranch. Data for mean tree

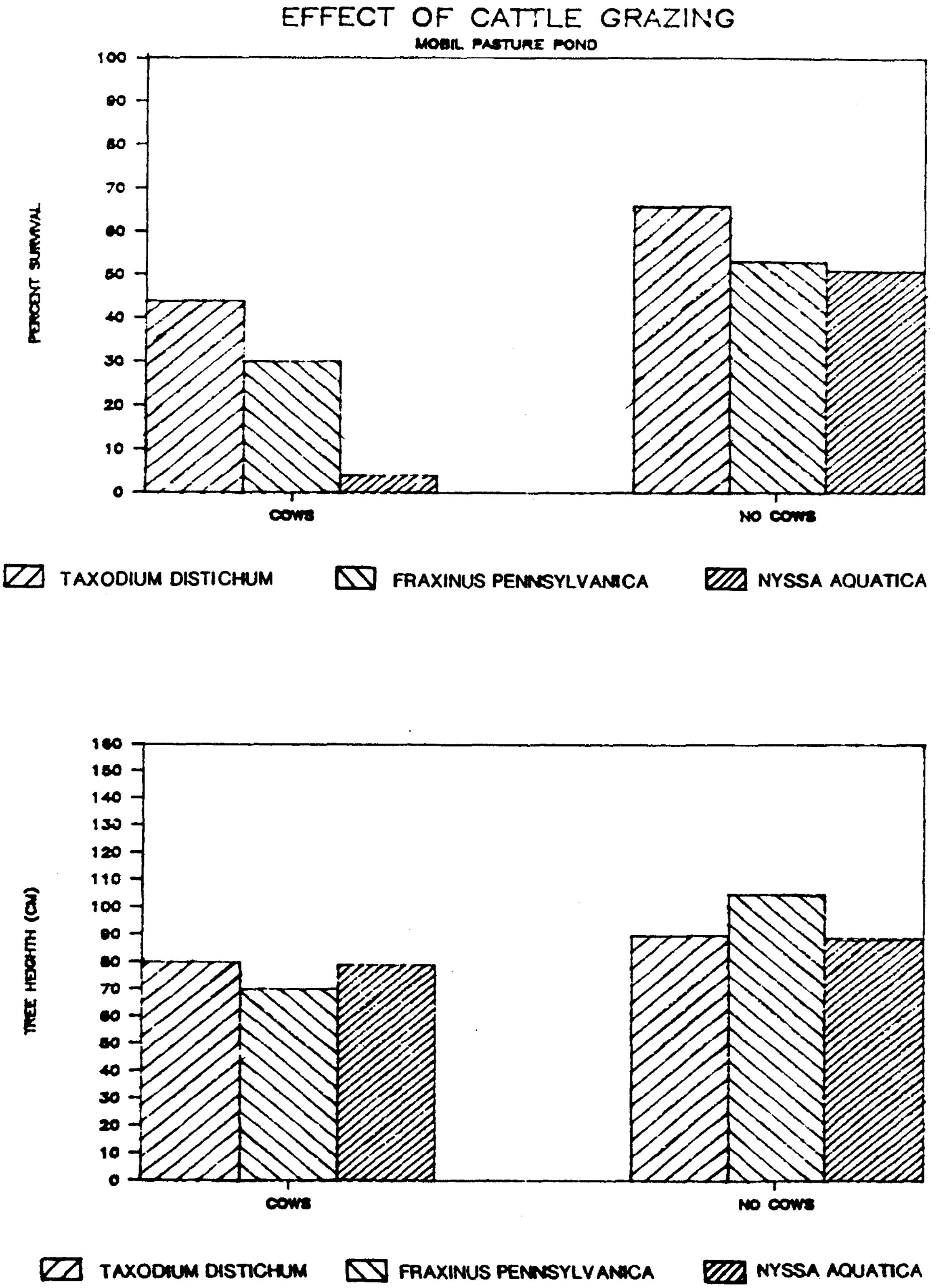


Figure 5.21. Percent survival and tree height of transects without cows compared to transects grazed by cows. Data is for third growing season. Survival of trees grazed by cows was significantly different from ungrazed trees for each species.

height and percent survival after 2 1/2 years are presented in Figure 5-22.

Tree survival at all three sites appears to be better for baldcypress than pond cypress. The difference is only statistically significant (p=0.05) for Alderman Ford Ranch and Tenoroc.

Growth of trees does not follow a discernible species pattern. Differences in mean tree height were site specific. Other factors dependent on site influenced tree growth rather than species of cypress.

Cleared Versus Uncleared Transects

Cleared and uncleared pairs of transects were planted at O.H. Wright and Tenoroc. Both bareroot and tubelings were planted. Tubeling species included black gum, pond cypress, and bald cypress. Bareroot seedlings included water tupelo, bald cypress and green ash. Figures 5-23 through 5-26 are graphs comparing percent survival and tree height between treatments at both sites. The vegetation that grew back in the cleared sets was willow, cattail and primrose willow. The same species dominated there before clearing.

Comparisons of net growth of each species between treatments yielded variable results (Figures 5-23 and 5-25). Species and seedling type responses differed between sites. Only cleared and uncleared transects of baldcypress at Tenoroc and bareroot green ash and bald cypress at O. H. Wright were statistically different (p=0.05) when subjected to a t-test.

Treatment had little effect on survivorship of species and seedling types. Only green ash at Tenoroc and water tupelo at O. H. Wright were significantly different by treatment type (chi square significant at p= 0.03 and 0.06). The variability in results indicates that local site conditions may be more important in growth and survival than the effect of removing vegetation.

Comparison of Reclamation Methods

Three reclamation methods were compared with respect to their influence on growth and survial of hardwood seedlings. Comparisons were made in two different manners (Figure 5.27). 1) All three tree species were combined to yield net survival and growth and 2) each individual species was tested for survival and growth with respect to each reclamation technique (Figure 5.28).

When all tree species were combined, percent survival was best on the sand/clay mix at CF Industries and poorest at sites with pure clay substrates. Differences in survival were significantly different at the p=0.001 level (X2 = 26.13). Net growth was poorest on the sand cap site and best on the sand/clay mix soil.

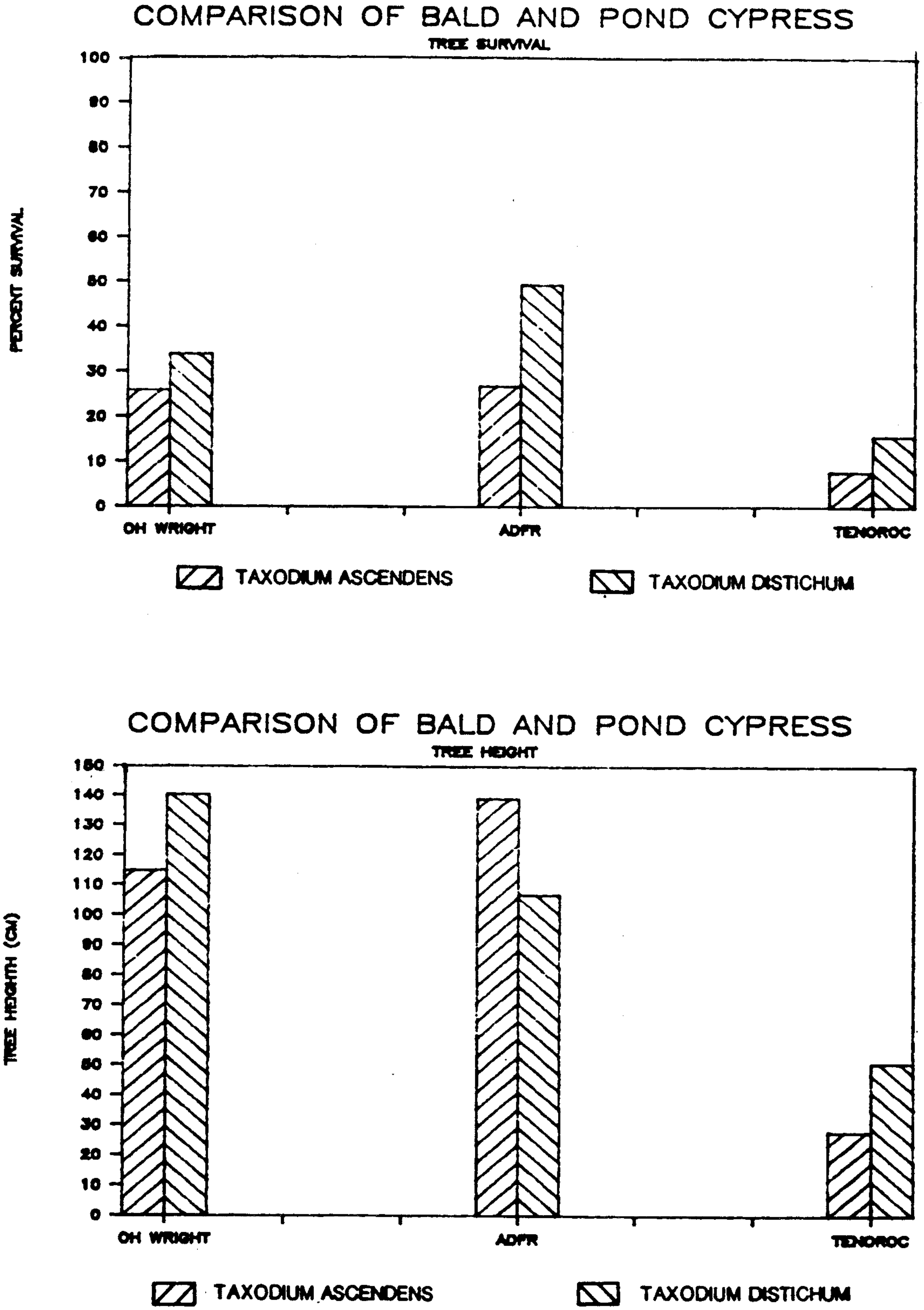


Figure 5.22. Comparison of tree height and percent survival of bald and pond cypress planted in paired transects at 3 clay settling ponds.

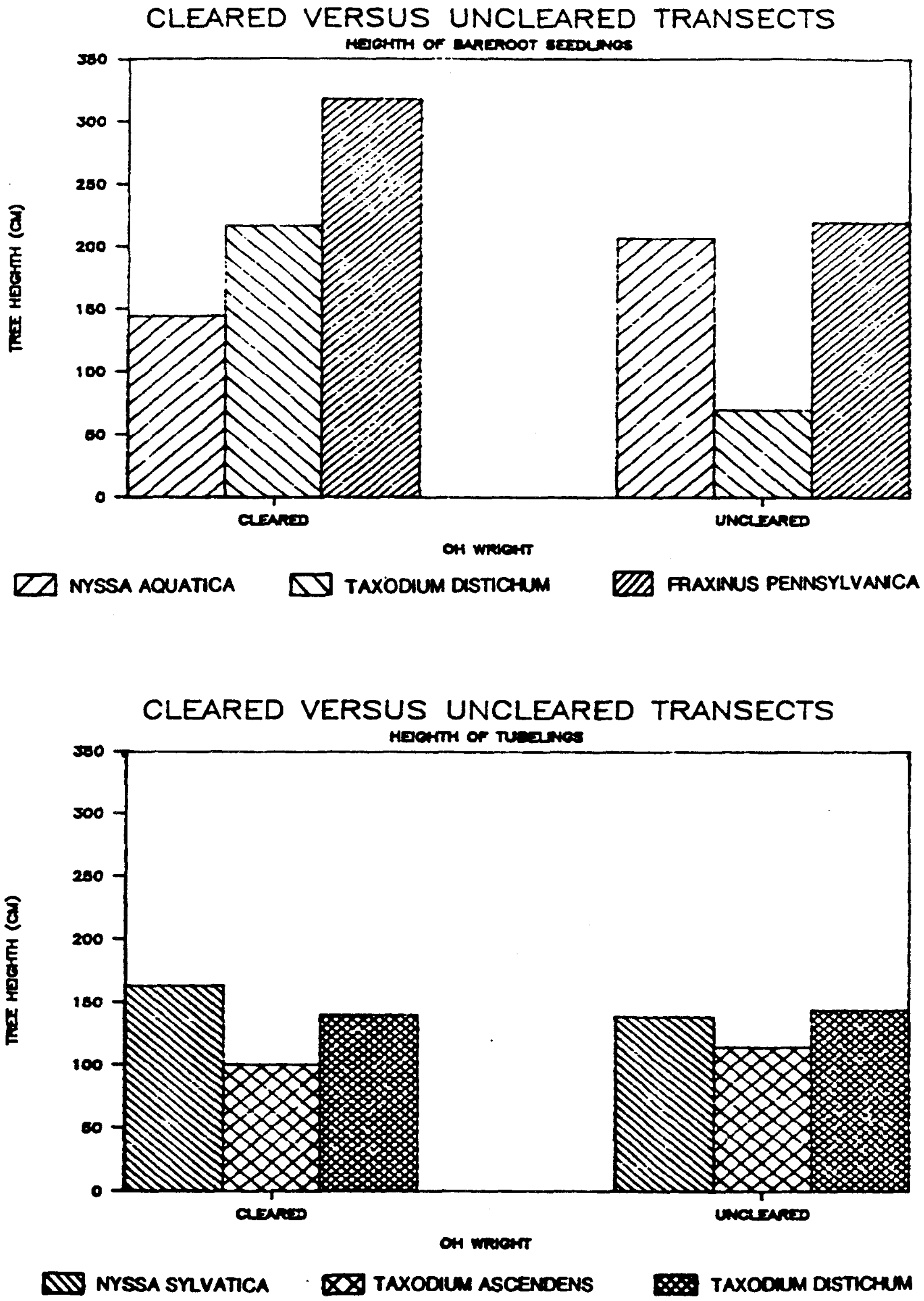
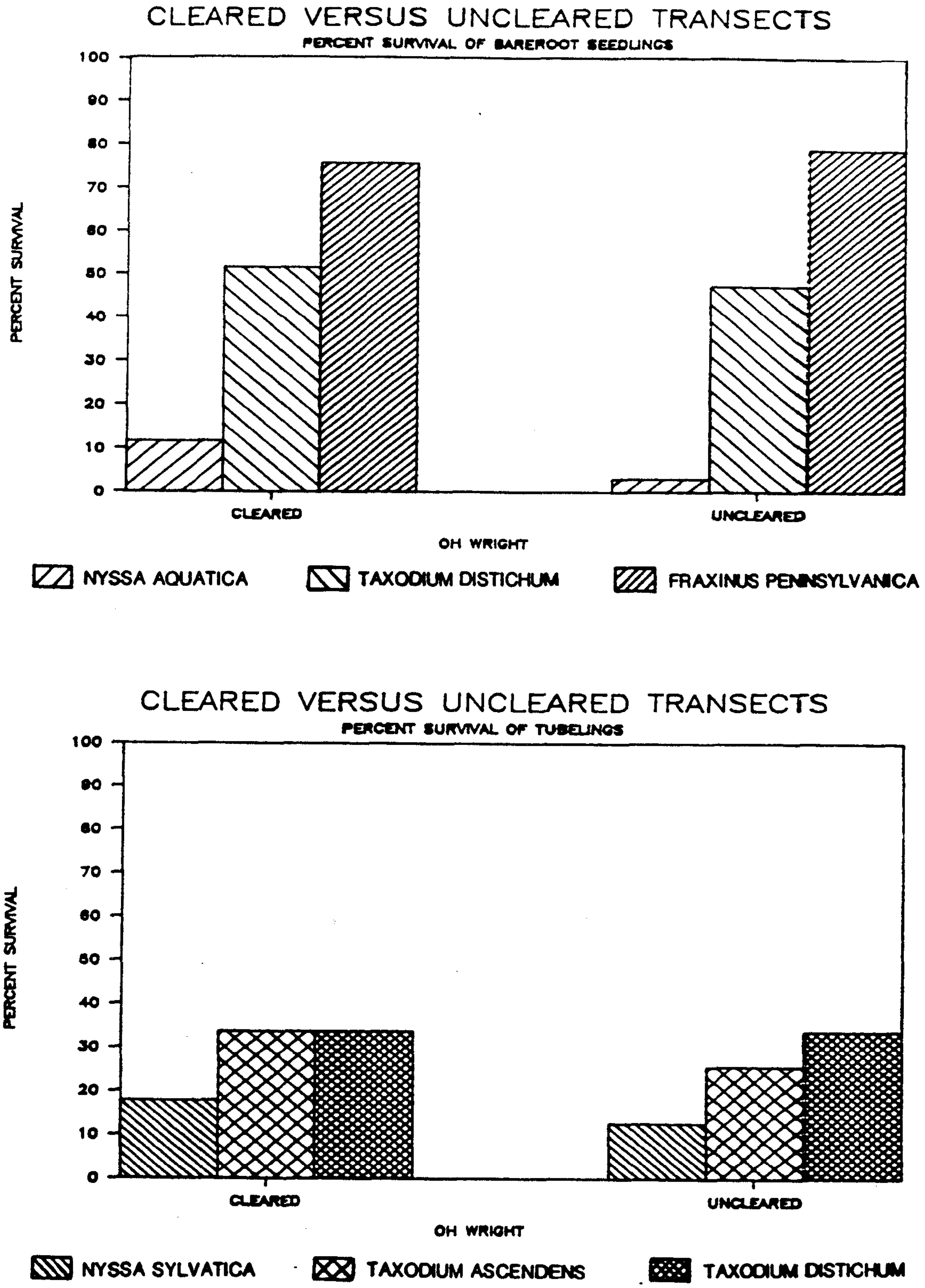


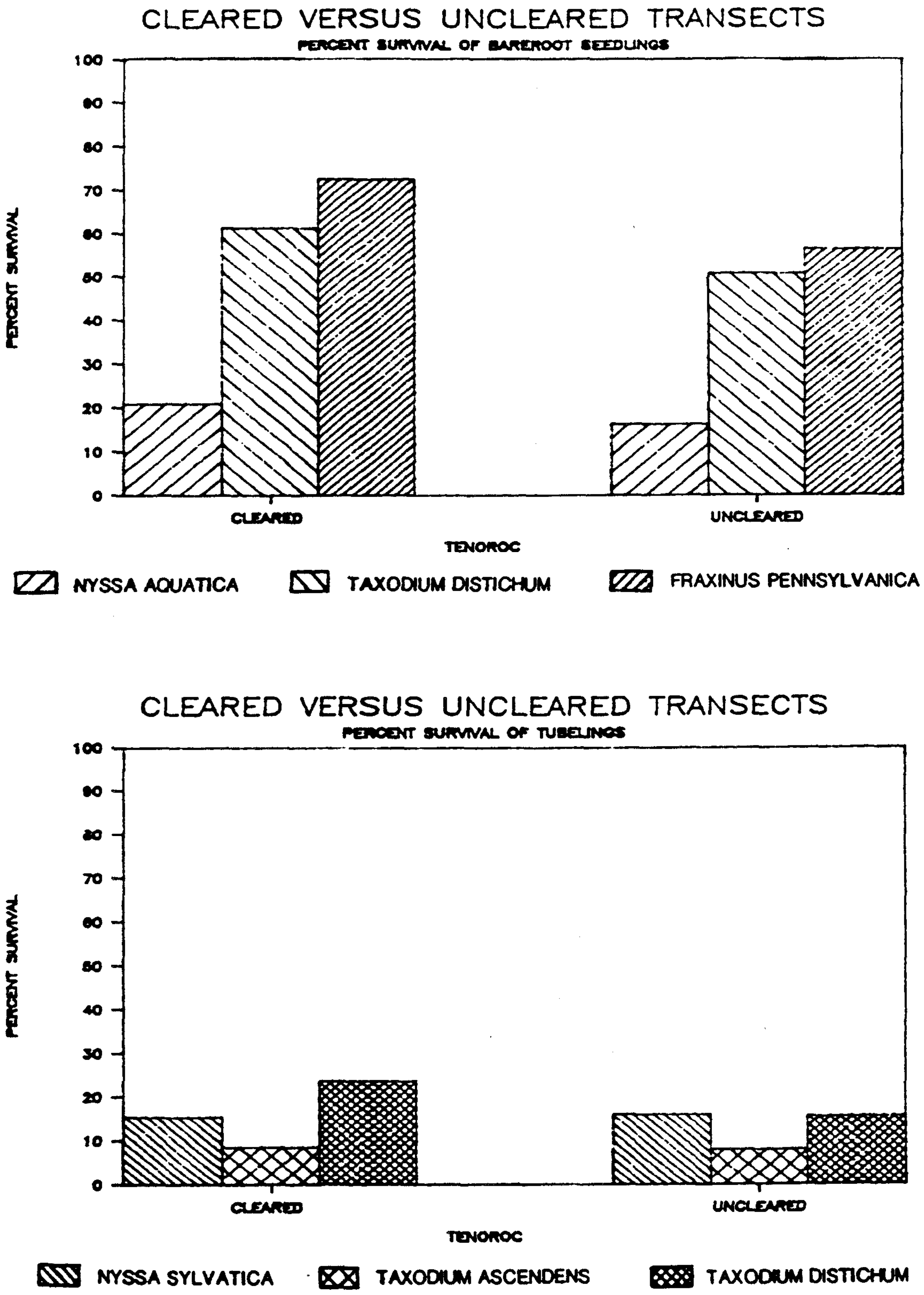
Figure 5.23. Comparison of tree height for cleared and uncleared transects planted at O.H. Wright. (a) Bareroot seedlings; (b) tubelings.



CLEARED VERSUS UNCLEARED TRANSECTS
PERCENT SURVIVAL OF BAREROOT SEEDLINGS

CLEARED VERSUS UNCLEARED TRANSECTS
PERCENT SURVIVAL OF TUBELINGS

Figure 5.24. Comparison of percent survival of cleared and uncleared transects at O.H. Wright. (a) Bareroot seedlings; (b) tubelings.


CLEARED VERSUS UNCLEARED TRANSECTS

PERCENT SURVIVAL OF BAREROOT SEEDLINGS

CLEARED VERSUS UNCLEARED TRANSECTS

PERCENT SURVIVAL OF TUBELINGS

Figure 5.25. Comparison of tree heights of cleared and uncleared transects planted at Tenoroc. (a) Bareroot seedlings; (b) tubelings.

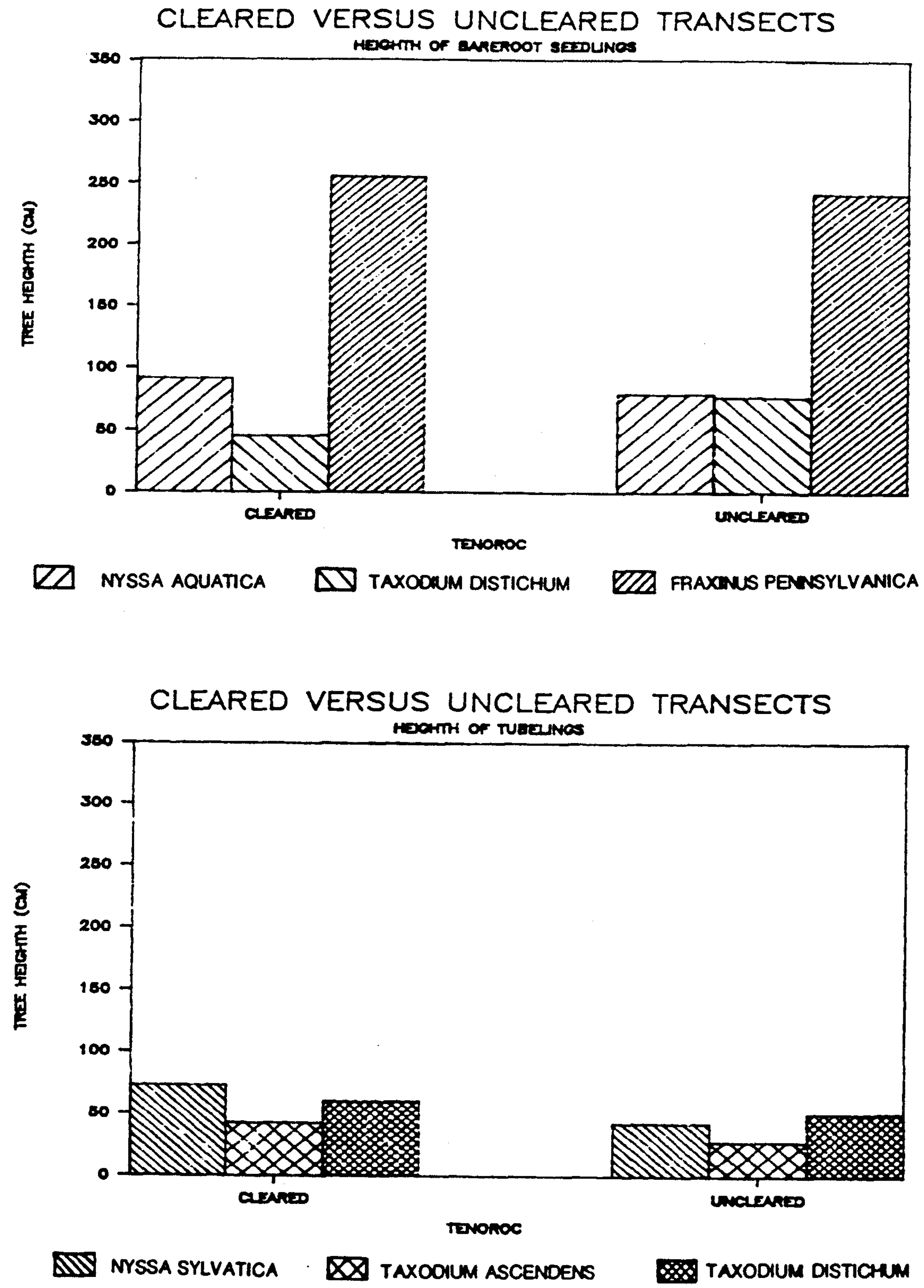


Figure 5.26. Comparison of percent survival of cleared and uncleared transects at Tenoroc. (a) Bareroot seedlings; (b) tubelings.

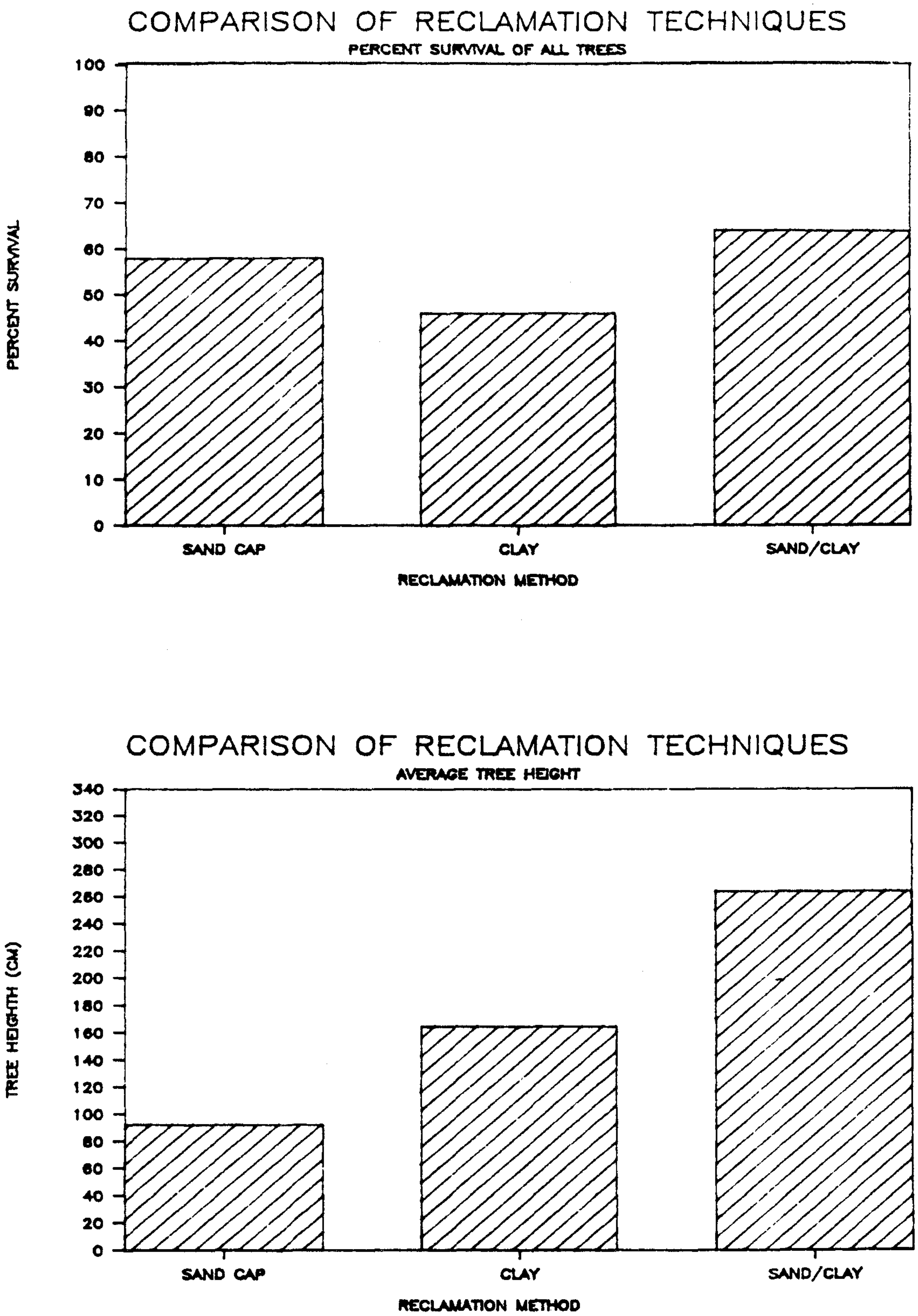


Figure 5.27. Comparison of reclamation methods for percent survival and tree height. Graphs represent pooled data for all species planted. Best tree survival and growth was on sand/clay mixed soil.

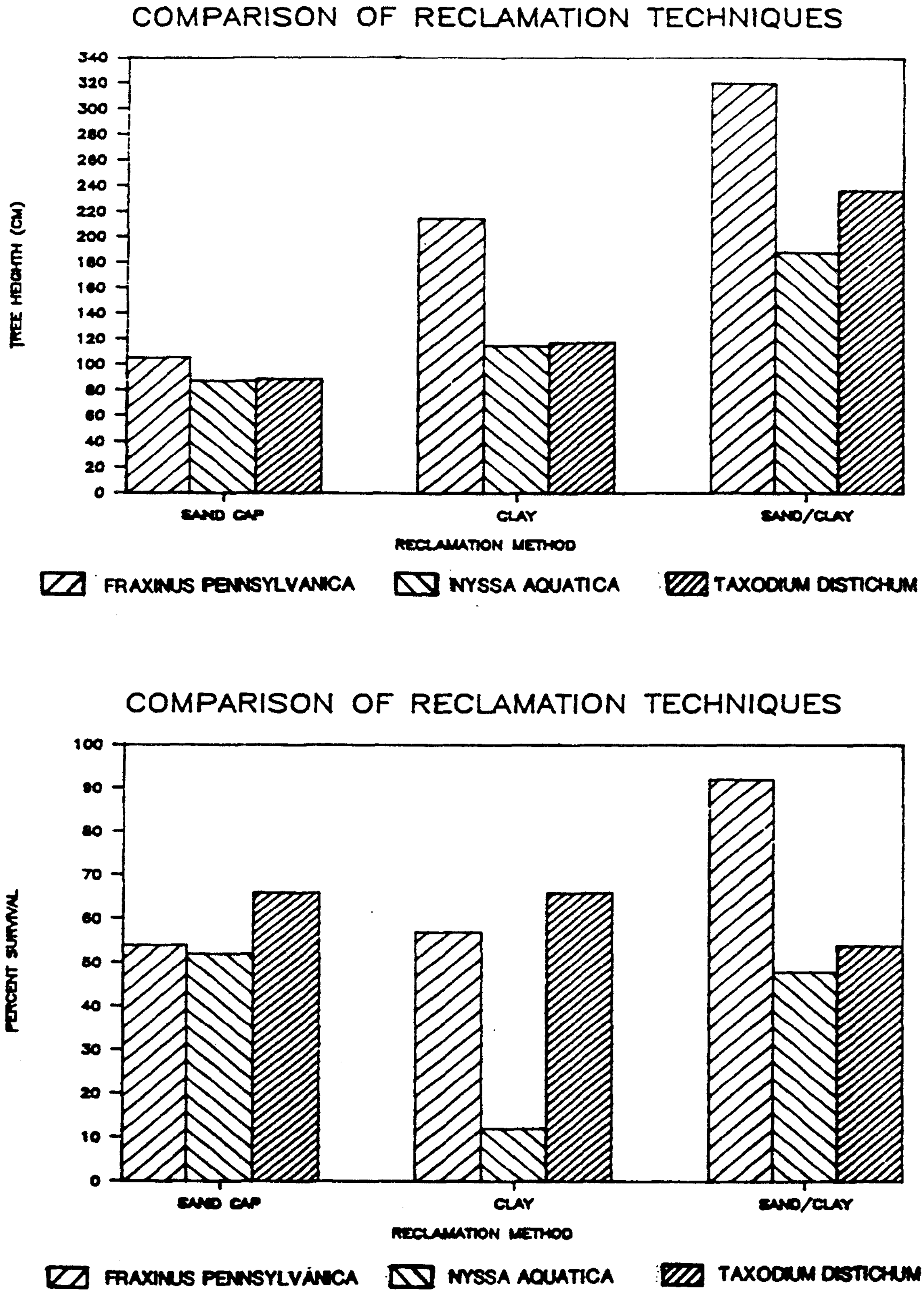


Figure 5.28. Comparisons of percent survival and tree height for each species planted on clay settling ponds reclaimed by different methods.

Some interesting results were obtained when each individual species was compared to reclamation method. Water tupelo performed very poorly on pure clay sites (less than 15% survivorship), but did equally well on either sand capped or sand /clay soil. Green ash survival was almost 40% greater on sand/clay than on either sand capped or pure clay. Baldcypress was equally tolerant of clay and sand capped and less tolerant of sand/clay mix soils. Survival of each species was statistically significantly different (p=0.05) when compared by soil type.

All tree species had their best growth (tree height) on the sand clay mix and poorest on the sand capped site. The effect of distribution of soil particle size was particularly dramatic for green ash. Mean tree height increased by one meter by reclamation method when arranged in order of sand capped, clay, to sand/clay.

Comparison of Tubelings and Bareroot Seedlings

Only baldcypress was planted as both bareroot and tubeling seedlings, therefore comparisons of growth and survival could only be made using this one species. Trees were planted at O. H. Wright, Tenoroc, and Alderman Ford Ranch, all clay soil sites.

Survival of tubelings was lower than bareroot seedlings for all sites (31% and 59%). This was consistent with the first years data. For all sites tubelings were slightly taller, 97 cm, than bareroot, 91 cm, but these heights were not significantly different from each other (p=0.05).

Other researchers have found either similar or different results. Tubeling survival was 87% for trees planted on Tennessee mine soil while only 3% of their bareroot counterparts survived (Vogel, 1981). The bareroot stock had been refrigerated prior to planting. In contrast, a study performed in Pennsylvania on coal mine soils found no difference between survival of container grown (tubeling) and bareroot seedlings planted in the spring (Vogel, 1981). Haynes and Crabill (1984) and Robertson (1985) described initiated work involving wetland reestablishment including the use of potted and bareroot seedlings. Neither study had conclusionary data comparing the two seedling types.

DISCUSSION

The data presented in this report represent the third growing season's growth and survival measurements for selected wetland hardwood and cypress species planted at five different consolidated clay settling ponds. When possible, comparisons of results were made between the first and third growing seasons.

Environmental Parameters

Two important factors in the growth and survival of planted trees are available soil water and good soil conditions. The source of soil moisture is rainfall. The general pattern of rainfall at the experimental sites was high rainfall in summer and early fall with low rainfall and potential drought conditions in late winter and spring. When the trees were planted in the winter of 1984-85 (November to March) below normal rainfall conditions prevailed resulting in drought conditions in the late winter. Cumulative rainfall for the period from June to September averaged 12 cm more than the thirty year average. Trees were stressed from lack of water only to be drowned during the summer rains. An average of 50% of the trees planted died. Water stress affected Nyssa more than the other species. 1987 witnessed two unusual rainfall events. Heavy rains occurred in both March and May. Monthly rainfall for both months was greater than the recorded thirty year average. May is typically a very dry month. The large input of rainfall would have increased soil moisture at the beginning of the growing season and potentially been beneficial to the growth of trees. It can only be speculated without water table measurements that increased soil moisture accounted for the good growth of green ash between the first and third growing seasons on clay and clay-sand soils. It has been documented by Broadfoot and Williston (1973) and Dickson et al. (1965) that green ash have their best growth on saturated soils.

Soil conditions which can influence the survival and growth of trees include physical properties, pH, organic matter, and nutrient concentrations. Particle size distribution had the greatest influence on tree growth and survival. There was no significant difference in percent organic matter between clay and clay-sand mix sites. Values averaged between 1.7 and 2.5%. This range is low when compared to native clay soils such as O'Leno and Apalachee clays which have organic matter contents of 2.4 to 2.85%, respectively (Carlisle et al., 1985). Less than 1% organic matter was present in the sandy soil at Mobil. Growth of trees was poor at this site. Organic matter is recognized as important to the maintenance of good soil structure and retention of soil moisture (Brady, 1974). A minimum of 2% is recommended for nursery potting soils (Pritchett, 1979).

Soil pH was lower in clay soils than either the clay-sand mix or sand. The highest pH (7.6) was found at C.F. Industries in a sand clay mix accompanied by good growth and survival of all tree species. The three species planted there are most often found on soils with surface pH's of 5.1 to 7.3 (Broadfoot et al., 1971). The same three species were also planted on clay and sandy soils, but did not grow as well.

Potassiumm was the only nutrient measured which differed significantly between sites. The lowest soil concentration was found at Mobil. As stated earlier, tree growth was the poorest at this site. Other measured nutrients were comparable. Comparisons of soil nutrient content to tree growth should be viewed as plausible reasons for the observed result, but caution should be exercised in correlating soil nutrient concentrations to tree growth because (1) not all possible nutrients were measured (no nitrogen data were available) and (2) nutrient data represent total soil concentration and not necessarily what is available to the tree or what the tree will actually use. Little is known about the nutrient needs of noncommercially harvested trees.

Growth and Survival of Seedlings

The greatest mortality of trees occurred in the first growing season, but continued mortality (1-20% with an average of 10%) was observed for all sites, species, and nursery stock type after the third growing season with two exceptions. There were more green ash present at C.F. Industries and O.H. Wright in 1987 than in 1986. Trees were found alive in 1987 that had been damaged the previous year and asssumed dead or were never found.

Growth and survival of trees was species and site specific. Particularly poor survival was obtained with both Nyssa species on unreclaimed clay sites. For all three sites, an average of 21% of the water tupelo and 15% of the blackgum were alive after three growing seasons. In contrast, water tupelo survival on non pure clay sites was bettern than 50%. On the clay sites, Nyssa survival was poorest at O.H. Wright, but growth was best. Higher soil potassium levels at O.H. Wright may have been one of the factors accounting for better tree growth. Other measured nutrient levels are comparable. The cause of poor blackgum and water tupelo survival on clay soils was not readily apparent. Water level data collected at the time of planting indicates the trees at clay sites were planted under dry soil conditions and then severely flooded during the growing season (Rushton, 1986). Nyssa at the other two sites were planted along lake edges. Though dry soil conditions were evident, the impact of water stress was not as severe because of the proximity to water and less variation in water levels. Nyssa aquatica has low tolerance for rapid changes in water level. Applequist (1960) and Klawitter (1963) concluded that extended flooding was harmful to Nyssa during the growing season.

Tubeling and bareroot baldcypress averaged 34% survival on clay soils after three growing seasons. Average percent survival of pond cypress was 19%. Bareroot baldcypress survived comparatively well on non-pure clay soils (62%). After two years, the Florida Division of Forestry (Harrell, 1987) obtained 75% survival for bareroot baldcypress on clay soils and after three years 66% survival on overburden soils. The large difference in survival between the two cypress species indicates that baldcypress is bettter adapted to the type of environment offered by a clay settling pond.

Baldcypress averaged 1.0 m in height on clay soils and pond cypress averaged 91 cm. Neither species of cypress grew well at Tenoroc. The reason for this was the extensive grazing of cypress by rats, mice, rabbits, and deer. The impact appeared to be greater for pond cypress than baldcypress. Pond cypress averaged approximately 50% of the height of bald cypress at that site. It is undetermined whether grazers had a preference for pond cypress or the pond cypress were more accessible to them.

Green ash had the best tolerance of clay soils. Better than 60% of the trees planted were alive after three growing seasons and averaged 2.5 meters in height. In contrast, ash grew poorly at Mobil on sandy soil. Tree heights averaged 1.0 meters. Significantly lower amounts of soil potassium and organic matter were present at Mobil than at either of the clay sites and may be a contributing factor to the poorer growth.

Comparable success has been obtained with green ash by other investigators. It has been listed by Broadfoot (1976) as a best growth species for a wide range of soil types including clay. Trees planted on spoil banks from strip mining in Pennsylvania, West Virginia, and the midwest had good survival (Clark, 1954).

Cleared Versus Uncleared Plots

The experimental clearing of all herbaceous ground cover before planting yielded variable results. The expected result was that clearing the plots would give seedlings a growth and survival advantage by removing competition from other vegetation for light and nutrients. In reality, after three growing seasons, differences in survival and growth of trees were due to differences in nursery stock and location rather than treatment. There were no discernible long term benefits to the success of seedling establishment by removing herbaceous ground cover at the time of planting.

Grazed Versus Ungrazed Trees

Cattle grazing affected the survival of all species planted. Severity of impact was species specific. Only 4.5% of the water tupelo in the grazed transects were still alive after three growing seasons compared to 52% in the ungrazed transects. The most obvious impact of grazing would be the trampling and breaking of young trees by cattle. It is possible that water tupelo is less able than baldcypress or green ash to recover from damage to its stem or apical bud.

Water tupelo that survived grew equally well in either grazed or ungrazed transects. Apparently those trees with the genetic and physiological stamina would survive.

In contrast, green ash that were ungrazed grew taller than trees that were grazed. Green ash is considered an early succesional species. As such it exploits its environment better than baldcypress and water tupelo by growing faster. It is possible it recovers quicker than the other two species to continue growth only to be damaged again.

Reclamation Method

The manner in which derelict lands are reclaimed may make a difference in the success of planted seedlings. Three different species of trees were planted and when their growth and survival were combined, the best survival and growth of trees was obtained on sand/clay mix soils. The addition of sand to a clay soil will increase pore space and soil aggregation. Increased soil pore space allows water to drain faster and makes it easier for tree roots to penetrate the soil (Pritchett and Fisher, 1987). The prescence of clay supplies necessary nutrients for good growth. The poorest survival and growth for all trees was on sand capped soils. Sands drain well and allow good root penetration, but have poor soil aggregation, low nutrient content and poor water holding capacity.

Individual species varied in their response to substrate type. Green ash survival was better than 50% on all plots with 92% on sand/clay mixed soils. Baldcypress performed equally well on all substrate types. In contrast, water tupelo attained 50% survival on sand clay mixed soils and sand capped sites, but fared poorly, 10%, on pure clay soils. Only two of the clay sites were included in this part of the study, thus the lower survival than when all three sites were averaged together. Water tupelo is naturally found on alluvial soils ranging in texture from plastic clays to silty loam (Howell, 1979). The lack of success of this species on clay soils is incongruous with habitat information. Hydrology may be a factor in this discrepancy. Water tupelo prefers constantly submerged sites and is not tolerant of rapid changes in water level (Howells, 1979). Though specific water data is not known for the past growing season, past records indicate that dry soil conditions prevailed in many of the transects at the time when water tupelo was planted and then later in the growing season sites were flooded (Rushton, 1986).

Each species had its best growth on the sand/clay mix soil. Green ash are now 3-4 meters tall after three growing seasons. Water tupelo and baldcypress averaged over 2 meters in height. These heights are approximately double the tree heights obtained on sand capped and pure clay sites. Similar results were obtained in the first growing season, but with less dramatic differences in tree heights between treatments.

Baldcypress Versus Pond Cypress

Baldcypress showed significantly better survival at O.H. Wright and Alderman Ford Ranch than pond cypress. Survival was not statistically different at Tenoroc; rather it was poor for both species because of grazing pressure. Baldcypress are commonly found along lake edges and alluvial rivers where nutrient concentrations are high. In contrast, pond cypress grow in shallow stagnant depressions low in nutrients. Clay settling ponds are rich in nutrients which may account for the better survival of baldcypress.

Net growth of the two cypress species does not follow a consistent pattern. Growth was dependent on location and the inherent environmental and ecological conditions at that site. Trees grew better at O.H. Wright and Alderman Ford Ranch than Tenoroc because they were not grazed. Differences in growth between species at O.H. Wright and

Alderman Ford Ranch were probably caused by microclimatic and hydrologic differences at that site.

Comparison of Nursery Stock

Bareroot baldcypress seedlings had better survival than tubelings at the three sites where they were planted, but growth was comparable. Most mortality occurred in the first growing season. As reported in an earlier report (Rushton, 1986), part of the reason for that was the difference in time of year during which the seedlings were planted. Tubelings had been planted during a dry period in early winter while bareroot seedlings were planted in early spring. Though still relatively drier than average, better soil moisture conditions existed. Another factor could be potential differences in quality of stock. Bareroot and tubeling seedlings were obtained from different sources.

Other studies have reported comparable success with both bareroot and tubeling seedlings. A study in Pennsylvania found equal survival between container grown and bareroot seedlings planted in the spring (Vogel, 1981). Survival of container and bareroot stock was similar for red pine, but spring planted stock had significantly greater survival than seedlings planted in the fall (Marion and Alm, 1986).

CONCLUSIONS

The Bureau of Land Reclamation (Chapter 16C-17, Florida Administrative Code) uses 50% survival of seedlings during the establishment stage as a guideline for the success of planted seedlings on mined soils. For the first growing season, with the exception of Nyssa, average tree survival by species for all sites was adequate to meet this guideline (Rushton, 1986). The question arises whether meeting that guideline will insure longterm success of planted trees and the establishment of a forested wetland. The variability of the results obtained in this study by species and site complicates this determination. The dependence of seedling success on site conditions only increases the difficulty in reclaiming mined lands. The importance of matching tree species to site specific conditions cannot be overstressed.

Given all these complicating factors, a few general comments can still be made in regard to longterm seedling success. Most seedling mortality occurs in the first growing season, but continued death of trees is likely in later years. The results of this study indicate that after three growing seasons an average of 10% more of the trees will be lost. Further annual measurements need to be taken to determine if trees will continue to be lost or an age will be reached when the situation will stabilize.

Of the trees planted in this experiment bareroot green ash (Fraxinus pennsylvanica) and bareroot baldcypress (Taxodium distichum) would be recommended for planting over a wide range of reclaimed lands.

Survival of both species was better than 50% for the first growing season and continued to be good after three growing seasons.

Wetland forest reclamation and cattle grazing are not compatible activities. At the one site where cattle were allowed to graze, significantly lower survival was obtained for all species when compared to ungrazed transects at the same site.

The manner in which land is reclaimed for later wetland reclamation has an impact on the success of the wetland reclamation. At C.F. Industries, where a sand and clay soil mix is used, the best overall growth and survival of trees was obtained. Poorest growth was obtained where the clay settling pond was capped with sand. Pure clay and sand and clay mixes appear to be the best soils for the reestablishment of trees. It is in the best interests of the phosphate industry to use techniques which will enhance the success of reclamation and assist the industry in meeting Florida Department of Environmental Regulation milestones for reclamation.

Summary Chapter 5

Three years of research and data collection have yielded consistent observations of the reforestation process of clay settling ponds. Experiments were designed to evaluate the impacts of site preparation techniques (clearcutting, mulching and litter transfer), type of nursery stock used for planting, and mining and reclamation techniques on the growth and survival of selected wetland hardwood tree species. Trees were hand planted in both transects and plots in clay settling ponds of various ages and subjected to different reclamation methods (sandcapping and mixing clay with sand). The results of these studies are summarized in the following paragraphs.

Tree seedlings which were habitat generalists or common to alluvial floodplains were the most successful in both projects. In particular, green ash, baldcypress, sweetgum, red maple, popash and elm had good survival. Both studies found the greatest mortality of trees in the first growing season, with continued mortality, but with smaller percentages, in later growing seasons.

Site specific conditions can have dramatic impact on the success of wetland reclamation of these areas. As noted at Tenoroc and Pruitt Ranch, heavy grazing pressure resulted in poor growth and survival of some trees.

Hydrology plays an important role in determining tree survival. Many of the wetland trees planted require moist soils for at least part of their growing season, for best growth. Trees planted in wetter plots had better survival when compared to the same species in drier plots.

Too much water can be as detrimental as too little. Many Nyssa and laurel oaks were lost where flooding of long duration occurred.

The clearing of herbaceous vegetation from plots and transects and the addition of mulch did not have any significant influence on the growth and survival of trees. Both these activities require extra labor. Without obvious benefit it is not cost effective for the phosphate industry to engage in these activities for site preparation.

6. MATCHING TREE SPECIES TO SITE CONDITIONS IN RECLAMATION

BETTY T. RUSHTON

INTRODUCTION

Understanding and managing succession may be a practical way to restore lands to useful functions after mining. Apparently lack of adequate seeding is retarding succession in many phosphate mined areas (Wolfe, 1987, Rushton, 1988). Experiments were designed to test the feasibility of accelerating succession by planting eleven hydric hardwood tree species in six clay settling areas. Average water table depth and pH, both of which may affect survival, were measured for one growing season. Two mulching techniques were compared to a control.

STUDY SITES

Six clay settling ponds were selected to plant eleven species of tree seedlings (Figure 5.1). Gardinier (area A) located at their Ft. Meade mine, was abandoned as a spoils area in 1973. The pond built on unmined land is rectangular in area with clays approximately 10 m thick with a surface area of 130 ha (Blue and Mislevy, 1982). In 1975 a perimeter ditch drained the higher ground and the dikes were lowered as a reclamation method. At the time of this study outfall pipes were above the level of the clays providing drainage only during periods of above average rainfall. Two plots were in the flooded, lower end of the pond and four plots were in drier areas. One year after planting, phosphate mining was begun adjacent to the site and the clay pond was drained for use as a disposal area. During these alterations, four of the plots were buried under spoils. Data for the remaining two plots in the wetter, lower end are included in this report.

The O. H. Wright site, also owned by Gardinier, Inc., is located adjacent to the Whidden Creek floodplain. Aerial photographs from 1957 show the old mine cuts being filled with clays. The four study plots were located at the wetter end adjacent to the floodplain. Mining activity nearby interrupted the normal hydroperiod causing both wetter and drier conditions than normal. Tenoroc (area 4A) is a large clay area located in a State Reserve under the jurisdiction of the Dept. of Natural Resources. Aerial photographs show the site being mined in 1958 and clays being pumped into mine cuts in 1968.

Pruitt Ranch is a conventional clay settling pond deactivated 36 years ago. The clays formed a layer about 50 cm deep in the study plots. Reclamation activity by a consultant involved draining and burning the site before the seedlings were planted. Further reclamation activity included disking under three of the plots about a year after the seedlings were established. The one remaining plot, which has been grazed by cattle, is included in this report.

The IMC - Peace River Park site is a conventional clay settling pond estimated from aerial photography to have been mined from 1952 to 1956 and used as a settling area until 1968. It was leased as pasture until 1986 when it was acquired by Polk County for a park and the seedlings were planted. A fire in 1987 killed 70% of the trees. One wet plot with good survival is included in the data set.

The Agrico site is a 193 ha clay settling area located at their Ft. Greene mine. Pumping of clays was terminated in the late 1970s but the pond was used for tailings and debris until 1983. Depth of clays varies from 1 to 10 m. A successful agriculture research project was begun at the site in 1984. By 1986 the surface soils had been dried with ditches 5 to 15 m apart and alfalfa had been planted to accelerate drying further. Three of the tree seedling plots were planted on shallow clays (1 m) where alfalfa was already established and three plots were on deeper clays (> 10 m) near a drainage spillway.

METHODS

Six clay settling ponds were planted with eleven species of hydric swamp seedlings during late February 1986. Thirty-two 9 X 12 m plots were established. Plots contained eighteen individuals of 6 species for a total of 109 seedlings. Plots were cleared of all herbaceous vegetation at time of planting, but the tree canopy, where it existed, was not disturbed. Seedlings were purchased from a nursery where they had been grown in plastic flats and maintained for 6 months to a year in a shade house. They were planted in the field on 1 m centers using a KBC planting bar, commonly called a dibble.

Plots were divided into three mulch treatments. Leaf litter from a nearby floodplain forest representing the same size area (9 X 4 m) was transported to the sites in garbage bags (nine 113 liter bags for each plot). One bale of hay purchased from a feed supply store was spread over a 9 X 4 m area in each plot for the straw mulch treatment, and no ground cover was used for the 9 X 4 m control section.

Hydrology measurements were made using a shallow (2.8 m) water table monitoring well with 0.5 m well screen at the bottom. Wells installed near the center of each plot were measured monthly during the summer of 1986. Average readings from April through October of 1986 were used for comparison between plots.

Soil cores were collected in each plot (except Pruitt Ranch) during a one day period in August 1986. Cores were taken from the portion of the plot with no mulch treatment using a sampler with a mud auger head. The top 5 cm was discarded because it was predominately leaf litter and soils from the 5 to 15 cm depth were air dried and mixed for analysis.

Soil pH was determined in a 1:2 soil:water suspension at the IFAS soil testing lab on the University of Florida Campus.

The Duncan Multiple Range test and Chi-square tests were used to determine significant differences using a SAS program at the University of Florida Computing Center.

RESULTS

Measurements of seedling survival is presented in relation to average water table, mulch treatments and pH. Data for 1986 includes all the plots; for 1987 only those plots not impacted by fire, burial, or disking are used.

Seedling Survival

When plots are compared by year and site (Figure 6.1) there is over 50% survival after the first year which compares favorably with the standard set for bareroot seedlings by the Florida Department of Natural Resources Bureau of Land Reclamation. Additional mortality of 8 to 35% occurred during the following year (except Pruitt Ranch which had been grazed by cattle and was more). The time elapsed since sites were abandoned as active disposal areas did not appear to enhance success but other factors, especially water table and cattle grazing, may have influenced the results. More plots are needed to test the theory that early successional vegetation prepares the way for more mature species thus increasing growth and survival of tree species.

When measured two years after planting considerable differences were seen in survival between species. Best survival was found for pop ash (99%) and elm (88%) which were planted at the wettest sites. Red maple planted in drier plots also survived well (70%) but did much better (91%) where the water table was near the surface. Baldcypress (63% survival) also showed its best growth and survival at wet sites (79%). Magnolia had poor survival (41%) overall, but did well (69%) at two plots where the average water table for 1986 was over a meter below the surface. Laurel oak did well at some sites in an intermediate moisture range, but could not tolerate extended periods of standing water. Only one species, loblolly bay, indicated a preference for low pH. Its best survival (38%) was at sites where the pH was below 6.8. In contrast, survival at the higher pH sites was 13%. Swamp bay (28% survival) was killed by standing water greater than two months but did not show a preference for low pH soils typical of bay swamps.

Soil Amendments

Plots were divided into three treatment areas. Hay from a feed supply store, floodplain forest litter and a control with no additions were used as treatments to assess their value as soil amendments. No significant difference was found in survival or growth between soil additions and the control treatment ($P > 0.05$) (Table 6.1).

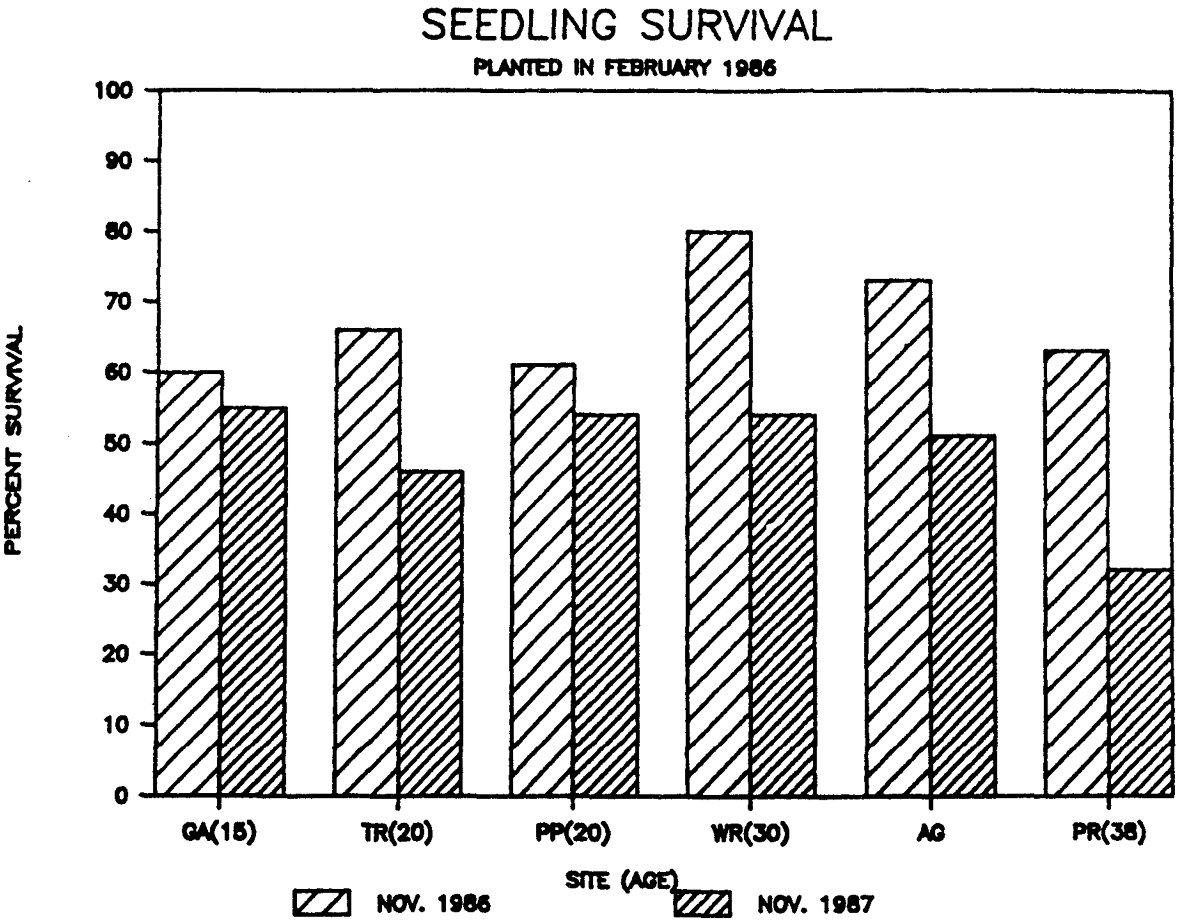


Figure 6.1. Seedling survival for trees planted in February 1986 and measured in November 1986 after one growing season and November 1987 after two years. Site abbreviations are listed below. The number in parenthesis is the number of years since abandoned as active disposal site.

AG	Agrico
TR	Tenoroc
PR	Pruitt Ranch
PP	Peace River Park
WR	O. H. Wright
GA	Gardinier

Table 6.1. Percent survival and growth for two mulch treatments and a control shows no significant differences between treatments. Percent growth is defined as the change in height from planting compared to the initial height.

Tree species	Control	Litter	Hay	Probabilities
PERCENT SURVIVAL AFTER 2 YEARS				Chi-square
Acer rubrum	63	69	76	0.270
Gordonia lasianthus	13	18	14	0.702
Nyssa biflora	29	23	23	0.486
Quercus laurifolia	30	38	35	0.457
Sabal palmetto	19	18	24	0.584
Taxodium distichum	68	66	62	0.702
PERCENT GROWTH 1986 TO 1987				
Acer rubrum	104	126	100	0.462
Gordonia lasianthus	57	84	67	0.637
Nyssa biflora	38	39	73	0.361
Quercus laurifolia	43	73	80	0.372
Sabal palmetto	246	324	350	0.771
Taxodium distichum	35	24	24	0.463

Differences in survival and growth that existed were between species of trees.

The only advantage to adding forest litter was the introduction of some seeds which increased the diversity of planted plots. Better results would have been seen if more attention had been paid to time of collection and donor site selection. Litter collected at the end of February had the most seedlings germinate (Table 6.2).

DISCUSSION

Seedling Success

Forested wetlands in the south are organized along a resource gradient from small often stagnant isolated wetlands and headwater streams to strong water flow alluvial rivers and floodplains (Odum, 1984). For example, evergreen bay trees grow in bogs with no nutrient or water flow except from rainfall. Isolated wetlands of upland swamps which have small drainage basins are colonized by pond cypress. As more water converges from larger areas, a baldcypress strand association is typical. Finally with large inflows of water on a regional scale diverse mixed hardwood swamps predominate. Which system is the most suitable as a reclamation alternative for clay settling ponds in central Florida?

Monk (1966, 1968) divided Florida wetlands into two climax types according to pH, nutrients, and depth of maximum flooding. In general the bayhead swamp was more sterile, more acid, and not flooded as deeply as the mixed swamp habitat. Dominated by broad-leaved evergreen trees whose acid soils are high in organic matter, bayhead vegetation includes sweetbay, swamp bay, and loblolly bay. Bay swamps are typical of seepage areas and headwater streams and not floodplains of larger rivers (Gross, 1987, Clewell et al., 1982). Mixed hardwood swamps are dominated by broad-leaved deciduous species (Monk, 1966, 1968). They occur along high energy, nutrient enriched creeks, rivers, sloughs and basins that are seasonally flooded. Typical tree species are cabbage palm, ash, elm, and baldcypress. Other wetland species are generalists with a wide environmental tolerance and are common in a variety of wetland habitats. These include laurel oak, water oak, red maple, sweetgum, and blackgum.

When one compares the survival rate for the eleven species planted in clay settling ponds, the most successful seedlings were habitat generalists and those found in mixed swamps along alluvial floodplains (Table 6.3). None of the species common to low nutrient wetlands had greater than 27% survival.

A slightly different conclusion emerges from seedlings planted in several clay settling ponds by the Florida Division of State Forestry (Harrell, 1988). Many pioneer species had poor success when counted after the first year. Only 45% of laurel oak survived, 46% of red maple and 17% of cottonwood. However, sweetgum did well with 66% survival and two pine species became established, slash pine had 58% survival and

Table 6.2. Number of seeds germinating from litter transferred from wetland forest to clay settling pond seedling plots.

Site name	Date introduced	# Plot plots	* Donor site	# Seeds germinating	Species germinating
Gardinier	7-12-85	2	Whidden Creek floodplain	0	
	2-1-86	4	Ft. Meade Park at Peace River	0	
Tenoroc	7-23-85	2	Saddle Creek floodplain	0	
	8-4-85	2	Saddle Creek floodplain	0	
	9-28-85	2	Saddle Creek floodplain	0	
Pruitt Ranch		4	Adjacent Creek S. prong Alafia	0 0	
Peace River Park		5	Peace River at 640 bridge	0	
Agrico	2-8-86	2	Ft. Meade Park at Peace River	1	*Carya aquatica*
	3-11-86	4	Lake Alice	55	*Acer rubrum*
O.H. Wright		4	Ft. Meade Park	20	*Ulmus americana*
	2-8-86		at Peace River	10	*Celtis laevigata*
				8	*Carya aquatica*

* Nine 113.55 liter garbage bags of litter were placed in 4 x 9 meter section in each plot.

** Description of dominant tree species in donor site (see next page).

Table 6.2 (continued)

Dominant tree species in donor sites:

Saddle Creek floodplain: *Taxodium distichum*, *Liquidambar styraciflua*, *Acer rubrum*, *Ilex cassine*, *Cephalanthus occidentalis*, *Quercus laurifolia*, *Fraxinus caroliniana*.

Pruit Ranch floodplain: *Quercus laurifolia*, *Sabal palmetto*, *Magnolia virginiana*, and *Pinus elliotii*.

South prong of Alafia River: *Quercus laurifolia*, *Gledistia aquatica*, *Fraxinus caroliniana*, *Ulmus americana* var. *floridana*, and *Cephalanthus occidentalis*.

Peace River floodplain: *Taxodium distichum*, *Acer rubrum*, *Ulmus americana* var. *floridana*, *Quercus* spp., *Gledistia aquatica*, *Carya aquatica*, and *Fraxinus caroliniana*.

Whidden Creek: *Magnolia virginiana*, *Acer rubrum*, and *Ulmus americana* var. *floridana*.

Table 6.3. Percent survival two years after planting compared to wetland community type.

Scientific name	Common name	Community type	Edaphic* factors	Percent survival
Fraxinus caroliniana	Pop ash	Mixed swamp	High	99
Ulmus floridan	Florida elm	Mixed swamp	High	88
Acer rubrum	Red maple	Generalist	All	71
Taxodium distichum	Bald cypress	Mixed swamp	High	65
Magnolia grandiflora	Magnolia	Mixed swamp	High	41
Liquidambar styraciflua	Sweet gum	Generalist	All	39
Quercus laurifolia	Laurel oak	Generalist	All	35
Persea palustris	Swamp bay	Bay swamp	Low	27
Nyssa biflora	Black gum	Cypress dome	Low	25
Sabal palmetto	Cabbage palm	Mixed swamp	High	23
Gordonia lasianthus	Loblolly	BayBay swamp	Low	14

* Sensu Monk 1966, 1968
Edaphic factors: pH, maximum flooding, Ca, Mg, K, and P.

loblolly pine had 63%. A cypress-gum association did well with 60% survival for baldcypress and 64% for blackgum. Loblolly bay was the only evergreen bay planted and 54% survived.

Conflicting results from the two studies indicate it is probably premature to predict the most appropriate climax community type for the new situation of clay settling ponds. However, the results of this study indicate the diverse association found along alluvial floodplains with clay soils are a more promising alternative than those from cypress domes or bayheads.

Mulch Treatments

Loamy soils are considered ideal for plant growth. Clay settling pond substrate are heavy clays (about 70% clay sized particles and 30% silt). Sharkey clay soils in Mississippi with characteristics similar to clay pond substrate demonstrate clays are not as productive as medium texture soils for silviculture (Krinard and Kennedy, 1983, Johnson and Krinard, 1985). Organic matter can modify the effects of clay by promoting granular-type aggregates in surface soils which increases soil porosity (Brady, 1974, Ferry and Olsen, 1975). In an effort to ameliorate the negative effect of clay soils, forest litter and straw mulch were introduced as treatments to clay settling pond soils. It did not significantly improve seedling growth or survival when added on top of the clay. Greater benefit might have been seen if the mulch had been incorporated into the clay surface. However, other experiments on clay soils also showed little effect with mulch treatments. For example, in one three year experiment (Unger and Jones, 1981) sorghum planted on clay loam soils responded to mulch treatments only on plots with moisture stress. In another experiment (Laverdiere and De Kimpe, 1984) adding organic amendments at the rate of 10 t/C/ha as peat or manure on heavy clay soils did not improve the yield of oats in growth chamber experiments.

Experiments with topsoiling have shown beneficial effects from added seeds (Farmer et al., 1982, Howard and Samuel, 1979, Tacey and Glossop, 1980). Fresh topsoil from 5 to 20 cm thick provided quick effective cover and the most successful species were those that spread by rhizomes. In this study mulching with forest litter during the winter introduced tree seedlings and increased diversity (see Table 6.1). If a layer of topsoil had also been used an even greater benefit may have been realized.

7. RECRUITMENT OF BIRD-DISPERSED PLANTS ON PHOSPHATE MINED LAND

T.R. McCLANAHAN AND R.W. WOLFE

INTRODUCTION

In our previous study of the processes of reclamation by natural processes of succession (Odum et al., 1988), evidence was obtained of the importance of birds in seed dispersal in phosphate areas (McClanahan and Wolfe, 1987; Wolfe, 1987), a process that may be limiting restoration of vegetation and soils. This chapter reports later data that show the effect of bird perches and planted bushes over a longer period (6 years).

Plant ecologists have largely focused on post-germination processes such as resource competition (Clements, Weaver and Hanson, 1929; Salisbury, 1936; Tilman, 1986), herbivory (Harper, 1969; Colley, 1983; Clark and Clark, 1985; Walker, Zasada and Chapin, 1986; Risch and Carroll, 1986; Sork, 1987; Bach, 1990; Schupp, 1990) and longevity (Connell and Slatyer, 1977; Walker et al., 1986) as determinants of plant community structure. Predispersal processes and seedbank storages are often assumed sufficient for regeneration as seeds fall into forest gaps (Young, Ewel and Brown, 1988; Hoppes, 1988) and seedbank storages (Roberts, 1981) are high and persist for long periods of time (Kivilaan and Bandurski, 1981; Chancellor, 1986).

Yet, some work suggests that colonization can be limited by poor seed set from pollen limitations (McClanahan, 1986a; Jennersten, 1988; Worthen and Stiles, 1988; Allison, 1990), large distances from seed sources (McClanahan, 1986b,c; Hughes and Fahey, 1988) a lack of dispersing organisms (Brown and Archer, 1987), dispersal sites (DeBussche, Escarre and Lepart, 1982; McDonnell and Stiles, 1983; McClanahan and Wolfe, 1987) and high early post-dispersal mortality (Janzen, 1970; Clark and Clark, 1984; Goldberg, 1985; Sork, 1987). These limitations can potentially determine species composition, rates of vegetative development and ecosystem processes (Vitousek and Walker, 1989). These factors are likely to be most important in highly fragmented landscapes where forest patches are small, distances to seed sources are great and seedbank storages have decayed or, in the case of primary succession, have not developed.

This study reports on early developmental stages of plants with bird-dispersed (ornithochorous) seeds in the phosphate mining region of central Florida. The quantities, timing and species composition of seeds dispersed to perches (dead trees) and control plots, their subsequent storage in the seedbank and germination were studied. These data were used to determine the role of seeds and early recruitment stages on vegetative regeneration of mined sites undergoing primary succession.

MATERIALS AND METHODS

Research was conducted on the Whidden Creek phosphate reclamation site located in central Florida (27o42'N, 81o51'W). The site is adjacent to a small floodplain creek and was mined and recontoured prior to 1982. In 1983 seven large (mean height = 11.3 + 2.8 m) dead trees (snags) were erected with a pole-driving machine at convenient locations throughout the site. Beneath each snag three seed traps were placed at 1, 2 and 3 m from the base of each snag and a control trap placed at >10 m from the snag. Seed traps were constructed from plastic seedling trays (0.135 m2), with a fiberglass mesh bottom (1.4mm) and a wire covering (2.5 cm). The three snag seed traps were averaged and considered one sample in the data analysis.

McClanahan and Wolfe (1987) reported seed deposition beneath snags for two seasons (July to November 1983 and 1984). In this study we report on 20 continuous months of seed dispersal between July 1984 and February 1986. Traps were visited monthly, seeds found in traps were collected, tested for hardness, and identified. Seeds were easily identifiable to the genus with the exception of the Vitaceae which were classified at the family level. Dry seed weights of the genera were measured (n=20 to 100 seeds/genus) and used in the data analysis. Most genera consisted of one species but seed weights used averages from traps such that weights reflected the species relative abundance in traps. Three species not caught in traps were found in germination studies, their seed weights were determined from samples available from the University of Florida Herbarium. In the winter of 1989 a fire swept through most of the site and burned all but one snag.

Two types of seedbank studies were undertaken to determine the total (>1.4 mm) and viable ornithocorous seeds in the seedbank after the 1989 fire. The total ornithocorous seedbank was determined by taking (September 1989) a soil sample (0.25 m2) to a depth of 10 cm beneath six snags and three control sites. Above ground vegetation was removed, samples washed through a 1.4 mm sieve and the remaining sample dried (50oC for 2 days). Dried seeds and organic matter were floated off using a sodium bicarbonate, sodium hexametaphosphate solution (Malone, 1967), dried again and sorted for seeds. Seeds were identified and tested for viability using the tetrazolium technique (Grabe, 1970).

The second seedbank study estimated the germinable seedbank. Beneath six snags and three control sites, six cores were taken (May 1989) using PVC pipe (surface area= 63.6 cm2/core) to a depth of 10 cm. Three cores were combined to make 1 sample resulting in 2 samples per snag. Soil samples were maintained in a greenhouse in seedling trays and spread over a bed of vermiculite, watered daily and fertilized (6N-6P-6K) biweekly for the first 3 months. Three control seedling trays were covered with sterilized peat. Samples were visited for 10 months and emergent ornithocorous plant seedlings identified (Wunderlin 1982) and counted. Greater than 95% of the seedlings emerged in the first 2 months. The sieving and flotation technique sampled a greater (ca. 3.3x) soil volume per sample than the germination study.

To determine field germination rates of plants at the site, surveys were taken in August 1989 and March 1990. Beneath each snag ($n=6$) 5 1 m2 quadrats were randomly placed within a 5 m radius of the snags. Ornithocorous plants were identified and counted. A few individuals estimated (<5%) may have resprouted from rootstock left from the fire and therefore germination as used here includes resprouting. At greater than 10 m from snags an equivalent number of control quadrats were examined for ornithocorous plants.

Data were analyzed to determine patterns of dispersal, seedbank densities, germination success, diversity, the effect of seed weight and species similarity patterns between successive stages of development. Diversity was calculated using a modification of the Simpson's (1949) Index ($D=1-pi2$) which results in a number between 0 and 1, 0 being the lowest and 1 the highest possible diversity. Cluster analysis was performed on the data to determine if the relative importance of species changed between seedrain, seedbank and germination. The Bray and Curtis (1957) measure of similarity was used with average between-group linkages. Cluster analysis used only those species found in the seedfall.

RESULTS

Seedfall was highly affected by the presence of snags and the time of year (Table 7.1, Figure 7.1). Seedfall beneath snags was ca. 3 orders of magnitude greater than areas without snags. The majority of the seedfall by biomass occurred between July and November, particularly for tree species (Figure 7.1b). Total seedfall during the seasonal peaks was similar but some species showed different seedfall densities between 1984 and 1985. The Vitaceae had a high seedfall peak in 1984 and a much smaller peak in 1985 while Cornus displayed the opposite pattern. Magnolia seedfall was similar for both years. Myrica, which had the highest seedfall density (see Figure 7.2), had a seedfall peak between December and April offset from most species (Figure 7.1a). Total seedfall varied with peak densities in August and March (Figure 7.1c) but data analyzed by total seed weight indicated that August was the peak of seedfall mass. Seedfall density beneath snags regressed negatively with seed weight ($\ln(y) = 3.26 - 0.021x$, $r= 0.69$, $p<0.05$).

Seedbank results differed depending on the technique applied. Sieving produced a higher density and species richness than the germination technique (Table 7.1, Figure 7.3). We refer to this as the total seedbank. Testing by tetrazolium, however, indicated that less than 2% of seeds were viable. For the 8 species found, smaller seeds were more abundant than larger seeds (Figure 7.3; $\ln(y) = 4.18-0.95\ln(x)$, $r=0.86$, $p<0.01$). Assuming a constant yearly seedfall beneath snags for their seven years of existence an average of ca. 3% of the seedfall is currently in the seedbank (Table 7.2).

Table 7.1. Total density (#/m^2, x ± 1 s.e.m. (sample size) and diversity (Simpson's Index, D) of seeds and plants found beneath snags and controls (>10 M from snags). No statistical test is provided as there is clearly a difference between snags and controls.

	Snags	Controls	Diversity
Seedfall	340.9 ±66.1 (7)	2.04 ±2.04 (7)	0.76
Nonviable seedbank	77.3 ±33.6 (6)	0.0 (6)	0.67
Viable seedbank	17.0 ±5.2 (12)	0.0 (3)	0.37
Germinated 1989	1.4 ±0.25 (30)	0.00 (30)	0.77
1990	2.0 ±0.45 (30)	0.07 ±0.04 (30)	0.78

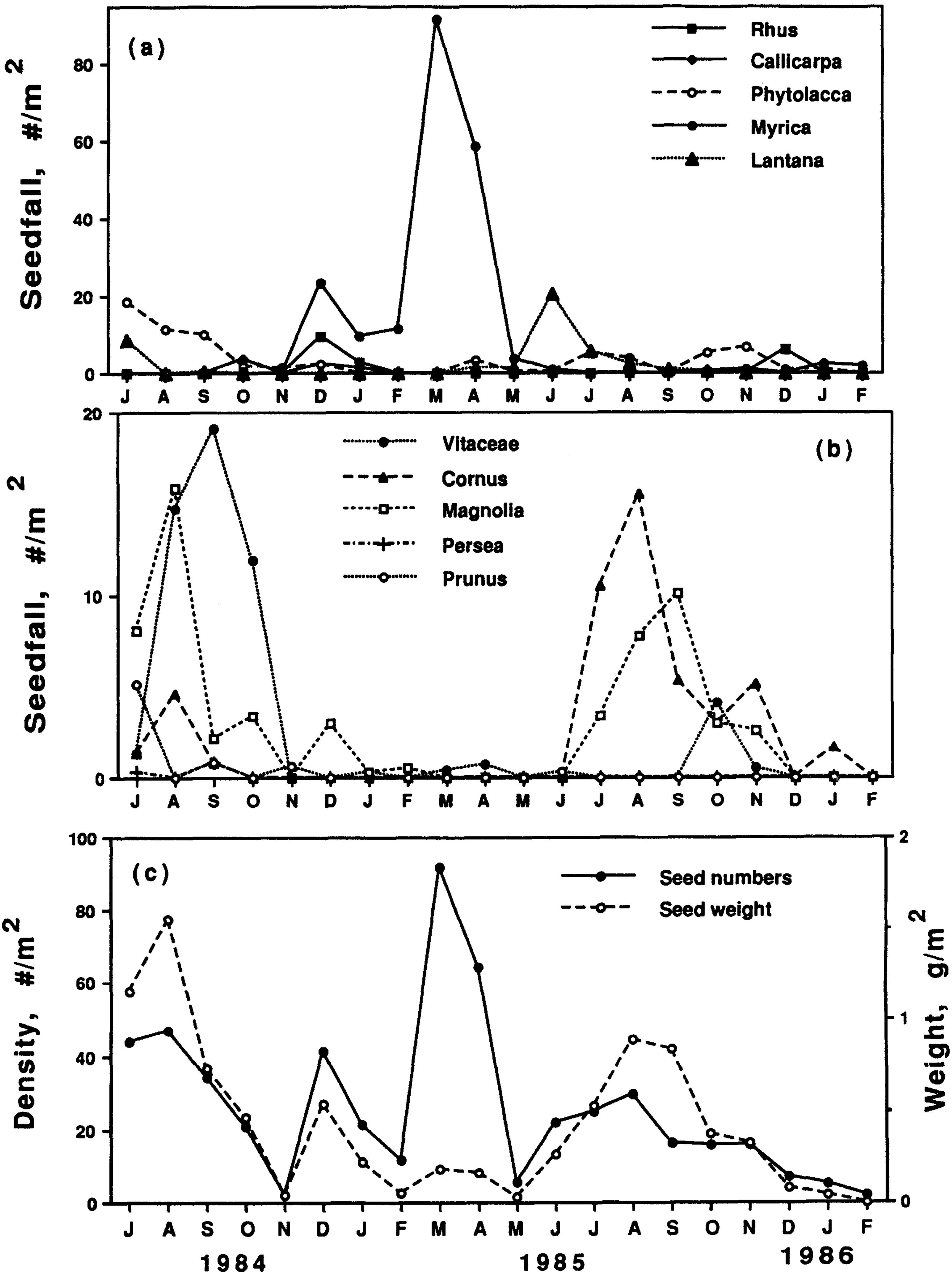


Figure 7.1. Seedfall patterns of (a) shrubs, (b) trees and vines, and (c) total seed numbers and seed weights collected under snags during the 20 month collection period.

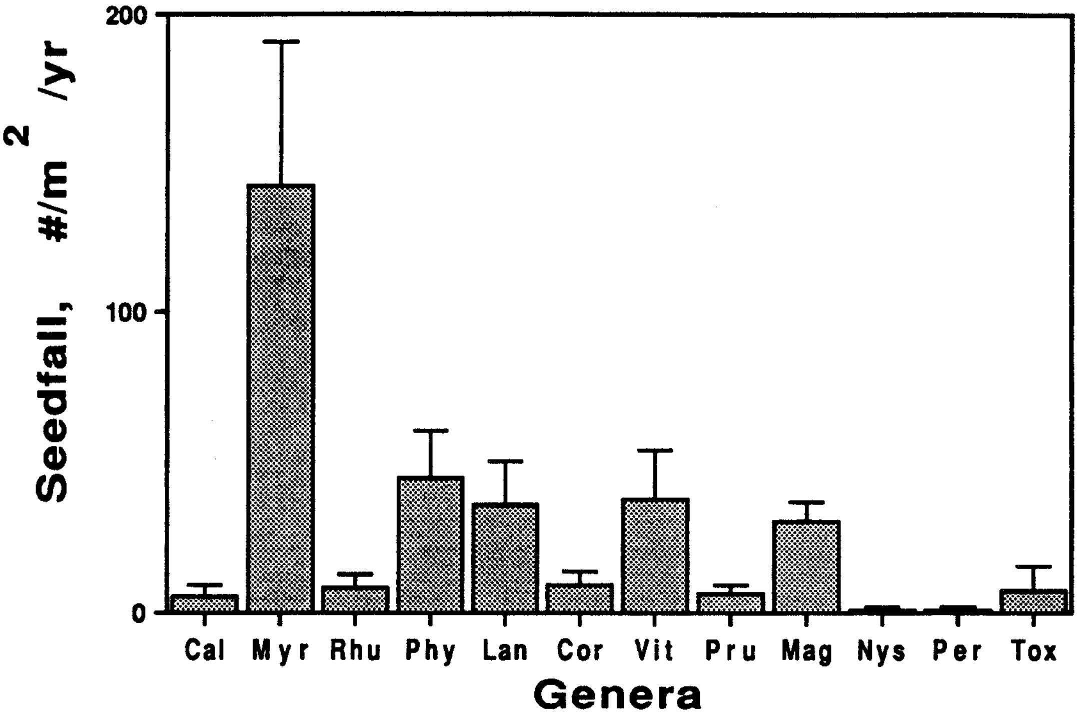


Figure 7.2. Total annual seedfall (x ± s.e.m.) of each genera collected beneath snags. Genera code is the first three letters of the genus name (see Table 2). Data arranged from smallest seeds on the left to largest seeds on the right.

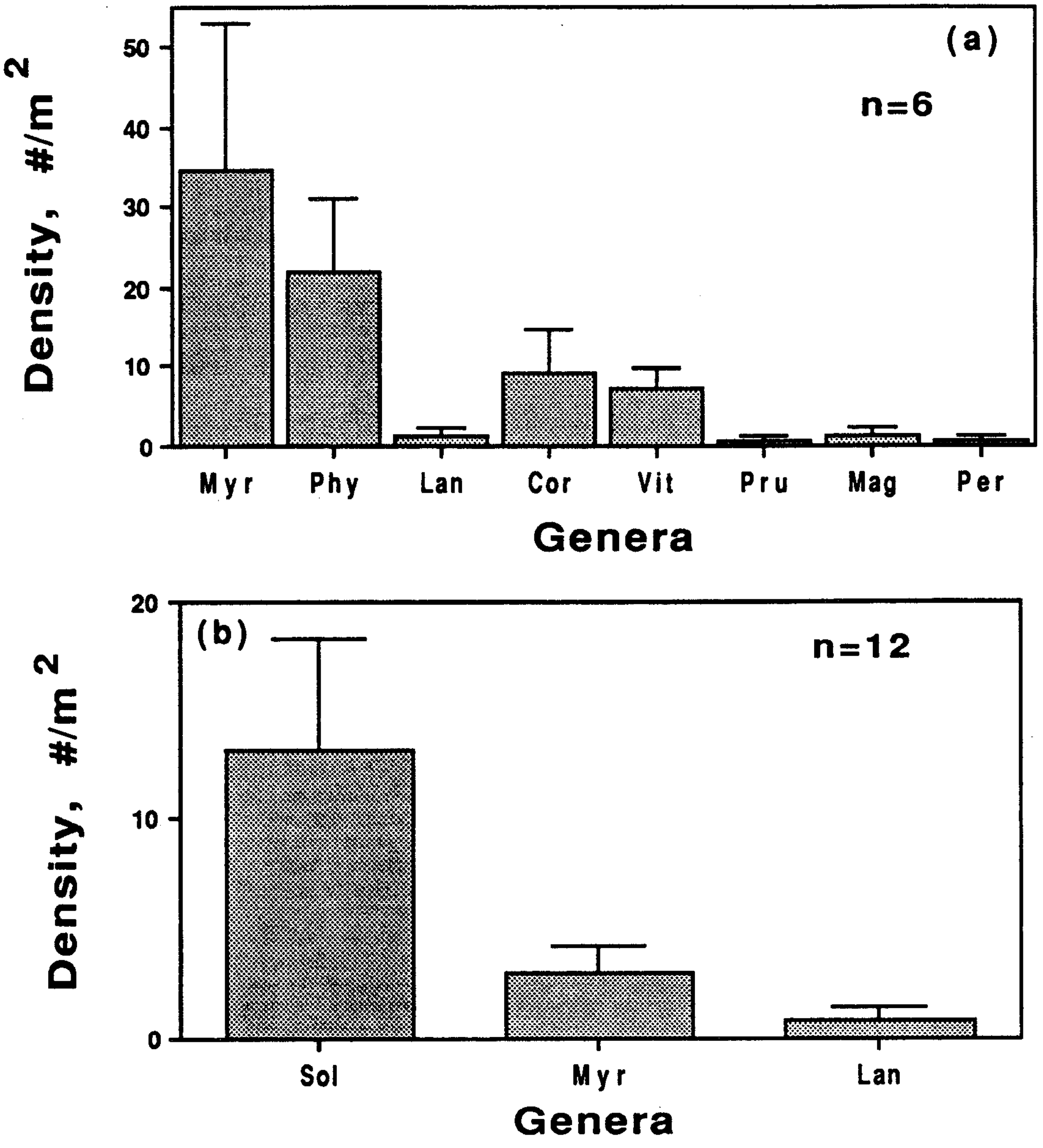


Figure 7.3. Seed density (x ± 1 s.e.m.) of genera found in the seedbank by (a) a sieving and floatation technique and (b) germination technique. Genera code is the first three letters of the genus name (see Table 7.2, Sol = *Solanum*). Data arranged from smallest seeds on the left to largest seeds on the right.

Table 7.2. Genera found within seed traps, their genera code used in figures, seed weight (dry weight, mg), percentage of the seedfall which reached the nonviable seedbank and the percent of seedfall which germinated based on the assumption that seedfall was constant during the 7 years of the perches existence.

Genus	Code	Weight, mg	Seedbank	Germination
Callicarpa	Cal	0.70	0.0	0.0
Myrica	Myr	1.9	3.4	0.028
Rhus	Rhu	12.5	0.0	0.0
Phytolacca	Phy	5.6	7.0	0.13
Lantana	Lan	12.1	0.53	0.15
Toxicodendron	Tox	14.3	0.0	0.0
Cornus	Cor	18.0	14.0	0.0
Vitaceae	Vit	17.5	2.83	0.038
Prunus	Pru	51.0	1.51	0.11
Magnolia	Mag	73.0	0.63	0.0
Nyssa	Nya	105.0	0.0	0.0
Persea	Per	159.0	9.0	0.22
Average (± s.d.)			3.2 ±4.5	0.056 ±0.076

Only three species were found in the greenhouse-germinated seedbank. We refer to this as the viable seedbank. *Solanum*, a species not found in seedfall probably due to its small size, was numerically dominant. As in the total seedbank, smaller seeded genera were more common than larger seeded ones (Figure 7.3b) although the presence of only three species makes this observation statistically untestable. Ornithochorous seeds were not found in either the control total seedbank samples or control greenhouse seedling trays (Table 7.1).

The density of seedlings from ornithocorous seeds beneath the perches was low (< 2 individuals/m2) but about 2 orders of magnitude greater than sites without perches (Table 7.1). Both sites were inhabited by herbaceous annuals with other seed dispersal mechanisms. The most abundant germinated species were shrubs or herbs such as *Myrica*, *Phytolacca* and *Lantana* which have small to intermediate size seeds. There was no significant correlation between seed weight and germination success largely due to the lack (i.e. zero values) of some species which were present in the seedfall. Most germinated species were constant between years (t-test, NS) with the exception of Phytolacca and Sambucus (t-test, $p<0.01$). Cluster analysis of the species relative importance (Figure 7.4) indicates that the seedfall and total seedbank species composition were similar as were the two surveys of germinated plants. The viable seedbank was intermediate between seedfall and the germinated species composition. The percentage of seedfall which germinated in the field was less ca. 0.06% (Table 7.2).

DISCUSSION

The intention of this study was to follow bird-dispersed seeds through their early post-dispersal stages and to determine the importance of these stages in the resultant plant community. The techniques used were sufficient to develop a basic knowledge of the processes but details were lost due to sampling at different scales. Seedtraps used for seedfall measurements were sufficient for intermediate to large seeds (i.e. shortest axis. > 2 mm) but it was apparent from the germination results that some genera with small seeds (i.e. *Solanum*, *Sambucus* and *Rubus*) were probably not retained or missed while searching seed traps. The germinable seedbank study resulted in only 3 species which may be attributable, in part, to the small area and low seed density in the samples.

Unless a large area of greenhouse space is available this is likely to be a problem of many seedbank studies. This technique allows sampling at a larger scale but smaller seeds may be lost or missed during sieving and sorting. The sieving technique is sufficient for determining total seedbank quantities and species composition but because a large percentage of this seedbank is not viable (Schneider and Sharitz 1986, this study) the tetrazolium technique for testing seed viability is necessary. It is not clear why most seeds tested appeared to be nonviable. The tetrazolium test, however, is fairly subjective and relies heavily on expertise and intuition (Leadem 1984). The seed removal procedure (i.e. floating and

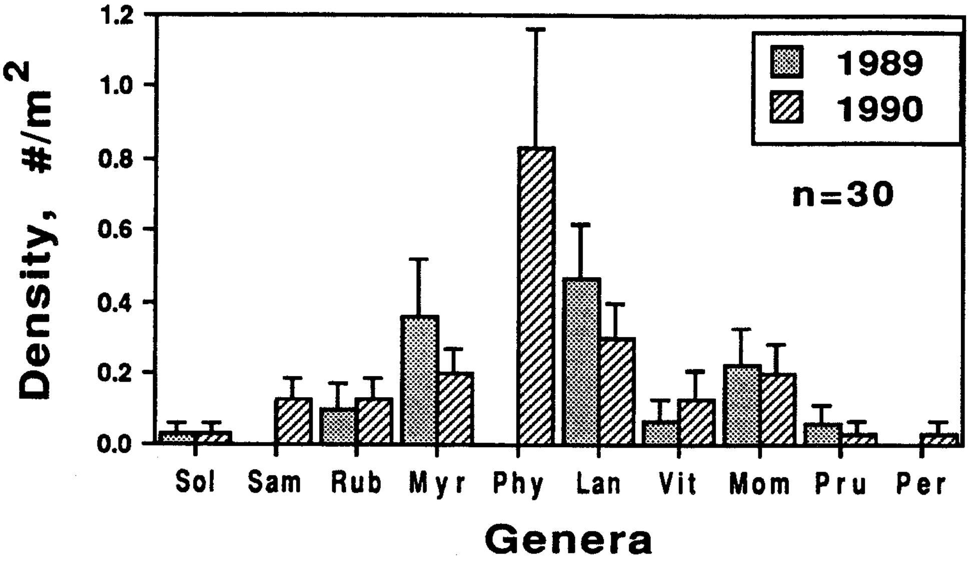


Figure 7.4. Density of plants with ornithocorous seeds found beneath snags for two time periods. Genera code is the first three letters of genus code (see Table 7.2, Sol = Solanum, Rub = Rubus, Mom = Momordica). Data arranged from smallest seeded genera on the left to largest seeded genera on the right.

drying) may also have a detrimental effect on the seeds. It is perhaps possible to develop an optimal sampling technique for one or a few species with similar seed size and quantities of dispersal, storage and germination but to study a large array of species becomes more difficult and a certain amount of detail will be lost unless extensive sampling is possible.

Seed dispersal to sites was highly seasonal. Seasonal peaks were consistent for combined genera between studied years but some genera showed marked variation between years. Skeate's (1987) data on fruiting species in northern Florida (ca. 300 km north of our study site) also showed marked between-year variation in some species. There was a consistent difference in fruiting times of forest species between north and central Florida. Skeate (1987) found a strong correspondence between peak fruiting and the presence of migratory birds reaching a peak between November and January. Our study shared many of the same species but seed weight and diversity of dispersed seeds peaked in August, long before the arrival of migratory birds. This indicates that most dispersal in central Florida results from resident birds. In central Florida the lack of frequent freezes may maintain a more stable population of frugivorous birds than regions to the north. Earlier fruiting may also occur do to the longer growing season in central Florida.

The unique dispersal season of *Myrica* during winter and spring suggests that it is an important food source for frugivorous birds between the seasonal peaks. The low pericarp/seed ratio of *Myrica* (McClanahan and Wolfe, personal observation) suggests that it may be a less preferred fruit but its availability between peaks of preferred fruits suggests that it may be a "keystone species" (Terborgh, 1986) of the frugivore guild. McClanahan and Wolfe (1987) underestimated the rates of *Myrica* seedfall to snags by restricting sampling to the fall and early winter.

It is clear that the existence of snags and vegetative structure have the ability to attract birds and associated seeds (DeBussche et al., 1982; McDonnell and Stiles, 1983; Guevara, Purata and Van der Maarel, 1986; McClanahan and Wolfe, 1987; Vitousek and Walker, 1989) and this in turn can affect plant community structure and ecosystem processes (Vitousek and Walker, 1989). But, to what extent is the resultant plant association a reflection of dispersal? From vegetation studies it is clear that areas with perches had bird-dispersed plants growing beneath them while areas without perches had very few. Yet, plant associations under perches did not simply reflect seed input. Between the stage of dispersal and germination a selection process occurred which changed relative species composition (Figure 7.5). Dispersal to snags indicates that smaller seeded species were more likely to be deposited beneath snags (a semi-log relationship) while small seeds were even more likely to become part of the seedbank (a log-log relationship). At germination and up to 2 years later the plant association is typified by early successional shrubs with small seeds. Many of the later successional and tree species are not present at the time of germination.

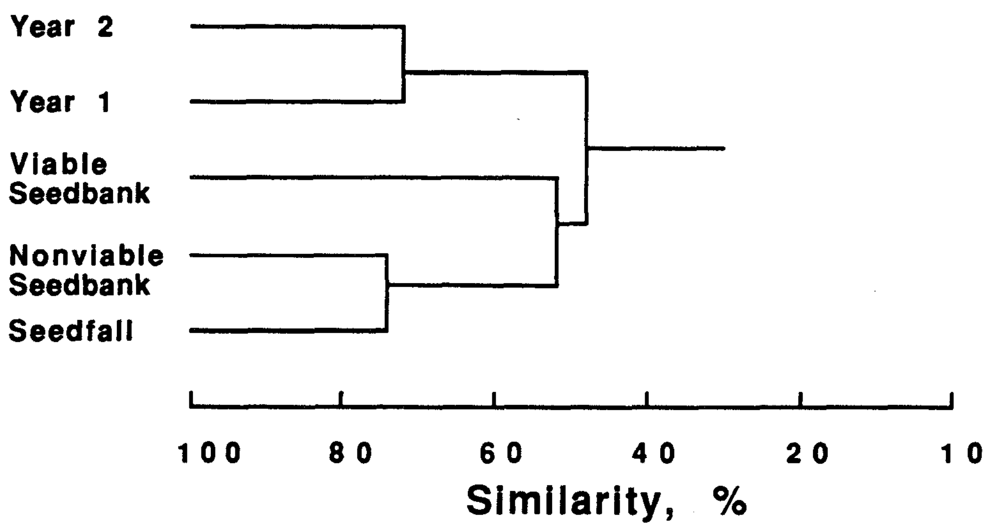


Figure 7.5. Similarity (Bray and Curtis, 1957) of the relative species abundance in the seedfall, nonviable and viable seedbank and germinated plants at 1 and 2 years after a fire. Analysis based on genera which were found in the seedfall.

The above results have several possible interpretations. The simplest interpretation is that under conditions where seed mortality is high and random then species which have the highest seed inputs (i.e. small seeded species) are likely to become increasingly dominant with time simply due to the increased probability of localized extinction of the less abundant species. A second plausible explanation is that there are selective processes (i.e. predation, competition, physical stress (i.e. fire (Zannet and Zedler 1988), soil conditions) which increase mortality of the late successional (i.e. large seeded) species relative to the early successional shrub species. Our study was largely descriptive and cannot determine the causes of the mortality. The primary succession conditions on the study site were likely to be harsh for most species but perhaps more so for late successional large-seeded species. The soil has a high clay and low nitrogen and organic matter content (Wallace and Best, 1983) and abundant seed-predating ants (Dunn, 1988). Fewer larger seeded species entered the soil seedbank. Wilson and Whelan (1990) studied similar genera and found that predation was high on larger seeds. A high clay and low organic matter soil may have fewer spaces for large seeds to enter the seedbank. Germination success appeared less dependent on seed size but the lack of relationship cannot compensate for the already reduced density of large seeds.

Myrica, a successful species on the site, is nitrogen fixing (Vitousek and Walker, 1989), perhaps allelopathic (Dunevitz and Ewel, 1981) and can dominate early successional land in the phosphate mining region (Rushton, 1983). Many of its dispersal and vegetative characteristics appear to make it well suited for colonization of primary substrate (Vitousek and Walker, 1989). _Myrica_ colonization may provide nitrogen, organic matter and vegetative structure but its potential allelopathy may be detrimental to the establishment of other plants.

Sites may be recruitment-limited in the sense that seed availability may affect the site's resultant plant composition but the initial floristics model (Egler, 1954) is not entirely sufficient to explain colonization as selective processes (either random or deterministic) result in species composition changes. From the reclamation perspective the placement of snags may be useful in maintaining a continuous and stable input of seeds over the life of the snag (in this case 7 years) but it will not necessarily insure the establishment of the desired late successional forest species. It may be more effective to germinate collected late-successional seeds and plant seedling in order to avoid high in situ mortality during the earliest stages of the plant's development.

8. TRANSPIRATION IN CLAY SETTLING PONDS

M. MUNROE

Measurements of evaporation and transpiration of vegetation in clay settling ponds were made with chamber enclosure methods in order to consider the role of vegetation in eliminating water. Transpiration was related to infrared reflectance (Chapter 8), one of the factors in heat budgets which differ widely from one species to another. Our initial hypothesis was that the adaptive features of eutrophic vegetation colonizing the settling ponds--cattail, willow, buttonbush, etc included high rates of transpiration and more absorption of near infrared rays of sunlight (less reflectance).

Background of Methodology

Several investigators have used tubular environmental chambers or plastic bags to measure the moisture liberated by photosynthesizing vegetation, usually in concert with production-respiration measurements. The method was adapted from earlier use in rain forests of Puerto Rico, where chambers included small bags over leaves and a giant plastic sleeve 20 meters across (Odum, Lugo, 1970). See also studies of marshes (Lugo, 1988; Burns, 1978; Brown, 1978; Woodall, 1981 and many others. Schwartz (1990) adapted the chamber method for transpiration of limbs in titi-bay swamps alone without measuring carbon-dioxide metabolism. The studies reported here were adapted from his procedures, and acknowledgement of his advice is made with thanks.

METHODS

Evapotranspiration was measured by monitoring water vapor changes before and after air flowed through chambers enclosing parts of plants. Moisture condensation on the inside surface of the chamber was used as an indicator of inadequate flow.

By maintaining a strong airflow, living components were kept as natural as possible. Inside the chamber, sunlight, temperature, and air flow were closely monitored and maintained close to external conditions.

The chamber was run as an open system in which a pump pushed air, taken from canopy level, through a soft, transparent, cylindrical chamber enclosing the vegetation, with the intake and exhaust vents at opposite ends. Several volumes were used - 10, 15, and 20 liters - as well as irregular volumes and shapes in the earlier October measurements.

Rapid air turnover maintained conditions inside the chamber like those of the outside. Insufficient air flow limited carbon dioxide uptake due to an increase in boundary layer resistance,overheated the chamber, and saturated (100% relative humidity) the chamber air. These conditions caused underestimates of actual transpiration. To avoid low limiting air flow rates, rates of volume turnover in the chamber were regulated as high as possible without reducing the difference in water vapor content below detection levels inseparable from instrument noise. Previous studies have shown that for a cylindrical chamber of 52 liters, 6 turnovers per minute are sufficient to prevent heat buildup and carbon dioxide uptake limitation (Brown, 1978), whereas a chamber near a tenth of that volume, 4.2 liters, was found to require approximately 30 turnovers per minute. This dependency on increased air flow for smaller volume chambers was taken into account in regulating our intermediate sized chambers. In all cases moisture condensation on the inside surface of the chamber was used as an indicator of inadequate flow. An accurate measurement of airflow was required for reasonable precision in the calculation.

Change in absolute humidity x air flow = evapotranspiration (1)

A bypass flowmeter (Cole-Palmer Model J-3218) was used to monitor the entire volume of air passing through the chamber. The intake air was sampled in the system at a point before the bypass flowmeter, and exhaust air was sampled just inside the opposite chamber opening (outflow). The differences in absolute humidity between the intake and the exhaust air represented the increase in humidity due to the transpiring vegetation.

An air sampling system was made from tygon plastic tubing with an inside diameter of 6mm. A dew point hygrometer (EG & G International, Inc., Model 880) was used to determine successively the water vapor content of the air in the tubes leading from the intake and outlet described above. Small vacuum pumps (2-5 liters/min.) were used to draw the samples through the tubes. A larger 1/3 horsepower vacuum pump with a capacity up to 200 liters/min. was used to push the volume of air necessary through the environmental chamber.

The dew point hygrometer was factory calibrated and the front panel was read for dew point temperature (temperature at which the relative humidity would be 100%), using the background mirror to avoid inaccurate recordings due to parallax. Six readings, one every 5 seconds, were recorded for both intake and outlet air samples in succession. Average dew point temperature along with the ambient temperature were used to convert data to absolute humidity values in g/m3. Flow rates were recorded directly and converted from the scale on the flow meter to air flow by the calibration chart provided by Cole-Palmer with the bypass instrument. The flow through the actual flow meter was 1/5 the total flow and was multiplied by five to obtain the full value.

At the same time, a Li-cor solar radiometer was used to measure solar irradiance in watts/m2. Fall (October), winter (January), and spring (March through May) measurements were made on clear, sunny days to relate the rates measured to differences in solar energy. After a run, the leaves and stems inside the chamber were harvested up to the point of the exhaust sampling tube. Wet weight was obtained immediately upon returning from the field as was dry weight measured after 48 hours of oven drying (78°C).

Data Calculations

The calculations of the evapotranspiration rates followed the pattern established in the computer program by Schwartz (1989). The format was converted to a form suitable for LOTUS spreadsheets, the details of which can be found at the end of this chapter. The calculations were made as follows:

$$\text{Evapotranspiration rate in g } H^2O\text{/hr/g dry wt.} = \text{Fl (AbOT - AbIN)/dry wt.} \qquad (2)$$

where:

Fl = flow rate in m^3/hr
AbOT = absolute humidity of outlet air
AbIN = absolute humidity of intake air

Absolute humidity was obtained by first calculating the saturation vapor pressure with an equation relating dewpoint temperature (C) to saturation vapor pressure (e) based on the Smithonian Meteorological Tables. An exponential model with the best fit is described by the Clausius-Clapeyron equation and is the one used:

$$Es(mb) = 6.841 \exp (0.0608) * T^{o}C \qquad (3)$$

where:

es = saturation vapor pressure

This value was used to obtain absolute humidity according to the gas laws for the partial pressure due to vapor as:

$$Ab(g/m^3) = \frac{es * MW * 10^3 \ erg*cm\text{-}3*mb^{-1} * 10^6 \ cm^3*m^3}{R * T} \qquad (4)$$

where:

Ab = absolute humidity at saturation in g/m^3
MW = molecular weight of water, 18 g/mole
R = $8.31 * 10^7$ erg/°K/mole, gas constant
T = ambient temperature in °K

Flow rates and leaf weights were then used to express the evapotranspiration rates in g H_2O/g dry leaf weight, according to the equation (1) in this section, performed using calculations made with a LOTUS spreadsheet. Rates were plotted as a function of solar insolation.

RESULTS AND DISCUSSION

The plant transpiration measurements are summarized in graphical form chronologically. The field equipment was continually adapted during this period, reflecting both developing expertise in the field and the change in solar irradiance through the seasons. Greater air flow and turnover was needed with greater solar loads to keep plants cool and chambers dry. Apparently air flows used in measurements were not limiting transpiration. Figure 8.1 shows no consistent dependence on air flow in the range of flows used.

The October, 1988, data are grouped together in Figure 8.1 for all species measured at that time: cattail (*Typha latifolia*), willow (*Salix caroliniana*), buttonbush (*Bacharis halimifolia*), and primrose willow (*Ludwigia octovalis*). The chamber size was considerably smaller than used later in the spring and designed to use a higher ratio of chamber surface area to leaf area to reduce chamber effects. No obvious trend between evapotranspiration rate and air flow is seen. Sunlight ranged between 450 and 970 watts/m2 on this mostly sunny weekend of October 6 and 7.

Table 8.1 contains the average evapotranspiration rates for the four major early successional species found growing on clay settling ponds, including the standard deviation, expressed in kilograms of water per kilogram of dry weight per hour. These tentative rates were measured during a low light period (but few clouds) and are generally less than those reported by Brown (1978) using similar methods. A north Florida cypress tree measured on the same weekend is included for comparison.

The results of a more critical examination of light as a factor was performed in January, 1989, narrowed to two species: willows and cattails, Figure 8.2 and Table 8.2. No clear trend in increasing transpiration with light intensity was evident. March measurements on cattail in Figure 8.3 show higher rates over the range of turnover used.

Measurements in a favorable, non-limiting range of flow were plotted against light in Figure 8.4 for cattail only. Any relationship appears slight in this range of light intensities, which are higher than the October measurements, while occurring close to the same temporal distance from the winter solstice. The least squares simple regression is included for comparison. The average rate over the midday measurements is 5.9 kg H2O/kg/hr (STD = 1.9), which, extrapolated to a full day, results in the high estimate of over 30 millimeters of actual transpiration (assuming approximately 1 kg of dry weight per m2 of ground).

Although there was considerable variation, some inherent in the heterogeneity of vegetation and measurement method, there seems no doubt that the plants had high rates of transpiration. High transpiration rates are consistent with high rates of plant growth observed by others in phosphate-rich settling basins. The magnitude of transpiration observed is as great or greater than evaporation rates observed in open waters of Florida. Rates are as high or higher than potential evapotranspiration predicted for the region using temperature relations by Dohrenwend (1977).

The transpiration of rapidly-growing, early successional plants helps dry out settling basins in addition to other roles the vegetation mat and organic detritus may contribute to consolidation. Reflectance measurements (Chapter 9) show that the energy for transpiration is returning from the field as was dry weight measured after 48 hours of oven drying (78°C).

Data Calculations

The calculations of the evapotranspiration rates followed the pattern established in the computer program by Schwartz (1989). The format was converted to a form suitable for LOTUS spreadsheets, the details of which can be found at the end of this chapter. The calculations were made as follows:

$$\text{Evapotranspiration rate in g } H^2O/\text{hr/g dry wt.} = \text{Fl (AbOT - AbIN)/dry wt.} \qquad (2)$$

where:

Fl = flow rate in m^3/hr
AbOT = absolute humidity of outlet air
AbIN = absolute humidity of intake air

Absolute humidity was obtained by first calculating the saturation vapor pressure with an equation relating dewpoint temperature (C) to saturation vapor pressure (e) based on the Smithonian Meteorological Tables. An exponential model with the best fit is described by the Clausius-Clapeyron equation and is the one used:

$$Es(mb) = 6.841 \exp (0.0608) * T^oC \qquad (3)$$

where:

es = saturation vapor pressure

This value was used to obtain absolute humidity according to the gas laws for the partial pressure due to vapor as:

$$Ab(g/m^3) = \frac{es * MW * 10^3 \text{ erg*cm-3*mb-}^1 * 10^6 \text{ cm}^3\text{*m}^3}{R * T} \qquad (4)$$

where:

Ab = absolute humidity at saturation in g/m^3
MW = molecular weight of water, 18 g/mole
R = 8.31 * 10^7 erg/°K/mole, gas constant
T = ambient temperature in °K

Flow rates and leaf weights were then used to express the evapotranspiration rates in g H_2O/g dry leaf weight, according to the equation (1) in this section, performed using calculations made with a LOTUS spreadsheet. Rates were plotted as a function of solar insolation.

RESULTS AND DISCUSSION

The plant transpiration measurements are summarized in graphical form chronologically. The field equipment was continually adapted during this period, reflecting both developing expertise in the field and the change in solar irradiance through the seasons. Greater air flow and turnover was needed with greater solar loads to keep plants cool and chambers dry. Apparently air flows used in measurements were not limiting transpiration. Figure 8.1 shows no consistent dependence on air flow in the range of flows used.

The October, 1988, data are grouped together in Figure 8.1 for all species measured at that time: cattail (Typha latifolia), willow (Salix caroliniana), buttonbush (Bacharis halimifolia), and primrose willow (Ludwigia octovalis). The chamber size was considerably smaller than used later in the spring and designed to use a higher ratio of chamber surface area to leaf area to reduce chamber effects. No obvious trend between evapotranspiration rate and air flow is seen. Sunlight ranged between 450 and 970 watts/m2 on this mostly sunny weekend of October 6 and 7.

Table 8.1 contains the average evapotranspiration rates for the four major early successional species found growing on clay settling ponds, including the standard deviation, expressed in kilograms of water per kilogram of dry weight per hour. These tentative rates were measured during a low light period (but few clouds) and are generally less than those reported by Brown (1978) using similar methods. A north Florida cypress tree measured on the same weekend is included for comparison.

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Measurements in a favorable, non-limiting range of flow were plotted against light in Figure 8.4 for cattail only. Any relationship appears slight in this range of light intensities, which are higher than the October measurements, while occurring close to the same temporal distance from the winter solstice. The least squares simple regression is included for comparison. The average rate over the midday measurements is 5.9 kg H20/kg/hr (STD = 1.9), which, extrapolated to a full day, results in the high estimate of over 30 millimeters of actual transpiration (assuming approximately 1 kg of dry weight per m2 of ground).

Although there was considerable variation, some inherent in the heterogeneity of vegetation and measurement method, there seems no doubt that the plants had high rates of transpiration. High transpiration rates are consistent with high rates of plant growth observed by others in phosphate-rich settling basins. The magnitude of transpiration observed is as great or greater than evaporation rates observed in open waters of Florida. Rates are as high or higher than potential evapotranspiration predicted for the region using temperature relations by Dohrenwend (1977).

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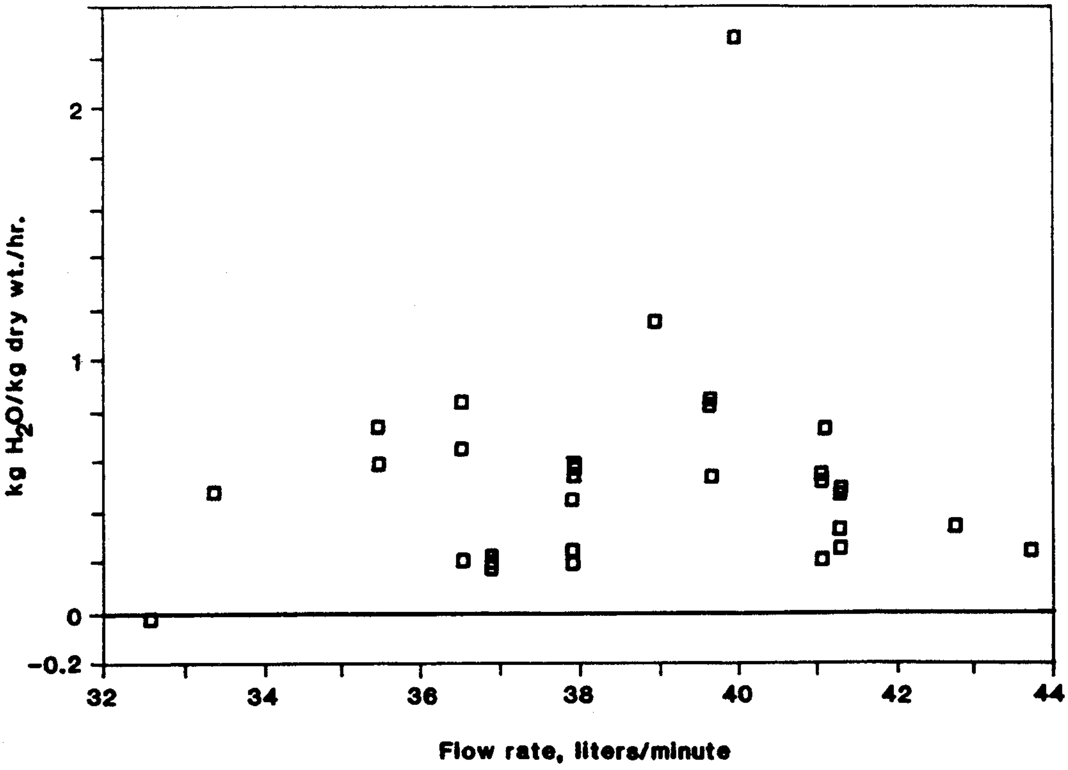

Figure 8.1. Transpiration of all vegetation measured, including cattail, willow, primrose willow, and buttonbush, against air flow, October 6 and 7, 1988.

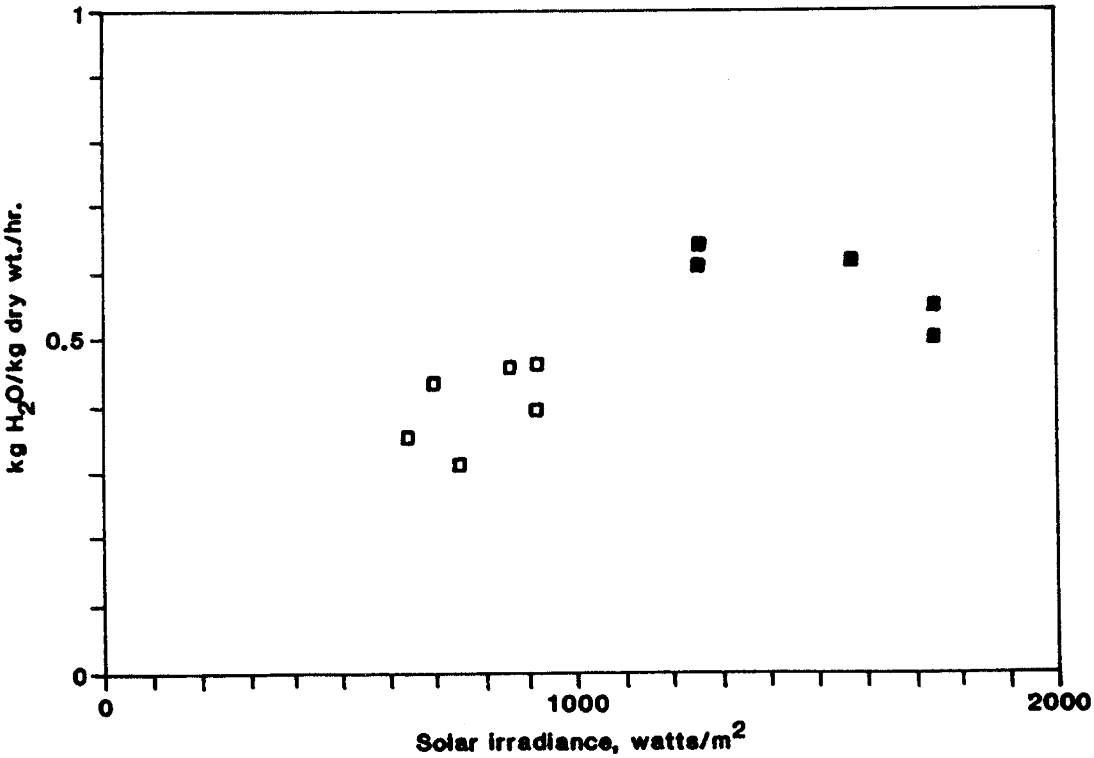

Figure 8.2. Transpiration as a function of light intensity. Willows, open squares; cattails, solid squares. January, 1989.

Table 8.1. Transpiration of clay settling pond vegetation, grams of water per hour per kilogram of plant dry weight.

Type of vegetation	Transpiration g/Kg	Standard deviation
Baccharis halimifolia	0.348	0.040
Salix caroliniana	0.400	0.055
Ludwigia octovalis	0.591	0.132
Taxodium	0.927	0.210
Typha latifolia	1.126	0.114

Table 8.2. Transpiration of phosphate settling pond vegetation Typha *latifolia* and *Salix caroliniana*, January 28, 1989.

Light meter Watts/meter^2	Flow rate liters/min.	Ambient temp. C	Intake dewpoint C	Outflow dewpoint C	Plant code	Dry weight	Transpir. g/kg/hr
750	40.36	26.3	16.61666	23.76666	Ty	14.8	1211.468
750	40.36	27.0	16.36666	23.9	Ty	14.8	1270.029
950	40.013	26.3	17.05	24.13333	Ty	14.8	1218.968
1050	38.626	28.5	15.8	23.2	Ty	15.5	1091.175
1050	41.558	28.0	15.91666	22.3	Ty	15.5	988.3930
1050	39.666	28.0	14.88333	21.81666	Ty	15.5	979.6089
640	40.36	29.0	14.51666	19.5	Wi	29.1	349.2881
750	40.36	27.8	14.1	18.68333	Wi	29.1	310.4814
700	39.66	28.0	14.43333	20.5	Wi	29.1	431.8745
860	40.36	27.7	14.61666	21.71666	Wi	34.5	454.1114
920	39.319	29.0	14.03333	21.63333	Wi	34.5	462.5767
920	40.36	28.7	14.73333	21.01666	Wi	34.5	392.8454

Ty = Cattail
Wi = Willow

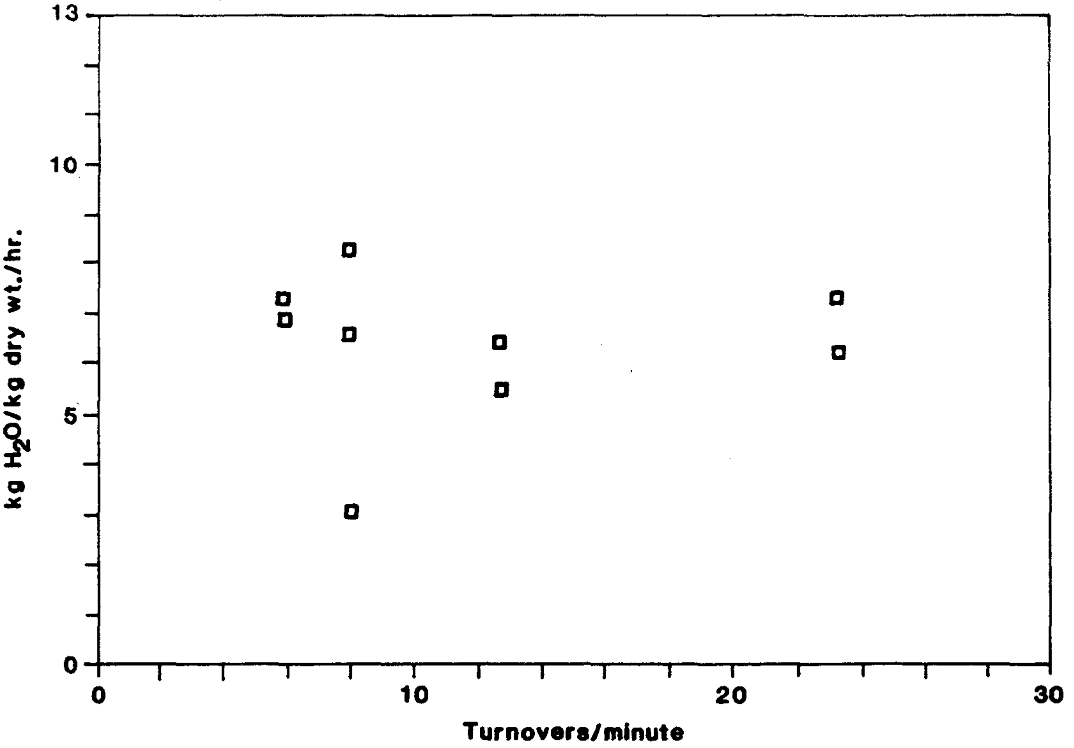

Figure 8.3. Transpiration of cattails as a function of air turnover, March, 1989.

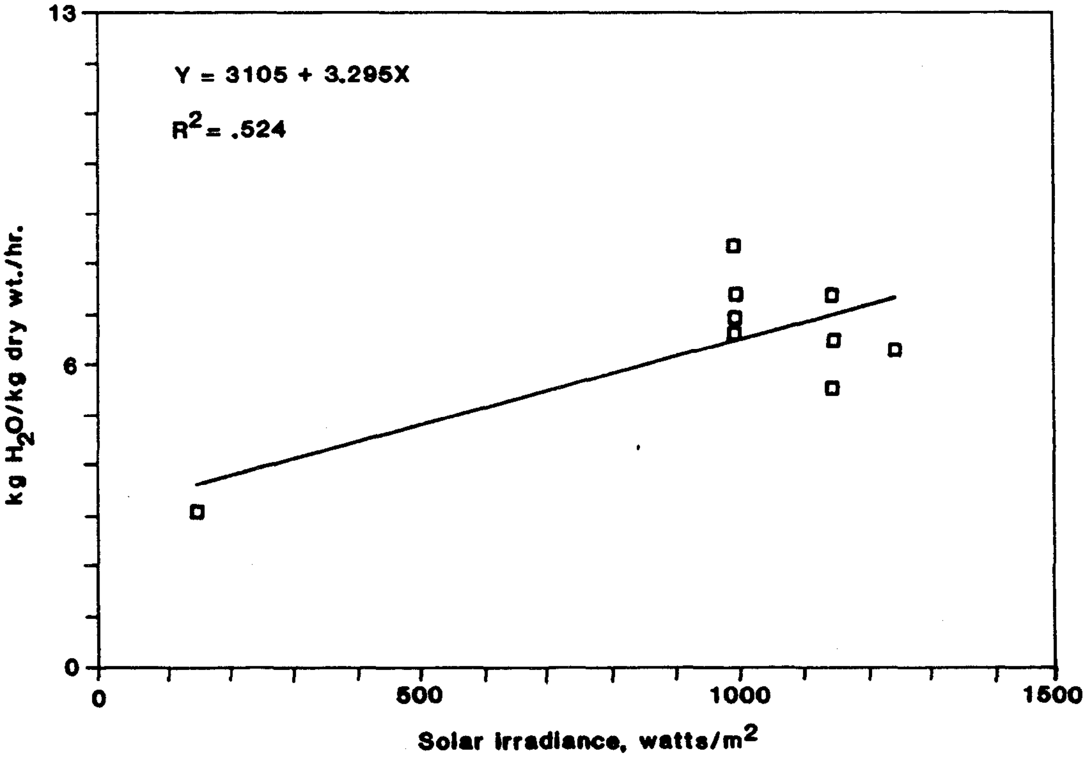

Figure 8.4. Transpiration of cattails as a function of increasing light intensity at higher rates of chamber air turnover. March, 1989.

available from the solar insolation absorbed. Mature willows and cattails on settling basins absorb 50% of the near infrared insolation energy and most of the insolation in visible wave-lengths.

9. INFRARED REFLECTANCE AND WATER BUDGETS OF VEGETATION IN RECLAMATION AFTER PHOSPHATE MINING

T.R. McCLANAHAN AND H.T. ODUM

Much of the process of land restoration after mining depends on the energy received from solar insolation. Settling basins depend on the sun's energy to evaporate water, to develop the successional vegetation, and generate productivity in land uses that follow. The availability of water in depressions, wetlands, and superficial groundwaters depends on the evapotranspiration, largely controlled by the way land and vegetation absorb or reflect the energy of the solar insolation. Portable optical equipment now available makes it possible to evaluate the percent solar insolation being reflected, thus evaluating the energy that was absorbed. Reflectance is determined for the various wave-lengths being received from the sun. In this study measurements of spectral reflectance were made in different stages of land restoration and related to questions about alternative ways of dewatering and restoring vegetation.

Shown in Figure 9.1 is the normal spectral distribution of sun's energy (irradiance) received on earth in different wavelengths. Half of the energy at the ground is in the visible range which is utilized by plants for photosynthesis and half is in the infra-red range, not visible, nor supporting photosynthesis directly. However, all of the energy absorbed, but contributing heat, tends to increase the evapotranspiration. Transpiration, the evaporation of water from the tiny leaf pores (stomata) is usually correlated with photosynthesis, because open stomata are required to take in more carbon-dioxide when nutrient conditions favor photosynthesis. Transpiration keeps the leaves from overheating (evaporative cooling). However, when nutrient conditions do not favor photosynthesis and stomata are not so open, leaves would tend to overheat. Plant species which are adapted for low nutrient conditions develop chemicals on their surfaces that reflect more of the infrared insolation.

Clear water bodies absorb most of the visible and infrared insolation, whereas many bare land surfaces, such as dry sand or white shiny roofs, reflect more of the insolation. Reflectance from the top of an old gypsum stack (Figure 9.2) was 30% to 65%. This preliminary survey includes spectral reflectance of some principal stages in post-mining land restoration starting with open water.

Spectral Reflectance and Drying-out of Phosphate Settling Basins

Return of phosphate settling basins to normal land uses for forestry, agriculture, wetlands, and other natural vegetation has required years

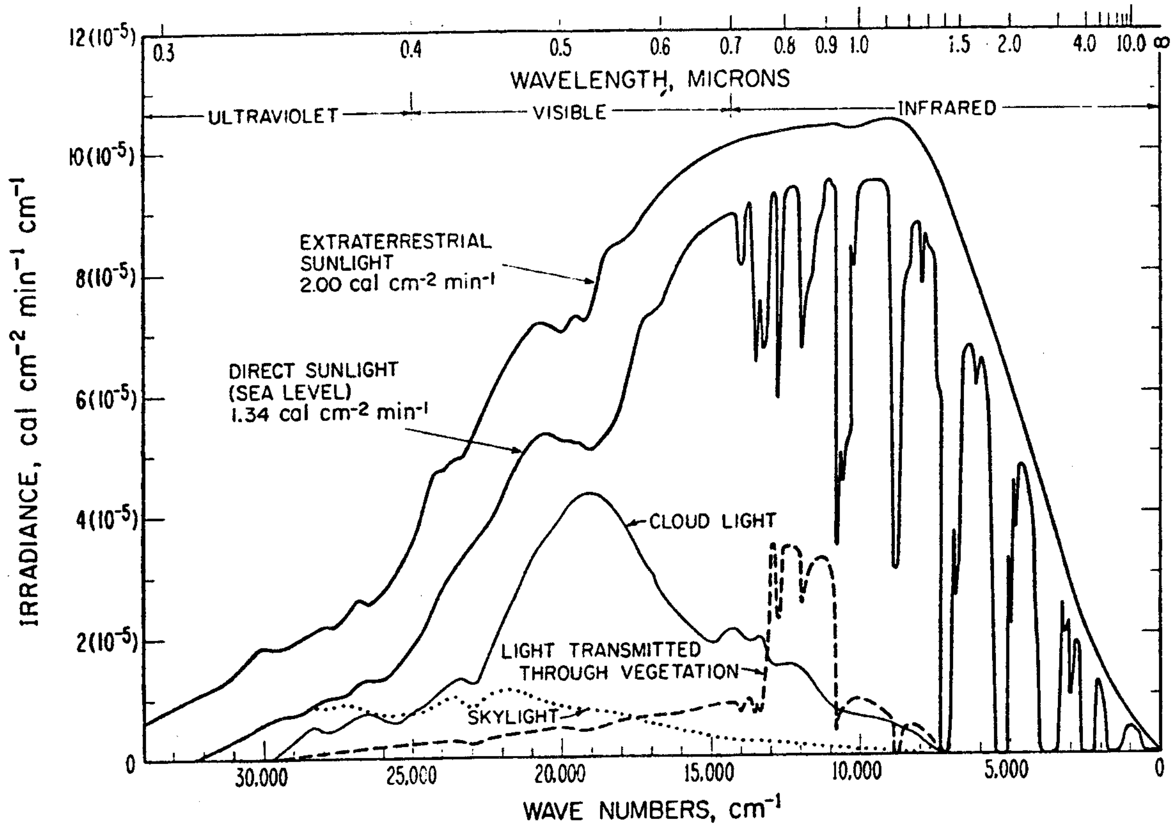

Figure 9.1. Solar spectrum (after Licor after Gates, 1955).

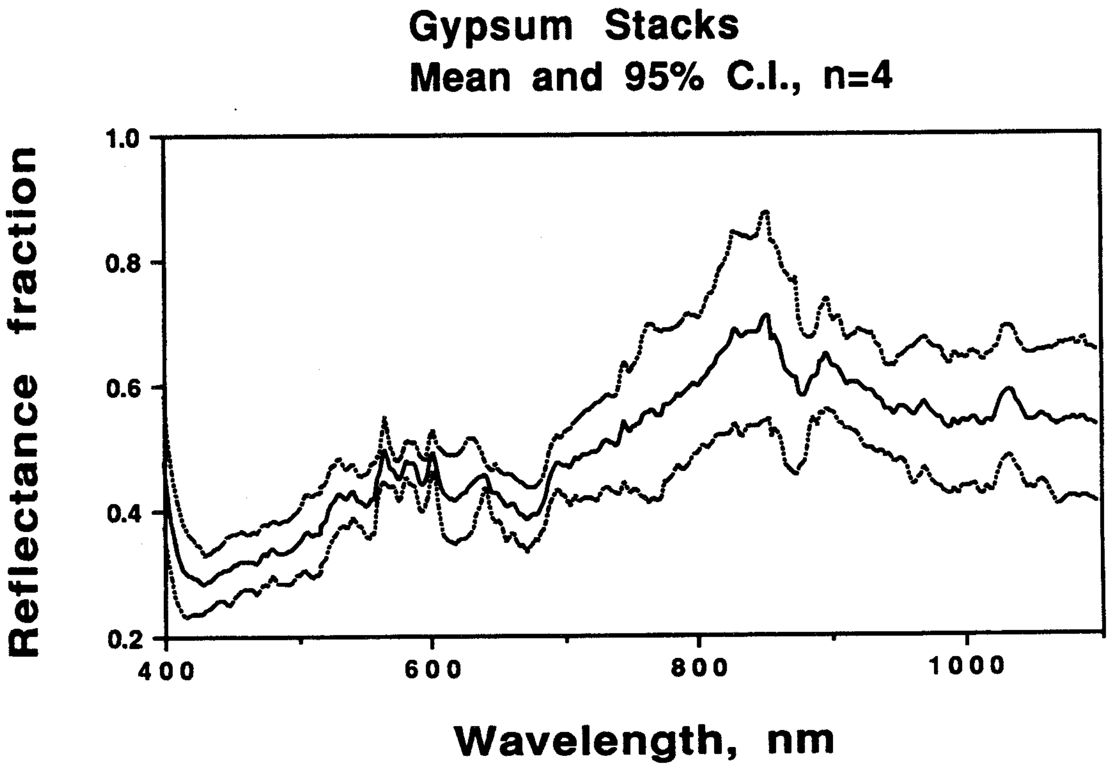

Figure 9.2. Spectral reflectance for gypsum stacks.

because of the colloidal stability of the clay-water suspensions. At considerable cost, some ponds have been converted with special machinery for clearing vegetation and developing a clay crust. The low cost alternative is to encourage the natural vegetation succession to develop which is fast growing with high rates of transpiration. Questions have been raised about which of the two systems is better at removing the water. Since the energy for evapotranspiration comes from the solar insolation, spectral reflectance measurements can indicate which systems absorb more of the solar energy to drive evapotranspiration.

Spectral Reflectance, Phosphate Mining and Landscape Design

After phosphate mining, restoration of vegetation and soil structures is an essential stage in preparing for later use of the land for forestry, agriculture, or wilderness purposes. In our previous reports evidence has accumulated showing that natural succession, accelerated somewhat by planting tree seedlings, may be the cheapest way to restore wetlands and other vegetation. Control of vegetation depends in part on management of water regimes, and vice versa. Because of plant transpiration, water budgets depend on the vegetation types. For different water and nutrient regimes different kinds of vegetation are better adapted for rapid restoration.

When it became apparent that the different kinds of wetland vegetation had very different reflectance to the infrared (invisible "heat" radiation) wavelengths of solar radiation, we suggested that infrared reflectance measurements could be used to evaluate water and heat budgets for alternative reclamation management. For example, reclamation situations where water conservation was needed would require different vegetation from that in phosphate settling basins where drying-out was needed. Since near infrared reflectance could be read from remote aircraft or satellite sensors, the whole phosphate area could inexpensively be considered in relation to its water regimes.

A one year exploratory study using Li-cor spectral reflectance equipment was authorized by the FIPR board with the results reported here.

Concept of Eutrophic Water-Using Vegetation versus Oligotrophic Water Conserving Vegetation

Based on studies at the Center for Wetlands by several graduate students during the period 1974-1982, which showed wide ranges of evapotranspiration of wetland tree species, we proposed the hypothesis (Odum, 1984) that wetland vegetation differs in infrared reflectance which is related to water-using or water-conserving modes depending on nutrient availability. The modes are as follows:

Water Using Mode:

> Where nutrients are rich, high organic productivity is possible, and the vegetation is adapted for fast growth. High photosynthetic rates require open stomates for inflow of carbon-dioxide, which consequently results in

greater potential loss of water through transpiration. Since there is much transpiration, the leaves are readily cooled by evaporation of the water rather than depending on high reflectance to reduce heat buildup. This mode of operation tends to dry out wetlands, and this pattern fits an intermittent hydroperiod.

Water Conserving Mode:

Where nutrients are scarce, net organic productivity is less, and stomates need not be open as much to draw in carbon-dioxide. Cooling by transpiration is less, and greater infrared reflectance is necessary to prevent overheating of leaves. The resulting wetland water budget strategy keeps the area wet longer. When nutrients are scarce, leaf area may be reduced. This vegetation mode contributes more to regional productivity by conserving water. Water and trees with this pattern are adapted to a long hydroperiod.

Regional Implications for Reclamation Planning

Many of Florida's wetlands, especially the bays, bogs, and pond cypress areas, are on high plateaus with relatively small drainage areas and nutrient poor. These areas stay wet by minimizing transpiration (Brown, 1981; Odum, 1984). In the larger, regional self-organizing dynamics of landscapes, areas that conserve and recharge water contribute to the organic productivity of other areas downstream. Big Cypress, Okeefenokee, and Green Swamp are examples. In our initial survey of spectral reflectance of wetland vegetation in Florida, we confirmed the role of these areas as high reflectance-low transpiration type. Further downstream are floodplain wetlands with larger drainage areas, more nutrients, and photosynthetically productive species that absorb more infra-red insolation and transpire more.

Following the clues from patterns prior to mining, good regional management may require locating the water-conserving wetlands on high plateaus so that areas surrounding receive abundant runoffs or superficial ground waters that make them more productive. Thus, high reflectance vegetation on the higher grounds might be surrounded by areas of less reflectance and higher productivity. The high reflectance, slow growth areas are best adapted for wilderness, parks, and recreation, whereas the surrounding productive lands are more adapted for forestry and agriculture.

In order to explore ways to use spectral reflectance to manage landscape restoration after mining, a one year exploratory study using Li-cor spectral reflectance equipment was authorized by the FIPR board with the results reported here. Included are measurements of water surface, wet-clay surface, successional vegetation on settling basins, and alternative wetland vegetation which may be selected for restored wetlands.

METHODS

Spectral reflectance was measured with a portable spectroradiometer (Li-cor 1800) which can measure the intensity of spectral reflectance between 300 and 1100 nanometers. The spectroradiometer can take multiple readings and averages readings. An inclinometer was fastened to the optical receptor in order to maintain a constant angle between the optical receptor and the reflecting object during readings. Light intensity is highly variable and therefore each reading must be compared to a standard with high reflectance. The standard was a board painted with white enamel. In these measurements we used a titanium paint and found the reflectance not greatly different from a board of barium sulfate made available by W.T. Lawrence, Center for Energy and Environment, University of Puerto Rico. Locations and dates of spectral scans in this chapter are given in Table 9.1.

Readings were taken during periods with clear skies as constant light intensity is essential for maintaining valid comparisons between objects and the standard. During each object reading the optical receptor was held facing downward (20o to 40o) with the sun directly behind the receptor to avoid the reception of backscatter. Typically 2 to 5 scans were taken per reading. The standard was held next to the measured object and scanned within a short period (<10 min) after the object reading. Object readings were divided by standard readings in order to get a relative reflectance for each object.

RESULTS

Spectral reflectance of gypsum and clay (Figures 9.2 and 9.3) indicate a fairly even reflectance with no strong absorption or reflectance peaks. Both substrates reflect between 40% and 50% of the incoming sunlight relative to the white board. There is a weak trend for greater reflectance of the longer wavelengths (i.e. 700 to 1100 nm) but short wavelengths are reflected in higher proportion than plant spectra (Figures 9.4 and 9.5). Open water, on the other hand, has very low reflectance (Figure 9.6) in all wavelengths but particularly in the longer (near red) wavelengths.

Plant spectra have a singular shape with a high absorption at the short wavelengths (<700 nm) and high reflectance at longer wavelengths (>700 nm). Depending on presence of carotenoid and other pigments, plants typically have two reflectance troughs or absorption peaks which correspond with the chlorophyll absorption maxima at 380 to 470 nm and 620 to 690 nm. Reflectance beyond 700 nm is highest but appears variable and dependent on the plant species. Cattails and willows reflect approximately 50% of the longer wavelengths relative to the white surface (Figures 9.4 and 9.5). Both species are very close in their reflectance characteristics. The Peace River forest floodplain has high absorption for all wavelengths (Figure 9.7). The chlorophyll reflectance troughs, while present, are not nearly as distinct as for other species. Additionally, reflectance beyond 700 nm was only 30% of the white boards. This forest edge was composed of a mixture of species including red maple, elms, bald cypress, sweetgum and oaks.

Table 9.1. Spectral reflectance readings, location, time and number of replicates (n).

Reading	Location	Date	n
Gypsum stacks	Polk County	5/5/89	4
Clay, soil and water	Polk County	3/24/89	4
Open pit water	Polk County	1/28/89	1
Cattails	Polk County (Mobil PR3 site)	1/28/89	1
"	"	3/28/89	2
"	"	5/5/89	1
"	"	4/24/90	3
Willows	"	1/28/89	1
"	"	3/24/89	1
"	"	3/28/89	2
"	"	5/5/89	2
"	"	4/24/90	3
Floodplain forest	Polk County	3/28/89	4
Bald cypress	"	3/24/89	4
Bald cypress bark	Alachua County (Univ. of Fla.)	2/16/90	2
Pond cypress	Alachua County (Austin Carey)	4/16/90	11
Pond cypress understory	Alachua County (Morningside)	4/13/90	4

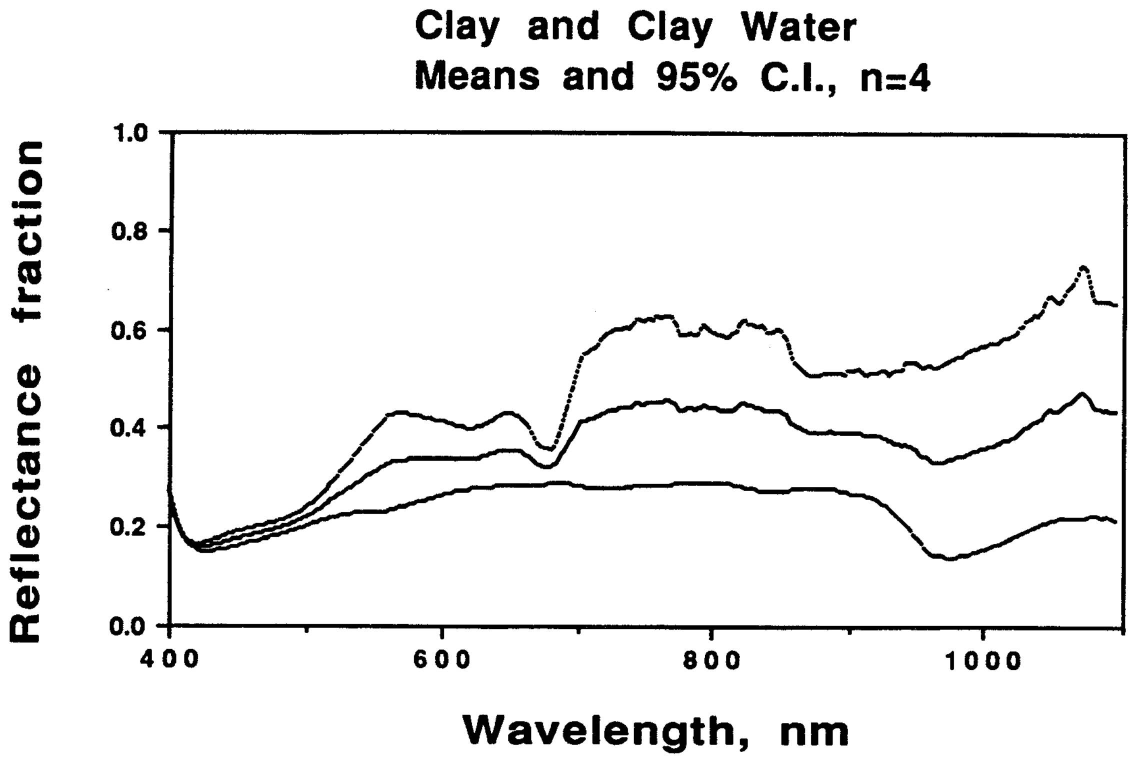

Figure 9.3. Spectral reflectance from clay and clay-water of unvegetated clay settling ponds.

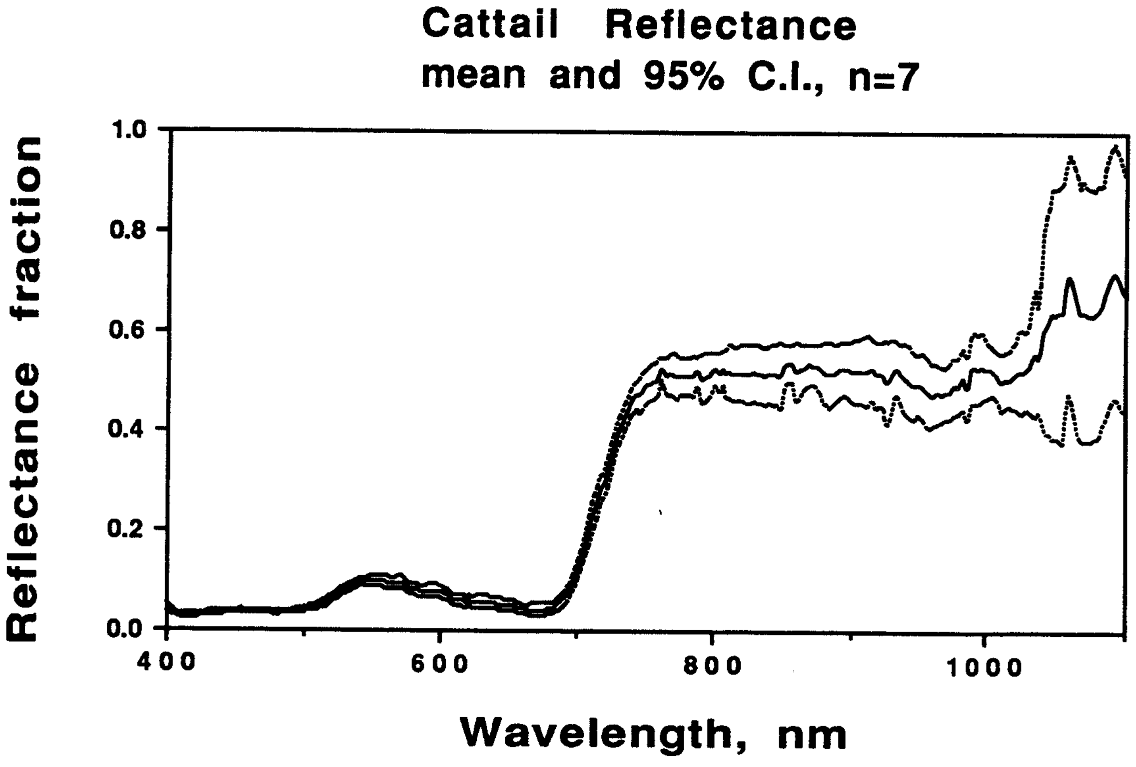

Figure 9.4. Mean curve of spectral reflectance of cattails with 95% confidence limits shown by upper and lower graphs.

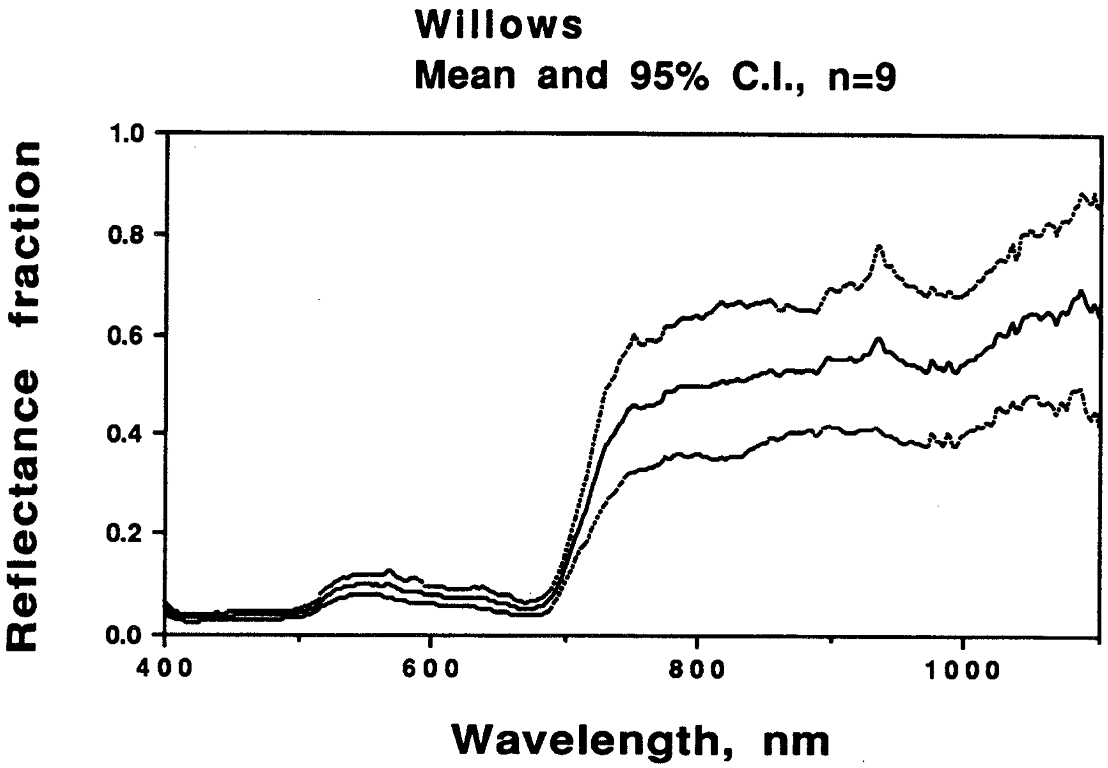

Figure 9.5. Spectral reflectance for willows.

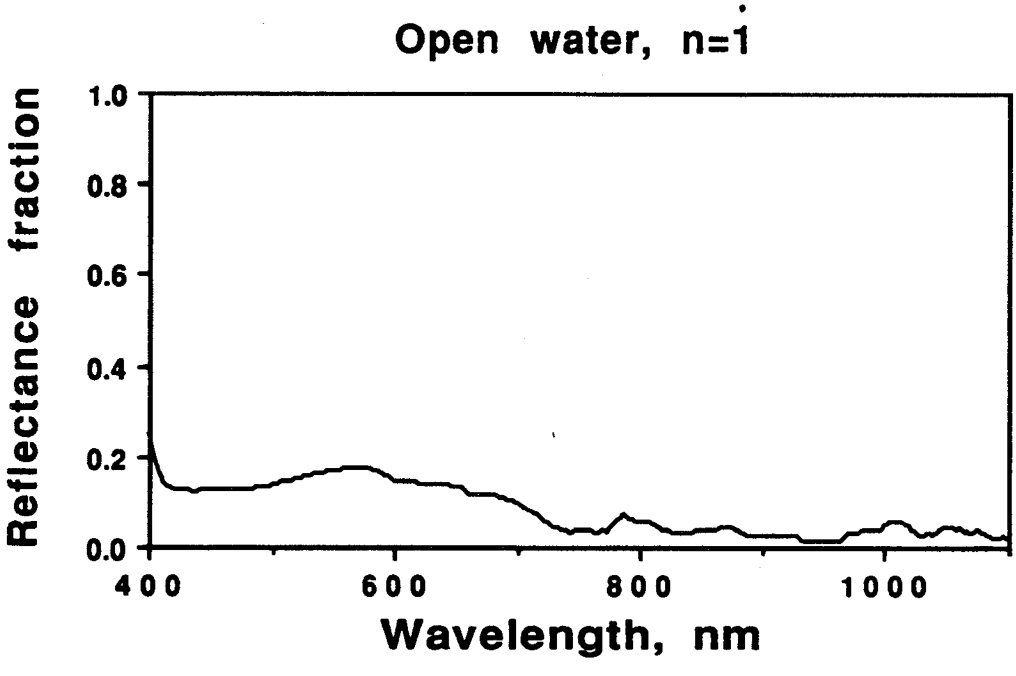

Figure 9.6. Spectral reflectance curve for open water.

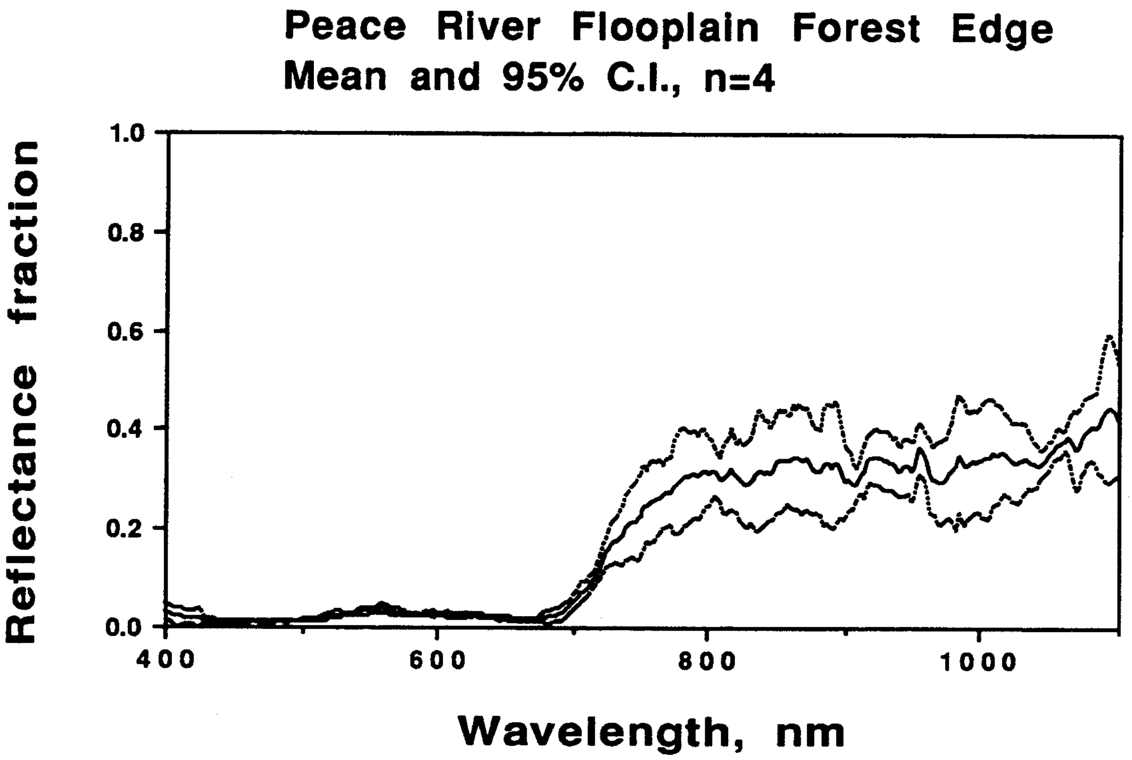

Figure 9.7. Spectral reflectance for hardwoods in the Peace River floodplain.

The two species of cypress, bald and pond cypress, have distinctly different spectral signatures (Figures 9.8 and 9.9). Bald cypress has high absorption in the shorter wavelengths compared to pond cypress overstory leaves. Pond cypress overstory leaves have the highest reflectance in the longer wavelengths of any measured species, reflecting >80% of the standard reflectance. Bald cypress reflectance in the longer wavelengths was similar to other measured wetland species at ca. 45% of the board's reflectance. Pond cypress understory leaves (Figure 9.10) have a distinctly different reflectance signature than the overstory leaves, reflecting less of the longer wavelengths. The bark and bare stems of bald cypress (Figure 9.11) taken during the winter reflect between 10% to 60% of the energy compared to the standard. Bark absorbs less of the short wave lengths than plants with leaves.

DISCUSSION

The latent heat of evaporation has been described by the following equation:

$$LE = Rn - G - H$$

where LE is the latent heat flux, Rn the net radiation, G the soil heat flux, and H the sensible heat flux. Rn is the difference between incoming and outgoing radiation and includes both short and long wavelengths. The soil heat flux (G) is usually small (10% of net radiation) for bare soils and smaller for soils with a developed canopy. The sensible heat flux is energy transferred to the atmosphere and is dependent on the temperature gradient between the earth's surface and atmosphere and the heat capacity of the air (Reginato et al., 1985). This equation makes it clear that latent heat of evaporation will be highly dependent on net radiation of the surface. Plants cannot control incoming radiation but they can, in part, control reflectance. The reflectance measure used in this study measures the relative short wave reflectance of different surfaces. Reflectance can control the net radiation and consequently latent heat flux of a plant. Plants may have the capacity during their development or over evolutionary time to adjust reflectance in order for sufficient light to be absorbed for photosynthesis and temperature dependent chemical processes but to avoid overheating and excessive water losses.

Soils and bare trees (i.e. bark) reflect more of the short wavelength energy than leaves. Reflectance in the longer wavelengths (>700 nm) is similar. Additionally, soils and leafless plants have smaller surface/volume ratios than plants and are less exposed to the air, which will result in lower water losses. Bare soils may develop a dry "mulch" layer at the surface which greatly reduces evaporation. These results are supportive of the knowledge that bare soil and leafless plants have lower evaporative losses than surfaces with photosynthesizing leaves (Dolan, 1984; Sammis et al., 1986).

Open water absorbs a large percentage of incoming radiation in all measured wavelengths. This would suggest that it has the potential for high evaporative losses but water has (1) a high heat capacity and (2) a low surface/volume ratio, which will reduce evaporative losses.

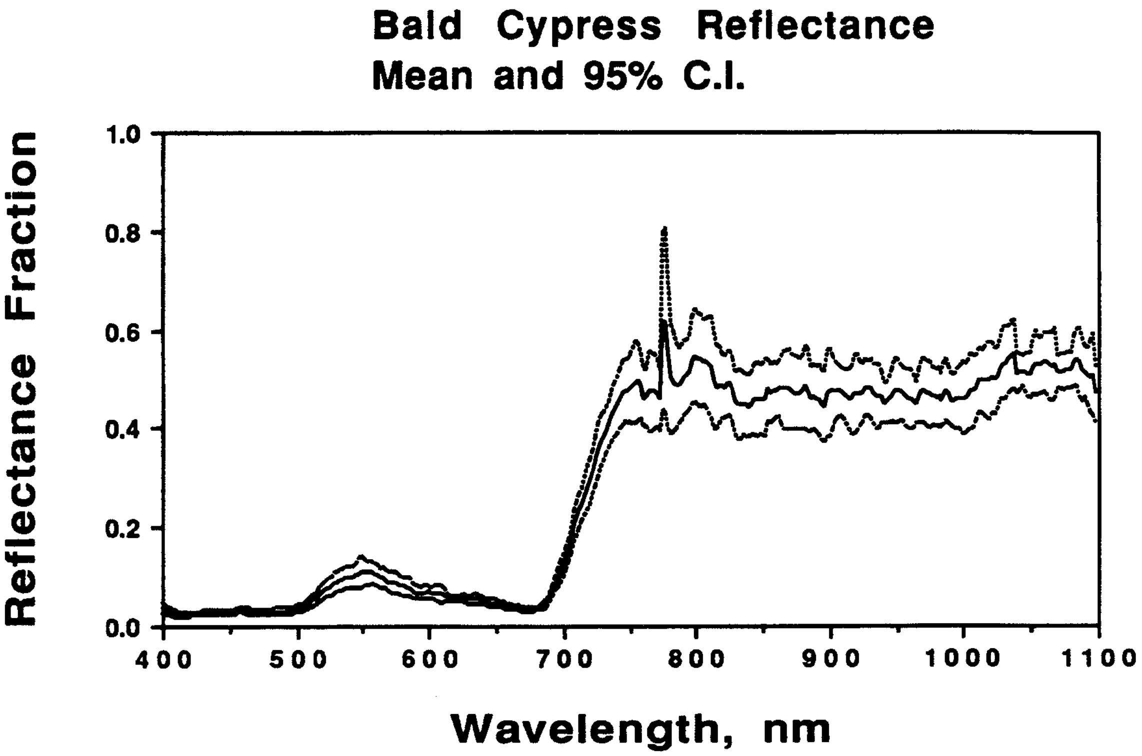

Figure 9.8. Spectral reflectance for bald cypress.

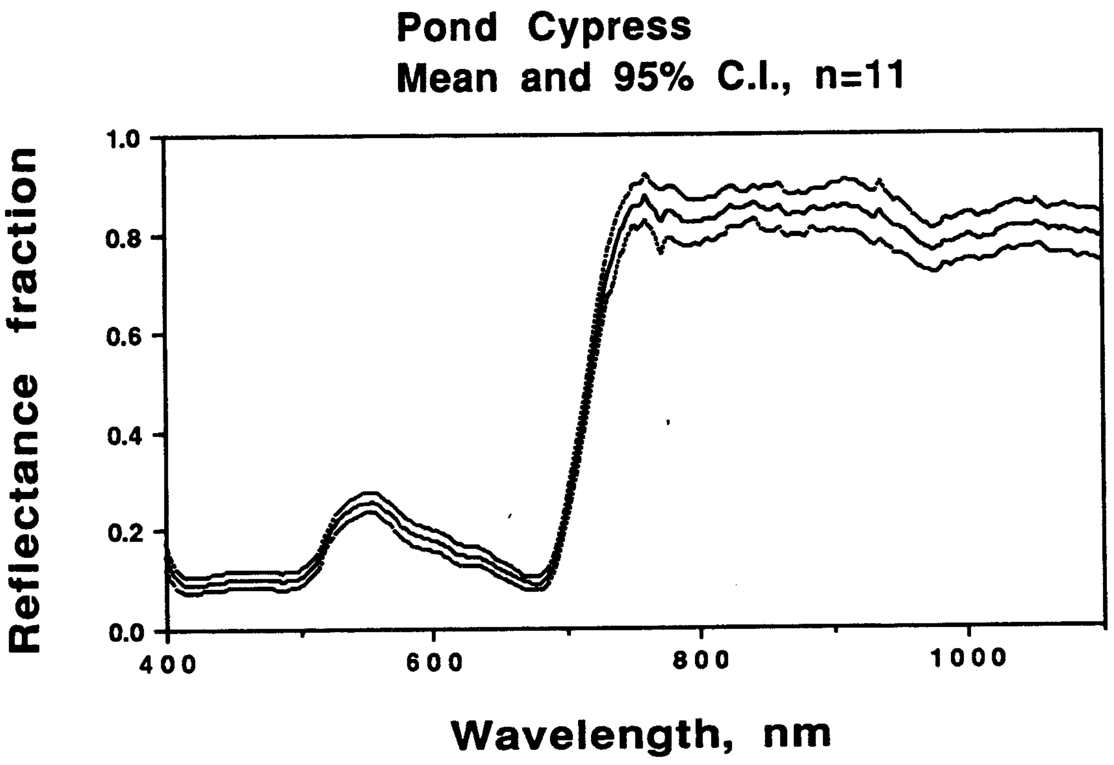

Figure 9.9. Spectral reflectance for pond cypress.

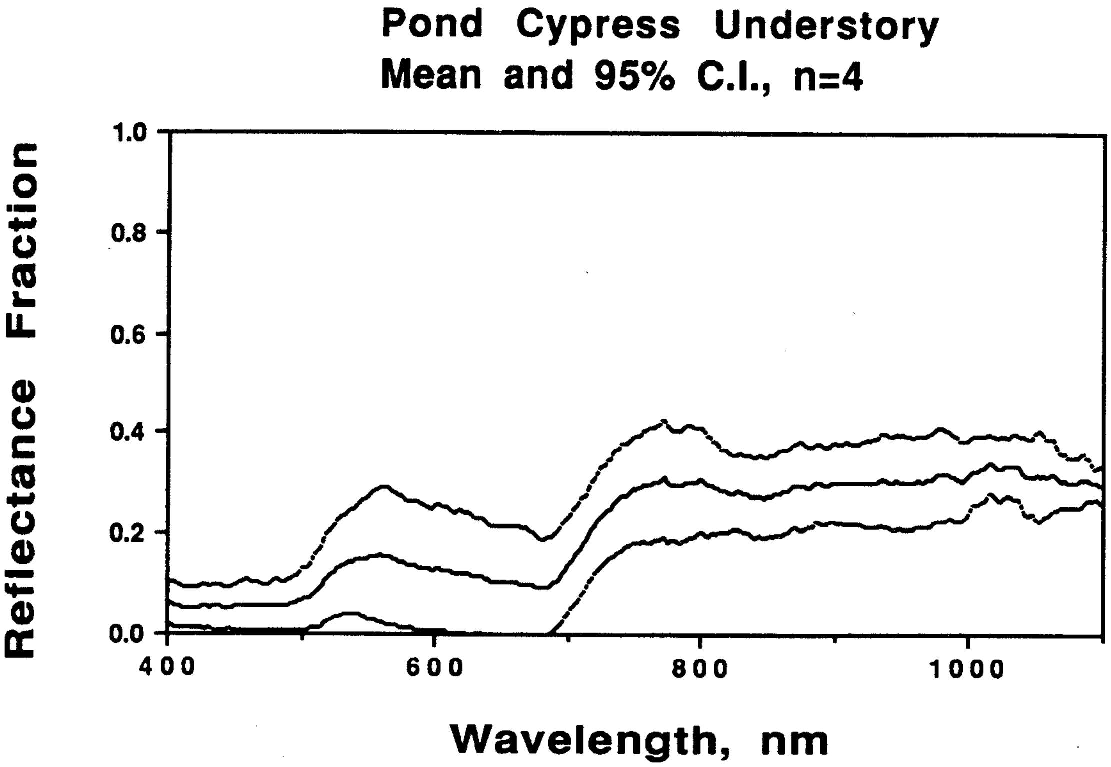

Figure 9.10. Spectral reflectance for understory pond cypress.

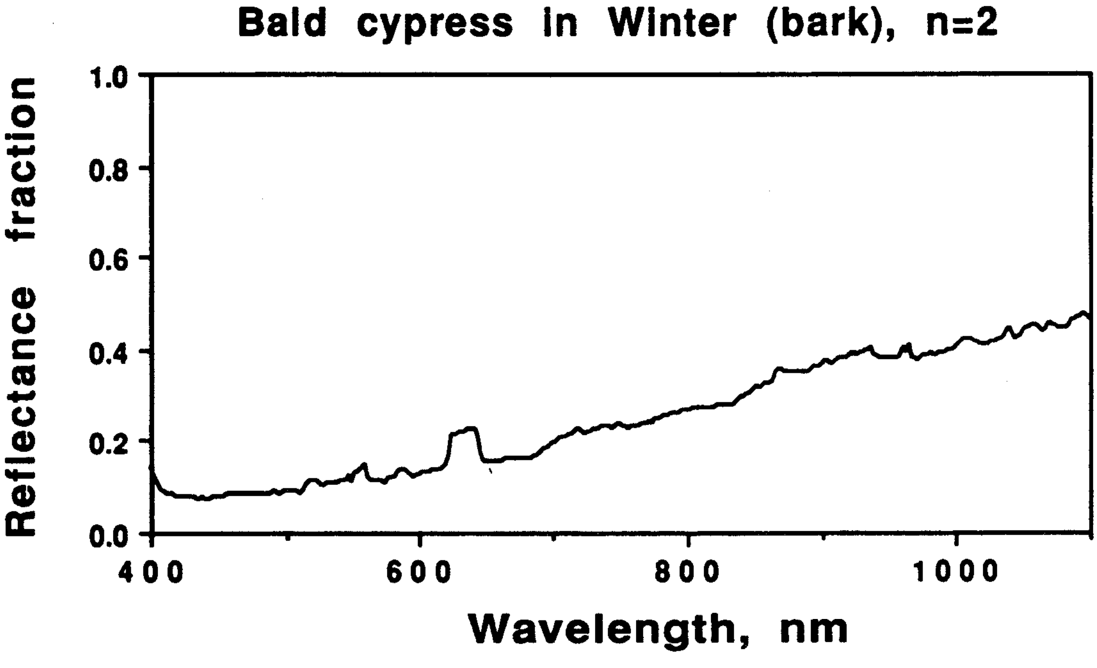

Figure 9.11. Spectral reflectance for bald cypress tree trunks in winter.

Ecosystem Use of Leaf Deflection to Absorb and Utilize Infrared Energy

Traditionally, the spectral reflectance of plants has been done on one leaf at a time in laboratory conditions. The 40% or more of the total sun's energy reflected was regarded as means for preventing leaf overheating in sunny, high temperature climates. Our survey suggests this is an incomplete story. Our sensor collects reflectance from a 15 degree telescope which collects light from a whole forest at a distance. Where reflectance was supposed to be high, the more distant scanning shows little infrared returning. Since leaves are normally at an angle, the reflecting surfaces may serve to deflect the infrared down into the lower forest, where its absorption may aid transpiration of shade plants in humid microclimates, circulation, soil respiration, etc. It has long been known that more infrared light is found below forest canopies than visible light, the latter being much more effectively absorbed by chlorophyll and other pigments.

Other Adaptive Modes for Vegetation and the Infrared Insolation

Our exploratory survey of other vegetation suggests additional patterns of heat and water control by the control of reflectance or absorption of the near infrared insolation. Plants with very high absorption of visible and infrared insolation were fast-growing Australian pine and mangroves.

In order to accomplish necessary transpiration, mangroves and salt marsh must separate fresh water from salt water. More energy is required in this situation than in fresh waters. Our measurements show mangroves absorb infrared where the heat contributes to separating fresh water and transpiration. However, the transpiration per unit heat absorbed is not as large as in fresh water as shown by Lugo et al. (1978). With less heat going to evaporate water (more into freshwater-salt separation), more of the absorbed heat goes into the mangrove microclimate, well known for its high daytime temperatures.

Among the studied plants, willows, cattails and bald cypress had intermediate absorption patterns, the floodplain forest edge had high absorption and the pond cypress overstory had a very low absorption. Brown's (1981) cypress study found that bald cypress inhabiting a floodplain had the highest measured leaf area index, growth and evapotranspiration, while pond cypress had low values for these measurements. She attributes this to different phosphorus inputs in the two study sites. Giurgevich and Dunn (1979) suggest that nitrogen may limit CO2 and water vapor exchange rates for short form *Spartina alterniflora*. Burns' (1984) study of cypress strands found that evapotranspiration and net carbon fixation were positively and closely correlated. Leaf area index, canopy height and increased nutrient availability have all been shown to increase evapotranspiration from plants (Otis 1914; DeBusk and Ryther, 1983; Sammis et al., 1986).

Dolan (1978) developed a simulation model which suggested that increased nutrient loading would result in elevated plant transpiration of a wetland marsh. The implication is that nutrient availability can increase the need for both carbon fixation and light energy. Eutrophic ecosystems are likely to be water consuming. Floodplain forests (Brown, 1981), arrowhead and pickeral weed marshes (Dolan et al., 1984), cattails (Snider and Boyd, 1987), duck weed (DeBusk and Ryther, 1983) and particularly water hyacinth (Van der Weert and Kamerling, 1974; Benton et al., 1978; DeBusk and Ryther, 1983; Snyder and Boyd, 1987) are known to lose water at greater rates than open water bodies. Pond cypress, on the other hand, transpires less than open water (Brown, 1981). During winter, when these plants become dormant or reduce their absorption of sunlight and carbon dioxide, evapotranspiration may be reduced below those of open water as plants insulate the water surface. Pond cypress inhabit perched wetlands common to the Florida Ridge and their water conservation may be an important source of groundwater recharge and water supply to other ecosystems. Eutrophic marshes, on the other hand, may be major water consumers and this may be proportional to their degree of eutrophication.

Modes for Maximum Power

A priori ecosystems may be expected to utilize whatever sources of energy are available to them. Transpiration uses the combined energies of water, the wind, the saturation gradients between water saturated leaf stomata and the air masses, and especially the sun's heating. The ability to combine and interact energies of several types may be one of the reasons for terrestrial productivity being so much higher generally than the sea.

Infrared Use by the Clay Settling Ponds in Stages of Succession

So long as there is standing water, much of the infrared is absorbed, contributing to evaporation. The graphs show that the bare wet clay surface absorbs 70% of visible insolation and 60% of infrared. The cattails and willows absorb most of the visible insolation and about half the near infrared. These communities have large quantities of dead matter as well as some freshly growing new shoots. Only part of the vegetation is fast growing. Chapter 8 showed high rates of transpiration of willows and cattails. In willow stage the absorption is slightly less than half. When rapid water drainage is desired, as in phosphate mined clay settling areas, it may be useful to encourage fast growing wetland species. Growth may be enhanced by the addition of nutrients such as nitrogen which may limit productivity in clay settling areas. During winter months this vegetation may reduce evaporative losses but due to the long growing season in this region, the presence of fast-growing wetland species is likely to be a positive attribute to the dewatering process in clay settling ponds, and therefore, wetland plants should be encouraged.

REFERENCES

Allison, T.D. 1990. Pollen production and plant density affect pollination and seed production in Taxus canadensis. Ecology, 71, 516-522.

Armson, K.A., H.H. Krause, and G.F. Weetman. 1975. Fertilization response in the northern coniferous forest, in Forest Soils and Forest Land Management. B. Bernier and C.H. Winget, eds. Quebec: Les Presses De L'Universite Laval.

Bach, C.E. 1990. Plant successional stage and insect herbivory: flea beetles and sand-dune willow. Ecology, 71, 598-609.

Benton, A.R., W.P. James and J.W. Rouse. 1978. Evapotranspiration from water hyacinth (Eichhornia crassipes (Mart.) Solms) in Texas reservoirs. Water Res. Bull. 14:919-930.

Bengston, G.W. 1975. Fertilizer use and water quality: considerations for agriculture and forest, in Forest Soils and Forest Land Management. B. Bernier and C.H. Winget eds. Quebec: Les Presses De L'Universite Laval.

Best, G.R., P.M. Wallace, W.J. Dunn and H.T. Odum. 1988. Enhanced Ecological Succession Following Phosphate Mining. FIPR Publ. No. 03-048-54. Bartow, FL: Florida Institute of Phosphate Research. 160 pp.

Bloom, A.J., F.S. Chapin and F.S. Mooney. 1985. Resource limitation in plants - an economic analogy. Ann. Rev. Ecol. Syst. 16:363-392.

Bloomfield, H.E., J.F. Handley and A.D. Bradshaw. 1982. Nutrient deficiencies and the aftercare of reclaimed derelict land. Journal of Applied Ecology 19:151-158.

Blue, W.G. and P. Mislevy. 1982. Accelerated drying of the surface of colloidal phosphate settling ponds from phosphate strip mining in Florida. Soil and Crop Science Society of Florida Proceedings 41:205-208.

Brady, N.C. 1974. The Nature and Properties of Soils, 8th ed. New York: Macmillan Publ. Co.

Bray, J.R. and J.T. Curtis. 1957. An ordination of the upland forest communities of southern Wisconsin. Ecological Monographs, 27, 325-349.

Bromwell, L.G. 1982. Physico-chemical Properties of Florida Phosphatic Clays. Bartow, Florida: Florida Institute of Phosphate Research Contract No. 80-02-003.

Brown, C.A., and N. Montz. 1986. Cypress--The Tree Unique, The Wood Eternal. Baton Rouge, LA: Clairtor's Publishing Division.

Brown, J.R. and S. Archer. 1987. Woody plant dispersal and gap formation in a North American subtropical savanna woodland: the role of domestic herbivores. Vegetatio, 73, 73-80.

Brown, S. 1978. A comparison of cypress ecosystems in the landscapes of Florida. Ph.D. Dissertation. Gainesville, FL: University of Florida. 570 pp.

Brown, S. 1981. A comparison of the structure, primary productivity and transpiration of cypress ecosystems in Florida. Ecol. Monogr. 51:403-427.

Brown, S. and A.E. Lugo. 1982. A comparison of structural and functional characteristics of saltwater and freshwater forested wetlands, in Wetlands: Ecology and Management. B. Gopal, R.W. Turner, R.G. Wetzel, and D.F. Whigham, eds. Jaipur, India: International Scientific Publications.

Burns, L.A. 1978. Productivity, biomass and water relations in a Florida cypress forest. Ph.D. Dissertation. Gainesville, FL: University of Florida. 213 pp.

Burns, L.A. 1984. Productivity and water relations in the Fakahatchee Strand of south Florida, in Cypress Swamps. K.C. Ewel and H.T. Odum, eds. Gainesville, FL: University of Florida Press. pp. 318-333.

Campbell, G.S. 1977. An Introduction to Environmental Biophysics. New York: Springer-Verlag. 159 pp.

Capehart, B.L., J.J. Ewel, B.R. Sedlik, and R.L. Myers. 1977. Remote sensing survey of Melaleuca. Photogrammetric Engineering and Remote Sensing 43:197-206.

Chancellor, R.J. 1986. Decline of arable weeds during 20 years in soil under grass and the periodicity of seedling emergence after cultivation. Journal of Applied Ecology, 23, 631-638.

Clark, D.A. and D.B. Clark. 1984. Spacing dynamics of a tropical rain forest tree: evaluation of the Janzen-Connell model. American Naturalist, 124, 769-788.

Clark, D.B. and D.A. Clark. 1985. Seedling dynamics of a tropical tree: impacts of herbivory and meristem damage. Ecology, 66, 1884-1892.

Clark, J.R. and J. Berforado, eds. 1981. Wetlands of Bottomland Hardwood Forests. Amsterdam, Netherlands: Elsevier. 401 pp.

Clements, F.E., J.E. Weaver and H.C. Hanson. 1929. Plant competition: an analysis of community functions. Carnegie Institution of Washington Publication No. 398.

Clewell, A.F., J.A. Goolsby, and A.G. Shuey. 1982. Riverine forests of the south Prong Alafia River System, Florida. Wetlands, 2:21- 72.

Connell, J.H. and R.O. Slayter. 1977. Mechanisms of succession in natural communities and their role in community stability and organisation. American Naturalist, 111, 1119-1144.

Date, R.A. 1972. Nitrogen, a major limitation in the productivity of natural communities, crops and pastures in the Pacific area. Soil Biol. Biochem. Vol. 5:5-18.

Davey, C.B. 1968. Biological considerations in fertilizer evaluation. Forest Theory and Practice. Muscle Shoals, Alabama: Tennessee Valley Authority, National Fertilizer Development Center.

Day, P.R. 1965. Particle fractionation and particle-size analysis, in Methods of Soil Analysis. Agronomy Series (9). C.A. Black, ed. Madison, Wisconsin: American Society of Agronomy.

Debusk, T.A. and J.H. Ryther. 1983. Evapotranspiration of Eicchornia crassipes (Mart.) Solms and Lemna Minor L. in central Florida: Relation to canopy structure and season. Aquatic Botany 16:31-39.

DeBussche, M., J. Escarre and J. Lepart. 1982. Ornithocory and plant succession in Mediterranean abandoned orchards. Vegetatio, 48, 255-266.

Deghi, G.S. 1984. Seedling survival and growth rates in experimental cypress domes, in Cypress Swamps. K.C. Ewel and H.T. Odum, eds. Gainesville, FL: University of Florida Press.

Dickson, R.E. and T.C. Broyer. 1972. Effects of aeration, water supply, and nitrogen source on growth and development of tupelo gum and bald cypress. Ecology, 53(4)626-634.

Dohrenwend, R.E. 1977. Evapotranspiration patterns in Florida. Florida Scientist, 40:2.

Dolan, T.J. 1978. Effect of secondarily treated effluent on a central Florida freshwater marsh ecosystem with estimation of phosophorus budget. M.S. Thesis. Gainesville, FL: Center for Wetlands, University of Florida. 208 pp.

Dolan, T.J., A.J. Hermann, S.E. Bayley, and J. Zoltek. 1984. Evapotranspiration of a Florida, U.S.A. Freshwater wetland. Journal of Hydrology 74:355-371.

Dunevitz, V. and J. Ewel. 1981. Allelopathy of wax myrtle (Myrica cerifera) on Schinus terebinthifolius. Florida Scientist, 44, 13-20.

Dunn, W.J. 1988. Ecological Paradigms, Species Interactions, and Primary Succession on Phosphate-mined Land. Ph.D. Dissertation. Gainesville, FL: University of Florida.

Egler, F.E. 1954. Vegetation science concepts. 1. Initial floristic composition: a factor in old-field vegetation development. Vegetatio, 4, 412-417.

Everett, S.B. 1987. The comparison of survival and growth of pondcypress and baldcypress in 5 different post-mining soils. Proceedings of the 15th Annual Conference on Wetlands Restoration and Creation.

Farmer, R.E., Jr., M. Cunningham, and M.A. Barnhill. 1982. First-year development of plant communities originating from forest topsoils placed on southern Appalachian minesoils. J. of Applied Ecology 19:283-294.

Ferry, D.M. and R.A. Olsen. 1975. Orientation of clay particles as it related to crusting of soil. Soil Science 120(5):367-375.

Foster, A.A. 1968. Damage to forests by fungi and insects as affected by fertilizers. Forest Fertilization Theory and Practice. Muscle Shoals, Alabama: Tennessee Valley Authority, National Fertilizer Development Center.

Fowells, H.A. 1965. Silvics of Forest Trees of the United States. Agriculture Handbook 271. Washington, D.C.: U.S. Dept. of Agriculture. 762 pp.

Gardner, W.H. 1965. Water content, in Methods of Soil Analysis. C.A. Black, ed. Madison, Wisconsin: American Society of Agronomy.

Giurgevich, J.R. and E.L. Dunn. 1979. Seasonal patterns of CO2 and water vapor exchange of the tall and short height forms of Spartina alterniflora Loisel in a Georgia salt marsh. Oecologia 43:139-156.

Goldberg, D.E. 1985. Effects of pH, competition, and seed predation on the distributions of two tree species. Ecology, 66, 503-511.

Grabe, D.F. 1970. Tetrazolium testing handbook for agricultural seeds. (29). Association of Seed Analysts.

Grace, J. 1977. Plant Response to Wind. New York: Academic Press. 204 pp.

Gross, F.E.H. 1987. Characteristics of Small Stream Floodplain Ecosystems in North and Central Florida. M.S. Thesis. Gainesville, FL: Center for Wetlands, University of Florida.

Guevara, S.E., S.E. Purata and E. Van der Maarel. 1986. The role of remnant forest trees in tropical secondary succession. Vegetatio, 66, 77-84.

Gunderson, L.H. 1984. Regeneration of cypress in logged and burned strands of Corkscrew Swamp Sanctuary, Florida, in Cypress Swamps. K.C. Ewel and H.T. Odum eds. Gainesville, FL: University of Florida Press.

Harrell, J.B. 1988. The Development of Techniques for the Use of Trees in the Reclamation of Phosphate Lands. Bartow, FL: Florida Division of Forestry for Florida Institute of Phosphate Research.

Hauck, R.D. 1968. Nitrogen source requirements in different soil-plant systems. Forest Fertilization Theory and Practice. Muscle Shoals, alabama: Tennessee Valley Authority, National Fertilizer Development Center.

Hawkins, W.H. 1983. Agricultural uses of reclaimed phosphate land, in Reclamation and the Phosphate Industry. D.J. Robertson, ed. Bartow, FL: Institute of Phosphate Research.

Haynes, R.J. 1984. Summary of Wetlands Reestablishment on Surface-mined Lands in Florida. Lexington, KY, 40506-0046: Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation, University of Kentucky.

Haynes, R.J. and F. Crabill. 1984. Reestablishment of a Forested Wetland on Phosphate Mined Land in Central Florida. Proceedings of the Fourth Annual Conference on Better Reclamation with Trees. West Lafayette, IN: Purdue Univ. pp. 51-63.

Hoppes, W.G. 1988. Seedfall pattern of several species of bird-dispersed plants in an Illinois woodland. Ecology, 69, 320-329.

Howard, G.S. and M.J. Samuel. 1979. The value of fresh-stripped topsoil as a source of useful plants for surface mine revegetation. Journal of Range Management 32:76-77.

Hughes, J.W. and T.J. Fahey. 1988. Seed dispersal and colonization in a disturbed northern hardwood forest. Bulletin of the Torey Botanical Club, 115, 89-99.

Janzen, D.H. 1970. Herbivores and the number of tree species in tropical forests. American Naturalist, 104, 501-528.

Jennersten, O. 1988. Pollination in Dianthus deltoides (Caryophyllaceae): Effects of habitat fragmentation on visitation and seed set. Conservation Biology, 2, 359-366.

Johnson, R.L., and R.M. Krinard. 1985. Oak seeding on an adverse field site. USDA. Forest Service Research Note SO-319.

Jones, J.E. 1977. Calculation of evapotranspiration using color-infrared photography. U.S. Geological Survey Professional Paper 655-0. 45 pp.

Kivilaan, A. and R.S. Bandurski. 1981. The one 100-year period for Dr. Beal's seed viability experiment. American Journal of Botany, 68, 1290-1292.

Klute, A., ed. 1986. Methods of Soil Analysis Part 1, Physical and Mineralogical Methods. Madison, WI: American Society of Agronomy, Inc. and Soil Science Society of America, Inc.

Krinard, R.M. and H.E. Kennedy, Jr. 1983. Ten-year growth of five planted hardwood species with mechanical weed control on sharkey clay soil. USDA Forest Service. SO-303.

Lamont, W.E., J.T. McLendon, L.W. Clements, Jr., and I.L. Field. 1975. Characterization Studies of Florida Phosphate Slimes. Washngton, D.C.: U.S. Dept. of the Interior, Bureau of Mines.

Laverdiere, M.R. and C.R. De Kimpe. 1984. Agronomic use of clay soils from Abitibi, Quebec: 2. Effects of organic amendments and cultivation on crop production. Soil Science 137(2):128-133.

Leadem, C.L. 1984. Quick tests for tree seed viability. British Columbia Ministry of Forests, Report no. 18.

Little, T.M. and F.J. Hills. 1978. Agriculture Experimentation-Design and Analysis. New York, NY: John Wiley and Sons.

Lugo, A.E. 1969. Energy, water and carbon budgets of a granite outcrop community. Ph.D. Dissertation. Chapel Hill, NC: University of North Carolina. 233 pp.

Lugo, A.E., Gonzalez-Liboy, B. Cintron, and K. Dugger. 1978. Structure, productivity and transpiration of a subtropical dry forest in Puerto Rico. Biotropica 10(4):278-291.

Lugo, A.E., S. Brown, and M. Brinson. 1988. Forested wetlands in freshwater and saltwater environments. Limnology and Oceanography 33:4 part 2, 894-909.

Malone, C.R. 1967. A rapid method for enumeration of viable seeds in soil. Weeds, 15:381-382.

McClanahan, T.R. 1986a. Pollen dispersal and intensity as criteria for the minimum viable population and species reserves. Environmental Managment, 10, 381-383.

McClanahan, T.R. 1986b. The effect of a seed source on primary succession in a forest ecosystem. Vegetatio, 65, 175-178.

McClanahan, T.R. 1986c. Seed dispersal from vegetation islands. Ecological Modelling, 32, 301-309.

McClanahan, T.R. and R.W. Wolfe. 1987. Dispersal of ornithocorous seeds from forest edges in central Florida. Vegetatio, 71, 107-112.

McDonnell, M.J. and E.W. Stiles. 1983. The structural complexity of old field vegetation and the recruitment of bird-dispersed plant species. Oecologia, 56, 109-116.

Miller, M.A. 1987. Groundwater Control of Wetlands Restoration in Reclamation of Clay Settling Areas. Accelerating Natural Processes for Wetland Restoration after Mining. Gainesville, FL: Center for Wetlands, Univ. of Fla.

Mislevy, P. 1988. Personal communication.

Mitsch, W.J. and J.G. Gosselink. 1986. Wetlands. New York: Van Nostrand Reinhold Co.

Monk, C.D. 1965. Southern mixed hardwood forest of northcentral Florida. Ecological Monographs 35:335-354.

Monk, C.D. 1966. An ecological study of hardwood swamps in north-central Florida. Ecology 47:649-54.

Monk, C.D. 1968. Successional and environmental relationships of the forest vegetation of northcentral Florida. American Midland Naturalist 79:441-57.

Monk, C.D. and T.W. Brown. 1965. Ecological considerations of cypress hads in north central Florida. The American Midland Naturalist, 74(1)126-140.

Murphy, B.J., R.G. Stanley, and C.A. Hollis III. 1974. Seedling Studies in Cypress Wetlands for Water Management, Recycling and Conservation. Annual Report on Research Project to National Science Foundation (GI 38721) and The Rockefeller Foundation (RF 783029). Gainesville, FL: Center for Wetlands, Univ. of Fla.

Neufield, H.S. 1983. Effects of Light on Growth, Morphology, and Photosynthesis in Baldcypress (Taxodium distichum (L.) Rich) and Pondcypress (T. ascendens Brongn.) Seedlings. Bulletin of the Torrey Botanical Club, Vol. 110, 1:43-54, Jan-Mar 1983.

Odum, H.T. 1984. Summary: Cypress swamps and their regional role, in Cypress Swamps. K.C. Ewel and H.T. Odum, eds. Gainesville, FL: University Presses.

Odum, H.T., G.R. Best, M.A. Miller, B.T. Rushton, R. Wolfe, C. Bersok, and J. Feiertag. 1990. Accelerating Natural Processes for Wetland Restoration after Phosphate Mining. FIPR Publ. No. 03-041-086. Bartow, FL: Florida Institute of Phosphate Research. 408 pp.

Odum, H.T. and C.F. Jordan. 1970. Metabolism and evapotranspiration of the lower forest in a giant plastic cylinder. in A Tropical Rainforest, H.T. Odum and R.F. Pigeon, eds. Springfield, VA: U.S. Atomic Energy Commission, NTIS. pp. 1165-1190.

Odum, H.T., A. Lugo, G. Cintron, and C.F. Jordan. 1970. Metabolism and evapotranspiration of some rainforests plants and soil, in A Tropical Rainforest, H.T. Odum and R.F. Pigeon, eds. Springfield, VA: U.S. Atomic Energy Commission. pp. 1103-1164.

Odum, H.T., M.A. Miller, B.T. Rushton, T.R. McClanahan and G.R. Best. 1983. Interaction of Wetlands with the Phosphate Industry. FIPR Publ. No. 03-007-025. Bartow, FL: Florida Institute of Phosphate Research. 164 pp.

Otis, C.H. 1914. The transpiration of emersed water plants: its measurement and its relationships. Botanical Gazette 58:457-494.

Peterson, J.D. 1945. The role of clay minerals in the foundation of soil structure. Journal Paper No. J. 1309 of the Iowa Agricultural Experiment Station, Soils Subsection, Project No. 583.

Pittman, W.E. Jr., and J.W. Sweeney. 1983. State-of-the-art of Phosphatic Clay Dewatering and Disposal Techniques, Vol. 1, A Review of Phosphatic Clay Dewatering Research. U. S. Bureau of Mines for Florida Institute of Phosphate Research. NTIS # PB84 185016.

Pritchett, W.L. 1979. Properties and Management of Forest Soils. New York: John Wiley and Sons.

Pritchett, W.L. and W.H. Smith. 1975. Forest fertilization in the U.S. southeast, in Forest Soils and Forest Land Management. B. Bernier and C.H. Winget, eds. Quebec: Les Presses De L'Universite Laval.

Putnam, J.A., G.M. Furnival, and J.S. McKnight. 1960. Management and Inventory of Southern Hardwoods. U.S. Dept. of Agriculture Forest Service, Agriculture Handbook No. 191.

Ravina, I. and J. Magier. 1984. Hydraulic conductivity and water retention of clay soils containing coarse fragments. Soil Science Society American Journal 48:736-740.

Ray, A.A., J.P. Sall, and M. Saffer. 1982. SAS User's Guide: Statistics. Box 8000, Cary, N.C. 27511.

Reginato, R.J., R.D. Jackson and P.J. Pinter. 1985. Evapotranspiration calculated from remote multispectral and ground station meteorological data. Remote Sensing of Environment 18:75-90.

Rhue, R.D., and G. Kidder. 1983. Procedures Used by the IFAS Extension Soil Testing Laboratory and Interpretation of Results. Circular 596. Gainesville, FL: Institute of Food and Agriculture Sciences and Florida Cooperative Extension Service.

Risch, S.J. and C.R. Carroll. 1986. Effects of seed predation by a tropical ant on competition among weeds. Ecology, 67, 1319-1327.

Roberts, H.A. 1981. Seed banks in soils. Advances in Applied Biology, 6, 1-55.

Robertson, D.J. 1985. Sink Branch: Stream Relocation and Reclamation by the Florida Phosphate Industry. Draft of Final Report (unpublished). Bartow, FL: Florida Institute of Phosphate Research. 61 pp.

Rushton, B.T. 1983. Ecosystem organization in phosphate clay-settling ponds. M.S. Thesis, Gainesville, FL: University of Florida.

Rushton, B.T. 1983. Examples of natural wetland succession as a reclamation alternative, in Symposium on Reclamation and The Phosphate Industry. D.J. Robertson, ed. Bartow, FL: Florida Institute of Phosphate Research. pp. 148-189.

Rushton, B.T. 1988. Wetland Reclamation by Accelerating Succession. Ph.D Dissertation. Gainesville, FL: Univ. of Fla. pp. 266.

Rushton, B.T. 1989. Successional sequences for wetland restoration; seedlings for enhancing wetland succession; seedlings of hydric swamp species for reclamation, in Accelerating Natural Processes for Wetland Restoration After Phosphate Mining. H.T. Odum, G.R. Best, M.A. Miller, B.T. Rushton, R. Wolfe, C. Bersok, and J. Feiertag. Bartow, Florida: Florida Institute of Phosphate Research. FIPR Contract No. 83-03-041R.

Salisbury, E.J. 1936. Natural selection and competition. Proceedings of the Royal Society of London (B), 121, 47-49.

Sammis, T.W., S. Williams, D. Smeal, and C.E. Kallsen. 1986. Effect of soil moisture stress on leaf area index, evapotranspiration and modeled soil evaporation and transpiration. Transactions of the American Society of Agricultural Engineers 29:956-961.

Schneider, R.L. and R.R. Sharitz. 1986. Seed bank dynamics in a southeastern riverine swamp. American Journal of Botany, 73, 1022-1030.

Schultz, R.C. 1978. Tree growth responses to changes in soil moisture, fertility and microorganisms on difficult sites. Proceedings: Fifth North American Forest Biology Workshop. Gainesville, FL: School of Forest Resources and Conservation, University of Florida.

Schupp, E.W. 1990. Annual variation in seedfall, postdispersal predation, and recruitment of a neotropical tree. Ecology, 71, 504-515.

Schwartz, L.N. 1989. A titi swamp ecosystem in Apalachicola, Florida. Ph.D. Dissertation. Gainesville, FL: Center for Wetlands, University of Florida. 262 pp.

Shelford, V.E. 1954. Some lower Mississippi Valley flood plain biotic communities: their age and elevation. Ecology 35:126-142.

Skeate, S.T. 1987. Interactions between birds and fruits in a northern Florida hammock community. Ecology, 68, 297-309.

Smith, D.H. 1986. The Practice of Silviculture. New York: John Wiley & Sons.

Snyder, R.L. and C.E. Boyd. 1987. Evapotranspiration by Eichhornia crassipes (Mart.) Solms and Typha latifolia L. Aquatic Botany 27:217-227.

Sork, V.L. 1987. Effects of predation and light on seedling establishment in Gustavia superba. Ecology, 68, 1341-1350.

Tacey, W.H. and B.L. Glossop. 1980. Assessment of topsoil handling techniques for rehabilitation of sites mined for bauxite with the Jarrah Forest of western Australia.

Terborgh, J. 1986. Community aspects of frugivory in tropical forests, winy Frugivores and Seed Dispersal. A. Estrada and T.H. Fleming eds. Dordrecht: Dr. W. Junk Publishers. pp. 371-384.

Tilman, D. 1986. Resources, competition and the dynamics of plant communities, winy Plant Ecology. M.J. Crawley, ed. Oxford: Blackwell. pp. 51-65.

Unger, P.W. and O.R. Jones. 1981. Effect of soil water content and a growing season straw mulch on grain sorghum. Soil Sci. Soc. Am. J. 45:129-134.

Van der Weert, R. and G.E. Kamerling. 1974. Evaporation of water hyacinth (Eichhornia crassipes). Journal of Hydrology 22:201-212.

Vitousek, P.M. and L.R. Walker. 1989. Biological invasion by wMyrica fayay in Hawaii: Plant demography, nitrogren fixation, ecosystem effects. Ecological Monographs, 59, 247-265.

Vogel, W.G. 1981. A guide for regetetating coal mine soils in the eastern United States. Northeast Forest Experiment Station, U.S. Dept. of Agriculture, General Technical Report NE-68.

Walker, L.R., J.C. Zasada and F.S. Chapin. 1986. The role of life history processes in primary succession on an Alaskan floodplain. Ecology, 67, 1243-1253.

Wallace, P.M. and G.R. Best. 1983. Enhancing ecological succession: 6. Succession of vegetation, soils and mycorrhizal fungi following strip mining for phosphate. Proceedings of the 1983 National Symposium on Surface Mining, Hydrology, Sedimentology, and Reclatmation. Lexington, KY: University of Kentucky.

Wallace, P.M. and G.R. Best. 1983. Enhancing ecological succession-succession of endomycorrhizal fungi on phosphate strip mined lands, in Reclamation and the Phosphate Industry. J. Robertson, ed. Bartow, FL: Florida Institute of Phosphate Research.

Wharton, C.H., H.T. Odum, K.C. Ewel, M. Duever, A. Lugo, R. Boyt, J. Bartholomew, E. DeBellevue, S. Brown, M. T. Brown, and L. Duever. 1977. Forested Wetlands of Florida: Their Management and Use. Final Report to Division of State Planning. Gainesville, FL: Center for Wetlands, Univ. of Fla. pp. 348.

Willson, M.F. and C.J. Whelan. 1990. Variation in postdispersal survival of vertebrate-dispersed seeds: effects of density, habitat, location, season, and species. Oikos, 57, 191-198.

Wissa, A., N.F. Fuleihan, T.S. Ingra. 1982. Evaluation of Phosphatic Clay Disposal and Reclamation Methods: Mineralogy of Phosphatic Clays. NTIS #PB83 21--88.

Wolfe, R.W. 1987. Mechanisms of seed dispersal and revegetation of mined lands, in Accelerating Natural Processes for Wetland Restoration after Mining. H.T. Odum, ed. Bartow, FL: Florida Institute of Phosphate Research # 83-03-041R.

Wolfe, R.W. 1987. Seed dispersal and wetland restoration. M.S. Thesis, Environmental Engineering Sciences. Gainesville, FL: University of Florida. 74 pp.

Woodall, S.L. 1981. Evapotranspiration and melaleuca, in Proceedings of Melaleuca Symposium, Sept. 23-24, 1980, Florida Division of Forestry, R.K. Geiger, ed. 140 pp.

Worthen, W.B. and E.W. Stiles. 1988. Pollen-limited fruit set in isolated patches of wMaianthemum canadense Desfy. in New Jersey. Torrey Botanical Club, 115, 299-305.

Wunderlin, R.P. 1982. Guide to the vascular plants of central Florida. Tampa: University Presses of Florida.

Young, K.R., J.J. Ewel and B.J. Brown. 1987. Seed dynamics during forest succession in Costa Rica. Vegetatio, 71, 157-173.

Zammet, C.A. and P.H. Zedler. 1988. The influence of dominant shrubs, fire and time since fire on soil seed banks in mixed chaparral. Vegetatio, 74, 175-187.

Zar, J.H. 1974. Biostatistical Analysis. Edgewood Cliffs, NJ: Prentice-Hall, Inc.